

**Port of Gladstone
Gatcombe and Golding Cutting
Channel Duplication Project**

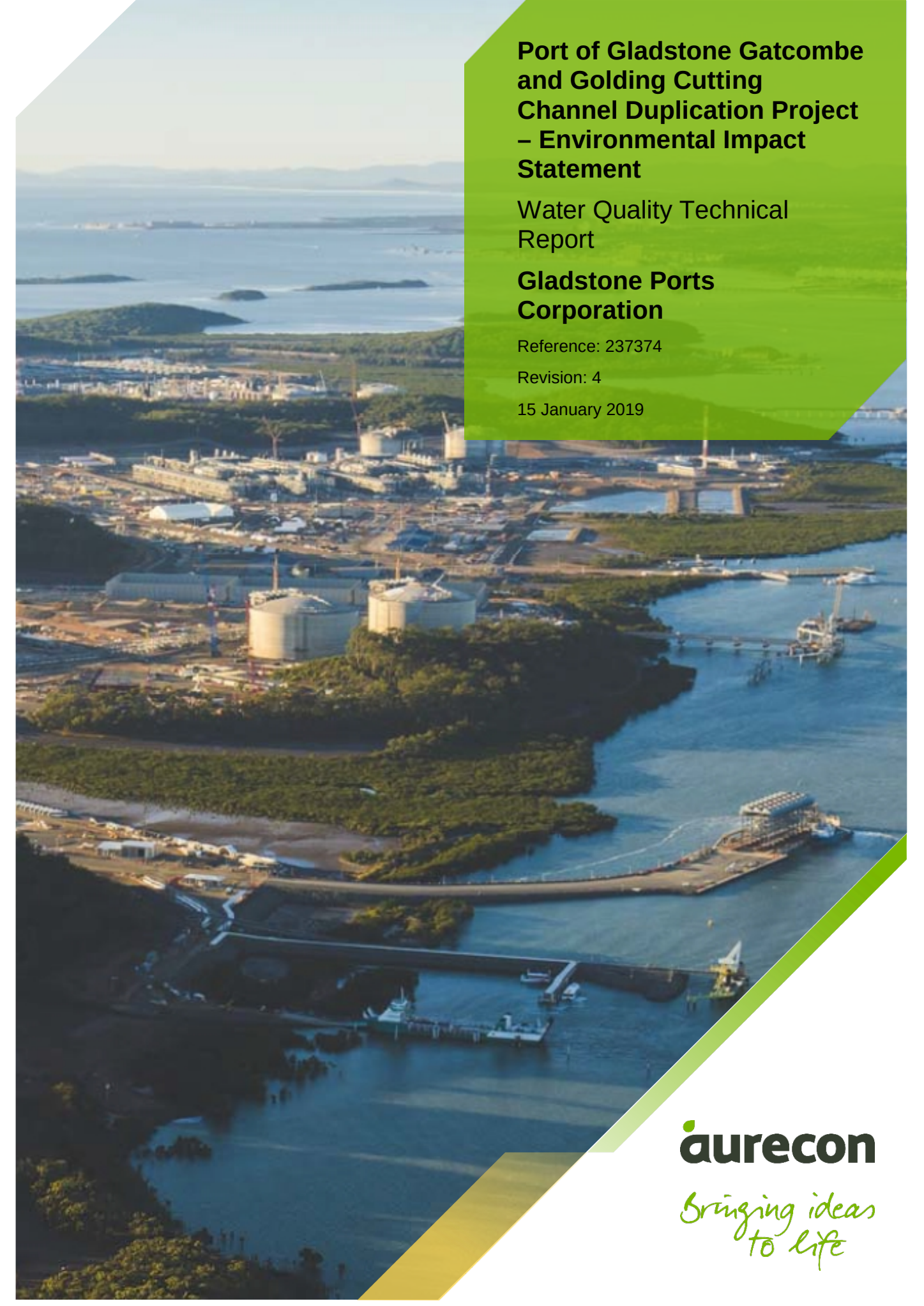
Environmental Impact Statement



Gladstone Ports Corporation
Growth, Prosperity, Community

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**Appendix H1
Water Quality
Technical Report**



Port of Gladstone Gatcombe and Golding Cutting Channel Duplication Project – Environmental Impact Statement

**Water Quality Technical
Report**

**Gladstone Ports
Corporation**

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Acronyms and abbreviations

Abbreviation	Explanation
% sat	percent saturation
°C	Degrees Celsius
µg/L	micrograms per litre
ADCP	Acoustic Doppler Current Profiler
AHD	Above Height Datum
AIMS	Australian Institute of Marine Science
Amm N	Ammonia as N
ANZECC	Australian and New Zealand Environment and Conservation Council
APHA	American Public Health Association
AQIS	Australian Quarantine Inspection Service
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
As	Arsenic
ASS	Acid sulfate soils
AWQG	Australian Water Quality Guidelines
BACI	Before-After, Control-Impact
BOD	Biochemical Oxygen demand
BOM	Bureau of Meteorology
BPAR	benthic photosynthetically active radiation
BTEX	Benzene, Toluene, Ethyl Benzene, Xylenes
BUF	barge unloading facility
Cd	Cadmium
CG	Coordinator-General
Chl-a	Chlorophyll a
CQPA	Central Queensland Port Authority
CQU	Central Queensland University
CRC	Cooperative Research Centre for Coastal Zone, Estuary and Waterway Management
CSD	cutter suction dredger
CSIRO	Commonwealth Scientific and Industrial Research Organisation
Cu	Copper
Cth	Commonwealth
DAFF	Department of Agriculture, Fisheries and Forestry
DEEDI	Department of Employment, Economic Development and Innovation (former)
DERM	Department of Environment and Resource Management (former)
DGT	Diffuse Gradients in Thin films
DMPA	dredge material placement area
DMPOI	Dredge Material Placement Options Investigation
DO	Dissolved Oxygen
DoE	Department of the Environment (Cth)
DSITI	Department of Science, Information Technology and Innovation
DSITIA	Department of Science, Information Technology, Innovation and the Arts (former)

Abbreviation	Explanation
DTRP	Dredging Technical Reference Panel
DWT	Deadweight Tonnage
EA	Environmental Authority
EC	Electrical Conductivity
ECL	Environmental concern level
EHMP	Ecosystem Health Monitoring Program
EHP	Department of Environment and Heritage Protection
EIS	Environmental Impact Statement
EPBC Act	<i>Environment Protection and Biodiversity Conservation Act 1999</i>
EPP (Water)	<i>Environment Protection (Water) Policy 2009</i>
ERMP	Ecosystem Research and Monitoring Program
EV	Environmental value
EWMA	Exponentially Weighted Moving Average
FRP	Filterable Reactive Phosphate
g/L	grams per litre
GBRMP	Great Barrier Reef Marine Park
GBRMP	Great Barrier Reef Marine Park
GBRMP Act	<i>Great Barrier Reef Marine Park Act 1975</i>
GBRMP Regs	<i>Great Barrier Reef Marine Park Regulations 1983</i>
GBRMPA	Great Barrier Reef Marine Park Authority
GBRWHA	Great Barrier Reef World Heritage Area
GBRWQG	Water Quality Guidelines for the Great Barrier Reef Marine Park
GHHP	Gladstone Healthy Harbour Partnership
GIS	geographic information system
GPC	Gladstone Ports Corporation
ha	hectare
HCB	Hexachlorobenzene
HD	Highly Disturbed
HEV	High Ecological Value
Hg	Mercury
HSEQ	Health, Safety, Environment and Quality
Hsig	significant wave height
IALA	International Association of Marine Aids to Navigation and Lighthouse Authorities
JCU	James Cook University
km	kilometre
km ²	square kilometre
LAT	lowest astronomical tide
LNG	liquefied natural gas
LOR	Limits of reporting
m	metre
m/s	metres per second

Abbreviation	Explanation
MD	Moderately disturbed
mg/cm ² /day	milligrams per square centimetre per day
mg/kg	milligrams per kilogram
mg/L	milligrams per litre
mm	millimetre
Mm ³	million cubic metre
Mn	Manganese
MNES	Matters of National Environmental Significance
Mo	Molybdenum
MSQ	Maritime Safety Queensland
Mt	megatonnes
N	Nitrogen
n	Dataset sample size
N/A	not applicable
NAGD	National Assessment Guidelines for Dredging 2009
Ni	Nickel
NPI	National Pollutant Inventory
NTU	Nephelometric Turbidity Units
NWQMS	National Water Quality Management Strategy
OC	Organochlorine pesticides
OP	Organophosphate pesticides
OUV	Outstanding Universal Value
Oxid N	Oxidised Nitrogen as N
P	Phosphorus
PAH	Polycyclic Aromatic Hydrocarbon
PAR	photosynthetically active radiation
PASS	Potential Acid Sulfate Soils
Pb	Lead
PCBs	Polychlorinated Biphenyls
PCCC	Port Curtis Coral Coast
PCIMP	Port Curtis Integrated Monitoring Program
pH	pH units
PN	Particulate Nitrogen
Ports Act	<i>Sustainable Ports Development Act 2015</i>
PP	Particulate Phosphorus
PPDA	Priority Port Development Areas
QA/QC	Quality Assurance/Quality Control
QDEH	Queensland Department of Environment and Heritage (former)
QER	Queensland Energy Resources Pty Ltd
QPS	Queensland Ports Strategy
QWQG	Queensland Water Quality Guidelines

Abbreviation	Explanation
RGTCT	RG Tanna Coal Terminal
RL	Relative Level
SD	Slightly Disturbed
se	standard error
Sea Dumping Act	<i>Environment Protection (Sea Dumping) Act 1981</i>
SEWPaC	Commonwealth Government Department of Sustainability, Environment, Water, Population and Communities (former)
SLERA	Screening level ecological risk assessment
SMART	Self-Monitoring Algorithm in Real Time
SMD	Slightly to Moderately Disturbed
SS	Suspended Solids
Strategic Plan	Gladstone Ports Corporation's <i>50 Year Strategic Plan</i> (July 2012)
TBT	Tributyltin
TDP	Total daily PAR
TN	Total Nitrogen
TOC	total organic carbon
ToR	Terms of Reference
Total diss N	Total Dissolved Nitrogen
Total diss P	Total Dissolved Phosphate
TP	Total Phosphorous
TPH	Total Petroleum Hydrocarbon
TRH	Total Recoverable Hydrocarbon
TSS	Total Suspended Solids
UNESCO	United Nations Educational, Scientific and Cultural Organization
VE	Vision Environment Queensland
WBDDP	Western Basin Dredging and Disposal Project
WB	Western Basin
WBE	Western Basin Expansion
WICT	Wiggins Island Coal Terminal
WQMP	Water Quality Management Plan
WQOs	Water Quality Objectives
Zn	Zinc
μmol/m ² /s	micromoles per square metre per second

Glossary of commonly used terms

Term	Meaning
altimeter	Acoustic instrument used to obtain high precision seabed level measurements (millimetre scale) using a high frequency acoustic sensor and an inbuilt data logging device. Used to measure continuous loss/gain of sediments in addition to particle size.
anthropogenic	Produced or caused by humans
aquatic ecosystem	A community of organisms living within or adjacent to water, including riparian or foreshore area
baseline (water quality)	Ambient water quality conditions and natural variability
bed-shear stress	Forces exerted by the ocean on bed sediments (at rest). When bed shear stress exceeds the critical shear stress for the bed sediments, the sediments will become transported by the ocean.
benthic	The benthic zone is the ecological region at the lowest level of a body of water including the sediment surface and some sub-surface layers. Organisms that live on, in or attached to the sea floor are known as benthos.
benthic photosynthetically active radiation	Benthic photosynthetically active radiation. Light that reaches the benthos that is available to primary producers (e.g. seagrass species) for photosynthesis. Can be effected by turbidity levels in water and cloud cover. Changes in the availability of light is the primary factor affecting the distribution of seagrasses in Queensland
bioavailability	The amount of an element or compound that is accessible to an organism for uptake or absorption
Chlorophyll a	A plant pigment which occurs in all marine phytoplankton. Can provide a useful proxy indicator of the amount of nutrients incorporated into phytoplankton biomass, because phytoplankton have predictable nutrient-to-chlorophyll ratios. Chlorophyll a is the most commonly used parameter for monitoring phytoplankton biomass and nutrient status, as an index of water quality.
contaminant of concern	A contaminant that poses a risk to a human or ecological environmental values
daily light integral	The amount of photosynthetically active radiation received each day as a function of light intensity, expressed as moles per square metre per day
dredging – capital	Dredging for navigation, to create new or enlarge existing channel, port, marina and boat harbour areas. Dredging for engineering purposes, to create trenches for pipes, cables, immersed tube tunnels, to remove material unsuitable for foundations and to remove overburden for aggregate.
dredging – maintenance	Dredging to ensure that previously dredged channels, berths or construction works are maintained at their designated dimensions
dry season/wet season	EHP have defined the following seasons for Gladstone in regards to water quality. Seasonal definitions may differ between projects. Wet season: 1 November to 30 April Dry season: 1 May to 31 October Rainfall during December, January, and February accounts for half the annual rainfall in the Curtis Coast region.
ebb tide/flood tide	An ebb tide is a falling tide, the phase of the tide between high water and the succeeding low water while a flood tide is a rising tide, the phase of the tide between low water and the next high tide
environmental value	The qualities of water that make it suitable for supporting aquatic ecosystems and human water uses, e.g. irrigation, recreation, and cultural and spiritual values. Environmental values need to be protected from the effects of habitat alteration, waste releases, contaminated runoff and changed flows to ensure healthy aquatic ecosystems and waterways that are safe and healthy for human use.
EWMA	Exponentially weighted moving average. A moving average calculation commonly used in environmental monitoring projects where a weighting factor is assigned to each value in the data series according to its age. The EWMA retains an element of 'history' in its computation and ensures a variance that is weighted or biased towards more recent data.

Term	Meaning
Gladstone Harbour	Generally known as the area in Port Curtis between the Boyne Wharf and APLNG Wharf. However, it may be used as a general term for the wider Port area in other documents such as in the EPP(Water) (e.g. 'coastal waters outside Gladstone Harbour').
Great Barrier Reef Marine Park	The area subject to protection under the <i>Great Barrier Reef Marine Park Act 1975</i> covering 344,400 square kilometres (km ²) including the subsoil beneath the seabed (1000m below) and the airspace above (915m high). It is a multiple-use marine park area that supports a range of communities and industries that depend on the Reef for recreation or their livelihoods (including tourism, fishing, boating and shipping). The Great Barrier Reef Marine Park is a matter of national environmental significance and the Great Barrier Reef Marine Park Authority is responsible for its protection and management.
Great Barrier Reef World Heritage Area	The Great Barrier Reef World Heritage Area extends from the top of Cape York in north-east Australia to just north of Bundaberg, and from the low water mark on the Queensland coast to the outer boundary of the Marine Park, which is beyond the edge of the continental shelf. The area was declared a World Heritage Area in 1981 because of its 'outstanding universal value'. About 99 per cent of the World Heritage Area is within the Great Barrier Reef Marine Park but encompasses: ■ Some 980 islands which are under Queensland jurisdiction ■ Some internal waters of Queensland (for examples, some deep bays, narrow inlets or channels between islands) ■ Intertidal areas protected by Queensland legislation ■ A number of small exclusion areas (state waters) around major ports and urban centres
hydrodynamics	The movement (dynamics) of water due to the action of tides, waves, winds and other influences
indicator	A physical, chemical or biological property for an environmental value that can be measured or decided in a quantitative way
management monitoring site	Water quality monitoring sites that are linked to a management strategy with established trigger values and management response actions. Can be located at ecological receptors to prevent or minimise ecological impacts during dredging activities.
Outstanding Universal Value	Cultural and/or natural heritage which is so exceptional as to transcend national boundaries and to be of such significance to humanity as a whole to make it worthy of special protection. (Adapted from Operational guidelines for the implementation of the World Heritage Convention).
percentile	A statistical term meaning the value below which a certain percent of observations fall. E.g. the 30th percentile is the value (or score) below which 30% of the observations may be found
photosynthetically available radiation	The amount of light available for photosynthesis, which is light in the 400 to 700 nanometer wavelength range. Changes seasonally and varies depending on the latitude and time of day. Can be reduced by cloud cover and pollution.
Port Curtis region	The marine and coastal region between Port Alma and Rodds Peninsula, including Port Curtis, Curtis Island, Facing Island, Wild Cattle Island, other islands within Port Curtis and all related estuaries
Port of Gladstone	The area defined by the Port of Gladstone Port Limits together with adjoining islands and landside areas, including reclamation areas, that support existing or consented industrial developments or are proposed to cater for future port-related industrial activities and supporting infrastructure
Project	Gatcombe and Golding Cutting Channel Duplication Project
reference monitoring site	A reference site is a site whose condition is considered to be a suitable baseline or benchmark for assessment and management of sites in similar water bodies. The condition of the site is reference condition and values of individual indicators at that site are the reference values. Reference values can encompass not only physicochemical characteristics but also the biological and habitat characteristics of a system. Most commonly, reference condition refers to sites that are subject to minimal/limited disturbance.
resuspension	Dislodging of bedded sediment material and disbursement into the water column

Term	Meaning
sensitive receptors (marine)	Certain key reef marine organisms, habitats and communities that are sensitive to dredging and at-sea dredge material placement activities. Coral reefs, seagrass, macroalgal and macroinvertebrate communities are 'sensitive receptors' that occur within the Great Barrier Reef World Heritage Area. Impacts can result from both direct effects (e.g. burial by dredge material) and indirect effects (e.g. reductions in light availability to seagrasses due to elevated suspended sediment concentrations in the water column).
sentinel monitoring site	Sites located at the boundaries of modelled zones of impact. Particularly important for large projects, especially if a zone of high impact is predicted, it may be useful to place sensitive receptor monitoring sites within 'sentinel sites' at the boundaries of model-predicted zones of influence and impact.
spring tides/neap tides	Spring tides are the tides with the biggest range from low to high tide that are associated with new and full moon events which occur approximately every 14 days. This tidal range in Port Curtis is > 4m. Neap tides occur when the difference between high and low tide is the least.
toxicity	The inherent potential or capacity of a material to cause adverse effects in a living organism
water quality guidelines	Numerical concentration levels or statements for indicators that protect a stated environmental value. Under the environmental values setting process contained in the EPP (Water), water quality guidelines are used as an input to the development of WQOs
water quality indicator	A property that is able to be measured or decided in a quantitative way. May include physical indicators (e.g. temperature), chemical indicators (e.g. nutrients), and biological indicators (e.g. seagrass).
water quality objective	The set of water quality guidelines for all indicators that will protect all environmental values selected for the water. Water quality objectives may be the same as technically derived water quality guidelines, or may be altered by consideration of the social and economic impacts of protecting the environmental values.
zones of impact	Established through predictive modelling of sediment plumes zones of high impact, moderate impact and influence based on quantitative threshold criteria for the boundary of each zone can be established.

Executive summary

Overview

The Port of Gladstone is one of the most studied ports in Australia and water quality is one of the key ecological health indicators that is regularly monitored in the area. The water quality condition and health of the Port of Gladstone, adjoining waterways and the wider Great Barrier Reef World Heritage Area have become a key focus of attention in recent years. With the ongoing development of the Queensland coastline, the Queensland Government is committed to ensuring that the outstanding universal value of the Great Barrier Reef World Heritage Area and health of marine ecosystems is an intrinsic consideration in future port development.

The Port of Gladstone is Queensland's largest multi-commodity port, with RG Tanna Coal Terminal being the world's fourth largest coal export terminal (by throughput) in the world in the 2014/15 reporting period. Cumulatively, the Port handles the export of mineral resources from Central Queensland and products from local industries, and the import of raw materials from national and international sources. Major industrial development has occurred in the region since the 1950s accompanied by an expanding Port and a steady increasing population. The continued operation of the Port plays a significant role in the local, state and national economies.

The Gatcombe and Golding Cutting Channel Duplication Project (the Project) involves the deepening of existing bypass channels which is needed to improve the Port's operational efficiency and to improve an existing and increasing potential shipping incident risk as the Port's throughput increases in the future. The duplication of the Gatcombe and Golding Cutting shipping channels will facilitate improved flexibility for vessel passing within the Port which will address the above mentioned need.

The purpose of this water quality technical report is to describe the past and current water quality of Port Curtis, and to assess the potential water quality impacts of the Project. This report also identifies the mitigation measures to be implemented during the Project activities to minimise the potential impacts to water quality. This report has been prepared by Aurecon and Vision Environment Queensland.

This water quality technical report describes the existing water quality values of the Port, using information from a combination of available information sources, including desktop reviews and documentation of previous studies in the area, a baseline field monitoring program, and additional baseline data provided from other monitoring programs, including the Port Curtis Integrated Monitoring Program and Gladstone Healthy Harbours Partnership. The potential impacts of the Project on the environmental values of the area, including any cumulative impacts related to other projects and activities, have been assessed.

Monitoring area

Port Curtis comprises the Boyne, Calliope and Curtis Island basins, Gladstone Harbour, The Narrows and adjacent estuarine/coastal waters. The greater area contains several water types (as defined in the Queensland Water Quality Guidelines), including freshwaters, estuarine and coastal waters. The two different but connected water types monitored during this baseline water quality assessment are lower estuary/enclosed coastal waters, and coastal waters.

The waters of Port Curtis have been divided into zones, based on previous water quality data, for the purposes of assigning water quality objectives and environmental values, under the *Environmental Protection (Water) Policy 2009*. These zones, comprising The Narrows, Western Basin, Inner Harbour, Mid Harbour, Outer Harbour, and open coastal waters, are referenced throughout the report and are outlined in Figure 1. The boundaries of each zone are indicative only.

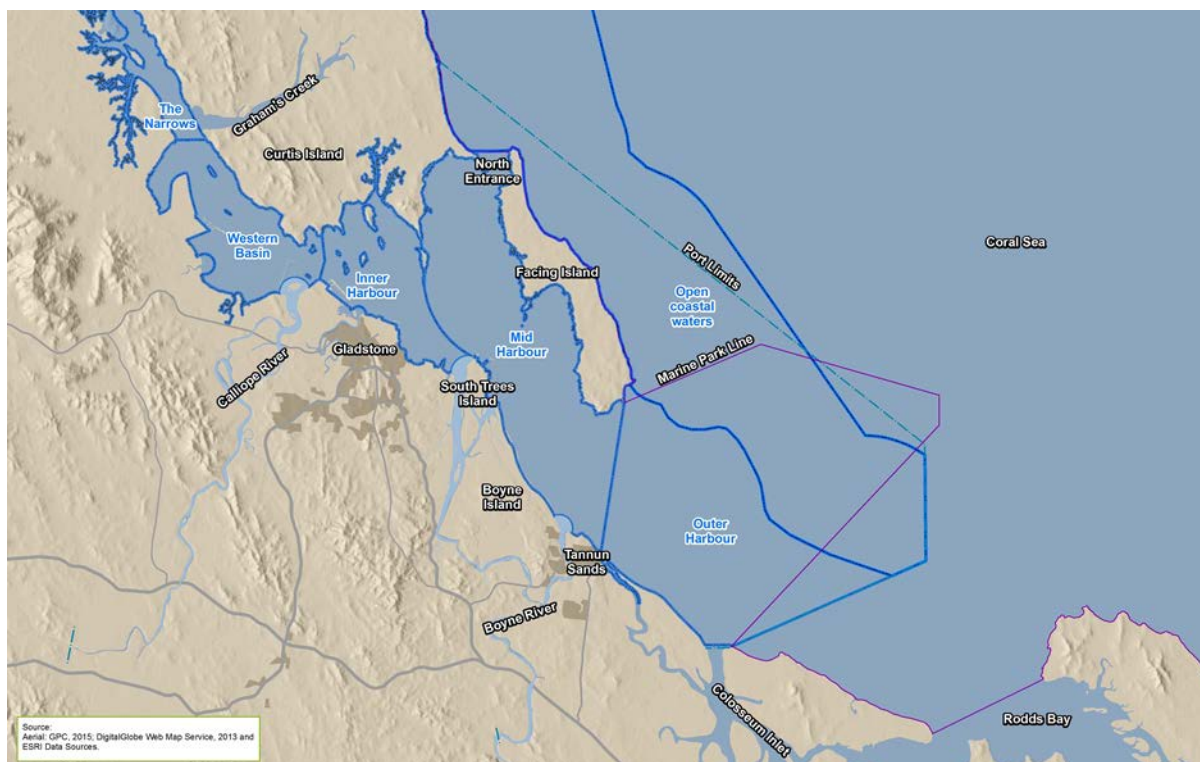


Figure 1 Port Curtis zones

Desktop review and documentation of previous studies

A desktop data review and documentation of existing historic studies within the Port was undertaken as part of the Project baseline water quality assessment. This desktop review revealed that there is a large amount of information available from studies previously undertaken within Port Curtis. Data sources include reports from industry initiatives such as the Port Curtis Integrated Monitoring Program, regional environmental inventory reports commissioned by Gladstone Ports Corporation, Commonwealth Government and State Government reports, and various reports from independent proponents as part of development impact assessments, including previous dredging campaigns.

Previous water quality studies have consisted of short and long term monitoring programs, capturing biological and physicochemical water quality parameters, contaminant concentrations, photosynthetically available light, and nutrients. Studies have predominantly focussed on sites in the Calliope and Boyne estuaries and the Western Basin, Inner Harbour and Mid Harbour zones (between Facing Island and The Narrows) although more recent work has included reference sites within the zones of Outer Harbour and Rodds Bay, and sites in Queensland coastal waters. A large number of the investigations have focussed on water quality and its potential to impact on the conservation of significant marine species (e.g. seagrass meadows, cetaceans, corals) found in Port Curtis. This includes significant research into the benthic photosynthetic light available to benthic primary producers, and the impacts that reduced light through increased turbidity and total suspended solids have on these species.

Historical studies show the water quality of Port Curtis is strongly correlated with tidal state and associated bedload resuspension. Previous studies have described the Port as having a large tidal range (up to approximately 4 metres) and the associated tidal regime induces high current velocities in the main channel. The harbour has naturally high turbidity during large spring tides, associated with new and full moon events, which generate strong tidal currents eroding and resuspending fine sediments. Turbidity at the surface is generally lower than at the bottom of the water column due to bottom sediment resuspension.

The estuary receives freshwater flows from the Boyne and Calliope Rivers, along with occasional flows through The Narrows from the Fitzroy River. It is a well-connected estuary which allows dissolved material to be dispersed evenly, although material does not as readily leave the estuary to the offshore environment. Hydrodynamic studies have found that dissolved material within Port Curtis has difficulty in moving outside coastal waters as a result of the estuary's flow regime, which may contribute to some metals bioaccumulating in Port Curtis biota.

Contaminant pathway studies, have found that flows from the Fitzroy River have the potential to supply contaminants to Port Curtis via The Narrows to the north and that various industrial and other anthropogenic discharges, along with mobilisation of contaminants from mangrove regions, are likely to contribute to trace distributions in Port Curtis.

Dissolved oxygen and pH also show increasing gradients of dissolved oxygen and decreasing acidity from the Inner Harbour towards the Outer Harbour and open coastal waters, typical of estuarine environments.

Project baseline water quality monitoring program

As part of the Project Environmental Impact Statement a water quality monitoring program was undertaken by Vision Environment from 1 June 2014 to 5 July 2015 to provide interpreted baseline water quality data. Water quality monitoring methods included continuous automated water quality loggers, sedimentation rates recorded with acoustic altimeters, benthic photosynthetically available radiation monitoring, and discrete water sampling from a vessel for analysis of suspended solids, metals, nutrients and organic contaminants. Baseline water quality data was also supplemented by data collected through the Port Curtis Integrated Monitoring Program and the Gladstone Healthy Harbour Partnership which conduct long term water quality monitoring within the Port of Gladstone.

Ambient baseline data was collected and analysed to account for spatial, temporal and vertical variations.

Eight monitoring sites (labelled CD1, CD2, CD3, CD4, CD5, P5/MH10, P2B/WB50, and QE3) were positioned across Port Curtis from The Narrows to open coastal waters east and south of Facing Island. The location of each monitoring site was guided by the results of preliminary hydrodynamic modelling (BMT WBM 2014), and located inside and outside of the Project direct impact and potential indirect impact areas, as well as in the vicinity of known sensitive receptors (i.e. seagrass meadows and coral reefs).

Water quality monitoring sites were spread across a wide area throughout Port Curtis and as a result, the factors influencing the background conditions at the surface and seabed varied between some sites. For the purposes of this report the water quality monitoring sites were split into two groups, 'inshore' and 'offshore' (refer Figure 2), for the purposes of discerning environmental influences on water quality, and based on historical knowledge of Port Curtis waters. The inshore sites were generally characterised by a shallow environment (approximately 5 metres depth), highly tidally influenced with a large tidal run (approximately 0.4 metres per second) with a well-mixed depth profile of the water column, including little to no stratification during rain events (i.e. sub-surface measurements are similar to those above benthos). The offshore sites were generally characterised by a deeper water environment (generally > 15 metres) highly influenced by wind and wave action affecting the resuspension of material from the benthos. The two water quality monitoring groups include the following sites:

- Offshore sites: CD1, CD2, CD3, CD4 and CD5
- Inshore sites: P5/MH30, P2B/WB50 and QE3.

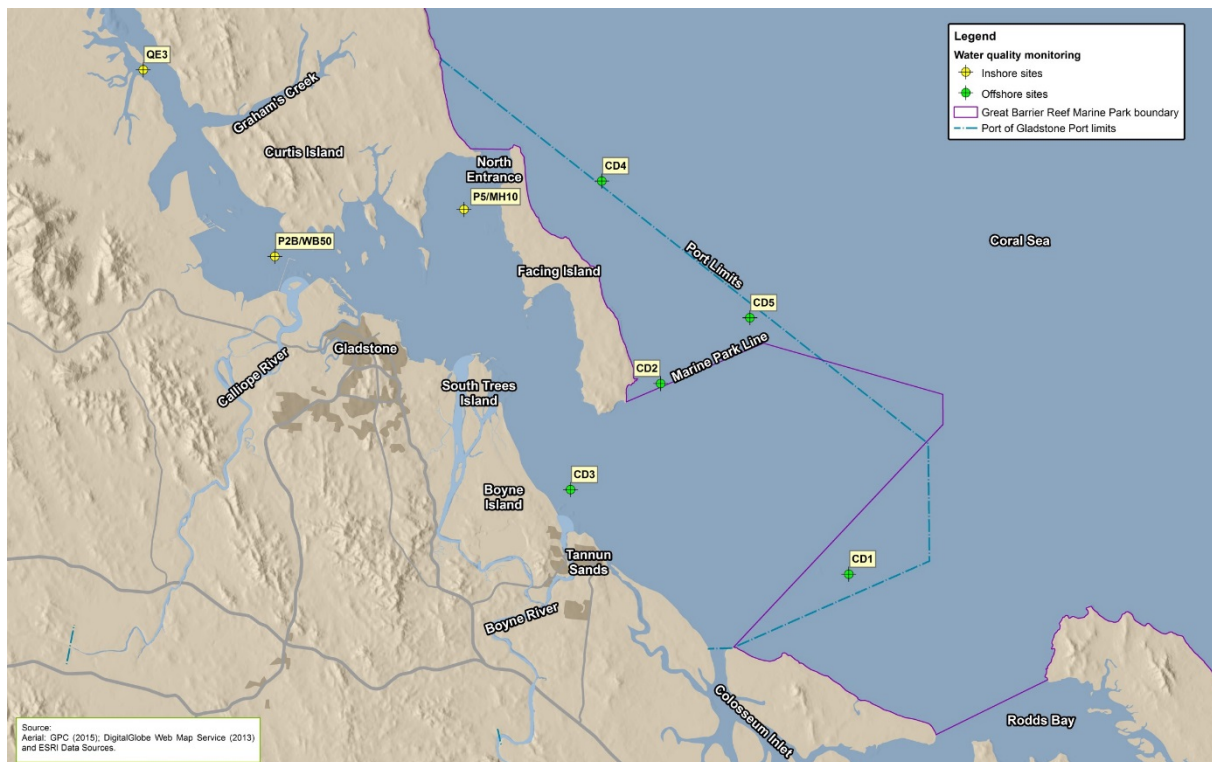


Figure 2 Water quality monitoring sites

Note monitoring site CD3 was grouped among the offshore sites, although the site's location exhibits both inshore and offshore characteristics (CD3 lies within the Mid Harbour zone, close to the Outer Harbour zone boundary).

Monitoring at offshore sites included both sub-surface and benthic water quality monitoring equipment, while inshore sites had sub-surface monitors only (due to a well-mixed water column). Water quality in Port Curtis can vary between the wet and dry seasons, therefore water quality was monitored during both wet season (1 November to 30 April) and dry season (1 May to 31 October) periods between June 2014 to July 2015.

For reference purposes water quality results have been compared against their relevant water quality objectives under the *Environmental Protection (Water) Policy 2009*, specific to each zone.

Key findings from the Project baseline water quality monitoring program

Turbidity

The results of the Project Environmental Impact Statement baseline water quality monitoring program indicate surface turbidity was significantly higher at inshore sites than at offshore sites with the highest turbidity results recorded during spring tides. Of the inshore sites, consistently higher turbidity values during both wet season and dry season were recorded in the inner estuarine areas of Port Curtis in the Narrows and the Western Basin. Oceanic forces are likely to influence turbidity in the Mid Harbour in waters close to the North Entrance between Curtis Island and Facing Island. Turbidity results were higher in the wet season at the monitoring sites in the Mid Harbour and The Narrows.

Benthic turbidity at each offshore monitoring site was significantly higher than surface turbidity which is most likely due to the proximity of the loggers to the benthic sediment. The offshore benthic sediments tended to be resuspended during strong winds and elevated wave heights. Turbidity at the majority of offshore sites also tended to be significantly higher during the wet season than during the dry season.

Higher turbidity was evident during the wet season across both inshore and offshore monitoring sites. Significant weather events, such as Tropical Cyclone Marcia in mid-February 2015 resulted in short term elevated turbidity at offshore sites, particularly at the seabed. Significant rain events recorded in mid-January and mid-February 2015 resulted in elevated turbidity at inshore sites. One offshore site located at the mouth of the Boyne River, tended to display more elevated benthic turbidity for several weeks during increased wind speed events following Tropical Cyclone Marcia in mid-February 2015. It is likely that fine sediments washed down from the Boyne River were being easily resuspended during these events.

When comparing turbidity results across the offshore sites, the monitoring sites closest to land masses in Port Curtis exhibited the highest turbidity values at both the surface and seabed, during both the wet and dry seasons. These sites also showed some effects from tidal action. The offshore monitoring sites located furthest offshore, east of Facing Island, recorded the lowest turbidity values across all monitoring sites, particularly during the dry season. Turbidity at offshore sites located in deeper waters was found to be less affected by wind driven resuspension.

Other physicochemical parameters

A spatial pattern was evident across the eight monitoring sites in regard to pH and dissolved oxygen, with inshore monitoring sites in The Narrows and the Western Basin exhibiting consistently lower values, similar to what has been previously recorded in other studies in Port Curtis. At these sites, diurnal patterns for dissolved oxygen due to plant photosynthesis and respiration was evident, particularly during the warmer months. At the offshore sites, only marginal differences were evident between benthic and surface temperature, conductivity, pH and dissolved oxygen, indicating the offshore water column was generally well-mixed, similar to the inshore sites. This was supported by water quality data collected from depth-profiling during monthly water sampling.

Sedimentation

To record the rate of sediment movement at each monitoring site (either deposition or erosion of sediment), acoustic altimeter instruments were positioned at the seabed at each monitoring site. Similar to a side-scan sonar, the instruments record seabed level measurements (i.e. millimetre scale) using a high frequency acoustic sensor. The two forms of information recorded by the altimeters were instantaneous bed level change (bed level flux) and cumulative bed level change over a given period.

Bed level flux at the furthest offshore sites was more stable and appeared to be wind driven. At those offshore monitoring sites located closest to land masses in Port Curtis bed level flux was influenced by significant rain events and spring tides. This was particularly evident during Tropical Cyclone Marcia in mid-February 2015, in which wind direction appeared to highly impact whether sediment was deposited or eroded. Bed level flux was quite volatile at the offshore monitoring site close to Facing Island, where erosion was most commonly recorded. Overall deposition was primarily recorded at the offshore site located at the mouth of the Boyne River, particularly after significant rain events. Erosion and deposition was generally equal at most inshore sites, resulting in low cumulative bed level change. Although increased sediment flux corresponded with increases in turbidity, there appeared to be a critical minimum threshold of turbidity for offshore and inshore sites for this to occur in some cases.

Benthic photosynthetically active radiation

Previous research has determined the light requirements for certain species of seagrass in Port Curtis, which has been used as an ecological trigger value during previous Port of Gladstone capital and maintenance dredging campaigns. Benthic photosynthetically active radiation was therefore monitored at all offshore monitoring sites using underwater light sensors, along with a 'control' site on land to record surface photosynthetically active radiation. Benthic photosynthetically active radiation was recorded at inshore areas in conjunction with seagrass surveys undertaken by James Cook University TropWATER, and are reported in the Project *Ecology and Matters of National Environmental Significance Technical Report*.

The main variables found to influence the benthic light climate at monitoring sites were the daily light integral, turbidity and water depth. Although the daily light integral, expressed as moles per square metre per day, was higher on average during the wet season, when daylight periods are longer, benthic photosynthetically active radiation was significantly higher at all five benthic sites in the dry season, suggesting that ambient photosynthetically active radiation was only a partial influence on variations in benthic photosynthetically active radiation at these sites. Benthic photosynthetically active radiation was significantly higher at the shallower offshore sites which did not record the lowest turbidity values. Despite the relatively shallow depth (~ 6 metres), benthic photosynthetically active radiation was lower at site CD3, located at the mouth of the Boyne River. This was likely due to the Boyne River causing elevated total suspended solids in water column.

Water sample analysis

Water samples were collected at each monitoring site for laboratory analysis of total suspended solids, nutrients, and metals (all collected monthly), and organic compounds (collected quarterly). Samples for total suspended solids were collected at three depths at each offshore monitoring site (sub-surface, mid-column, and seabed). Due to the well-mixed water column of the inshore areas, only one sample was collected (at the sub-surface) at these monitoring sites.

Surface total suspended solids were significantly higher in samples collected from the inshore monitoring site located in the Western Basin area, outside the mouth of the Calliope River. Samples from other inshore sites exhibited intermediate total suspended solids concentrations.

At offshore sites, total suspended solids were significantly higher at the seabed than at mid-column and the surface. As expected, a strong and significant correlation was evident between total suspended solids results and turbidity, indicating that as total suspended solids increased, so did turbidity. However, no significant seasonal difference for total suspended solids could be inferred from monthly sample results over the baseline monitoring period.

Nutrients (total phosphorus, total nitrogen and orthophosphate) and chlorophyll a were significantly higher in samples from the inshore monitoring sites located in the Western Basin and The Narrows zones, with intermediate concentrations found in samples from the Mid Harbour inshore site. Results were significantly lower in samples from the offshore sites, indicating a geographical gradient which has been previously recorded in Port Curtis. No statistically significant seasonal variation in nutrient concentrations could be inferred from monthly sample results, although chlorophyll a concentrations were significantly higher during the wet season.

As with nutrient results, concentrations of a number of metals (including total aluminium, lead, iron and vanadium, and total and dissolved cobalt, copper, nickel and manganese) were significantly higher in samples collected from the inshore monitoring sites located in the Western Basin and The Narrows zones, with intermediate concentrations found in samples from the Mid Harbour inshore site. Again, this geographical gradient has been previously recorded in Port Curtis.

Total and dissolved copper, nickel, vanadium and dissolved manganese were the only metals to exhibit seasonal differences, being significantly higher in samples collected during the wet season compared to the dry season. Total suspended solids sample concentrations were strongly correlated with a number of total metals, suggesting that a high proportion of metals are bound to suspended particulates in the water column. This is supported by the considerably lower dissolved concentrations found for most metals.

Water quality objectives for metals were most notably exceeded in samples from QE3, where a 99% species protection level is adopted, including concentrations of total aluminium in both the wet season and dry season, and total and dissolved cobalt and copper in both seasons. Total aluminium sample concentrations from all sites were above the water quality objectives during both wet and dry seasons, with the exception of samples from CD4 and CD5 which exceeded during the wet season only. However, dissolved aluminium sample concentrations remained well below the water quality objectives at each site. Additionally, in samples from site P2B/WB50, concentrations of total copper in both the wet and dry season were above the water quality objectives, with dissolved concentrations remaining below the water quality objectives. Although Australian Water Quality Guideline exceedances of certain total metals in Port Curtis have been recorded previously, the majority of dissolved and therefore potentially bioavailable metals have generally been below these guidelines, and are therefore not considered current contaminants of concern in terms of biological or toxicological risk for this Project.

None of the organic compounds analysed were detected in any samples collected from any sites during the four sampling occasions of the baseline data collection period.

Overall the findings of the Project Environmental Impact Statement baseline water quality monitoring program were generally consistent with results from previous water quality monitoring programs undertaken in the Port.

1 Introduction

1.1 Purpose and objective

The purpose of this Water Quality Technical Report is to describe the past and current water quality of Port Curtis, and to assess the potential water quality impacts of the proposed Gatcombe and Golding Cutting Channel Duplication Project (the Project). This report also identifies the mitigation measures to be implemented during the Project activities to minimise the potential impacts to water quality. This report has been prepared by Aurecon and Vision Environment Queensland (VE). The proponent of the Project is the Gladstone Ports Corporation Limited (GPC).

The objective of this report is to address the Queensland Government's Environmental Impact Statement (EIS) Terms of Reference (ToR) and the Commonwealth Department of the Environment and Energy (DoEE) Guidelines for an EIS, to describe the existing water quality environment within areas which have the potential to be impacted by Project activities. Figure 1.1 shows the location of the Project.

This report has been prepared with information from a combination of available information sources, including desktop reviews of previous studies in the area, a baseline field monitoring program, and additional baseline data provided from independent monitoring programs.

By describing the water quality values of the Port, the potential impacts of the Project on these values, including any cumulative impacts related to other projects and activities, have been assessed and included in the Project EIS.

1.2 Project description

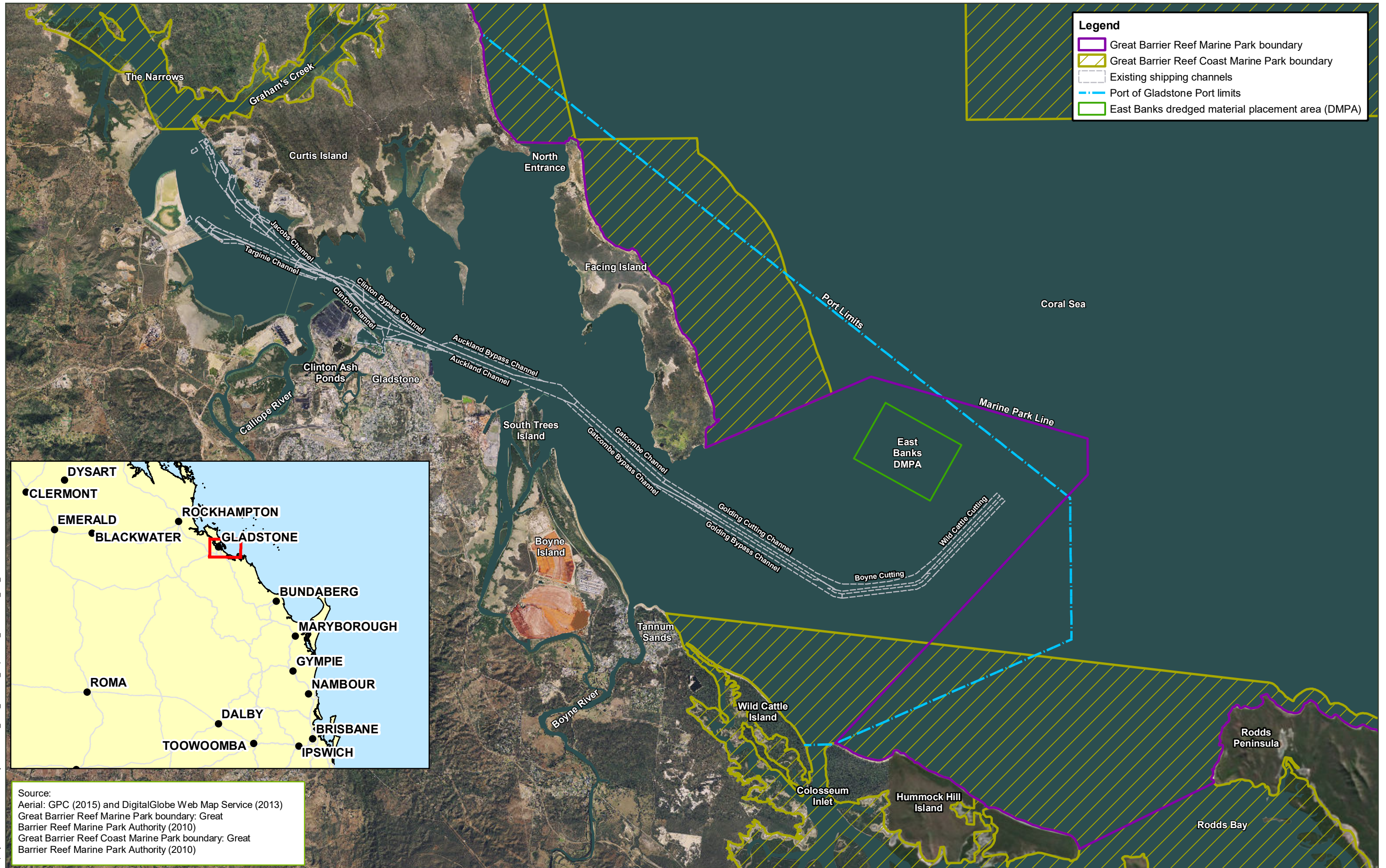
The Gatcombe and Golding Cutting Channel Duplication dredging is required to improve Port of Gladstone operational and economical efficiencies, and improve the existing and future safe passage of vessels within the Port as throughput and associated vessel numbers increase, and the portion of predicted Capesize vessels also increases in the future.

1.2.1 Location of shipping channels to be dredged and material volume

The major dredging component of the Project involves the duplication of the existing Gatcombe and Golding Cutting shipping channels to provide a permanent duplicated channel parallel to the main shipping channel with a sufficient depth to allow an improved two-way passage into the Port under all weather and tidal conditions. The location of the existing maintained channel and the proposed duplicated channels are shown in Figure 1.2.

The proposed duplicated channel will be approximately 15 kilometres (km) long and dredging is proposed to be undertaken to an ultimate depth of -16.1 metres (m) lowest astronomical tide (LAT), with a channel width (toe to toe) of 200m. The volume to be dredged (i.e. above -16.1m LAT) is 12.6 million cubic metres (Mm³) of seabed material (including dredging tolerance) requiring removal and placement during the Project.

Initial dredging of approximately .25Mm³ of seabed material (including dredging tolerance) is also required to establish a barge access channel to allow barges to transport dredged material from the Gatcombe and Golding shipping channels to a barge unloading facility (BUF) for unloading and placement within the Western Basin (WB) and Western Basin Expansion (WBE) reclamation areas.

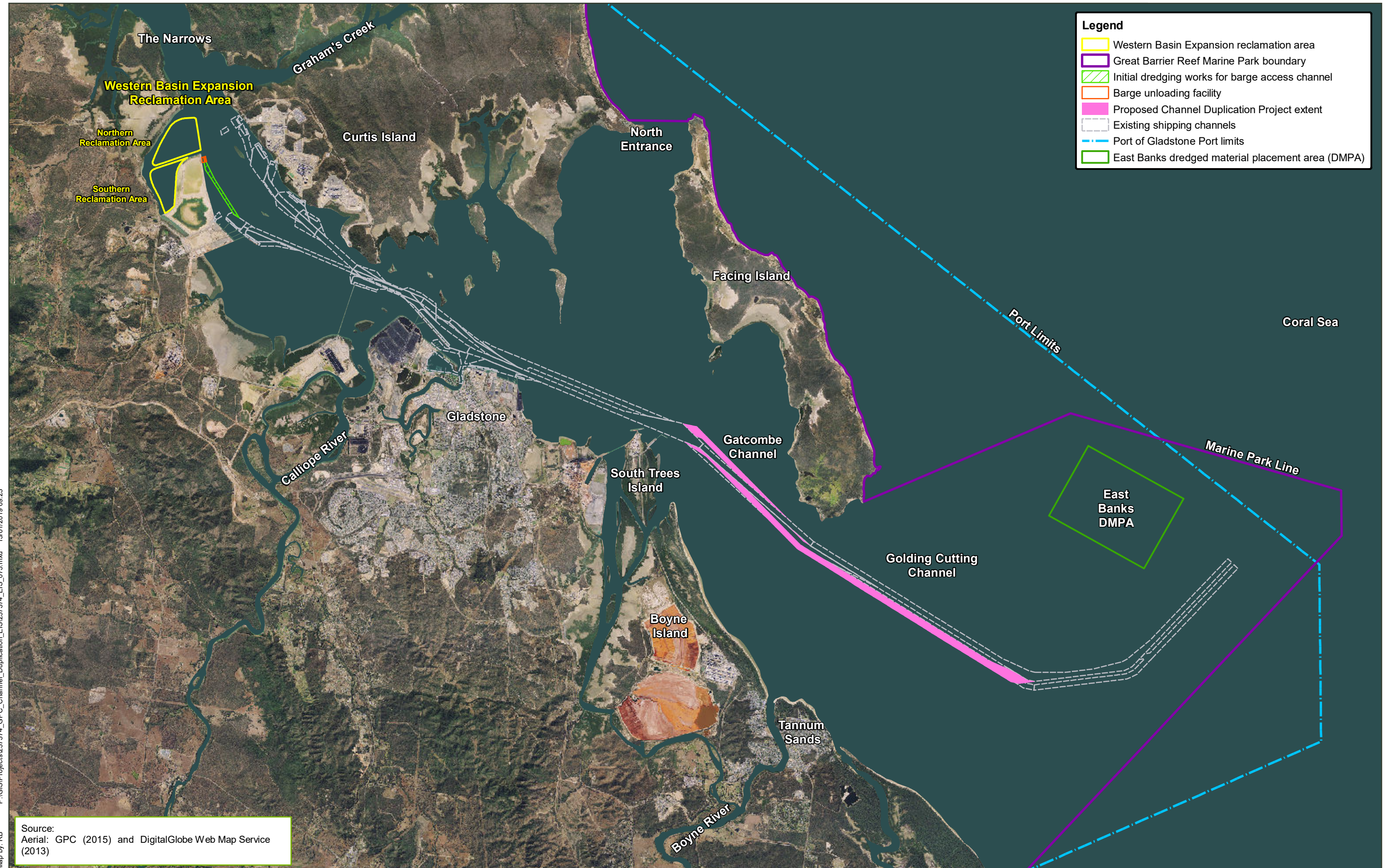


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Gatcombe and Golding Cutting Channel Duplication Project

Figure 1.2: Areas to be dredged and Western Basin Expansion reclamation area

Two dredging campaign options are proposed and will be selected upon availability of dredging equipment and operations within the Port of Gladstone. At this stage it is envisaged that the Project dredging will be undertaken over two dredging campaigns. However should the growth in deep draft Capesized vessels justify an early need for the final design channel depth, the two stages will be combined into one continuous dredging campaign. The likely volumes and timing of each dredging campaign option are outlined in Table 1.1.

There is potential for dredging to commence before and after 2023 subject to actual and predicted Port throughput and associated vessel movements over the next 5 to 10 years.

Table 1.1 Dredging campaign and staging options, location and volumes

Stage	Location	Timeframe – likely start date or later (duration)	Design depth (m LAT)	Volume (Mm ³) ¹
Initial dredging works	Barge access channel (to the north of the Fisherman's Landing swing basin)	2023 (6.5 weeks)	-7.0	0.25
1	Gatcombe and Golding Cutting Channels	2023 or later (33 weeks)	-13.5	7.25
2	Gatcombe and Golding Cutting Channels	2026 or later (25 weeks)	-16.1	5.35 ²
Singular campaign	Initial dredging works and Gatcombe and Golding Cutting Channels	2023 or later (64.5 weeks)	-16.1	12.60

Table notes:

- 1 Includes 0.3m (depth) allowance for average dredging tolerance
- 2 The Stage 2 dredged material volume assumes that the barge access channel is maintained at the Project design depth as part of the Port-wide maintenance dredging

1.2.2 Dredging equipment and dredged material placement scenarios

A Dredged Material Placement Options Investigation (DMPOI) and supplementary DMPOI were undertaken as part of the EIS.

The reclamation area option assessment and analysis undertaken during the EIS process which identified the WBE reclamation area as the preferred location to beneficially reuse the Project dredged material.

Based on the nature and volume of the material to be dredged, availability and limitations of dredging equipment, and location of the WB and WBE reclamation areas, the Project dredging methodology adopted for the EIS includes:

- A trailing suction hopper dredger (TSHD) and a cutter suction dredger (CSD) dredging a barge access channel from the Fisherman's Landing swing basin to a BUF. The dredged material from the barge access channel will be placed directly into the existing WB reclamation area by the TSHD and CSD.
- A large sized TSHD (i.e. 20,000 cubic metres (m³) hopper capacity with production in the order of approximately 0.2Mm³ per week) dredging the Gatcombe and Golding Cutting channel duplication areas
- The dredged material from the TSHD will be placed into a series of large barges (i.e. four barges with a capacity of approximately 7,000m³ to 10,000m³) which will transport the material to the BUF adjacent to the existing WB reclamation area, to be unloaded by large excavators into trucks for placement within the existing WB and WBE reclamation areas
- The dredged material placed within the reclamation area will be managed for dewatering purposes with licenced discharge of excess water into Port Curtis.

The global dredging fleet is limited and access to specific size plants at the required Project time cannot be guaranteed. It is also important to note that the proposed dredging works will undergo a tendering process. The available dredger equipment to execute the dredging works will depend on the market at the time of tendering and any environmental and technical performance requirements specified in the Project approval conditions.

The final dredging methodology adopted for the Project will be subject to Maritime Safety Queensland (MSQ) Regional Harbour Master acceptance of the successful dredging contractor's detailed execution plan. The dredging contractor will also need to comply with MSQ's Standard for Marine Construction Activities within Gladstone Harbour (DTMR 2013).

1.2.3 Navigational aids

The key operational infrastructure associated with the Project is the removal of two existing navigational aids (i.e. one front lead light and one rear lead light), the relocation of five existing navigational aids (i.e. beacons and lead lights) and the installation of five new navigational aids (i.e. beacons and lead lights). Outer bund wall warning lights will be installed every 100m along the outer WBE seaward reclamation area bund wall and BUF in accordance with MSQ requirements.

MSQ requires navigational aids to be located in the Gatcombe and Golding Cutting Channels to ensure safe boating and passage for commercial vessels. The proposed location and configuration of the navigational aids (refer Figure 1.3) are in accordance with the recommendations of the International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) and were developed in consultation with the Regional Harbour Master.

1.2.4 Final land uses of reclaimed land

Following the completion of the filling operations and a period of several years to allow dewatering and consolidation of the dredged material within the WB and WBE reclamation areas, GPC will undertake surface stabilisation works where practical for the portion of the reclamation areas that have achieved the final Project surface level. The final land uses for the WB and WBE reclamation areas post Project dredging (Stages 1 and 2) will be stormwater ponds and potential Port development area with three to four wharves attached to the northern area (refer Figure 2.25).

The eastern side of the barge dock wall within the BUF will form the wharf line for a future shipping berth for the WB port land when it is no longer required for unloading dredged material from Port dredging campaigns.

1.2.5 Maintenance dredging

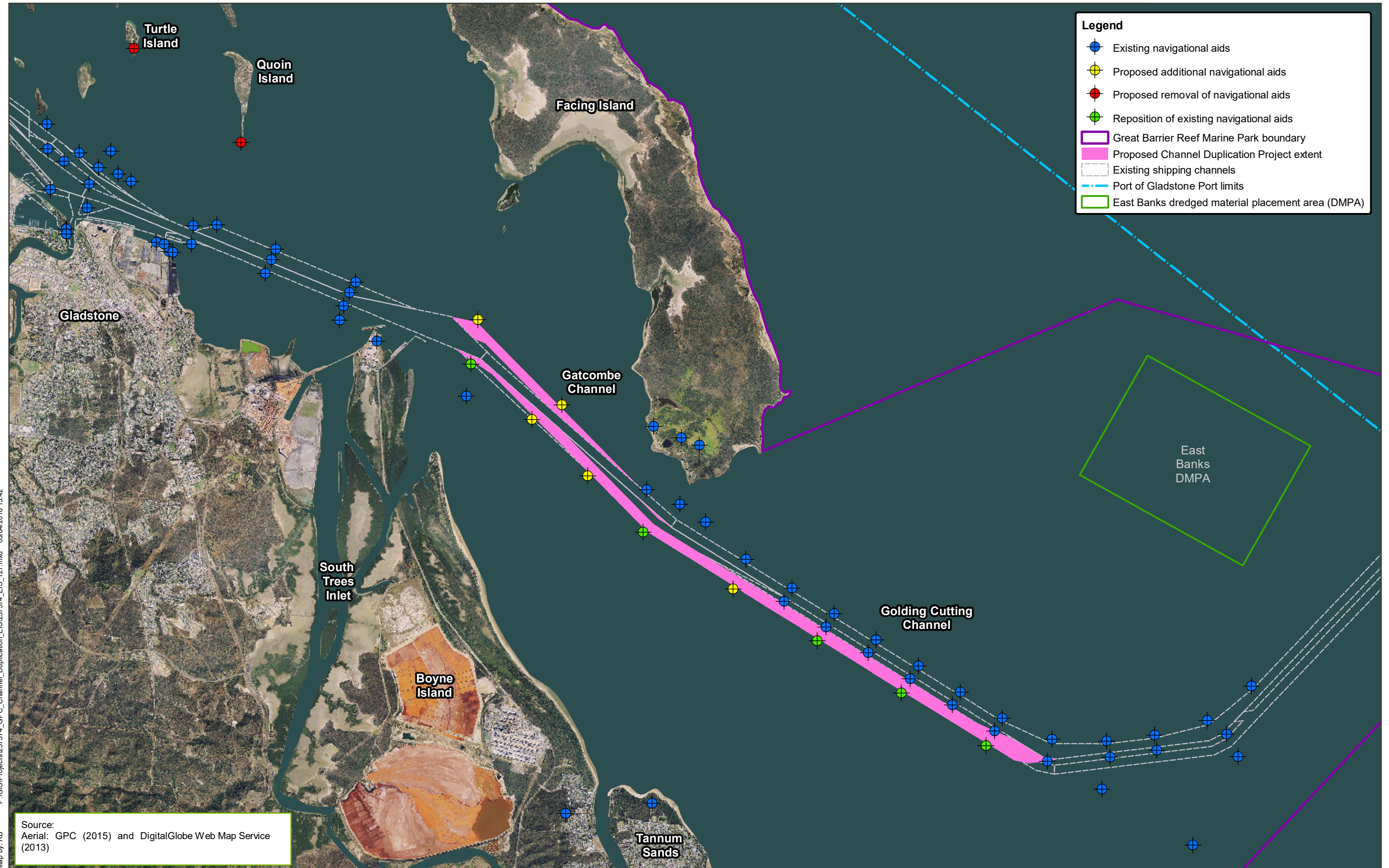
Maintenance dredging associated with the Project will be undertaken as part of the Port-wide maintenance dredging program.

1.3 Report structure

This report comprises the following sections:

- Section 2 Methodology for describing the existing water quality environment
- Section 3 Summary of previous water quality studies in Port Curtis
- Section 4 Project baseline water quality data collection.

Appendix B within this report contains the baseline water quality data collection study undertaken to support the Project EIS.



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1.4 Aspects of water quality monitoring

The physical, chemical and biological aspects of water provide valuable indications of the overall health of the ecosystem. The physical components (e.g. light, temperature mixing, flow, habitat) and chemical components (e.g. organic and inorganic carbon, oxygen, nutrients) of an ecosystem largely dictate what lives in that ecosystem, and the structure of the food web. Natural physical and chemical water quality variations can have important consequences for aquatic ecosystems. Human activities can cause variations in the living and non-living components of a system that can lead to biological changes more dramatic than those that occur naturally (Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand (ANZECC/ARMCANZ) 2000a).

Physical and chemical stressors include natural water quality parameters, nutrients, biodegradable organic matter, dissolved oxygen (DO), turbidity, total suspended solids (TSS), temperature, salinity, pH and changes in flow regime. Physical and chemical stressors are major contributors to changes in aquatic ecosystems, such as nuisance growth of aquatic plants, smothering of organisms living in aquatic environments, and stress to or death of native freshwater and marine fish. They may also modify the affects of toxicants.

The physical and chemical water quality components that are regularly monitored in the vicinity of the Project impact areas are outlined in Table 1.2 and Table 1.3, respectively.

Table 1.2 Physical water quality indicators

Indicator	Stressor	Impact on water quality
Turbidity and suspended solids	Increase	Turbidity is an optical property of water. The turbidity or 'muddiness' of water is caused by the presence of suspended solids and colloidal matter consisting of suspended clay, silt, phytoplankton and detritus. The main potential impact of these particles is the reduction of light penetration and thus the affect on primary producers. Turbidity is a measure of the degree to which light is scattered as it passes through water. Suspended solids are the suspended or colloidal particulate matter in the water column which do not settle out (e.g. sediment, silt). Many contaminants (e.g. heavy metals, nutrients, toxic organic compounds) have the potential to bind to suspended solids and be transported through aquatic systems. Suspended solids can also cause adverse effects by smothering benthic organisms and their habitats, and can cause direct adverse effects to fish and other marine life due to loss of food sources.
Light	Reduction	Water clarity and colour are changed by the attenuation of light (i.e. absorption and scattering) by suspended solids and dissolved matter (e.g. sediment, organics, chemicals and nutrients) (Kirk 1983, 1988, cited in ANZECC/ARMCANZ 2000b). Light is essential for an aquatic ecosystem to function properly. Plants require light to grow (i.e. autotrophs) and other organisms (i.e. heterotrophs), which feed on plants are therefore indirectly dependent on light to produce their food. When light quality (colour) and quantity (clarity and penetration) are changed significantly, the effects can cascade throughout an ecosystem from the highest plants and animals right down to the microorganisms. Management options for light changes are inextricably linked to managing elevated turbidity and suspended solids. Note: Benthic photosynthetically active radiation (BPAR) baseline results and the relationship with sensitive ecological receptors are presented in the <i>Project Ecology and Matters of National Environmental Significance Technical Report (Aurecon 2018a)</i>.

Indicator	Stressor	Impact on water quality
Water temperature	Increase or decrease	Aquatic ecosystem functioning is very closely regulated by temperature. Biota, physical and chemical processes like oxygen solubility and hydrophobic interactions are sensitive to temperature changes. Temperature closely regulates ecosystem functioning both directly (e.g. by influencing primary production) and indirectly (e.g. loss of biota as a consequence of loss of habitat). An organism's growth, metabolism, reproduction, mobility and migration patterns may all be altered by changes in ambient water temperature.
Salinity/ Electrical Conductivity	Increase or decrease	Salinity and electrical conductivity (EC) are measures of the total concentration of inorganic ions (salts) in the water. Measures of salinity and EC indicate whether the chemical nature of aquatic ecosystems is being altered and provides a warning of the potential loss of native biota. Aquatic organisms are classified as stenohaline (able to adapt to only a narrow range of salinities) or euryhaline (able to adapt to a wide salinity range, up to 10,000 to 15,000 milligrams per litre (mg/L)) with most organisms being stenohaline. Salinity changes may affect aquatic organisms in two ways: ■ Direct toxicity through physiological changes (particularly osmoregulation) – both increases and decreases in salinity can have adverse affects ■ Indirectly by modifying the species composition of the ecosystem and affecting species that provide food or refuge

Source: ANZECC/ARMCANZ (2000b)

Table 1.3 Chemical water quality indicators

Indicator	Stressor	Impact on water quality
pH	Increase or decrease	pH is a measure of the acidity or alkalinity of water and has a scale from 0 (extremely acidic) to 7 (neutral), through to 14 (extremely alkaline). pH changes in aquatic ecosystems need to be measured for two reasons: ■ Low pH can cause direct adverse affects on fish and aquatic insects (USEPA, CCREM cited in ANZECC/ARMCANZ 2000b) ■ Changes in pH changes (particularly reduced pH) can result in the toxicity of several pollutants (e.g. ammonia, cyanide, aluminium) to significantly increase (Collier & Winterbourn, Alabaster & Lloyd, CCREM cited in ANZECC/ARMCANZ 2000b) Most marine waters have a pH of around 8.2
Dissolved oxygen	Reduction	The DO concentration measured in a waterbody reflects the equilibrium between oxygen-consuming processes (e.g. respiration) and oxygen-releasing processes (e.g. photosynthesis and the physical transfer of oxygen from the atmosphere to the waterbody). Measures of DO indicate whether there is a disturbance to these competing processes and defines the living conditions for aerobic (oxygen requiring) organisms. Low DO concentrations can result in adverse effects on many aquatic organisms (e.g. fish, invertebrates and microorganisms) which depend upon oxygen for their efficient functioning. At reduced DO concentrations many elements and compounds become increasingly toxic (e.g. zinc, lead, copper, hydrogen sulfide and ammonia) (Davis cited in ANZECC/ARMCANZ 2000b).
Nutrients (phosphorus and nitrogen)	Increase of total nitrogen and total phosphorous concentration	Nitrogen (N) and phosphorus (P) are nutrients essential to life on earth. N makes up about 78% of the atmosphere, and P makes up about 0.1% of the earth's crust. N and P, like all nutrients, are essential to ecosystem biota (life-forms) at certain concentrations. However, an excess of N and P can stimulate nuisance growths of aquatic plants in waterbodies. Measures of N and P indicate how eutrophied (nutrient polluted) a waterbody is and how susceptible it will be to nuisance plant growths occurring. Although nutrients alone cannot indicate whether a waterbody actually has a nuisance plant problem, increased Chlorophyll a concentrations indicate that nuisance plants, algae or cyanobacteria are actually growing and that appropriate management action should be taken.

Indicator	Stressor	Impact on water quality
Inorganic compounds	Increase	Inorganic compounds can include heavy metals, fluoride, cyanide and organotins. Heavy metals are natural constituents of rocks and soils but all have the potential to be toxic to biota above certain threshold concentrations. Unnatural quantities of metals such as arsenic (As), cadmium (Cd), copper (Cu), mercury (Hg), lead (Pb), nickel (Ni) and zinc (Zn) are released into the aquatic environment through agricultural, urban stormwater and wastewater discharges. Once dissolved in the water column, metals may be accumulated by marine invertebrates from solution via passive uptake across permeable surfaces such as gills and the digestive tract (Cited in Great Barrier Reef Marine Park Authority (GBRMPA) 2010). Organism growth, reproduction and behaviour are potentially affected by elevated environmental metal concentrations (Langston 1990). Metals and metalloids in water quality risk assessments Particulate metals in suspension and in bottom sediments are not generally directly available to aquatic organisms (bioavailable) and it has been well established that the chemical form or speciation of metals critically influences their bioavailability and toxicity to aquatic organisms (ANZECC/ARMCANZ 2000b). Water quality trigger values for metals and metalloids in aquatic ecosystems are typically based on 'total metals' results (i.e. dissolved metals plus those in particulate form or bound to sediments and colloidal particles). The comparison of total concentrations will generally overestimate the fraction that is bioavailable. Given the major toxic effect of metals comes from the dissolved fraction, the dissolved metal concentration alone is important to consider against the relevant trigger values. To further assess the risks of metals in water to ecological health, the concentration of the bioavailable species of the metal or metalloid, can be determined. Furthermore, the risks of toxicity and bioaccumulation on aquatic species may be required if metals are found to be bioavailable. The rates at which metals are solubilised from particulates is closely linked to other water quality parameters including DO, pH, alkalinity, salinity and temperature (Waldichuk 1985). Metals and metalloids in relation to acid sulfate soils Acid sulfate soils (ASS) are soils and other soft sediments that contain iron sulphides (commonly pyrite) that occur naturally around Australia's coastline particularly in low-lying areas of Queensland. These iron sulfides are stable under oxygen-free (typically waterlogged) conditions. If the iron sulfides are exposed to atmospheric oxygen they can be oxidised and this process turns pyrite into sulfuric acid which can release dissolved metals like aluminium, iron and other metals. The disturbance of acid sulfate sediments in oxygenated waters can have a similar reaction and release dissolved metals and metalloids into the water column. The adverse impacts of ASS in coastal lowlands can include poor water quality, death of aquatic fauna and pathogens in fish assemblages. Contaminants in pore water Sediment pore water is the water that occupies the spaces between sediment particles. Pore waters have the potential to be a major contaminant exposure pathway because many benthic organisms have direct contact with pore waters. The measurement of dissolved metal or metalloid concentrations in sediment pore waters and comparison to water quality guidelines is useful for assessing the risk posed by these contaminants (Batley and Simpson 2016).

Indicator	Stressor	Impact on water quality
Organic compounds	Increase	Organic compounds can include detergents and surfactants, hydrocarbons derived from human activities (e.g. petroleum hydrocarbons), a large number of pesticides, phenolic compounds, and polychlorinated biphenyls (PCBs). Most of these originate from domestic, agricultural or industrial products and activities. The bioavailability, toxicity, and environmental fate of individual organic compounds are wide ranging. Details can be found in ANZECC/ARMCANZ (2000b).

Sources:

1. ANZECC/ARMCANZ (2000a)
2. Great Barrier Reef Marine Park Authority (2010)

2 Methodology

2.1 Overview

The existing environmental values of the area potentially impacted by the Project are comprised of a variety of marine, coastal and terrestrial habitats from the southern end of The Narrows to coastal waters east and south of Facing Island. The main coastal area of the Port is described as a shallow, semi-enclosed estuarine system, with the Calliope River entering Port Curtis approximately 10km to the south of The Narrows and the Boyne River entering approximately 5km to the southwest of the Golding Cutting shipping channel. Coastal habitats within Port Curtis are known to include intertidal habitats comprising sand and mudflats, mangroves, salt marsh, rocky reefs and seagrass meadows, and sub-tidal habitats comprising seagrass meadows, soft and hard coral communities, macroalgae communities and open soft substrate.

The Port Curtis region (i.e. coastal region between Port Alma and Rodds Peninsula) contains several areas of high conservation value either within or adjacent to the operational Port of Gladstone. The marine and intertidal areas (up to LAT) of the Port are located within the Great Barrier Reef World Heritage Area (GBRWHA), with the Port offshore areas within the Great Barrier Reef Marine Park (GBRMP).

The Port also forms part of the Rodds Bay Dugong Protection Area, and the Colosseum Inlet and Rodds Harbour Fish Habitat Area are located in the southern portion of the Port Curtis region.

Port Curtis comprises the Boyne, Calliope and Curtis Island basins, Gladstone Harbour, The Narrows and adjacent estuarine/coastal waters. The greater area contains several water types from freshwaters, estuarine and coastal waters. The two different but connected water types, as defined in the Queensland Water Quality Guidelines (QWQG), most relevant to the baseline assessment are outlined below.

2.1.1 Lower estuary/enclosed coastal waters

Enclosed coastal/lower estuarine waters lie at or near the mouth of an estuary channel, and are frequently subject to some degree of residual mixing with inflowing fresh water. As such, they fall within the broad definition of an estuary. They include shallow coastal waters in straits or enclosed bays adjacent to the mouth of inflowing streams or estuaries. They also include the most downstream reach of the main channel of the estuary, which exchanges with coastal waters on every tide (EHP 2009a).

2.1.2 Open coastal waters

Open coastal waters include all coastal waters except those with some residual influence from inflowing streams (enclosed coastal waters). Therefore, open coastal waters extend outwards from the outer limit of enclosed coastal waters, or directly out from the coastline if there are no enclosed coastal waters nearby, to the three nautical mile limit of the state (EHP 2013). The source of mapping for open coastal waters is either a depth contour or other defined spatial identifier based on the decision rules outlined above (e.g. salinity, other water quality parameters), or in the absence of these, expert judgement (EHP 2009a).

Most waters in the Port are described as 'moderately disturbed' (MD). Waters in The Narrows area to the north are described as 'slightly disturbed' (SD) and waters outside of the Port and seaward of the plume line (into the GBRMP) adopt a 'high ecological value' (HEV).

To describe existing water quality conditions within the potential Project impact areas, a large range of data sources have been used comprising:

- Previous water quality investigations and research in Port Curtis
- A baseline water quality monitoring program, specifically designed to meet the requirements of the Project activities
- Existing and ongoing monitoring programs used to supplement the baseline water quality monitoring program.

Baseline data has been collected and summarised with consideration to temporal (i.e. seasonal), spatial (across water types) and vertical (through the water column) variations.

An understanding of the role that external influences play in affecting water quality is also key to understanding baseline water quality conditions. Therefore, natural influences (i.e. waves, tides, currents, wind, depths, rainfall, extreme weather and the frequency and severity of storms and cyclones, and freshwater flows from surrounding catchments), and anthropogenic influences (i.e. contaminants from point source discharges, surrounding land use, and capital and maintenance dredging campaigns), have been described and analysed.

A review of relevant guidelines, environmental values and water quality objectives for potentially affected waters in the Port has been undertaken.

This report has been prepared with consideration of a number of other reports prepared for the Project EIS (refer Table 2.1). These reports are provided below and referred to throughout the report where appropriate.

Table 2.1 Project Environmental Impact Statement rated reports

EIS component	Report title	Author
Water quality	<i>Channel Duplication Baseline Water Quality Report</i>	Vision Environment 2016 (refer Appendix B)
Hydrodynamics	<i>Coastal Processes and Hydrodynamics Technical Report</i>	BMT WBM 2019
Marine sediments	<i>Sampling and Analysis Plan Implementation Report (area to be dredged)</i>	Aurecon 2015a
Marine sediments	<i>Geochemical Sediment Characterisation Plan Implementation Report (DMPAs)</i>	Aurecon 2015b
Marine sediments	<i>Sampling and Analysis Plan Implementation Report – Barge Access Channel</i>	Aurecon 2019c
Ecology	<i>Ecology Technical Report</i>	Aurecon 2019a
Impact assessment	<i>EIS Chapter 21. Cumulative impact assessment</i>	Aurecon 2019b

2.2 Desktop data collation of previous water quality studies

Port Curtis is one of the most studied ports in Australia (Commonwealth of Australia 2013). Relevant existing studies have been used throughout the EIS impact assessment to ensure a complete and accurate description of the existing and historical environmental conditions has been evaluated. A desktop data review of existing historic studies within the Port has been undertaken as part of the baseline water quality assessment. This desktop review revealed that there is a large amount of information available from studies previously undertaken within Port Curtis. A summary of the outcomes of these studies is provided in Section 3.

Previous water quality studies have consisted of short and long term monitoring programs, capturing biological and physicochemical water quality parameters, contaminant concentrations, photosynthetically available light, and nutrients. Studies have predominantly focussed on sites in the Calliope and Boyne estuaries and the Western Basin, Inner Harbour and Mid Harbour zones (between Facing Island and The Narrows) although some studies have included reference sites within the zones of Outer Harbour, Rodds Bay, and sites in Queensland coastal waters (refer Section 3.2) (GHD 2009; VE 2008). A large number of the investigations have focussed on water quality and its potential to impact on the conservation of significant marine species found in Port Curtis (i.e. seagrass meadows).

A range of data sources were reviewed and analysed to provide an account of previously reported water quality conditions in Port Curtis. Data from the reports has been reviewed and key results summarised in the relevant sections of this report. Note that this review has generally focussed primarily on ambient baseline water quality monitoring programs, as opposed to targeted compliance assessments. The findings of the previous water quality studies are described under the following themes/timeframes:

- Early studies pre-1980
- Major Port development 1980 to 1994
- Port Curtis studies 1995 to 2005
- Establishment of the Port Curtis Integrated Monitoring Program (PCIMP)
- Liquefied natural gas (LNG) development and Western Basin Dredging and Disposal Project (WBDDP).

The key existing reports and programs utilised in water quality assessment are summarised below.

2.2.1 Port Curtis Integrated Monitoring Program

Established in 2001, PCIMP is a consortium of members from 17 representative bodies from industry, government (both local and state), research institutions and other stakeholders. The aim of PCIMP is to develop a cooperative monitoring program to assess the ecosystem health of Port Curtis with a focus on maintaining the health and sustainability of Port Curtis marine environments. The PCIMP addresses themes including water quality (including biomonitoring), intertidal health (e.g. oil spill assessments), seagrass health and sediment assessments.

To date the PCIMP has funded two Port Curtis Ecosystem Health Report Cards. The report card system was established to document ecosystem health in Port Curtis using indicators that reflect ecological condition. The inaugural Port Curtis ecosystem health report card was released by PCIMP in 2007 (Storey et al. 2007) with the majority of these results collected under the 2005 and 2006 PCIMP programs. Another report card was released in 2011 (VE 2011a) based on data collected from July 2008 to November 2010.

PCIMP continues to undertake monitoring of water quality and other ecological indicators around Port Curtis. Data is now provided to the Gladstone Healthy Harbour Partnership (GHHP) who publish report cards covering the environmental, social, cultural and economic health of the Port (refer section on GHHP below).

Recent water quality data collected by PCIMP has been utilised in the EIS as supplementary data where appropriate (refer Section 2.4).

2.2.2 Curtis Coast Coastal and Marine Resource Inventory Report

The Curtis Coast Coastal and Marine Resource Inventory (GPC 2012) was commissioned by GPC to document the environmental, commercial and social values of the Curtis Coast region. This report is an update of the 1994 Curtis Coast Study and accounts for the changes to the marine environment in the previous 20 years. The report provides an inventory of the current state of the marine ecosystem and details information on a broad range of environmental and ecological values found in the area. It provides a summary of recent water quality investigations along with the key natural and anthropological influences on water quality in the region.

2.2.3 Government reports

Both the Commonwealth and Queensland Government have prepared reports focussed on Port Curtis in recent years. Queensland Government reports, published by (former) Department of Environment and Resource Management (DERM), Department of Environment and Heritage Protection (EHP) and (former) Department of Science, Information Technology, Innovation and the Arts (DSITIA) have utilised long term water quality datasets to inform studies on the water quality of Port Curtis and ecological investigations into fish health.

Independent reviews commissioned by the Commonwealth Government into the Port of Gladstone and the WBDDP bund wall, have provided a broad summary of environmental issues in the area and included key recommendations for environmental management of the Port for the future.

2.2.4 Cooperative Research Centre for Coastal Zone, Estuary and Waterway Management

The former Cooperative Research Centre (CRC) for Coastal Zone, Estuary and Waterway Management (the Coastal CRC) published a number of pivotal studies important to understanding the Port Curtis environment in terms of hydrodynamic modelling, contaminants of potential concern and contaminant pathways. These reports are regularly referenced in water quality reports for Port Curtis.

2.2.5 Investigations from independent proponents

Over the last 20 to 30 years a large number of water quality monitoring programs in Port Curtis have been undertaken for the purposes of impact assessment, compliance, and incident investigations. While investigations often differ in their objectives, spatial range and temporal continuity, they provide a large and varied source of baseline water quality data for Port Curtis. Baseline monitoring programs in recent years have been undertaken for the environmental impact statements associated with the Curtis Island LNG developments (e.g. Gladstone LNG (GLNG), Queensland Curtis LNG (QCLNG), Arrow Energy, Wiggins Island Coal Terminal (WICT)) as well as for the WBDDP. Reports for these assessments have also included desktop literature reviews, which have been reviewed for as part of this water quality assessment.

2.2.6 Gladstone Healthy Harbour Partnership

The GHHP was formed in November 2013 as a forum representing 25 partners, including community, industry, science, government and statutory bodies, to report and contribute to improving the health of Port Curtis. The role of the GHHP is to provide an annual report card on the health of Port Curtis focussing on four key indicators, environmental, social, cultural and economic health. The pilot GHHP report was released in November 2014. The first full report card was issued in February 2016. A technical report accompanies the report card and provides a comprehensive breakdown of grades, including the methodologies used to compile data.

The GHHP is informed by an Independent Science Panel comprising members with expertise such as water quality, ecosystem health, marine biodiversity, toxicology and biogeochemistry among others. The role of the panel is to provide independent scientific advice to the GHHP on the Gladstone Harbour Report Card, as well as on the monitoring programs that support the report card.

Water quality data collected by PCIMP will be published by GHHP as part of the report card process.

2.2.7 GPC internal data

GPC has undertaken its own water quality monitoring since the 1990s in Port Curtis and maintains several large data sets. Parameters monitored include turbidity, temperature, pH, conductivity, dissolved oxygen, metals, hydrocarbons, nutrients and other contaminants.

2.3 Project baseline monitoring program

A 13 month baseline water quality monitoring program was designed to collect continuous ambient water quality data to support the Project EIS. The monitoring program was conducted from June 2013 to July 2014.

It is noted that the ANZECC Guidelines for Fresh and Marine Water Quality (2000a) outline that the amount of water quality data required to calculate trigger values for a reference site is a minimum of two years of monthly sampling. The Queensland Water Quality Guidelines (QWQG) (2009) outline the amount of water quality data required to calculate reference site percentiles is a minimum of 12 months, preferably 24 months. The baseline water quality monitoring program complies with the guidelines due to the amount of existing water quality data available for the Port. The 13 months of Project EIS water quality monitoring will be supplemented with data from other monitoring programs including PCIMP and the GHHP.

The baseline monitoring program was designed to provide 13 months of continuous water quality data to describe the existing environment of the Port, to calculate trigger values for use during dredging and material placement works, and to potentially use the data to refine the water quality objectives assigned to the area.

Preliminary hydrodynamic modelling for the Project area to be dredged and potential dredged material placement areas (DMPAs) were used to generate a composite plot that provided a semi-quantitative indication of potential plume dispersion under a number of given dredging scenarios and assumptions. The location of eight water quality monitoring sites was based on the results of this preliminary modelling which suggested plumes will potentially disperse into the GBRMP to the north, northeast and south; through the Mid Harbour to north entrance; and to the Inner Harbour east to the Western Basin and the lower parts of The Narrows (refer Figure 4.3).

Given the Project activities have a number of potential impact sources, and at the time of the development of the water quality program, no clear gradient of impact was able to be discerned for those impacts, a cumulative impact monitoring approach was developed with monitoring sites spanning from The Narrows, the Western Basin, Mid Harbour, Outer Harbour, and in coastal waters (east and south of Facing Island).

Monitoring sites were located inside and outside of the potential Project impact areas as well as in the vicinity of known sensitive receptors (i.e. seagrass meadows and coral reefs). The rationale for the placement of these monitoring sites is further discussed in Section 4.7.1.

The water quality and benthic environments of the lower estuary/enclosed coastal waters and open coastal waters of Port Curtis (generally referred to as 'inshore' and 'offshore') behave differently with different factors influencing background conditions. The inshore area follows a gradient typical of estuarine water quality (VE 2008) which is heavily tidally influenced compared to offshore with waters generally more turbid, of lower pH, and generally well mixed. The influences of runoff from the land and freshwater flows from surrounding catchments is also more evident. The offshore area generally exhibits a more oceanic influence via wind and wave action.

The Project EIS baseline water quality monitoring program was designed to account for these two different water types, with two different configurations of monitoring equipment applied to water quality monitoring sites depending on their location either offshore or inshore. The key factors affecting benthic primary producers (e.g. seagrass, algae), including turbidity, light, temperature, nutrients, contaminants and sedimentation rates, were measured using a range of approaches. Details of the specific monitoring methodology for each parameter is outlined in Section 4.7.

It is important to acknowledge the influence of natural or extreme weather events on the variability of water quality during long term baseline monitoring programs. During the Project baseline data collection period two notable natural events impacted the Gladstone region. A low pressure system in mid-January 2015 brought heavy rain, flooding and high winds, and Tropical Cyclone (TC) Marcia which made landfall in Central Queensland in February 2015 also brought heavy rain and high winds to the region.

It should be noted that maintenance dredging was undertaken in the Port of Gladstone as part of GPC's regular maintenance dredging program in 2014 during selected dates in February, March and July, and in 2015 between 4 June and 18 June (refer Section 3.9.3.2 for further information). No other obvious anthropogenic events appear to have occurred in the Port during the Project baseline data collection period, outside of regular shipping and boating operations.

2.4 Supplementary water quality data

Water quality investigations that were being undertaken simultaneously during the Project EIS baseline monitoring period include the PCIMP/GHHP monitoring. The PCIMP and GPC water quality monitoring programs are continuing, with the data to be incorporated into future revisions of the Project Water Quality Monitoring Program prior to the commencement of dredging activities.

PCIMP monitoring comprises quarterly water quality monitoring at 54 sites across Port Curtis, including sites at The Narrows, Inner Harbour, Boat Creek, Inner Harbour/Calliope, Mid Harbour, Auckland Creek, Inner Harbour/South Trees, Boyne/Tannum, Colosseum Inlet (i.e. estuarine reference sites), Rodds Bay (i.e. estuarine reference sites), and open coastal waters reference sites.

3 State of Port Curtis – previous water quality studies

3.1 Introduction

Port Curtis is a slightly to moderately disturbed environment, with areas of high ecological value to the north, located within the GBRWHA (Commonwealth of Australia 2013) (Department of Environment and Heritage Protection 2014b). In order to determine the potential water quality impacts from the Project activities, it is important to understand the current environmental baseline conditions and the conditions that may have existed prior to major increases in industrial activity (i.e. pre-1960s) within the Port of Gladstone.

This section contributes to addressing the DoE EIS guideline item 5.9 h) to *describe the extent to which the general environment, ecosystems and matters of national environmental significance are already stressed by natural and anthropogenic effects* and the Queensland Government EIS ToR water quality requirements, by providing a review of previous water quality studies conducted in Port Curtis over approximately the last 30 years. This includes an assessment of natural and anthropogenic influences which have impacted the water quality of Port Curtis over time.

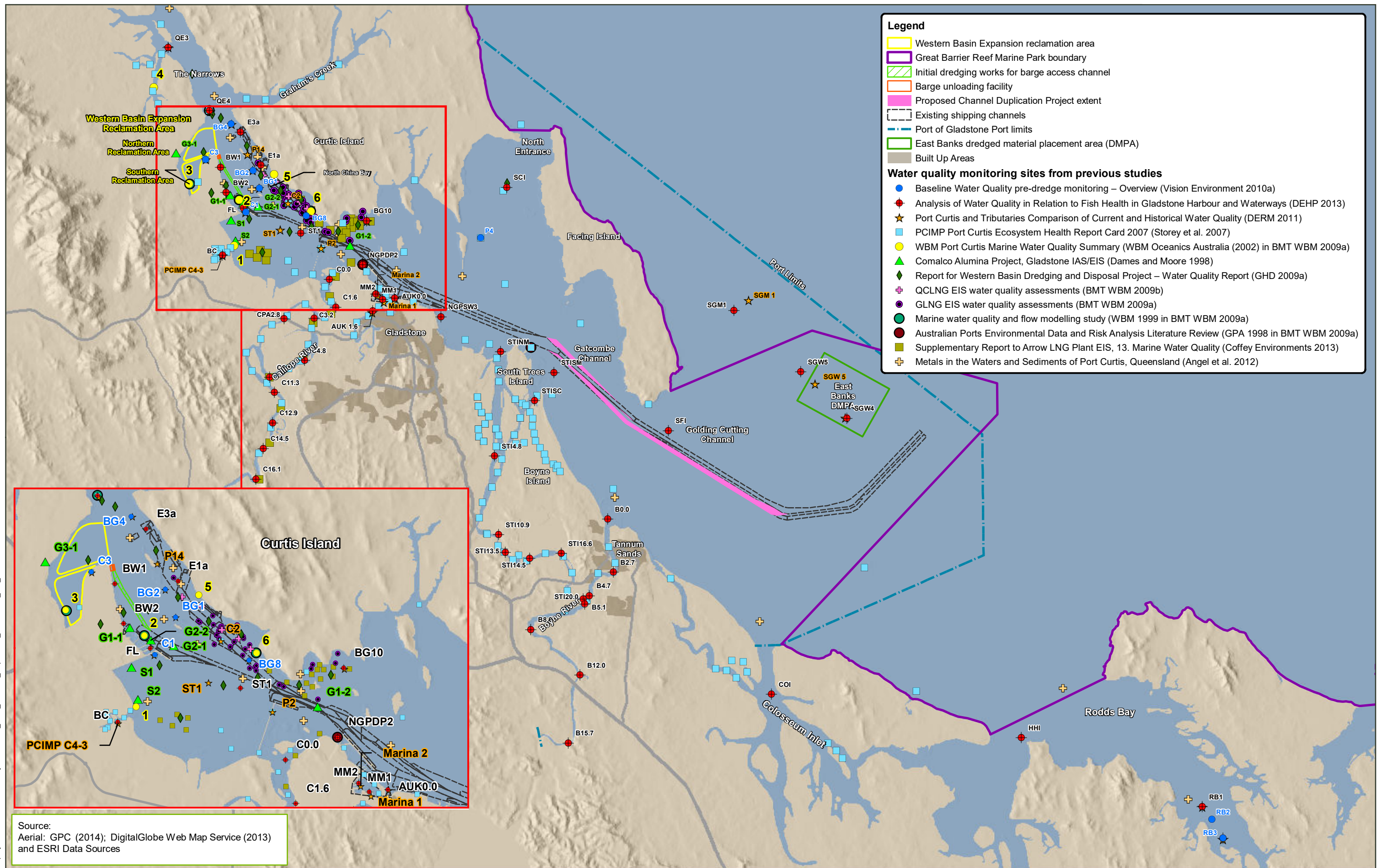
The physical, chemical and biological aspects of water provide valuable indications of the overall health of an ecosystem. In order to determine the potential impacts to water quality from the Project, it is important to understand the existing environmental baseline conditions, as well as how these baseline conditions may have changed over time in Port Curtis.

Numerous water quality studies have been conducted to assess and manage the impacts of industrial development within the Port, including earlier dredging campaigns. Previous studies have consisted of short and long term monitoring programs, capturing physicochemical parameters, contaminant concentrations and hydrodynamic modelling. These studies have predominantly focussed on sites in the Calliope and Boyne estuaries and the Western Basin, Inner Harbour and Mid Harbour zones (between Facing Island and The Narrows) although more recent work has included reference sites within the areas of Outer Harbour, Rodds Bay, and sites in Queensland open coastal waters (refer Section 4.6) (GHD 2009a; VE 2008). A large number of the investigations have focussed on water quality and its potential to impact on the iconic marine species that utilise Port Curtis.

A range of data sources were reviewed and analysed to provide an account of previously reported water quality conditions in Port Curtis. It is important to note that this review has generally focussed primarily on ambient baseline water quality monitoring programs, as opposed to targeted impact assessment studies. These monitoring programs are described under the following themes/timeframes:

- Early studies pre-1980 (Section 3.2)
- Major Port development 1980 to 1994 (Section 3.3)
- Port Curtis studies in 1995 to 2006 (Section 3.4)
- Establishment the Port Curtis Integrated Monitoring Program (Section 3.5)
- LNG developments and WBDDP (Section 3.6).

Where spatial information was available, water quality monitoring sites from previous studies have been illustrated in Figure 3.1.



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Map by NKM

3.2 Early studies pre-1980

During the 20 year period from 1955 to 1975 the Port of Gladstone established itself as Queensland's premier multi cargo port with total trade volumes increasing from 211,879 tonnes (t) to 15,655,035t (GPC 2013a). Records of water quality monitoring in Port Curtis and surrounding waters date back to the 1970s during this time of industrial activity and population growth.

Early water quality studies conducted at the Port from this period are generally limited in scope, lack consistency in survey techniques and temporal continuity. Compared to those used in present day, monitoring equipment and methods employed for these studies were also limited in accuracy.

3.3 Major Port development 1980 to 1994

During the period of 1975 to 1994, the Port of Gladstone grew into one of the world's leading resource ports in both trade and capacity. During this period, annual coal exports from the Port increased from 6 million tonnes (Mt) to 37Mt making Gladstone the third largest capacity coal exporting port in the world (GPC 2014b). In December 1982, the completion of Australia's largest dredging project at that time occurred which involved the deepening of the Port shipping channels. The project removed 18Mm³ of seabed material from the Port, with 12Mm³ of material placed in the East Banks DMPA, and 6Mm³ used for reclamation between Auckland Point and Barney Point, in the Gladstone Marina, and in the Clinton Estate west of Auckland Inlet. Further deepening and widening of Port channels continued and by 1989, the Port could accommodate Capesize vessels.

In 1994, the *Curtis Coast Resource Report* was released which was commissioned by the Gladstone Port Authority (GPA) (now GPC) for the purpose of providing a comprehensive environmental study of the Port of Gladstone and surrounding areas. Notably the report documented the environmental changes that had been observed over the coastal area as a result of the economic development of the region, such as the loss of mangrove and intertidal habitats due to reclamation areas and ecological stress. The risks of increasing amounts of pollutants entering Port Curtis from adjoining and upstream land uses were also noted.

Although many datasets and studies from this period are now more than 20 years old and should be interpreted with caution, the findings of the studies provide an insight into the historic water quality conditions during a time of increasing industrial activity and population growth in Gladstone. Relevant studies that document water quality conditions in Port Curtis during this time are outlined in Table 3.1 and discussed below.

Table 3.1 Water quality studies in Port Curtis 1980 to 1994

Report name	Reference
<i>Water Quality Plan for Port Curtis</i>	ETM (1980)
<i>Impact Assessment Study Reclamation of Land West of Calliope River</i>	WBM (1990)
<i>Fisherman's Landing, trade waste outfall benthic monitoring report 1990-91</i>	WBM (1992a)
<i>Environmental studies proposed channel dredging Port of Gladstone</i>	WBM (1992b)
<i>Port of Gladstone turbidity measurement study</i>	WBM (1993)
<i>Curtis Coast Study Resource Report</i>	QDEH (1994)

3.3.1 Water Quality Plan for Port Curtis (ETM 1980)

Of the studies listed in Table 3.1, the most comprehensive Port Curtis water quality data collection program during this period was undertaken on behalf of the Coordinator General's Department in 1978 in the *Water Quality Plan for Port Curtis* by ETM Consultants (1980), and subsequently by the former Water Quality Council of Queensland, between 1980 and 1986. Water quality was measured monthly during the development of this plan to detect any spatial variations in the estuarine water quality, to provide any indications of seasonal trends (ETM 1980).

Results from the report indicated that temperature throughout the estuaries was found to be relatively uniform with some stratification of 0.5 of Degrees Celsius (°C) throughout the water column (ETM 1980). Salinity throughout Port Curtis was also relatively uniform with slightly reduced salinity levels in The Narrows and estuaries, particularly following heavy rainfall (ETM 1980). pH was reported as alkaline ranging from 8.0 to 8.5, and dissolved oxygen (DO) above 5.6mg/L (ETM 1980). Oils, grease and hydrocarbon results were found to be slightly elevated (ETM 1980).

3.3.2 Curtis Coast Study Resource Report (QDEH 1994)

A summary of early water quality studies for the Curtis Coast region was undertaken in 1994 as part of a joint initiative between the GPA and the (former) Queensland Department of Environment and Heritage (QDEH). The *Curtis Coast Study Resource Report*, was initiated to investigate and document the various resources, including the environmental health of the Curtis Coast. The report utilises water quality results from the *Water Quality Plan for Port Curtis* (ETM 1980) along with various water quality impact studies conducted for individual project impact assessments. Table 3.2 outlines a summary of those results presented in the report.

Table 3.2 Port Curtis water quality conditions reported in Curtis Coast Study Resource Report

Parameter	Unit	Average of river, estuary and offshore sites
Temperature (summer/winter)	(°C)	18.0 to 29.0
Salinity	mg/L	31.8
Turbidity	Nephelometric Turbidity Units (NTU)	20 to 30 (Ebb) 2 to 5 (Flood)
Secchi depth	m	0.9 to 1.4 (Ebb)
DO	mg/L	6.5 (range 5.1 to 8.7)
pH	pH	8.0 to 8.5
Total Nitrogen (TN)	mg/L	0.02 (range 0.01 to 0.14)
Total Phosphorus (TP)	mg/L	0.05 (range 0.03 to 0.12)

Table note: Data sources include ETM (1980), WBM (1990), WBM (1991), WBM (1992), WBM (1993) in QDEH (1994)

Source: QDEH (1994)

The report describes the state of water quality in Port Curtis at the time of monitoring as 'generally very good' in relation to other industrialised international ports, including San Francisco, Townsville and Auckland. Some parameters showed naturally elevated levels, including turbidity and water temperature (potentially corresponding to reduced DO levels), as well as arsenic concentrations (QDEH 1994). Slightly elevated levels of P were identified in some areas, which were attributed to a combination of agricultural runoff, stormwater, and urban and industrial waste (QDEH 1994).

In the areas of Port Curtis, Rodds Bay and the northern end of The Narrows – Fitzroy River area, turbidity is described as being ‘naturally high’ and that there is a distinct difference in the turbidity between flood and ebb tides in Port Curtis (QDEH 1994). On the ebb tide, turbid water with a turbidity of typically 20 to 30NTU (0.9 to 1.4m Secchi disc) flows from the Port, while on a flood tide less turbid (clear) water with a turbidity of between 2 and 5NTU flows from nearshore coastal waters into the Port (WBM 1993 in QDEH 1994). Overall the large tidal range, with high tidal current velocities and an inherent flushing capacity, is attributed to assisting to maintain good water quality within the Port (QDEH 1994).

The region is also described as hosting significant mineral deposits (specifically shale deposits in The Narrows and heavy mineral sands in the sand masses of coastal areas) which may contribute to elevated levels of these compounds (QDEH 1994). Mining of manganese, gold, phosphate and construction materials (i.e. sand, rock, clay) has been common throughout the Gladstone area over time. The report also acknowledges that potential sources of pollution remain high within and around the Port, with major sources of pollutants such as urban stormwater runoff, vegetation clearance, residential development, ship ballast, oil spills, and industrial and waste sewage discharges, representing potential impacts to the future water quality and ecological health of Port Curtis (QDEH 1994).

3.4 Port Curtis studies in 1995 to 2006

The Port of Gladstone experienced continued growth in coal exports along with other commodities into the new millennium and by 2005 to 2006, 67.2Mt of cargo was being handled through the Port (CQPA 2007). The challenge of managing the long term potential environmental impact of further Port and industrial development, along with the city’s population growth, became an increasing focus, particularly through the works of the Cooperative Research Centre (CRC) for Coastal Zone, Estuary and Waterway Management. As a result of an increasing population and industrial activities, the quantities of contaminant inputs from diffuse sources (urban runoff) and point source discharges (industrial effluents) to Port Curtis continued to increase. Apte et al. (2005) notes that when the CRC first started its activities in Port Curtis in 1998, there were few published studies describing the contaminant distributions in Port Curtis. Dredging works during this period included works at Fisherman’s Landing, outer channel, inner channel and swing basin, and at the RG Tanna Coal Terminal berths. Table 3.3 outlines relevant water quality studies in Port Curtis undertaken during the period of 1995 to 2005.

Table 3.3 Relevant water quality studies in Port Curtis 1995 to 2005

Report name	Reference
<i>Comalco Alumina Project, Gladstone, Impact Assessment Study EIS Vol 1</i>	Dames and Moore (1998)
<i>Australian Ports Environmental Data and Risk Analysis Phase 1: Literature Review</i>	Harris and O'Brien (1998)
<i>Marine water quality and flow modelling study</i>	WBM (1999) in WBM 2009b
<i>WBM Port Curtis Marine Water Quality Summary</i>	WBM (2001) in WBM 2009b
<i>Cooperative Research Centre Coastal Zone, Estuary and Waterway Management, Screening and Risk Level Assessment</i>	Apte et al. (2005)
<i>Risk assessment approach to contaminants in Port Curtis, Queensland, Australia</i>	Jones et al. (2005)
<i>Cooperative Research Centre Coastal Zone, Estuary and Waterway Management, Contaminant Pathways in Port Curtis</i>	Apte et al. (2006)
<i>Report on the Long Term Water Quality Monitoring of Estuaries and Inshore Coastal Waters in Central Queensland, 1993 to 2006</i>	DERM (2012)

3.4.1 Comalco Alumina Project Gladstone Impact Assessment Study EIS Volume 1 (Dames and Moore 1998)

As part of the Comalco Alumina Project EIS (Dames and Moore 1998), marine and estuarine water monitoring was undertaken to establish baseline data. During September 1995 and November 1997, surface water grab samples were taken 0.2m below the water surface at the following (relevant) locations (refer Figure 3.1):

- G1.1 – Shipping channel near Tide Island
- G1.2 – Shipping channel near South Passage Island
- G2.1 – Fisherman's Landing – north east edge of ship turning circle at Fisherman's Wharf
- G2.2 – Fisherman's Landing – Corner of the large lower intertidal bank south of Friend Point
- G3.1 – Mouth of Targinnie Creek tributary – 2.5km north of Fisherman's Landing.

It should be noted that the water quality measurements, sample analyses and locations adopted for this study were not consistent for each survey date and therefore lack temporal continuity and results are provided for general reference only.

Samples were analysed for physicochemical parameters and nutrients (refer Table 3.4) and a range of metals (refer Table 3.5) and compared against ANZECC (1992) guidelines.

The laboratory limits of reporting (LOR) are greater than the trigger values for mercury. Concentrations of cadmium, copper and lead were less than trigger values at all sites (Dames and Moore 1998, in GHD 2009a).

Table 3.4 Physicochemical results September 1995

Parameter	Unit	G1.1	G1.2	G2.1	G2.3	G3.1
TSS	mg/L	12	12	13	23	23
TDS	grams per litre (g/L)	40.0	40.6	40.8	40.8	43.5
TOC	mg/L	1.0	1.5	1.2	3.4	10
TN	mg/L	< 0.2	0.6	0.3	0.3	0.2
TP	mg/L	0.02	0.01	0.02	0.05	0.02
pH	pH (lab)	8.0	8.0	8.1	8.2	7.9

Source: Dames and Moore (1998) in GHD (2009a)

Table 3.5 Metals results September 1995

Parameter	ANZECC (1992) guidelines	G1.1	G1.2	G2.1	G2.3	G3.1
Aluminium (µg/L)	-	60	30	50	260	110
Arsenic (µg/L)	50	3	3	3	3	2
Cadmium (µg/L)	2	< 2	< 2	< 2	< 2	< 2
Chromium (µg/L)	50	< 10	< 10	< 10	< 10	< 10
Cobalt (µg/L)	-	1	1	1	1	1
Copper (µg/L)	5	< 5	< 5	< 5	< 5	< 5
Iron (µg/L)	-	20	40	30	140	60
Lead (µg/L)	5	< 5	< 5	< 5	< 5	< 5
Manganese (µg/L)	-	< 10	< 10	< 10	< 10	< 10
Mercury (µg/L)	0.1	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5

Parameter	ANZECC (1992) guidelines	G1.1	G1.2	G2.1	G2.3	G3.1
Molybdenum (µg/L)	-	15	15	15	15	15
Nickel (µg/L)	15	< 10	10	10	< 10	10
Selenium (µg/L)	-	< 10	< 10	< 10	< 10	< 10
Tin (µg/L)	-	< 10	< 10	< 10	< 10	< 10

Source: Dames and Moore (1998) in GHD (2009a)

The water quality sampling program undertaken in 1997 included pH and turbidity results from two sites near Fisherman's Landing Wharf (refer Table 3.6). The sites were located at:

- S1 – Lower intertidal mud bank 200 to 400m due south of Fisherman's Landing Wharf (depth of sample 0.2m)
- S2 – Lower intertidal mud bank 800m south east of Fisherman's Landing Wharf (depth of sample 0.5m).

Table 3.6 pH and turbidity in water samples November 1997

Parameter	Unit	S1	S2
pH	pH (lab)	7.8	7.8
Turbidity	NTU	10	15

Source: Dames and Moore (1998) in GHD (2009a)

3.4.2 Australian Ports Environmental Data and Risk Analysis Phase 1: Literature Review (Harris and O'Brien 1998)

In 1998, the GPA provided a report to the Australian Quarantine Inspection Service (AQIS) summarising available water quality data and hydrology information for use within a Geoscience Australia and Australian Ports Environmental Data and Risk Analysis Literature review. Available data on turbidity, tidal regime, sediments and bedforms, and seagrasses and biota were provided.

Turbidity data collected by nephelometers in Gladstone Harbour at Clinton (GPA1) and Boyne Island Wharves (GPA2) recorded results in the range of 30 to 40NTU during spring tides and 0 to 5NTU during neap tides (Harris and O'Brien, 1998) (refer Figure 3.1). The mean spring tidal range was reported as 3.3m and spring current speeds of 1.75m/s were reported in the main shipping channel, according to model outputs (Harris and O'Brien 1998).

3.4.3 Marine water quality and flow modelling study (WBM 1999)

A flow modelling study prepared by WBM in 1999 undertook an assessment of historical water quality data in Port Curtis using datasets from 1977 to 1999. While not all data from these studies were used for the purposes of the investigation, 10 years of data from 1989 to 1999 was collated at four general locations in the Western Basin area with surface water results summarised and compared against ANZECC (1992) guideline values. A results summary of the study was presented by WBM in the *Proposed QCLNG Project EIS – Marine Water Quality Assessments*, July 2009 (BMT WBM 2009b) and are illustrated in Table 3.7 and Figure 3.1.

Table 3.7 Range of surface water quality data for Port Curtis compiled from previous reports (1989 to 1999)

Water quality parameter	Unit	Friend Point	Gully	Fisherman's Landing	Hamilton Point	ANZECC Guideline ¹
In situ measurements (minimum – maximum)						
Temperature	°C	19.5 - 25.0	23.0 - 25.0	19.6 - 32.7	20.1 - 27.0	-
Conductivity	Mill siemens per centimeter (mS/cm)	44.0 - 49.2	44.5 - 55.0	49.0 - 55.0	49.0 - 49.4	-
Salinity	g/L	32.0 - 32.1	-	30.5 - 36.0	32.1 - 32.4	[35.5]
DO	mg/L	7.27 - 7.53	-	7.41 - 7.61	7.56 - 7.59	>6
DO	Percent saturation (% sat)	96 - 99	-	94.8 - 101.0	76.1 - 102.0	>80
pH		8.0 - 8.2	8.0 - 8.1	8.0 - 8.3	7.9 - 8.3	[8.1]
Turbidity	NTU	4 - 10	11 - 28	3.3 – 16.0	7 - 10	< 10% change in seasonal mean
Secchi Disc	m	1.7 - 2.0	-	1.4 - 1.9	0.8 - 1.7	As above
Major elements						
Aluminium	µg/L	260 - < 500	< 300 - 700	30 - < 500	60	[5]
Boron	µg/L	4200 - 4300	4000 - 4200	-	-	[4440]
Fluorine	µg/L	900	900	900	-	[1300]
Iron	µg/L	80-480	< 100 - 460	30 - < 100	20	[3]
Manganese	µg/L	< 10 - < 200	< 30 - < 200	< 10 - < 100	< 10	[2]
Trace elements						
Arsenic	µg/L	3 - < 5	< 5	3	3	50
Barium	µg/L	< 100	< 100	< 100	-	-
Cadmium	µg/L	< 0.5 - < 2	< 0.5 - < 3	< 2 - < 3	< 2	2
Chromium	µg/L	5 - < 10	5 - < 50	< 10 - < 50	< 10	50
Cobalt	µg/L	1	-	1	1	-
Copper	µg/L	< 5 - < 500	< 500	< 5	< 5	5
Lead	µg/L	< 5 - < 10	< 10 - < 30	< 5 - < 30	< 5	5
Mercury	µg/L	< 0.5 - < 150	< 0.2 - < 150	< 0.2 - < 150	< 0.5	0.1
Molybdenum	µg/L	15 - < 500	< 10 - < 500	< 10 - 15	15	-
Nickel	µg/L	< 10 - < 300	< 30 - < 300	10 - < 30	< 10	15
Selenium	µg/L	< 10 - < 40	< 5 - < 40	< 5 - < 10	< 10	-
Tin	µg/L	< 10	-	< 10	< 10	-
Zinc	µg/L	< 60 - < 200	< 60 - < 800	< 800	-	50
Compounds						
Cyanide	µg/L	-	< 10	< 10	-	5
Phenols	µg/L	-	< 5	< 5	-	50

Water quality parameter	Unit	Friend Point	Gully	Fisherman's Landing	Hamilton Point	ANZECC Guideline ¹
Nutrients						
Total Nitrogen	µg/L	-	-	10 - 600	20 - 140	-
Organic Nitrogen	µg/L	-	200	300	-	-
Ammonia	µg/L	-	< 20	< 20	-	(< 5)
Nitrite	µg/L	-	< 20	< 20	-	
Nitrate	µg/L	-	< 20	< 20	-	(10 - 100)
Total Phosphorus	µg/L	< 10 - 50	30 - 40	< 10 - 40	< 10 - 20	-
Orthophosphorus	g/L	-	20	20	-	(5 - 15)
Total Organic Carbon	mg/L	< 2.0 - 3.4	-	1.2 - < 2	1 - 5	-
Biochemical Oxygen Demand	mg/L	-	1 - 2	< 1	-	[< 1]
Suspended Solids						
Suspended Solids	mg/L	8 - 23	-	10 - 25	8 - 14	< 10% change in seasonal mean

Table notes:

* ANZECC (1992) guideline values for the protection of aquatic ecosystems (marine waters).

Bracketed values shown thus (), indicate typical range for estuarine waters as outlined by ANZECC (1992). Bracketed values shown [], indicate typical concentration of oceanic seawater as outlined by Head (1985) and University of Sheffield (1999) in BMT WBM (2009a).

Source: WBM (1999) in BMT WBM (2009b)

Key points from the 1999 marine water quality and flow modelling study are outlined below:

- The range of physical measurements reported suggests that estuarine waters within Port Curtis are generally typical of seawater. Salinity appeared slightly below that for oceanic seawater (35.5g/L) at all monitoring sites and can sometimes be slightly higher due to local characteristics (e.g. high temperatures, evaporation and low rainfall) (BMT WBM 2009b).
- Secchi disc visibility indicated that water clarity was general poor, being less than 2m. Turbidity and suspended solids results were generally less than 30 NTU and 30mg/L, respectively (BMT WBM 2009b).
- Typical of high quality estuarine water, nutrient total organic carbon (TOC) and biochemical oxygen demand (BOD) concentrations appeared generally low (BMT WBM 2009b).
- Aluminium and iron concentrations in samples were found to be significantly higher than those typical of oceanic seawater (BMT WBM 2009b).
- Major elements (e.g. boron, fluoride, manganese) concentrations appeared to be consistent with those of oceanic seawater (BMT WBM 2009b).
- Cyanide and phenol concentrations did not exceed ANZECC (1992) guideline concentrations and were typical of seawater (BMT WBM 2009b).
- The limitations and deficiencies identified in the study were that some studies adopted LORs not consistent or less than the adopted ANZECC guidelines (e.g. nutrients and trace elements). This made the meaningful comparison of results with the criteria difficult (BMT WBM 2009b).
- Identifying potential varying or seasonal influences in Port Curtis was difficult given that much of the data summarised was sourced from studies limited to one or two surveys (BMT WBM 2009b).

3.4.4 WBM Port Curtis Marine Water Quality Summary (WBM 2001)

Between December 1998 to December 2000 a marine water quality monitoring program was undertaken by WBM and Capline to characterise the water quality in the region of proposed oil shale extraction works. Routine sampling was conducted bimonthly as well as after periods of extended or heavy rainfall, major dredging activities, or major industrial effluent discharges. Thirteen routine and four event based surveys were completed over the two year period. The water quality monitoring was focussed around the Western Basin zone of Port Curtis and monitored six water quality sampling sites for both the routine and event surveys (refer Figure 3.1 for locations) (BMT WBM 2009b) which were:

- Site 1 – Mouth of Boat Creek
- Site 2 – Fisherman's Landing Wharf
- Site 3 – Gully Creek
- Site 4 – Targinnie Creek
- Site 5 – Mouth of drainage line, Curtis Island
- Site 6 – Hamilton Point (Curtis Island).

Physicochemical water quality parameters (i.e. turbidity, Secchi disc, temperature, conductivity, salinity, DO and redox) were measured in situ through the water column at each of the above sites along with sampling of surface water. Samples were analysed for trace elements including: cyanide, nutrients, suspended solids and petroleum hydrocarbons. Water quality sampling was undertaken during high water spring tidal conditions for both routine and event surveys (BMT WBM 2009b).

Due to the temporal coverage of the data, results generally provided a wide variability for most water quality parameters, often exceeding the inter-site variation for a particular time (BMT WBM 2009b). It is important to note that despite the temporal range of data compiled, all the water quality data was collected during high water spring tidal conditions, therefore some parameters could be expected to be outside of the natural range encountered at other stages of the tidal cycle (BMT WBM 2009b).

For most parameters, results (mean and median concentrations) indicated that the water quality conditions between the sites were similar. The one exception was pH which was consistently slightly lower at Targinnie Creek (BMT WBM 2009b).

Turbidity results varied substantially between monitoring sites. Lower turbidity results were recorded close to the surface, as opposed to higher benthic turbidity results, likely due to the influence of strong tidal currents resuspending sediments into the water column (BMT WBM 2009b). The depth averaged turbidities at Sites 1, 3 and 4 generally ranged between 15 and 30NTU while results at Sites 2, 5 and 6 recorded average turbidity frequently within the range of 30 to 60NTU (BMT WBM 2009b).

Secchi disc visibility measurements demonstrated a seasonal peak in water clarity during August and October 1999 and again in June 2000 (BMT WBM 2009b). This correlated with turbidity results and suspended solids concentrations that were generally highest during the spring tidal conditions in February 1999, February 2000 and December 2000. Turbidity was lower (< 20NTU) at most sites in the cooler months of each year (August and October 1999 and April, June, August and October 2000) (BMT WBM 2009b).

On average, measured turbidity was highest and displayed greater variation during conditions of large spring tides and moderate winds during February 1999, than at any other time (BMT WBM 2009b). However, lower turbidity results were also recorded during tides of equal or higher range and height, but during times of light wind conditions, for example during August and December 2000 (BMT WBM 2009b). This suggests that seasonal or other influences, such as preceding weather conditions or the phase of tidal cycles, may effect turbidity results in Port Curtis (BMT WBM 2009b).

The study concludes that water turbidity levels in this area are influenced by a combination of season, wind speed, direction and tidal range and/or tidal height, as well as catchment runoff.

Other physicochemical parameter results indicated small changes in water temperature, conductivity/salinity, across all sites suggesting that the water was well-mixed at all locations at spring high water. DO concentrations were generally consistent and close to full saturation, with the exception of Site 4 (Targinnie Creek) where they were generally lower than the other sites (BMT WBM 2009b).

Trace element concentrations (e.g. aluminium, iron, manganese, nickel) found in samples were linked to sampling occurring at times of high water, where the processes of tidal resuspension of seabed sediments results in elevated turbidity and higher levels of TSS. Duplicate filtered water samples indicated that dissolved element concentrations were typically much lower (BMT WBM 2009b).

A limited range of elements (i.e. arsenic and barium) and cyanide were elevated in samples collected after rainfall events in January and March 1999 and in November 2000 (BMT WBM 2009b).

3.4.5 Hydrodynamic Modelling of the Port Curtis Region (Herzfeld et al. 2004)

In 2004, the CRC published a study which was developed for the Port Curtis estuary outlining the results of a pilot computer ocean model which, examined the oceanographic characteristics of the region. The model concentrated on predicted sea levels, currents and distributions of dissolved material in the water in response to the effects of wind, tides, slow sea level changes and density effects. The aim of this study was to aid future studies on the movement and mixing of contaminants throughout Port Curtis. The time period investigated was the first four weeks of 1999.

Results from the model show that the currents in the estuary are predominantly due to the effects of the tidal cycle, with the difference in water level between high and low tides being as large as 4m (Herzfeld et al. 2004). These large tides can generate correspondingly strong currents, with some current speeds reaching up to 2 metres per second (m/s) in the vicinity of the North Channel (North Entrance) (Herzfeld et al. 2004). This tidal range was not constant and showed variation over an approximate 14 day period. The smallest tidal range during this period was reported as approximately half of the largest range (Herzfeld et al. 2004).

Vertical mixing within the water column was also observed during large tides, meaning that dissolved material (e.g. salt, temperature, contaminants) demonstrated little variation from the surface to the seabed (Herzfeld et al. 2004).

Limited net displacement of particles over multiple tidal cycles was also observed, meaning that while a particle in the estuary may undergo a large displacement due to the tidal motion (up to 15km), tidal displacements are of a 'back-and-forth nature', meaning after a large displacement on one phase of the tide, the particle returns to essentially its original position on the next (Herzfeld et al. 2004).

In the lower estuary, this displacement is directed up-estuary and is evident '*as a series of small eddies in the upper estuary*' (Herzfeld et al. 2004). The net displacement is attributed to the relationship of the tides with the seabed (Herzfeld et al. 2004).

Outside of the estuary within coastal waters, the residual circulation is influenced by wind which is directed along-shore towards the northwest. Net flow enters the estuary through the Gatcombe Channel area and leaves through the North Channel. It is noted that if the model were run under differing climatic conditions, the net flow characteristics may vary (Herzfeld et al. 2004).

Overall it was reported that dissolved material within Port Curtis has difficulty moving outside to coastal waters as a result of the estuary's flow regime, although this material is evenly dispersed throughout the estuary (demonstrating that the estuary is well connected). Herzfeld et al. (2004) notes that 'the e-folding flushing time (i.e. the time for total mass of material to decrease to ~1/3 of its original mass) for the estuary is of the order of 19 days in January 1999'.

This value estimate applies to the estuary as a whole, as opposed to the smaller subregions in the estuary which have much shorter flushing times, due to the well connected nature of the estuary (Herzfeld et al. 2004).

The study by Herzfeld et al. (2004) represented an important investigation into hydrodynamics within Port Curtis. Further details on the existing hydrodynamic and coastal processes within Port Curtis are contained in the Project Coastal Processes and Hydrodynamics Technical Report (BMT WBM 2018). Contaminants in Port Curtis; screening and risk level assessment (CRC for Coastal Zone, Estuary and Waterway Management, Apte et al. 2005)

The CRC undertook a screening level risk assessment of water and sediment quality in Port Curtis over the dry and wet seasons of 2001/2002. The aim of this study was to identify contaminants of concern in Port Curtis using a screening level ecological risk assessment (SLERA). This study was the first of its kind for Port Curtis.

The study area was split into six geographical zones based on land use and potential contaminant sources (The Narrows; Targinnie section of the harbour; Middle harbour; Southern and outer harbour; Calliope River; Boyne River and South Trees Inlet; and Eastern side of Facing Island). Water quality data was collected in a winter dry season in 2001, and in summer wet season in 2002 from 50 locations (Apte et al. 2005).

Selected monitoring parameters were based on the likelihood of inputs from industry, surrounding catchments and Port activities, which included metals at all sites, polycyclic aromatic hydrocarbons (PAHs), cyanide, fluoride and tributyltin (TBT) (Apte et al. 2005).

All concentrations of metals in samples were below AWQG (ANZECC 2000a) for marine waters (Apte et al. 2005). Higher concentrations of some metals were detected in samples from around Inner Harbour than compared to samples from the Outer Harbour and coastal waters (note the boundaries of these zones vary to those outlined in EHP 2014). Concentrations of dissolved copper, nickel, lead and zinc were elevated compared to other pristine coastal sites in Australia (Apte et al. 2005).

TBT was detected at five out of seven samples analysed and exceeded the AWQG guideline trigger value (ANZECC 2000a). The highest TBT was recorded in the marina site. For contaminants in waters, the SLERA identified TBT as a potential ecological concern, although the report notes TBT concentrations are expected to decline in Port Curtis over the next decade following the phasing-out of TBT in anti-fouling paints worldwide (Apte et al. 2005).

Concentrations of dissolved metals in waters of the Port Curtis estuary were below levels of regulatory concern. Elevated concentrations were attributed to industrial discharges or natural inputs of metals from local geological formations (Apte et al. 2005).

A large portion of this study was based on the Masters thesis completed by Mary-Ann Jones (2003).

3.4.6 A risk assessment approach to contaminants in Port Curtis (Jones et al. 2005)

Jones et al. (2005) conducted a study to identify contaminants of potential ecological concern which occur within the Port Curtis estuary. The works conducted by Jones et al. (2005), herein referred to as 'the study', consisted of a screening-level ecological risk assessment which ranked the risks of individual contaminants in the Port Curtis estuary which presented a potential concern to biota and human health. The study was conducted due to the limited quantity of data available on contaminants within the Port Curtis estuary at the time.

Jones et al. (2005) defined the Port Curtis estuary as a composite estuarine system with a number of major component estuaries, including the Calliope River, Boyne River, The Narrows and Auckland Creek. The Port Curtis estuary formed the study area for Jones et al. (2005).

The study involved a review of existing data on metals and fluoride in the water and contaminants in benthic sediments and biota. Two surveys were conducted as part of the study: a winter dry season survey (August to October 2001) and a summer wet season survey (February 2002). The surveys involved 50 sampling plots distributed across seven zones of the Port Curtis estuary study area. Samples for metal analyses were taken at the sampling plots and water samples for analysis of cyanide, fluoride and TBT were collected at locations likely to be influenced by a source(s).

Bioaccumulation of contaminants in a range of biota was also used as an indicator of contaminant exposure. Biota, including seagrass (*Zostera capricorni*¹), oysters (*Saccostrea amasa*, *S. echinata* and *S. glomerata*) and mud whelks (*Telescopium telescopium*), were collected during the winter dry season survey to reduce variability due to spawning and seasonal differences.

For the human health risk assessment, adult individuals of Sea mullet (*Mugil cephalus*), Barramundi (*Lates calcarifer*), Banana prawns (*Penaeus merguensis*) and male Mud crabs (*Scylla serrata*) were randomly chosen from commercial and amateur catches in the region.

The study identified multiple chemical stressors from diffuse and point sources, including shipping, heavy and light industry, boating and fishing, landfill, sewage treatment plants, urban and agricultural runoff, aquaculture, motor vehicles and sporadic connection with the adjacent Fitzroy catchment.

The study found that dissolved metal concentrations in waters were below water and sediment quality guidelines (ANZECC/ARMCANZ 2000a) trigger values, suggesting a low risk of these contaminants.

Results of the sediment analysis found that arsenic, nickel and chromium concentrations exceeded interim sediment quality guidelines-low (ISQG-low). However the concentrations of arsenic, nickel and chromium in sediment samples collected at the study reference site were also high, suggesting a natural origin. The study's desktop review found that historical sediment data collected in the Port of Gladstone suggested naphthalene concentrations were of potential concern.

Jones et al. (2005) concluded that biota were generally enriched in metals and TBT. These contaminants were also elevated in water and sediment samples.

The human health risk assessment found safe levels of most metals and TBT in all seafood samples collected. Tissue concentrations of arsenic (inorganic), lead and mercury did not exceed the Australian Food Code Standards for the relevant species. However, mercury levels recorded in Barramundi samples indicated that mercury may be a contaminant of potential concern.

The study concluded that assessment endpoints² may be potentially at risk from chemical contaminants in Port Curtis, given that enrichment of metals and TBT was found in biota, and TBT and naphthalene were identified as contaminants of potential ecological concern.

3.4.7 Contaminant Pathways in Port Curtis (CRC for Coastal Zone, Estuary and Waterway Management, Apte et al. 2006)

The SLERA of contaminants in Port Curtis as summarised in Apte et al. (2005) indicated that the concentrations of dissolved metals in Port Curtis were below levels of regulatory concern. Trace metal concentrations were, however, generally elevated relative to other Australian coastal waters. This indicated that metals in Port Curtis may be potentially related to local industry or regional geology within the area (Apte et al. 2006). The contaminant pathways in Port Curtis report by Apte et al. (2006) formed Phase 2 of the CRC's activities in Port Curtis and focused on key issues that were identified in the SLERA.

The study surveys, undertaken during two sampling events in December 2003 and 2004, established transects away from potential point sources and within The Narrows and selected waterways. The study concentrated on contaminants of concern identified in Apte et al. (2005) such as dissolved metals: cadmium, copper, nickel, lead and zinc concentrations in waters, as well as the influence of pH variations and resuspension of sediment on metal release (Apte et al. 2006).

¹ In Queensland the species formerly known as *Zostera capricorni* was reclassified to subspecies and revised to *Zostera muelleri* ssp. *capricorni*.

² Assessment endpoints for the study included sustaining commercial fisheries, maintaining seagrass in richness/biomass and as feeding grounds for fisheries, maintaining health of mangrove and mud flats/banks communities and sustaining food sources and habitat for dugongs, turtles and dolphins

Apte et al. (2006) concluded the following:

- *'In the offshore coastal waters, dissolved metal concentrations were extremely low and were comparable to concentrations measured at open Pacific Ocean and New South Wales coastal water locations. Trace metal limitation rather than trace metal contamination is likely to be more of an issue for organisms inhabiting these waters'* (Apte et al. 2006).
- Elevated metal concentrations were confirmed to exist within Port Curtis. The highest concentrations of copper and nickel were found in samples from The Narrows region, previously thought to be a relatively pristine environment (Apte et al. 2006).
- Sampling of the Fitzroy River to above Rockhampton suggested that this is a major source of dissolved metals to the local coastal region. Under some flow conditions, the Fitzroy River plume may enter The Narrows region and potentially discharge dissolved metals to Port Curtis (Apte et al. 2006).
- There were no obvious sources of trace metals within Port Curtis. Results of metals in suspended and benthic sediments were low and are not likely to be a source of trace metals to the water column. *'The trace metal distributions in Port Curtis are likely to reflect a mixture of metal inputs, including industrial discharges and mobilisation of metals from mangrove regions in The Narrows and the Fitzroy River plume'* (Apte et al. 2006).
- Salinity tended to be higher in the north of Port Curtis than in the surrounding coastal waters, while water column pH was lowest in The Narrows region, indicating a gradient for both salinity and pH in Port Curtis (Apte et al. 2006).
- Particulate metals results indicated that desorption of metals from suspended sediments is unlikely to be a major source of dissolved trace metals for Port Curtis. The concentrations of copper and zinc in suspended sediments did not indicate enrichment of these metals and were, generally typical of the benthic sediments (Apte et al. 2006). *'Trace metal inputs to Port Curtis which contribute to the observed dissolved metal concentrations are most likely to be delivered in solution form'* (Apte et al. 2006).

3.4.8 Report on the Long Term Water Quality Monitoring of Estuaries and Inshore Coastal Waters in Central Queensland, 1993 to 2006 (DERM 2012)

In 2012, the (former) Department of Environment and Resource Management (DERM) published a study on the long term water quality monitoring at 80 sites in nine estuaries and two enclosed coastal areas in the Central Queensland region between Rockhampton and Tin Can Inlet. This program included monitoring sites located in the upper and lower Calliope River and Boyne River estuaries. The long term monitoring program, comprised of routine monthly sampling, was conducted by the Queensland Government and commenced in 1993.

The main aims of the program were to assess the quality of these waters with respect to both condition and long term trends, although the data collected serves other purposes, including input to project environmental impact statements and input to licensing decisions, use by natural resource management bodies, and use as base data for deriving water quality guidelines (DERM 2012).

The program scope included a range of basic physicochemical water quality indicators (e.g. conductivity, temperature, pH, DO, turbidity) and nutrients which are the same as those employed in estuary monitoring in the Ecosystem Health Monitoring Programme (EHMP) in South East Queensland. No indicators of any toxicants or heavy metals were included in the program.

The main findings of the monitoring included in the report were:

Calliope River

Water quality in the Calliope is generally good with nearly all indicators at all sites complying with the adopted QWQG (2009). Turbidity values at some sites exceed guidelines, but by only a small amount. There are no deteriorating trends in water quality (DERM 2012).

Boyne River

Water quality in the estuary is consistently good, with median indicator values at all sites complying with the adopted QWQG (2009). This indicates the absence of significant point discharges and also the effect of the dam trapping catchment inflows and their associated pollutants before they enter the estuary (DERM 2012).

A significant decreasing trend is observed in turbidity at the estuary mouth, the reason for this was not known. There were also small but significant increases in nutrients at the most upstream estuary site. There are no apparent causes for this and, given the very low levels of nutrients present, these trends may be related to minor changes in analysis techniques (DERM 2012).

In general, the review of the entire monitoring program concluded:

- While the water quality of many of the estuaries in this region is impacted to varying degrees, for the most part these impacts can be described as minor to moderate. Sources of these impacts include point discharges and inflows of catchment pollutant loads (DERM 2012).
- Over the 14 year monitoring period, water quality in most of the waters studied remained very stable (DERM 2012).
- A small number of significant improving trends were detected, such as upgrades to the quality of point discharges (DERM 2012).
- Some minor, deteriorating trends were also identified (DERM 2012).
- Overall in the study area, issues such as reductions of inflows due to impoundments and the reduction in connectivity with freshwater reaches have relatively much greater impacts on overall estuary condition. To address these issues, it is recommended that monitoring programs need to have a much broader focus than just water quality (DERM 2012).

3.5 Establishment the Port Curtis Integrated Monitoring Program

3.5.1 Port Curtis Integrated Monitoring Program overview

The Port Curtis Integrated Monitoring Program (PCIMP) was established in 2001 and is a consortium of members from 17 representative bodies from industry, government (both local and state), research institutions and other stakeholders. The aim of PCIMP is to develop a cooperative monitoring program to assess the ecosystem health of Port Curtis with a focus on maintaining the health and sustainability of Port Curtis marine environments.

The PCIMP comprises researchers from various institutions from across the country, including Central Queensland University (CQU), Griffith University, the Department of Primary Agriculture, Fisheries and Forestry (DAFF), and the Commonwealth Scientific and Industrial Research Organisation (CSIRO) among others. The PCIMP addresses the following research themes:

- Water quality (including biomonitoring and use of ecological indicators)
- Intertidal health (e.g. oil spill assessments)

- Seagrass health
- Sediment assessments.

Monitoring operations began with a pilot study 2005. The PCIMP study area covers eight different zones³ from The Narrows to Rodds Bay (refer Figure 3.2).

To date the PCIMP has funded two Port Curtis Ecosystem Health Report Cards (refer Table 3.8). The report card system was established to document ecosystem health in Port Curtis using indicators that reflect ecological condition. Data for each indicator are compared against appropriate guideline levels and a standardised score representing a departure from desired ecological health is then produced for that indicator. Indicators are then allocated into broad groups called 'performance categories' and an average score for each performance category in each zone is calculated. Finally the combined average score for all performance categories in each zone is determined and converted to the final health rating, a grade from A (equal to reference) to F (complete fail). Although a range for parameters is measured under each theme, not all parameters are included in the calculations used to derive an ecosystem health rating (Storey et al. 2007). The approach to the monitoring program and data collection was developed by the authors of report cards, following six years of involvement in Coastal CRC research in Port Curtis. The report and approach was peer reviewed by representatives from the CSIRO Dr Graeme Batley and Dr Simon Apte.

The inaugural Port Curtis ecosystem health report card was released by PCIMP in 2007 (Storey et al. 2007) with the majority of results collected under the 2005 and 2006 monitoring programs. Another report card was released in 2011 (VE 2011a) based on data collected from July 2008 to November 2010. A summary of recent data collected by PCIMP is provided in Section 4.9.2 after the Project baseline data collection summary.

Table 3.8 Port Curtis Integrated Monitoring Program ecosystem health report cards

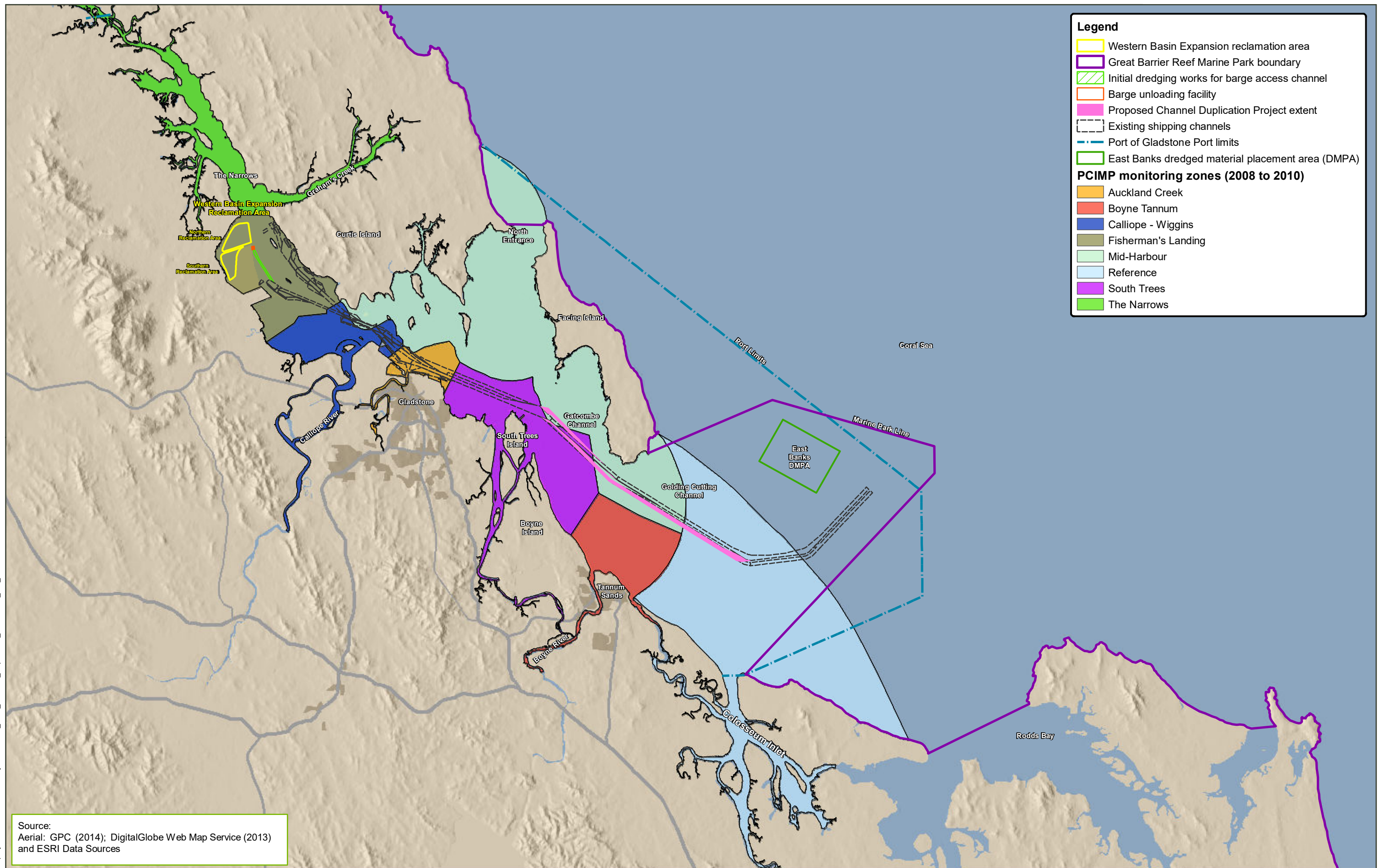
Report name	Reference
<i>Port Curtis Integrated Monitoring Program, Port Curtis Ecosystem Health Report Card</i>	Storey et al. (2007)
<i>Port Curtis Integrated Monitoring Program, Port Curtis Ecosystem Health Report 2008-2010</i>	VE (2011)

3.5.2 Port Curtis Integrated Monitoring Program biomonitoring

A large focus of the PCIMP monitoring program has centred on bioavailable metals which have been highlighted as potential contaminants of concern in the Port Curtis environment.

Contaminant concentrations in water are typically low, often below detection limits, and can vary over time and spatially (Villares et al. 2001 cited in Storey et al. 2007) as they are affected by tidal inundation and pulse discharge events. Biomonitoring techniques have therefore been utilised by PCIMP in the form of Diffuse Gradients in Thin films (DGT)-labile metals, and transplanted oysters. A correlation between pollutant concentrations found in biomonitoring studies and the ambient concentrations of the area being studied can assist to quantify contaminant concentrations.

³ New zone boundaries have been established for Port Curtis (refer Section 4.3.3)



P:\GIS\Projects\237374_GPC_Channel_Duplication_EIS\237374_EIS_122.mxd 15/01/2019 09:53
Map by RB



0 2,550 5,100 Metres

Date: 15/01/2019 Version: 5 Job No: 237374
Coordinate system: GDA_1994_MGA_Zone_56

The DGT technique is based on a simple device, which accumulates metal ions in a well-defined manner from solution. Soluble species diffuse through a layer of known thickness. Behind this diffusive layer is a binding layer in which reactive metal species are rapidly and irreversibly bound thereby maintaining a concentration gradient within the diffusive layer. The mass of accumulated metal is measured following retrieval and is used to calculate the average concentration of DGT-labile metal species in the measured water over the deployment time. As the device does not accumulate the major ions that cause interference with most elemental measurement techniques, the DGT measurement does not suffer the degree of interference often associated with the direct analysis of saline waters (Andersen et al. 2007). In accordance with the ANZECC/ARMCANZ (2000a) water quality guidelines, DGT may be used as a speciation measurement to provide a better estimate of the reactive metal concentration if the total and dissolved metal concentrations exceed the guideline trigger values (Teasdale et al. 2002 cited in Andersen et al. 2007).

Oysters (*Saccostrea glomerata*) were selected as biomonitors for PCIMP studies because they are accumulators of metals rather than regulators, and are a species common to coastal Queensland. Oysters can accumulate many contaminants in their tissues, which can then be measured to provide a time-integrated estimate of bioavailable contaminant concentrations (Cruz- Rodriguez & Chu 2002 cited in Andersen et al. 2007). Oysters are suspension feeders and take-up metals both directly from seawater and from suspended particles collected during feeding (Rainbow 1995, cited in Andersen et al. 2007). Oysters have been successfully used as biomonitors in several pollution assessment studies in Port Curtis, including:

- *Transplanted oysters and resident mud crabs as biomonitors in Spillway Creek* (Andersen et al. 2003)
- *Assessing the effects of harbour dredging using transplanted oysters as biomonitors* (Andersen et al. 2004)
- *Transplanted oysters and DGT devices to measure bioavailable metals: comparison of techniques* (Andersen et al. 2005)
- *Antioxidant enzymes as biomarkers of environmental stress in oysters in Port Curtis* (Andersen et al. 2006).

3.5.3 Port Curtis Integrated Monitoring Program Ecosystem Health Report Cards (2007 and 2011)

The majority of zones within the PCIMP Curtis Coast study area had ratings of between A+ (equal to reference) and B+ (mild departure from reference) in both the 2007 and 2011 report cards (refer Table 3.9). This suggests the water quality of the Curtis Coast for these monitoring periods was in very good condition with minimal deviation from reference conditions (VE 2011a).

Table 3.9 Port Curtis Integrated Monitoring Program zones summary (2007 and 2011)

PCIMP zone	Report card year	Score	Summary
1. The Narrows	2007	A	■ Tended to have lower pH, higher turbidity and slightly lower DO, typical of mangrove dominated areas, therefore the zone did not rate as highly as other zones for ecological health, but not due to anthropogenic influences ■ Zone recorded elevated TP, while metals (cobalt and manganese) were elevated in DGT, which is often observed in upper estuaries of Port Curtis, potentially due to lower DO and pH concentrations, or geological formations ■ All metals were below Australian Sediment Quality Guidelines. When compared to reference zones, copper and zinc uptake in oysters was higher, although lower than the inner harbour zone ■ Zone contains high amounts of potential acid sulfate soils

PCIMP zone	Report card year	Score	Summary
	2011	A	- Lower pH, higher turbidity and slightly lower DO - Elevated nutrients (in sediments and water) recorded the upper reaches, including bioavailable forms, resulting in elevated algal blooms. Possibly influence by agricultural runoff from the Fitzroy River catchment. - Total, oyster and DGT-labile metals were all generally low, similar to the reference zone except DGT-labile nickel, manganese and cobalt which are often elevated in upper north harbour estuaries and are thought to have natural geological sources. - Sediment metals scored lower than the reference zone
2. Fisherman's Landing	2007	B+	- Several low scores in some of the performance categories, influenced by conditions in Boat Creek, which recorded lower pH, higher turbidity, and lower DO in the upper estuary, similar to other mangrove-lined estuaries - Moderately elevated TP, consistent with other Port Curtis zones - Elevated concentrations in DGT recorded for aluminium, copper, cobalt and manganese, likely influenced by conditions in Boat Creek, and the lower DO and pH conditions, which promote bioavailability - Uptake of copper, nickel and zinc in oysters was noted for the whole zone. - All metals in sediments were below Australian Sediment Quality Guidelines (cobalt, copper and cadmium) were elevated compared to background estuarine sites
	2011	A-	- Zone 2 was provided with an A- rating, which was influenced by some low scores in several performance categories including metals and nutrients. Low scores were mainly attributed to Boat Creek samples sites because of lower pH, higher turbidity and low DO in the upper estuary. This was noted to be similar to other mangrove lined estuaries. It was also noted that Boat Creek does not receive point source discharges - Elevated TP was recorded - High levels of aluminium, copper, cobalt and manganese recorded were attributed to Boat Creek sample site results with metals being more bioavailable due to low pH and low DO conditions. For manganese and iron, the elevated concentrations are likely to be partly associated with natural mineral deposits as economically viable manganese mines operated in the upper reaches of Boat Creek in the early 1900s. - Copper, nickel and zinc uptake in oysters was noted - Cobalt, copper and cadmium were elevated compared to background estuarine reference zone although still below recommended guidelines (Australian Sediment Quality Guidelines) - Sediment PAHs were of a low concentration and scored well

PCIMP zone	Report card year	Score	Summary
3. Calliope - Wiggins	2007	A	- Apart from some elevated turbidity readings (mostly attributed to the areas surrounding the Wiggins Island seagrass meadows) the zone scored high for water quality - TP was elevated in this zone, consistent with other Port Curtis zones - Elevations of copper and aluminium in DGT were recorded but were generally confined to Calliope River and RG Tanna wharf sample sites - Compared to background reference areas accumulation of copper and zinc in oysters was elevated across the zone - Contaminants in sediments were below Australian Sediment Quality Guidelines, some elevations in copper and manganese were above the background estuarine reference zone
	2011	A-	- Although water chemistry in this zone was of a high standard, lower water clarity mainly associated with the naturally turbid Calliope River Anabranh and flood waters during the summer sampling, resulted in lower scores - Nutrients were generally at low concentrations with some elevated bioavailable forms likely to be associated with catchment land use practices - Similar to the Boat Creek area, natural elevations of manganese and iron contributed to lower water metal scores - In contrast to Zone 2 (Fisherman's Landing), low scores for total aluminium were translated to uptake in oysters and DGT suggesting this metal was potentially available to the food chain - Accumulation of copper and zinc in DGT and oysters was elevated compared to background reference areas and these metals also contributed to lower sediment scoring, suggesting some anthropogenic contributions of these metals. All metals in sediments were below recommended sediment guidelines (ANZECC 2000a).
4. Auckland Creek	2007	A	- Zone scored highly in regards to water quality - TP was elevated in this zone, consistent with other Port Curtis zones - Copper, zinc and aluminium accumulation in oysters was elevated across the zone, compared to background reference areas, while accumulation of metals in DGT were very low - Contaminants in sediments were below Australian Sediment Quality Guidelines, some elevated concentrations of copper and zinc were above the background estuarine reference zone

PCIMP zone	Report card year	Score	Summary
	2011	A	- Despite the shallow nature of the upper estuary, water chemistry rated quite highly. Nutrients were of a relatively high standard with bioavailable forms only occasionally detected. - Similar to Zones 2 and 3, natural deposits of manganese and iron contributed to lower metal scores apart from copper and zinc, sediment metals scored highly - All sediment metals were below recommended guidelines (ANZECC 2000a) - Aluminium, lead, copper and zinc uptake was noted in both DGT and oysters suggesting these metals are bioavailable in water - Copper and zinc accumulation in oysters in the marina has been associated with vessel antifouling and boating activities, and was a similar finding to 2007 - Contaminant contributions do not appear to be sourced from the Gladstone Refuse Station in the upper estuary but are more likely related to diffuse sources from small industry and urban practices along the estuary
5. Mid harbour	2007	A-	- Zone scored highly in regards to water quality, some isolated elevated turbidity readings indicate the potential for the zone to experience brief periods of higher turbidity - TP was elevated in this zone, consistent with other Port Curtis zones - Aluminium accumulation in DGT was elevated at some sites, all others were very low - Copper accumulation in oysters was elevated across the zone, compared to background reference areas - Contaminants in sediments were below Australian Sediment Quality Guidelines, despite some elevations of a number of metals, particularly from sampling sites on southern Curtis Island
	2011	A+	- This zone rated highly being comparable to the reference zone - Water chemistry in this zone was of a high standard with low concentrations of bioavailable nutrients. Total water metals and sediment metals scored highly, similar to reference concentrations. - All sediment metals were below recommended guidelines (ANZECC 2000a). Accumulation of metals in DGT was also very low with the exception of aluminium and cadmium, which were occasionally elevated at selected sites. - This did not translate to accumulation in oysters with this parameter also scoring highly - Similar to other zones, copper accumulation in oysters was slightly elevated compared to background reference areas and was mostly uniform across the zone

PCIMP zone	Report card year	Score	Summary
6. Inner harbour – South Trees	2007	B+	- Elevated turbidity and lower DO was recorded in this zone, particularly in the upper estuaries, typical of shallow mangrove lined muddy estuaries. Water quality therefore scored lower than other zones. - TP was elevated in this zone, consistent with other Port Curtis zones - Aluminium, cobalt and manganese accumulation in DGT was recorded in the zone, mainly attributed to sampling sites in the upper estuaries and wharf areas - Compared to background reference areas, copper, nickel, selenium and zinc accumulation in oysters was elevated - Contaminants in sediments were below Australian Sediment Quality Guidelines, despite some elevations of copper, manganese and zinc which were above the background estuarine reference zone
	2011	B+	- Water quality in this zone was affected by decreased water clarity and lower DO found in the narrow upper estuaries - The upper reaches of the creeks in this zone are inaccessible at low tide, forming shallow pools which are prone to oxygen depletion - Elevated bioavailable forms of nutrients which also resulted in measurements of increased algal production at upstream sites, also contributed to lower the scores - Similar to other zones, manganese and iron were elevated in water, DGT and oysters. Several other metals such as aluminium, copper, gallium and selenium were also elevated across at least two of the three media contributing to lower scores. - Not all elevated metals in water samples translated to elevated metals in oysters (e.g. molybdenum) and DGT suggesting the metals were not necessarily always available for uptake - Sediment metals and sediment nutrients however generally scored highly, except for gallium, copper and zinc, which had reduced scores
7. Boyne Tannum	2007	A+	- Despite some lower DO and higher TP readings, water quality scored relatively highly in this zone - Isolated results of elevated DGT for aluminium was recorded, although this was a harbour sampling site, not a river site. Some elevated manganese in DGT was recorded although this is common in Port Curtis estuaries. Overall metals in DGT scored highly. - Scores for oysters and sediment contaminants were also high
	2011	A	- Water quality was of a relatively high standard in this zone except for lower DO and water clarity at some sites - Despite the agricultural upper catchment, nutrients were also of a high standard. Similar to other zones, elevated manganese and iron in the upper estuary was typical of Port Curtis estuaries - Total metals concentrations scored well, however elevated aluminium and silver at some sites translated into accumulation in DGT and/or oysters - Sediment nutrients and metals also rated highly, however elevated gallium in sediments also translated to elevations in water and oysters. Low scores for nickel in DGT were not reflected in the other parameters whereas selenium accumulation in oysters did not relate back to elevated water selenium concentrations.

PCIMP zone	Report card year	Score	Summary
8. Reference	2007	A+	Estuarine: - Despite some lower DO recorded in the upper estuaries, water quality was of a high standard in this zone - TP was elevated in this zone, consistent with other Port Curtis zones - Scores for oysters and sediment contaminants were also high Oceanic: - Despite elevated TP (consistent with other Port Curtis zones), and some elevated manganese and cobalt in sediments, the zone rated highly across all categories.
	2011*	A+	- This zone rated highly across all performance categories. The water chemistry and nutrients in this zone were of a high standard with some lower water clarity restricted to the upper estuaries. - Additionally, slight elevations in TP which were also restricted to the upper estuaries, contributed to reduced scores which may be related to natural geological deposits. Scores suggested site uniformity and good water quality across all parameters. - The exception was DGT which scored lower for some metals but this did not translate into oyster accumulation indicating transient elevated measurements - Elevated total silver at oceanic sites resulted in accumulation in oysters and this is thought to be a natural phenomenon. All overall average scores (> 0.99) indicated the pristine nature of this zone

Table notes:

* Estuarine and Oceanic reference zones were combined in the 2008-2011 Report Card.

Sources: Storey et al. (2007), VE (2011a)

3.6 Liquefied natural gas developments and Western Basin Dredging and Disposal Project

To facilitate the development of the LNG export industry in the Port of Gladstone, GPC obtained approvals from the Commonwealth and State Government in 2010 to extend, deepen and widen existing shipping channels, and create new berth facilities through the WBDDP. Dredging for the WBDDP (Stage 1) commenced on 20 May 2011 for removal of approximately 25Mm³ of material from the Port spanning from Auckland Point (in the southeast) to The Narrows (in the northwest). Dredging works were conducted in order to create a suitable channel, berth pockets and swing basins to service new LNG plants on Curtis Island. Information on the environmental performance of the WBDDP is contained in Section 3.9.2.

Table 3.10 outlines the water quality studies in Port Curtis prepared directly before and after the WBDDP.

Table 3.10 Studies before and after the Western Basin Dredging and Disposal Project

Assessment or report name	Reference
<i>Western Basin Project baseline water quality monitoring</i>	GHD (2009a)
<i>GLNG EIS marine water quality assessments</i>	BMT WBM (2009a)
<i>QCLNG EIS water quality assessments</i>	BMT WBM (2009b)
<i>Port Curtis baseline water quality pre-dredge monitoring – Overview</i>	VE (2010a)
<i>Port Curtis and Tributaries, Comparison of Current and Historical Water Quality</i>	DERM (2011)

Assessment or report name	Reference
<i>Metals in the Waters and Sediments of Port Curtis, Queensland</i>	Angel et al. (2012)
<i>Analysis of Water Quality in Relation to Fish Health in Gladstone Harbour and Waterways (September 2011 to September 2012)</i>	EHP (2013)
<i>Supplementary Report to the Arrow LNG Plant EIS, Marine Water Quality</i>	Coffey Environments (2013)
<i>Post-flood Water Quality monitoring in Gladstone Harbour and Waterways – Summary</i>	Holmes et al. (2013) DSITIA

3.6.1 Western Basin Dredging and Disposal Project baseline water quality monitoring (GHD 2009a)

The WBDDP (Stage 1A) was a major capital dredging project undertaken by GPC for which an EIS was prepared. Baseline water quality information within the WBDDP area was summarised in the *Water Quality Report* for the WBDDP EIS (GHD 2009a).

This report was based on a combination of water quality results from field monitoring (i.e. vessel based and continuous loggers), along with other available information including data collected for hydrodynamic modelling purposes, seagrass studies and elutriate water quality monitoring. Water quality monitoring was undertaken in the study area which included the WB reclamation area, proposed Western Basin areas to be dredged, and surrounding areas of The Narrows, Targinnie Channel, Fisherman's Landing Basin, Pelican Banks, and southeast of Curtis Island (GHD 2009a).

Results for turbidity and suspended solids indicated that the study area is a naturally turbid system with continuous logger data regularly recording results above AWQG (ANZECC/ARMCANZ 2000a) and QWQG (EHP 2009a) guideline values. During the dry season it was found that turbidity during spring tide conditions is two to four times those in neap tide conditions (GHD 2009a). The study found that tidal state and current speeds induce sediment resuspension at the seabed therefore increasing sediment concentrations in the water column. Wet season inflows were also observed to increase suspended sediment concentrations (GHD 2009a). A summary of the turbidity results is provided in Table 3.11. Monitoring sites are included on Figure 3.1.

Table 3.11 Turbidity results - median and 95th percentile ranges (April to July 2009)

Season/sites	Median range (NTU)	95 th percentile range (NTU)
Dry season, deep water sites	3 to 9	11 to 35
Dry season, shallow water sites	9	30 to 90
Wet season, shallow water sites	10 to 23	127 to 176

It was noted that less data was collected over the wet season period for this program and therefore wet season statistics may be heavily biased towards individual wet season events. Despite this, it was concluded that sediment concentrations in the water column in the study area are influenced by two natural environmental variables, including the tidal state current speeds that induce resuspension of bottom sediments, and wet season inflows from the Port Curtis catchment (GHD 2009a).

The majority of water quality parameters analysed from the vessel-based monitoring program were below the LOR. Minor exceedances of guidelines for contaminants (i.e. herbicide, pesticide, cadmium and nutrients), indicated potential anthropogenic input from urban and agricultural sources, or naturally high levels in the study area. Elutriate water quality results indicated concentrations of metals, metalloids and ammonia were generally much higher than those levels recorded in the water column or the relevant ecosystem water quality guidelines (GHD 2009a). Additional information on the WBDDP is provided in Section 3.9.2.

3.6.2 Gladstone LNG EIS marine water quality assessments (BMT WBM 2009a)

Two separate water quality and hydrodynamic field data collection campaigns were undertaken as part of the preliminary GLNG project investigations during February and June 2008. Tidal, current, echo sounding, Acoustic Doppler Current Profiler (ADCP) and water quality measurements were made during both surveys in the China Bay area of Curtis Island. The later survey also conducted ADCP transects in the vicinity of Friend Point. Water quality field data collection campaigns included vessel-based water quality profiles and water grab samples at monitoring sites (refer Figure 3.1).

Key findings of the investigation were:

- Tides in the area are semi-diurnal and the spring tidal range is of the order of 4m, with significant wetting and drying of mangrove and intertidal areas occurring (BMT WBM 2009a)
- The study area is a high energy environment with strong tidal flows dominating the local hydrodynamics (BMT WBM 2009a)
- The locations that consistently experience the highest velocities are the natural and constructed channels, as measured with ADCP transects (BMT WBM 2009a)
- Turbidity increases with depth and tidal velocity, which is most likely related to bottom sediment resuspension (BMT WBM 2009a)
- Temperature and pH are relatively uniform throughout the water column and evidence of only slight thermal stratification (BMT WBM 2009a)
- Salinity appears to be related to rainfall and associated freshwater influx, although it is not clear whether local or remote inflows (or a combination of both) are dominant (BMT WBM 2009a)
- Freshwater inflows have the potential to bring pollutants from catchment-derived sources (BMT WBM 2009a)
- When compared with (relatively stringent) water quality guidelines (i.e. AWQG), it can be deduced that water quality is good, though variable in the area (BMT WBM 2009a)
- Tidal state and bedload resuspension are strongly influential on water quality levels, in particular, low tides generally exhibit a decrease in water quality than high tides, with the majority of nutrient and metal parameters during these times being associated with the particulate (rather than dissolved) phase (BMT WBM 2009a).

3.6.3 Queensland Curtis LNG EIS water quality assessments (BMT WBM 2009b)

A water quality sampling program was undertaken in Port Curtis on 20 November 2008 for the QCLNG project in the area of China Bay of Curtis Island. Five monitoring sites were chosen in the vicinity of the proposed project site (refer Figure 3.1). The three southern most sites were previously sampled in February and June 2008 for other related studies (BMT WBM 2009a). These three sites were replicated in the QCLNG water quality sampling program provide an improved dataset.

Water samples were taken at each site at low, medium and high tidal states, during a medium tidal range (in between spring and neap tides). One depth profile per tidal state was also undertaken using a YSI water quality instrument, measuring physical parameters.

Results were compared against the QWQG (EHP 2009a). Similar conclusions to those made in the GLNG marine water quality assessments (BMT WBM 2009a) were found in this study.

TN was at or above the water quality objectives (WQOs) at all sites, while the TP water quality guideline (WQG) was exceeded at Site 3 at high tide. All other parameters were within WQOs. TSS samples were noted to be highest at mid tide, with the exception of Site 1, where the highest level of TSS was recorded at high tide (consistent with the vessel-based monitoring). Chlorophyll a was low across all sites, recording 1-2µg/L. Low bioavailable forms of nitrogen were present which indicates that nitrogen is largely present in an organic form. An apparent trend was noted where median concentrations of TSS increased moving southeast away from The Narrows. No other clear trends for nutrients and physicochemical parameters were evident (BMT WBM 2009b).

Iron concentrations were found to be elevated at all sites and tidal states. Aluminium and manganese values were also slightly elevated. All other metals parameters were below the LORs (BMT WBM 2009b).

3.6.4 Port Curtis Baseline Water Quality pre-dredge monitoring – Overview (Vision Environment 2010a)

Prior to dredging and dredged material placement works for the WBDDP, water quality and marine ecology monitoring was undertaken as part of a series of long term environmental programs established by Queensland Gas Company (QGC), and later coordinated by GPC as jointly funded industry studies. Other study programs included sediment geochemistry, acid sulfate soils, hydrodynamic modelling and environmental statistics. The programs' overall management objective was to maintain the quality of the water in Port Curtis through periods of potential impacts (e.g. dredging works), so that existing environmental values were protected.

The focus of the water quality program was to establish background conditions at key benthic habitats in Port Curtis as part of a Benthic Primary Producer Habitat Assessment (BPPHA) project. The objectives of the water quality program were to:

- Establish baseline water conditions at selected sites in Port Curtis through the measurement of physicochemical parameters and light attenuation
- Examine physicochemical parameters (photosynthetically active radiation (PAR) and temperature) impacting benthic primary producers at selected meadows in the area of interest
- Utilise data collected in the monitoring program to interpret any changes in benthic primary producer habitats both spatially and temporally
- Collaborate with modellers to incorporate all pertinent data into predictive models.

A seagrass monitoring program was established to develop an understanding of the background relationships that exist between seagrass and environmental variables on a local scale.

Water quality monitoring commenced from November 2009 to September 2010. Results from this period were used to develop the WBDDP Water Quality Management Plan (WQMP). The methods for the water quality assessment included water sampling and depth profiling, continuous water quality logging, sediment traps, and light and temperature monitoring at seagrass meadows. A summary of key results from the water quality monitoring program are provided below.

3.6.4.1 Turbidity

Turbidity results for continuous data loggers are included in Table 3.12, calculated from raw data (refer Figure 3.1 for data logger locations). Statistics include means and standard error (se) (positive or negative), and 90th, 80th, 50th (median), and 10th percentiles.

Table 3.12 Seasonal turbidity statistics (NTU) at water quality logger sites (November 2009 to September 2010)

Site	Season	Mean $\pm$ se	Range (n)	Percentiles			
				95 th	80 th	50 th	10 th
QE4	Wet season	88 $\pm$ 5	0 to 3,000 (6,243)	213	44	15	4.7
	Dry season	9.5 $\pm$ 0.1	0 to 307 (1,5458)	28	14	5.9	1.0
P14	Wet season	102 $\pm$ 5	0 to 3,000 (6,266)	745	25	10	2.1
	Dry season	13 $\pm$ 0	0 to 313 (14,919)	36	20	9.4	2.8
C2	Wet season	29 $\pm$ 1	0 to 3,000 (5,520)	97	38	13	1
	Dry season	16 $\pm$ 0	0 to 325 (16,046)	42	19	9.1	2.6
P2	Wet season	29 $\pm$ 1	0 to 3,000 (5,520)	97	38	13	1
	Dry season	16 $\pm$ 0	0 to 325 (16,046)	42	19	9.1	2.6
BG10	Wet season	59 $\pm$ 2	0 to 3,000 (5,878)	242	73	15	0
	Dry season	16 $\pm$ 0	0 to 604 (16,085)	47	22	10	2.9
P5	Wet season	161 $\pm$ 6	0 to 3,000 (6,113)	992	52	9.8	0
	Dry season	5.7 $\pm$ 0.1	0 to 1,043 (15,149)	17	8.3	3.8	0.5
RB1	Wet season	113 $\pm$ 4	0 to 3,000 (5,641)	851	38	11	2.6
	Dry season	19 $\pm$ 1	0 to 1,734 (13,772)	69	14	3.8	0

Table note:

Wet season: 20 November 2009 to 31 March 2010, Dry season: 1 April 2010 to 30 September 2010
Standard error (se), sample size (n)

Source: VE (2010a)

Figure 3.3 to Figure 3.10 illustrate turbidity results adjusted for maximum turbidity values (>300NTU) and include a six hour exponentially weighted moving average (EWMA) presented for sites in The Narrows (QE4), Western Basin (P2), Inner Harbour (BG10), and Mid Harbour (P5) VE (2010a). Closed and open circles indicate full and new moons respectively. Black line indicates raw turbidity, while red line indicates adjusted turbidity values. Green line indicates six hour EWMA and blue bars indicate rainfall VE (2010a).

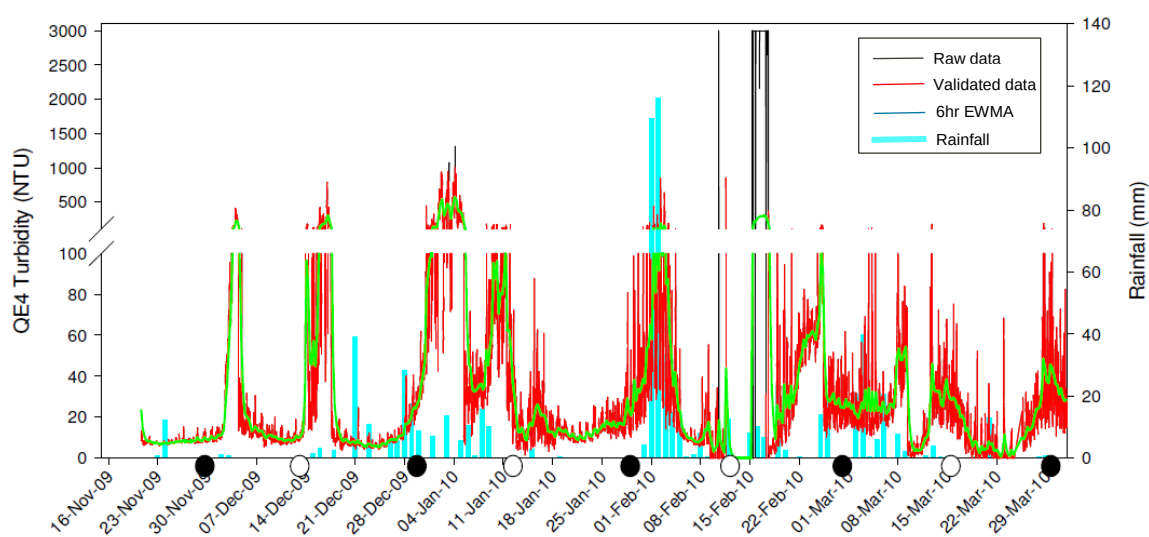


Figure 3.3 The Narrows (QE4) wet season turbidity (November 2009 to September 2010)

Source: VE (2010a)

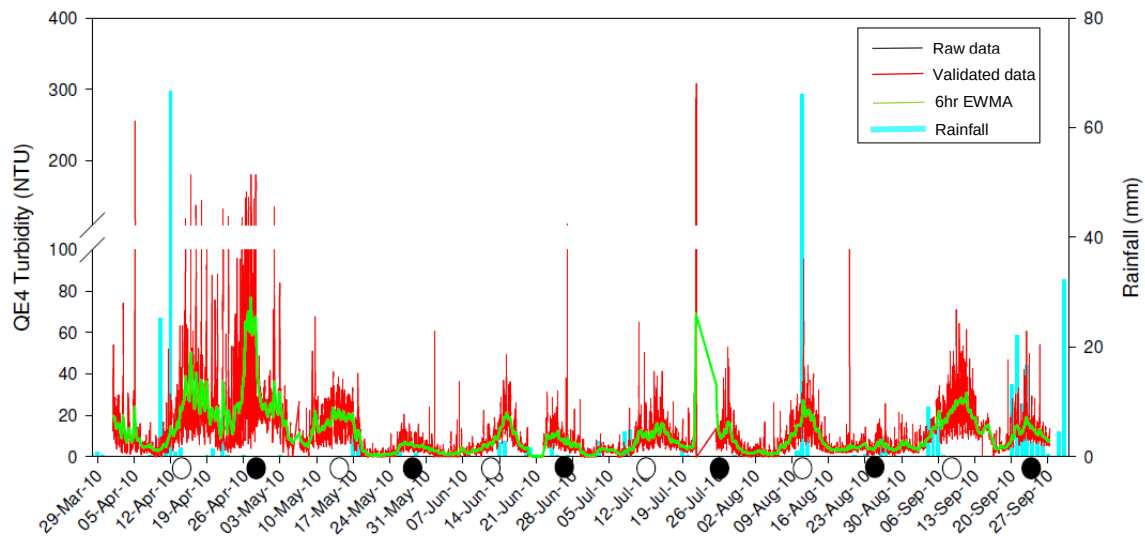


Figure 3.4 The Narrows (QE4) dry season turbidity (November 2009 to September 2010)

Source: VE (2010a)

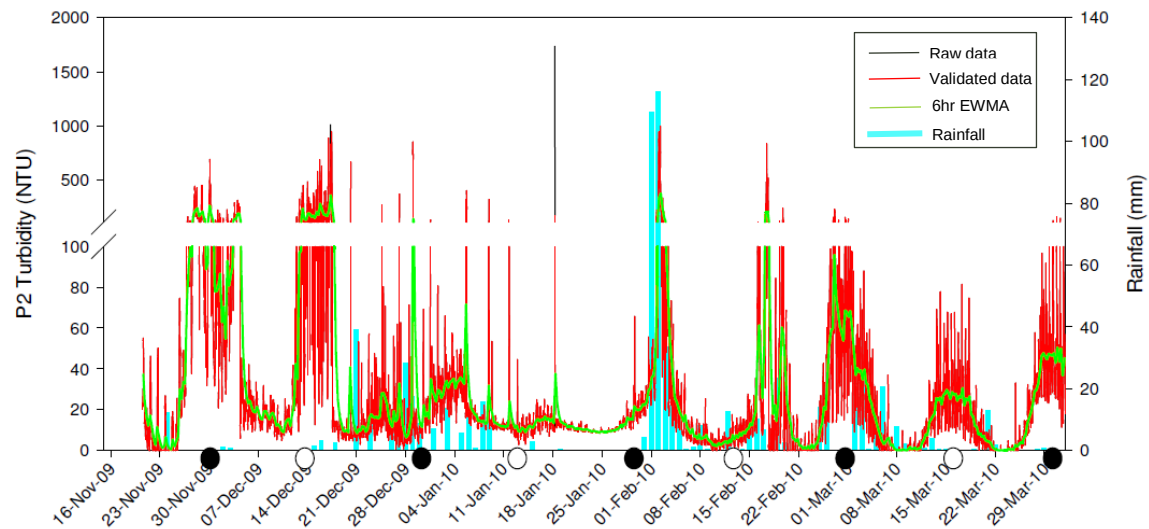


Figure 3.5 Western Basin (P2) wet season turbidity (November 2009 to September 2010)

Source: VE (2010a)

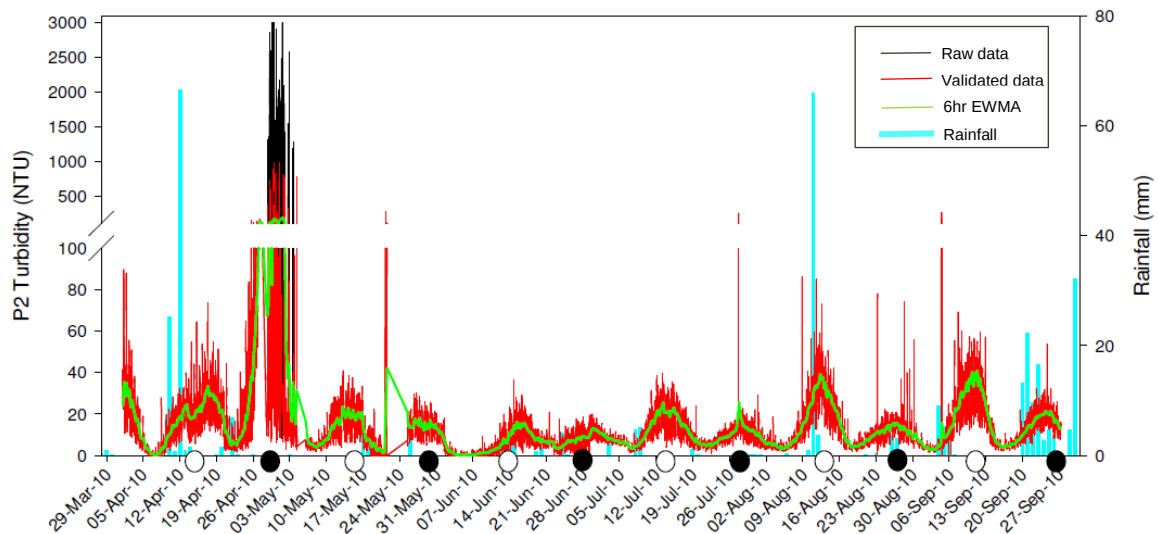


Figure 3.6 Western Basin (P2) dry season turbidity (November 2009 to September 2010)

Source: VE (2010a)

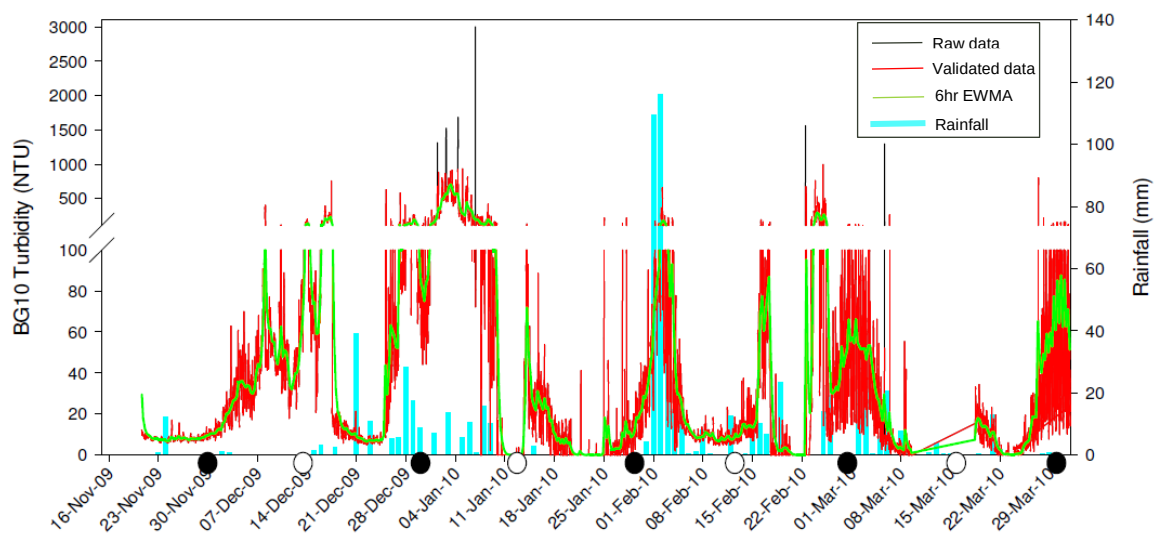


Figure 3.7 Inner Harbour (BG10) wet season turbidity (November 2009 to September 2010)

Source: VE (2010a)

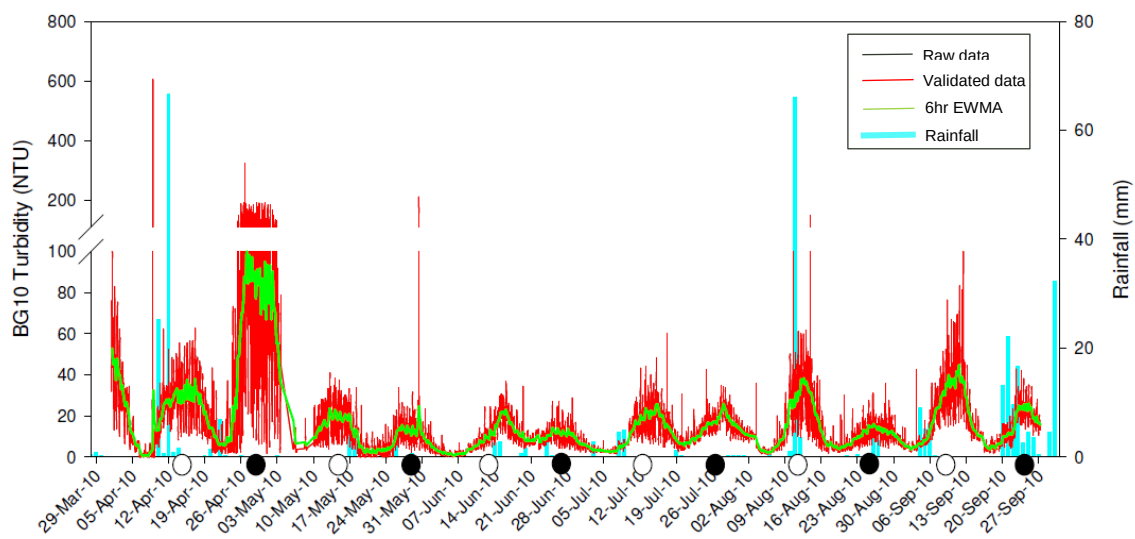


Figure 3.8 Inner Harbour (BG10) dry season turbidity (November 2009 to September 2010)

Source: VE (2010a)

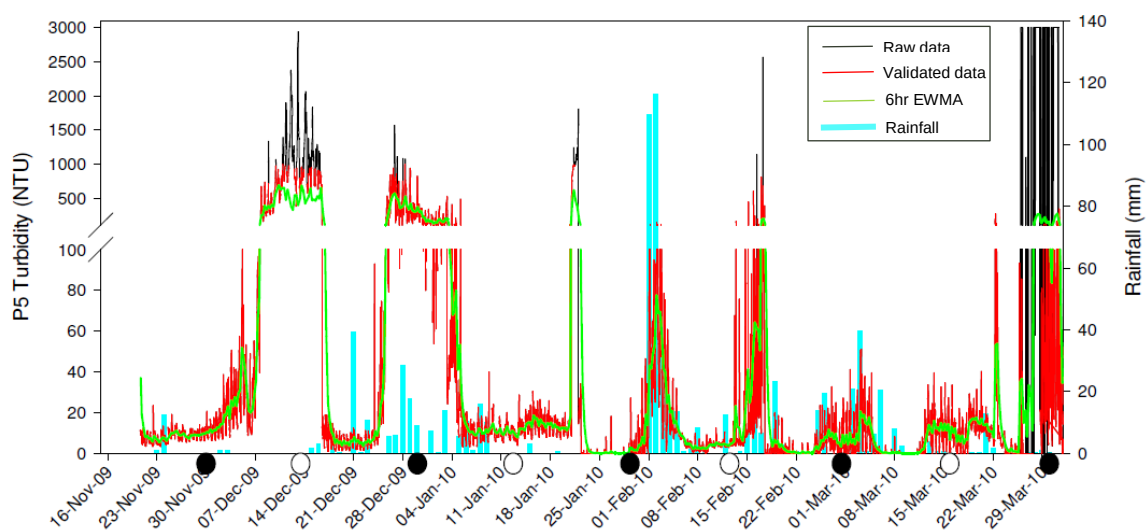


Figure 3.9 Mid Harbour (P5) wet season turbidity (November 2009 to September 2010)

Source: VE (2010a)

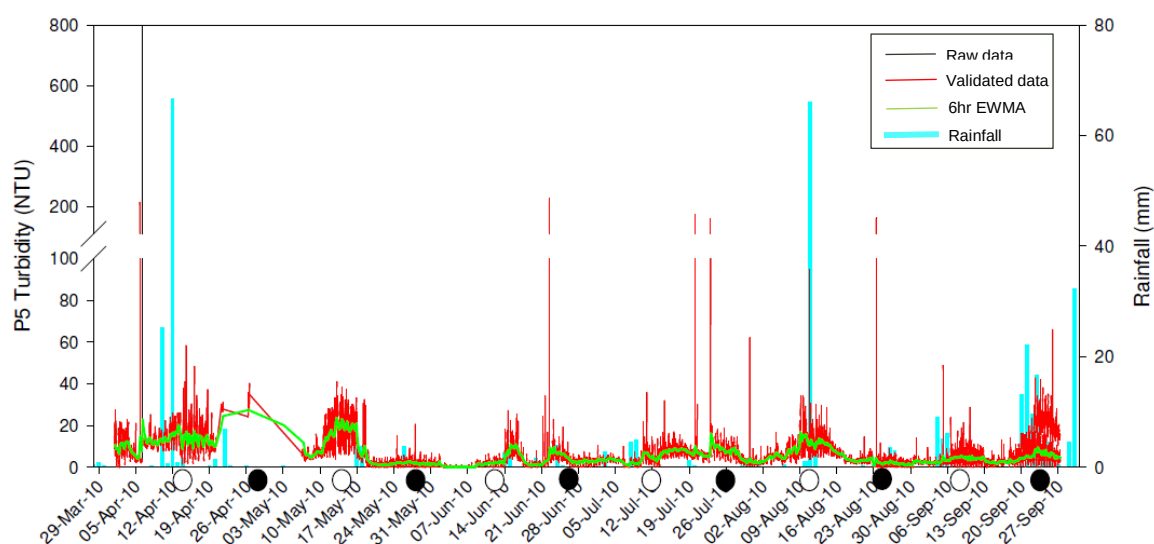


Figure 3.10 Mid Harbour (P5) dry season turbidity (November 2009 to September 2010)

Source: VE (2010a)

3.6.4.2 Other parameters

Continuous data logger results and statistics for other physicochemical parameters have been compiled for temperature and pH (refer Table 3.13), and conductivity and DO (refer Table 3.14) for wet and dry seasons. Water temperatures were higher during the wet season, while pH tended to remain reasonably consistent across both seasons, decreasing by up to 0.2 units during the dry season VE (2010a).

Lower conductivity was recorded during the wet season, influenced by freshwater runoff from rainfall during this period. DO remained reasonably consistent across the two seasons with mean concentrations approximately 2 to 7% saturation lower during the dry season than during the wet (VE 2010a).

Table 3.13 Seasonal temperature and pH statistics at water quality logger sites (November 2009 to September 2010)

Site	Season	Temp Mean $\pm$ se	Range (n)	pH Mean $\pm$ se	Range
QE4	Wet season	28.0 $\pm$ 0.0	23.9 to 33.7	7.9 $\pm$ 0.0	7.3 to 8.3
	Dry season	24.1 $\pm$ 0.0	17.6 to 32.2	7.8 $\pm$ 0.0	7.4 to 8.2
P14	Wet season	27.9 $\pm$ 0.0	24.6 to 31.1	7.9 $\pm$ 0.0	7.1 to 8.3
	Dry season	21.3 $\pm$ 0.0	18.2 to 29.1	7.8 $\pm$ 0.0	7.3 to 11.8
C2	Wet season	27.8 $\pm$ 0.0	24.7 to 30.5	8.0 $\pm$ 0.0	7.5 to 8.3
	Dry season	21.5 $\pm$ 0.0	14.2 to 28.4	7.8 $\pm$ 0.0	7.4 to 8.3
P2	Wet season	28.0 $\pm$ 0.0	23.9 to 31.6	7.9 $\pm$ 0.0	7.2 to 8.3
	Dry season	21.8 $\pm$ 0.0	18.0 to 30.5	7.9 $\pm$ 0.0	7.3 to 8.3
BG10	Wet season	27.7 $\pm$ 0.0	24.2 to 30.0	8.0 $\pm$ 0.0	7.4 to 8.3
	Dry season	21.4 $\pm$ 0.0	18.4 to 28.0	7.9 $\pm$ 0.0	7.4 to 8.4
P5	Wet season	27.6 $\pm$ 0.0	24.3 to 30.9	8.0 $\pm$ 0.0	7.8 to 8.5
	Dry season	21.2 $\pm$ 0.0	17.7 to 29.0	8.0 $\pm$ 0.0	7.5 to 8.5
RB1	Wet season	27.7 $\pm$ 0.0	23.5 to 30.8	8.1 $\pm$ 0.0	7.4 to 9.1
	Dry season	21.5 $\pm$ 0.0	17.0 to 29.1	7.9 $\pm$ 0.0	7.5 to 8.3

Source: VE (2010a)

Table 3.14 Seasonal conductivity and DO statistics at water quality logger sites (November 2009 to September 2010)

Site	Season	Conductivity Mean $\pm$ se	Range (n)	DO Mean $\pm$ se	Range
QE4	Wet season	50.4 $\pm$ 0.1	17.9 to 63.6	93 $\pm$ 0	4 to 159
	Dry season	53.8 $\pm$ 0.0	30.0 to 60.0	91 $\pm$ 0	67 to 173
P14	Wet season	51.6 $\pm$ 0.1	25.7 to 63.1	96 $\pm$ 0	3 to 153
	Dry season	54.3 $\pm$ 0.0	45.0 to 59.0	89 $\pm$ 0	55 to 122
C2	Wet season	52.4 $\pm$ 0.1	20.5 to 63.8	97 $\pm$ 0	77 to 155
	Dry season	54.6 $\pm$ 0.0	40.0 to 64.0	91 $\pm$ 0	1 to 143
P2	Wet season	51.5 $\pm$ 0.1	1.6 to 63.6	98 $\pm$ 0	56 to 176
	Dry season	54.2 $\pm$ 0.0	4.0 to 59.9	93 $\pm$ 0	81 to 117
BG10	Wet season	53.7 $\pm$ 0.1	10.0 to 68.0	97 $\pm$ 0	62 to 143
	Dry season	55.2 $\pm$ 0.0	47.0 to 60.0	92 $\pm$ 0	0 to 108
P5	Wet season	53.7 $\pm$ 0.1	37.3 to 60.6	102 $\pm$ 0	84 to 164
	Dry season	55.2 $\pm$ 0.0	47.0 to 65.9	97 $\pm$ 0	75 to 145
RB1	Wet season	54.2 $\pm$ 0.1	18.0 to 66.5	97 $\pm$ 0	5 to 126
	Dry season	56.6 $\pm$ 0.0	31.0 to 65.9	95 $\pm$ 0	64 to 129

Source: VE (2010a)

3.6.5 Port Curtis and Tributaries, Comparison of Current and Historical Water Quality (DERM 2011)

In September 2011, the DERM undertook an analysis of the available water quality data to determine if there had been any obvious or unusual deterioration in water quality outside of historical fluctuations in Port Curtis (refer Figure 3.1 for locations). This was in response to the (former) Department of Employment, Economic Development and Innovation (DEEDI) introducing an emergency disease and quarantine regulation for fisheries in Port Curtis and surrounding waters (DERM 2011). Increased numbers of diseased fish and health concerns had been raised by the commercial fishing industry in Gladstone, with speculation that the suggested decline in water quality was due to dredging in the Port of Gladstone for the WBDDP and the 2010/2011 wet season rain and flood events (DERM 2011).

Water quality data were compiled from DERM, GPC and PCIMP. The water quality indicators analysed and reported included DO, pH, salinity, turbidity, temperature, metals and chlorophyll a. The analysis for the estuaries and the harbour showed natural variation in water quality due to seasonal factors, flood events and drought (DERM 2011).

For the Port Curtis (including the Western Basin, Inner Harbour, Mid Harbour and Outer Harbour zones), water quality parameters for the February 2010 to August 2011 monitoring period were consistent, with no trend for water quality deterioration (DERM 2011). Highest metal and metalloid concentrations were recorded mostly in samples collected during January 2011, which was consistent with post-flood monitoring throughout the state. Metals and metalloids rarely exceed adopted AWQG trigger values (ANZECC/ARMCANZ 2000a), except during the January 2011 post-floods sampling (DERM 2011).

For the estuaries, except for salinity, all other water quality parameters for the 2010/2011 period were consistent with historical levels. Salinity was lower for an extended period, indicating the influence of the freshwater influx from the extensive flooding events in December 2010 to January 2011. Overall, water quality in the Port of Gladstone and the two estuaries, based on available data was consistent with historical trends, apart from the impacts of the January 2011 flood event, which was also observed in other parts of Queensland (DERM 2011).

Figure 3.11 which illustrates turbidity recorded in the Calliope River, generally reflects the same trends as the shorter term datasets from within Port Curtis, with turbidity ranging from 0 to 50NTU, and showing occasional spikes relating to spring tides and rainfall events (DERM 2011). Turbidity in the Boyne River estuary was highest in 1995 during a flood event which was the highest turbidity recorded at that site at the time of report publishing. (DERM 2011).

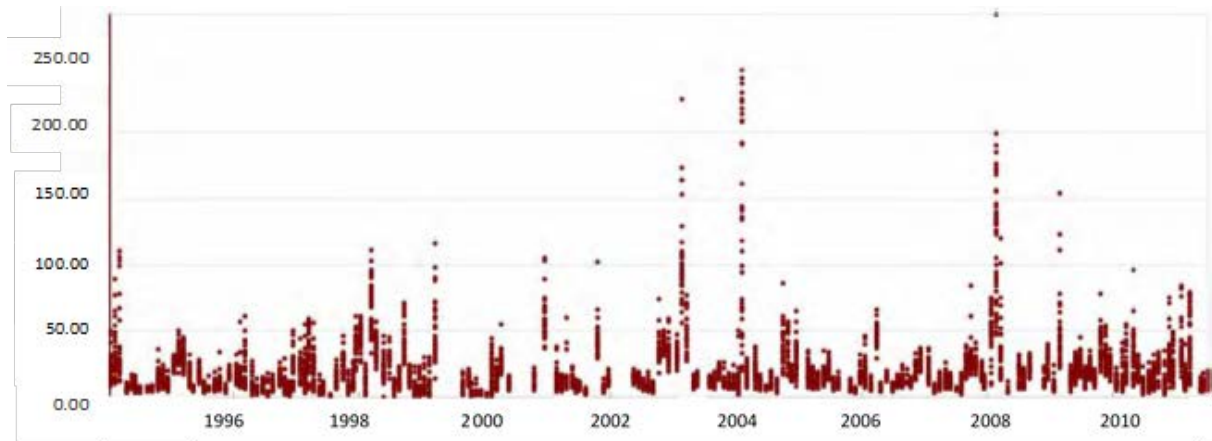


Figure 3.11 Calliope River estuary turbidity (1994 to 2010)

Source: DERM (2011)

3.6.6 Metals in the Waters and Sediments of Port Curtis, Queensland (Angel et al. 2012)

A study commissioned by GPC in 2011 was conducted by the CSIRO to investigate concerns about the impacts of dredging in Port Curtis. The purpose of the investigation was to accurately determine the concentrations of metals in the waters and sediments of Port Curtis. For this study the CSIRO utilised a range of sensitive analytical techniques to allow the accurate determination of dissolved metal concentrations in Port Curtis marine waters at sub- $\mu\text{g/L}$ concentrations. It was noted that the CSIRO has one of the few laboratories in Australia that possess this capability (Angel et al. 2012).

Members of the CSIRO study group had worked in Port Curtis previously as part of the CRC for Coastal Zone, Estuary and Waterway Management, and has produced a number of peer reviewed publications which detailed metal contaminant concentrations in Port Curtis (Jones et al. 2005; Angel et al. 2010). Water and sediment samples were collected from 6 to 8 December 2011 at 21 sites across the Port Curtis region (refer Figure 3.1) to provide a three-day snapshot of trace metal concentrations in Port Curtis. The study design was based on a sampling campaign conducted by CSIRO in 2003 and 2004 (Angel et al. 2010). A detailed interpretation of the data was provided including comparison to existing trace metals data for Port Curtis and other coastal locations impacted by anthropogenic activities. The data from Angel et al. (2010) notes were also compared to water and sediment quality guidelines for marine waters (ANZECC/ARMCANZ 2000a) that currently apply in Australia (Angel et al. 2012).

The study outlined the following findings:

- The concentrations of dissolved arsenic, cadmium, cobalt, chromium, copper, manganese, nickel, lead and zinc were below the ANZECC/ARMCANZ marine water quality guideline trigger values that apply in Australia in samples collected from all 21 sites. Concentrations were relatively low compared to other industrialised harbours around the world (Angel et al. 2012)

- Dissolved aluminium concentrations were above the ANZECC/ARMCANZ (2000a) environmental concern level (ECL) of 0.5µg/L at the majority of sites sampled. It was noted that this ECL value is a highly conservative value based on very limited toxicity data and that there is no reliable guideline value for aluminium in marine waters in Australia (Angel et al. 2012). It was also noted that there are no water quality guidelines that apply for aluminium in marine waters in Europe or North America. It was not possible to attribute a specific source of the dissolved aluminium from the data set (Angel et al. 2012).
- While the dissolved copper concentrations measured in Port Curtis in December 2011 were lower than the ANZECC/ARMCANZ guideline value of 1.3µg/L, they were noticeably higher than the concentrations measured in by the CSIRO in December 2003 and 2004. Some sites were only marginally lower than the ANZECC/ARMCANZ guideline value. This indicates a potential increase of inputs of these metals from various sources (Angel et al. 2012).
- Dissolved cadmium and zinc concentrations were comparable to those measured in 2003 and 2004 by CSIRO (Angel et al. 2012)
- Despite the large amount of industrial and shipping activity in Port Curtis, the Port compares favourably with other industrialised harbours around the world with respect to the relatively low metal concentrations of some dissolved metals concentrations (Angel et al. 2012)
- Particulate arsenic concentrations exceeded the ANZECC/ARMCANZ interim sediment quality guidelines-low trigger value in two samples from the Narrows and one site off Quoin Island. Previous studies indicate that the source of this arsenic is natural (geological formation in the area) and is not associated with anthropogenic inputs.
- Apart from arsenic, the concentrations of particulate metals in benthic sediments were below the ANZECC/ARMCANZ sediment quality guideline values
- Two samples from the Narrows and one from the site off Quoin Island exceed the ANZECC/ARMCANZ ISQG-low trigger value for particulate arsenic concentrations, although previous studies indicate that the source of this arsenic is natural (geological formation in the area) and is not associated with anthropogenic inputs (Angel et al. 2012)
- Consistent with the resuspension of fine sediments into the water column, metal concentrations in suspended sediments were not elevated and were comparable to the concentrations of metals in the < 63µm (fine) particle size fraction of benthic sediments (Angel et al. 2012)
- The study concluded that 'hot spots' metal concentrations could be detected and that there was no detectable elevation of metal concentrations at sampling sites where dredging was being conducted (Angel et al. 2012)

Recommendations from the study included the following:

- The forms of dissolved aluminium and copper (speciation) in the waters of the Port Curtis region and their bioavailability/toxicity should be examined, to investigate the proportion of non-bioavailable dissolved metals in the water and the potential risks to Port Curtis marine life (Angel et al. 2012)
- Continuous regular surveys, ideally under different tidal and climatic conditions should be undertaken in Port Curtis, including during/after pulse events (Angel et al. 2012)
- Metal concentrations in healthy and diseased fish specimens should be analysed to address public concerns around fish disease in the Gladstone region (Angel et al. 2012)
- Dissolved metals should be analysed in future monitoring programs in Port Curtis to provide a better indication of metal bioavailability and toxicity (Angel et al. 2012)
- Dissolved trace metal concentrations at the dredged material placement sites should be characterised (Angel et al. 2012)

3.6.7 Analysis of Water Quality in Gladstone Harbour and Waterways (September 2011 to September 2012) (EHP 2013)

In October 2013, the Department of Environment and Heritage Protection (EHP) undertook an analysis of available water quality data within Port Curtis to determine if there had been any obvious or unusual deterioration in water quality outside of historical fluctuations in Port Curtis.

The investigation used monthly monitoring data collected by DERM from the Boyne River and Calliope River estuaries since 1994 for the *Central Queensland Ambient Monitoring Programme*, along with data from GPC and the PCIMP. The water quality indicators analysed included DO, pH, salinity, turbidity, temperature, metals and chlorophyll a.

The investigation concluded that the water quality in the Port Curtis and the Boyne River and Calliope River estuaries was generally consistent with historical trends, apart from the impacts of the extreme wet season of 2010 to 2011 that occurred throughout Queensland (EHP 2013).

The dissolved metal concentrations in Port Curtis waters measured between September 2011 and September 2012 were comparable to values previously measured by other studies in Port Curtis and were at the lower end of the concentration ranges of metals measured in industrialised ports around the world. Metal and metalloid concentrations were mostly highest during January 2011, which is consistent with post-flood monitoring throughout the state, and rarely exceed adopted AWQG trigger values (ANZECC/ARMCANZ 2000a), except during January 2011 post-flood sampling (EHP 2013).

Repeated exceedances of ecosystem protection trigger values were detected for aluminium and molybdenum with the occasional exceedances for arsenic at South Trees Inlet. Further investigations of this area were initiated (EHP 2013).

Some increased turbidity levels were observed in the areas closest to the WBDDP dredging since 2010 with a possible increase in the turbidity observed across Port Curtis during the dry season. Despite this, there was no evidence to suggest the increase turbidity was related to increased concentrations of dissolved metals that were of potential ecological harm (EHP 2013). pH measurements were typical of the area with no readings below 7.6, and concentrations of pesticides, dioxins and petroleum hydrocarbons, indicated there were no exceedances likely to cause any environmental harm (EHP 2013).

Overall the analysis of water quality in the Port and surrounding estuaries showed natural seasonal variations over time (i.e. during periods of rain, flooding and drought), which were consistent with historical trends (EHP 2013).

3.6.8 Supplementary Report to the Arrow LNG Plant EIS, Marine Water Quality (Coffey Environments 2013)

A marine water quality study and impact assessment was completed in August and September 2012 for the proposed Arrow LNG Plant EIS. The water quality study was undertaken by Central Queensland University (CQU) with supplementary hydrodynamic modelling completed by BMT WBM.

Water quality results were reviewed against Arrow LNG project water quality criteria, derived from QWQG and AWQG, and were interpreted in the context of long term findings from previous studies. Thirty water quality sampling sites (refer Figure 3.1) were identified following a desktop review of previous studies. These sites were grouped into three main areas:

- Calliope River (sites 1 to 10)
- Offshore of Boat Creek South in the Western Basin area (sites 11 to 15)
- Offshore of Curtis Island from North China Bay, to around Hamilton Point (sites 16 to 30).

In situ measurements of physicochemical parameters (i.e. temperature, conductivity, salinity, turbidity, chlorophyll a and DO) were obtained using a water quality probe, measured at 0.5m intervals through the entire water column from surface to seabed. Water samples were collected at both the sub-surface and immediately above the seabed for analysis of metals, nutrients, TSS and TOC. Water samples and in situ measurements were collected across the tidal cycle at high, mid and low tide, and during both spring and neap tides, to allow water quality to be characterised across a range of tidal conditions (Coffey Environments 2013).

The study found existing water quality in the vicinity of the Arrow LNG Plant project infrastructure was generally good when compared to the greater Port Curtis area, although turbidity levels were naturally elevated due to sediment resuspension by tidal currents, exceeding the project criteria at the majority of sites. Considerable variation in turbidity was observed between the neap and spring tidal phases (Coffey Environments 2013).

The study found copper, zinc and cobalt were the only metals to occur in concentrations exceeding project water quality criteria, with most exceedances found in samples from sites around the area of Curtis Island and Tide Island. All these metals were found to be higher during the spring tidal phase, suggesting exceedances were likely due to metals being bound to sediments, suspended in the water column during spring tides (Coffey Environments 2013).

Concentrations of aluminium, iron, arsenic and manganese were found to be above LORs, although no water quality criteria were established at the time. The occurrence of these metals in the sediments and water of Port Curtis has been attributed to natural sources within geological formations, as outlined in Angel et al. (2012) among other studies. Several anthropogenic sources of metals within Port Curtis have also been reported in previous studies such as arsenic from gold workings and cattle dips (Pope 1994 and Vicente-Beckette et al. in Coffey Environments 2013), and aluminosilicates and runoff from surrounding aluminium industries (Angel et al. 2012 in Coffey Environments 2013).

A number of water quality results were recorded outside the limits of the project water quality criteria, including total metals, nutrients (filtered reactive phosphorus, TP and TN), and physicochemical parameters (chlorophyll a, DO and pH). These results were consistent with results from other recent monitoring studies carried out in Port Curtis and followed long term ranges reported by DERM (2012) (Coffey Environments 2013).

3.6.9 Post-flood Water Quality Monitoring in Gladstone Harbour Waterways (Holmes et al. 2013)

Following the 2013 rain event over the weekend of the 26 to 28 January, which saw the Awoonga Dam overflow into the Boyne estuary, water quality monitoring was conducted in Port Curtis by the Queensland Government over monitoring events in January, February, April, June, August and September 2013 (Holmes et al. 2013).

This monitoring was undertaken in light of past similar flooding events over 2010-2011 where the Awoonga Dam also overtopped. Monitoring parameters included physico-chemical parameters (48 sites), nutrients (32 sites), and dissolved metals and metalloids (32 sites) (Holmes et al. 2013; Arango et al. 2013). Sampling locations were consistent with those sampled as part of the Integrated Aquatic Investigation Program between September 2011 and September 2012 (DERM 2013).

Sampling was done in accordance with the AWQG for Fresh and Marine Water Quality (ANZECC and ARMCANZ 2000), with results compared against trigger values for slightly to moderately modified ecosystems (95% protection of all species) (Arango et al. 2013).

Elevated turbidity and nutrient level concentrations, associated with catchment runoff and re-suspended sediments, were recorded in Port Curtis in the first sampling round following the flood event (31 January to 1 February 2013). Sampling sites in the Boyne River estuary and South Trees Inlet recorded elevated dissolved aluminium concentrations (above the Australian low reliability aluminium trigger value of 0.5µg/L) (Holmes et al. 2013).

Turbidity, nutrients and aluminium concentrations were found to have declined by the February 2013 sampling round with levels similar to those recorded prior to the 2013 flood event (Holmes et al. 2013).

Dissolved aluminium concentrations were found to be in the less bioavailable form for water in the Awoonga Dam and the upper Boyne estuary suggesting a catchment source for this aluminium (Holmes et al. 2013). Consistent with historical results for South Trees Inlet, samples from this area often contained aluminium forms which were of low molecular weight. Previous investigations in this area have found elevated aluminium concentrations are likely due to the operation of QAL's red mud dam located nearby (Holmes et al. 2013). With the exception of aluminium, and molybdenum in samples from South Trees Inlet, dissolved metals concentrations were generally less than the applied trigger values (Holmes et al. 2013).

High DO (exceeding 100% saturation) readings were recorded occasionally over monitoring events, generally attributed to high photosynthetic activity from algal blooms (due to elevated nutrient concentrations immediately following the flood event, or in the upper reaches of estuaries and freshwaters). Lower DO readings were occasionally recorded, mostly associated with freshwaters with inconsistent flows (Holmes et al. 2013).

pH readings remained within standard ranges over the monitoring program, despite some lower acidic values recorded at sites such as Gravel Creek, a small freshwater stream with intermittent flows (Holmes et al. 2013).

Overall no major impacts on water quality were observed from the results collected during January to September 2013, following the flood events of 26 to 28 January, with the exception of those caused by catchment runoff, immediately following the flood event (Holmes et al. 2013). It is noted that aluminium concentrations in South Trees Inlet continue to exceed trigger values, with toxicity investigations initiated at the time of report publishing by QAL and GPC (Holmes et al. 2013).

3.6.10 Review of water quality studies (Hale 2013)

An assessment of trends in water quality in the Port Curtis and Port Alma region was undertaken by Jennifer Hale, Aquatic Ecology Consultant, under the Ecosystem Research and Monitoring Program (ERMP) (CA120020) to assist in a comparative assessment between the water quality conditions in the Port during the WBDDP and historical conditions. The purpose of this project was to conduct a review and gap analysis of existing data on water quality in the Port Curtis area.

The objective of the ERMP is to provide high level information on the health of Port Curtis and Port Alma ecosystems, and observe and provide advice on any potential impacts caused by the dredging program and associated practices. The ERMP covers marine megafauna, migratory shorebirds and seagrass, and includes an assessment of the WBDDP on each of these aspects which represent the ecology of the system. Integral to the assessment of impacts and trends in biotic components, is an understanding of the water quality of the region, both from an historical perspective and during the dredging works. Specific to this project is the consideration of the potential effects of dredging on water quality, and to place the effects of dredging in context of other influences on water quality within Port Curtis and Port Alma region (Hale 2013).

Data sources used for analysis in this review by Hale et al. (2013) included DERM historical ambient water quality monitoring data from Calliope and Boyne Rivers (refer Section 3.4.8), GPC WBDDP monitoring data, and DERM monitoring data from September 2011 to September 2012 (refer Section 3.6.7). Other previous monitoring reports and investigations were used for reference, including CRC and CSIRO studies (Hale 2013).

The gap analysis of the study focussed on:

- Identifying the potential threats and water quality parameters of interest
- Determining if there was adequate spatial and temporal monitoring coverage in the study area

- Assessing if water quality variables were within guideline values
- Determining if there was sufficient data to determine cause(s) of exceedances.

Overall the key threats and issues identified in the study included catchment inputs of nutrients, sediments and some contaminants as well as inputs of contaminants from surrounding urban and industrial sources (Hale 2013). Public perception that the WBDDP was having negative impacts on water quality in the study area through mobilisation of nutrients and contaminants from sediments and reducing water clarity was also identified as an issue. Water quality parameters of interest used in the study included water clarity, DO, pH, nutrients, and contaminants (e.g. metals) (Hale 2013).

In terms of spatial and temporal coverage, the study identified that there was a large amount water quality data available for Port Curtis and parameters covered the indicators of interest. This included specific point in time studies as well as ongoing monitoring (at the time of reporting) undertaken by GPC for the WBDDP. However, the rationale behind the selection of monitoring and reference sites was identified as a gap in the WBDDP methodology (Hale 2013).

Analysis of data from the WBDDP suggested that sites were adequate to detect spatial trends and that there may have been some redundancy in sampling sites, with the data analysis indicating that sites located within each of the study areas (The Narrows, Western Basin, Mid to Outer Harbour and offshore) were rarely significantly different from each other (Hale 2013). The WBDDP methods of telemetry logging turbidity and other physical chemical parameters was deemed sufficient to detect trends over time, such as the differences between pre and post dredging (Hale 2013). The less frequent monthly water sampling for nutrients and metals analysis was deemed as adequate to assess against water quality guidelines (Hale 2013).

The DERM (2012) estuary program was reported by Hale (2013) to have a large dataset of monthly sampling covering two decades, sufficient to show seasonal and longer terms trends (Hale 2013). The report also stated that current programs adequately covered parameters such as DO, pH and some nutrients, all which were consistently within guideline values and considered a low risk to aquatic ecosystems (Hale 2013). Contaminants other than metals (e.g. organotins, hydrocarbons, organophosphate pesticides (OP), organochlorine pesticides (OC)) represented a low risk and were not a high priority for water quality sampling in Port Curtis (Hale 2013).

Variables identified by Hale (2013) that have previously recorded results over guideline levels (e.g. turbidity, nutrients and metals) are discussed below in further detail.

3.6.10.1 Water clarity

Hale (2013) points out that the data analysed clearly shows the dual influences of river flow and dredging on turbidity in Port Curtis. Data collected for major river flows, despite the monthly snap-shot nature of samples collected, shows a clear trend of increasing turbidity between 2009 to 2012, as rainfall increased and a number of large floods occurred. The rivers that discharge into the Port Curtis and Port Alma region are characterised by high variability, with high loads of sediments and nutrients discharged during flood events, followed by lower contributions during base flows (Hale 2013). Hale (2013) notes that there are difficulties in quantifying river influences by sampling alone and that an integrated approach, which uses spatial-temporal modelling of water quality, with validation by sample collection, is ideal.

Hale (2013) states that the dataset was sufficient to detect spatial and temporal differences and the influence of dredging. For example, a significant difference between the control site at Rodds Bay and sites in the dredging footprint and between inshore and offshore sites can be observed in the data (Hale 2013). Turbidity data also allowed for a comparison of sites during periods of low river flow, comparing times pre and post dredging. This indicated that sites located within the Western Basin had significantly higher turbidity during dredging, but that this did not extend to sites located in the Outer Harbour area (Hale 2013).

Overall there were sufficient data to detect the influence of dredging and the spatial extent of those influences. Sufficient data from rivers existed to detect increased trends in turbidity following the increase in rainfall and flow post 2008 (Hale 2013).

3.6.10.2 Total phosphorus and nitrate-nitrite

Data for nutrients were limited to monthly samples collected over a 12 month period. This was sufficient to detect differences between inshore and offshore sites and between the inshore control site at Rodds Bay and some sites in Port Curtis (Hale 2013). In addition, data from inflowing rivers showed a distinct increasing trend in both TP and nitrate-nitrite in recent years suggesting this as a possible source of elevated nutrient concentrations. TP was statistically similar at the control site at Rodds Bay and inshore sites in Port Curtis indicating that the cause of the exceedances was not related to dredging (Hale 2013). The significantly lower concentrations at offshore sites support the hypothesis that elevated TP concentrations were related to catchment inputs (Hale 2013).

Nitrate-nitrite concentrations above guideline values were recorded at inshore sites in Port Curtis, but not in Rodds Bay. The data suggest the cause may be river discharges or it may be related to dredging. Continued data collection over time is required to determine the cause of elevated nitrate-nitrite with any degree of certainty (Hale 2013).

3.6.10.3 Metals

Exceedances of water quality guidelines were recorded for five dissolved metals (i.e. aluminium, arsenic, copper, mercury and zinc). However, approximately half of the reported exceedances occurred when the corresponding total metal concentration was lower than that for the dissolved concentration, indicating low confidence in the reported results (Hale 2013). This is common in water quality programs where guideline values are at or near the LOR for standard laboratory analyses (Hale 2013). All reported concentrations above guideline values were isolated, that is they were not sustained over time, indicating a lower risk to aquatic ecosystems. They also occurred at the full range of sites (i.e. inshore, offshore and control sites), suggesting that the causes were varied and not consistently related to dredging activities (Hale 2013). The data reviewed was shown to be consistent with other studies in Port Curtis which have reported comparatively low levels of dissolved metals and no 'hotspots' of metal contamination (Angel et al. 2012; Hale 2013). Overall, data provided by the former Department of Science, Information Technology, Innovation and the Arts (DSITIA), DERM and GPC (WBDDP data) was sufficient to detect risks associated with dissolved metal concentrations in Port Curtis (Hale 2013).

3.7 Natural influences on water quality in Port Curtis

3.7.1 Coastal processes

The Port of Gladstone is a deep estuarine embayment, bounded by Curtis Island in the north and Facing Island in the east. Component estuaries, including the larger estuaries of the Calliope and Boyne Rivers, as well as The Narrows and Auckland Creek, merge with deeper waters to form a naturally sheltered, 30km long deep water harbour. The coastal region encompasses three broad shoreline types including rocky cliffs and shore platforms, sand beaches, and mudflats and mangroves.

Combined with very large deposits of silt from the hinterland in times of flood, the estuary maintains an existing highly turbid character which can impact the marine water quality. The areas of Port Curtis, Rodds Bay and the northern end of The Narrows are commonly described as having 'naturally high turbidity' (GPC 2012) with generally higher turbidity found within the shallow muddy environments adjacent to the coast line. This is largely evident during local tidal cycles with ebb tides typically containing increased turbidity levels and flood tides containing clearer waters (GPC 2012).

Port Curtis is a macro tidal estuary subject to a large tidal range (i.e. 4 to 5m) which ensures that the water column is vertically well mixed most of the time, resulting in the natural resuspension of fine sediment. Tides in the region undergo a neap-spring cycle with a period of 14 days, with spring tides around 4m reducing to about 1m during neap periods (Herzfeld et al. 2004). Spring tides create stronger tidal action which results in the potential for greater resuspension of seabed sediment and therefore turbidity (GPC 2014c; GPC 2012; Herzfeld et al. 2004). Additional information on existing tidal and coastal processes within Port Curtis is provided in the Project *Coastal Processes and Hydrodynamics Technical Report* (BMT WBM 2018).

3.7.2 Climate

3.7.2.1 Rainfall

Port Curtis is located along the Central Queensland coast which lies 95km south of the Tropic of Capricorn. This coastal area experiences a sub-tropical maritime climate with a wet/dry regime which includes high rainfall in the summer months of December, January and February, which account for half the region's annual rainfall (refer Table 3.15). Drier conditions are experienced in the winter months. The annual rainfall average is around 891 millimetres (mm) in Gladstone, but variability between years is large, ranging from 433mm to 1,732mm per annum since 1957 (Bureau of Meteorology (BOM) 2018a).

Table 3.15 Gladstone long term rainfall average

Month	Long term rainfall average (1957 to 2018) (mm)
June	38.1
July	35.0
August	31.5
September	27.0
October	60.3
November	68.6
December	125.0
January	150.3
February	141.7
March	107.0
April	47.3
May	56.4

Source: Gladstone Radar 039123 BOM (2018a)

The water quality of Port Curtis varies naturally following rainfall events and between the wet and dry seasons. Water quality is strongly influenced by freshwater flows from surrounding catchments that discharge into the Port during rainfall events, particularly during the wet season. Flow into Port Curtis is from a number of streams such as the Boyne River, Calliope River and Auckland Creek. Along with increased turbidity due to the resuspension of sediments, wet season flows have been demonstrated to influence other water quality parameters, including temperature, salinity, pH, nutrients and contaminants. This has shown to be particularly evident during and after flood events (GHD 2009a).

3.7.2.2 Extreme events

Numerous flood events have occurred along the Calliope River and Boyne River catchments, and these events have generally been associated with cyclones or associated rain depressions (GPC 2012). Significant rainfall events in recent years that have resulted in flooding, include the rain depression associated with Cyclone Benni in February 2003, flood events of the 2010/2011 wet season (Queensland's largest rainfall on record), and the significant rainfall event associated with ex-tropical cyclone Oswald in January 2013 (GPC 2012). A low pressure system in mid-January 2015 brought heavy rain, flooding and high winds, and Tropical Cyclone Marcia which made landfall in Central Queensland in February 2015 also brought heavy rain and high winds to the region. Above average rainfall associated with ex-tropical cyclone Debbie was also seen in March 2017 (BOM 2017). The water quality of Port Curtis can be heavily influenced by these weather extremes, particularly turbidity and conductivity, with turbid freshwater flows reaching Port Curtis via the Calliope River and Boyne River. The Fitzroy River may also contribute some flows to the Port (via The Narrows) under some conditions (Apte et al. 2005).

The influx of freshwater into the Port during flood events has also been shown to increase the levels of contaminants such as nutrients, herbicides, pesticides and metals found in the water column. This was particularly evident during January 2011 post-flood monitoring undertaken by DERM (2011). This investigation concluded that most metals measured in the monitoring program displayed their highest concentrations in January 2011. This was consistent with similar monitoring conducted by PCIMP, as well as with other post-flood monitoring conducted elsewhere in effected coastal areas of Queensland (EHP 2013).

Extreme events such as cyclones can also generate high wave and water level conditions which can impact the water quality of Port Curtis.

3.7.2.3 Wind

Wind direction and speed are known to directly influence turbidity and TSS in Port Curtis, as a result of wave action and currents which can mobilise and transport sediments. The Port is subject to locally generated sea waves under the influence of local wind conditions (GPC 2012).

The wave climate is characterised by a predominance of southeasterly wind in the morning swinging to the east and northeast in the afternoon. However, the southeasterly winds in the morning are not as strong (20 to 30km/hr for 10% of time) as the easterly winds in the afternoon (30 to 40km/hr for 10% of time). In addition, easterly winds in the afternoon at 20 to 30km/hr occur for a further 25% of time (GPC 2012).

Further details of the wind climate in the Gladstone region are provided in Chapter 11 – Climate, Natural Hazards and Climate Change, of the Channel Duplication Project EIS.

3.7.2.4 Cloud cover

Benthic photosynthetically active radiation (BPAP) represents the amount of light that reaches benthic primary producers (e.g. seagrass species) that can be used for photosynthesis. Recent ecological research in Port Curtis has focussed on the relationship between BPAP and water clarity (e.g. levels of turbidity and TSS).

Cloud cover can result in a major reduction in the amount of solar radiation available on any given day and in turn reduces the amount of BPAP. An understanding of local climate and cloud cover is therefore important in monitoring BPAP.

Gladstone experiences an annual mean of 149.4 clear days and 86.7 cloudy days (BOM 2018).

3.7.3 Contaminants

The Curtis Coast area is known to contain significant mineral deposits, notably the Rundle and Stuart oil shale deposits, heavy mineral sands in the sand masses of coastal areas and a number of inshore islands, and a number of large limestone deposits (GPC 2012). Previous marine sediment investigations have indicated that heavy metals, including arsenic, chromium, manganese, iron, nickel, copper, and nutrient phosphorus occur naturally in the geological formations in the area (GPC 2012).

Angel et al. (2010) investigated dissolved metal levels in Port Curtis, including manganese and concluded that nickel and manganese are likely to be released by natural processes such as reduction of manganese (hydr)oxides and leaching by the lower sediment and water pH. Anastasi and Wilson (2010) also examined Port Curtis as a case study in reviewing manganese in subtropical estuaries and stated that naturally occurring manganese concentrations have been recorded in marine sediments with values up to 9,000 milligrams per kilogram (mg/kg).

Following investigations by Apte et al. (2005), Apte et al. (2006) undertook a study to determine the sources of the contaminants of concern in Port Curtis. The report concluded that the elevated concentration of arsenic, chromium and nickel in Port Curtis sediments were identified as being derived from natural geology and not anthropogenic sources. Vicente-Beckett et al. (2006) also reported elevated levels of arsenic at depth and attributed the arsenic levels as being due to natural geology rather than anthropogenic in origin.

Generally contaminants within the aquatic environment are not all bioavailable to aquatic organisms. However, dredging activities can place the integrity of a particular aquatic community at risk by mobilising potential contaminants such as heavy metal particulates bound to sediments (GPC 2012). This is potentially harmful to the marine environment depending on the level of contaminant concentrations in the water column and if contaminants are bioavailable to marine organisms.

Marine sediments may also be characterised by acid sulfate soils (ASS). ASS cover an area of approximately 3,471ha within Gladstone (consisting of 1,466.5ha of actual ASS and 2,004.5ha of potential ASS, with an additional 1,820ha of disturbed land identified as potentially containing ASS) (Flint et al. 2015). When disturbed, ASS can impact on water quality via the release of sulphuric acid, decrease in pH and heavy metal mobilisation.

Information on the characterisation of marine sediments in Port Curtis and the Project area to be dredged and reclamation areas can be found in the following Channel Duplication Project EIS reports:

- *Sampling and Analysis Plan (SAP)* (Aurecon 2015a)
- *Sediment Characterisation Plan (SCP)* (Aurecon 2015b)
- *Geochemical SAP Implementation Report (Dredge Footprint)* (Aurecon 2015c)
- *Geochemical Sediment Characterisation Plan Implementation Report (DMPAs)* (Aurecon 2015d)

3.8 Anthropogenic influences on water quality in Port Curtis

3.8.1 Industry

Several major industries that operate in and adjacent the Port of Gladstone have wastes that directly discharge into the Port waters via drains or pipes. These industries include power stations, sewage treatment facilities, manufacturing industries, mining industries and metal manufacturers. The largest of these industries are listed in Table 3.16. Licencing and monitoring requirements for point source discharges are generally administered by EHP. Other potential impacts associated with these industries include those from shipping, dredging, noise, light, air quality, soil and groundwater contamination, and changes to social amenity.

Table 3.16 Heavy industry located adjacent to Port Curtis

Type of industry	Current operator(s)	Commenced
Aluminium refinery	Queensland Alumina Ltd	1967
Aluminium smelter	Boyne Smelters Pty Ltd	1982
Coal fired power station	NRG Gladstone Operating Services Pty Ltd	1982
Sodium cyanide, ammonia nitrate, chlorine plant	Orica Australia Pty Ltd	1990
Aluminium refinery	Rio Tinto Aluminium Yarwun	2004
Oil shale miner and medium shale oil and naphtha plant	Queensland Energy Resources (QER Pty Ltd)	1980s
Cement and clinker plant	Cement Australia	1981
Liquefied natural gas	Queensland Curtis LNG (BG Group) Gladstone LNG (Santos/Petronas/Total/Kogas) Australia Pacific LNG (Origin/Conoco Phillips/Sinopec)	2015
Coal export	GPC	1920s
	Wiggins Island Coal Export Terminal Pty Ltd (WICET)	2015

Source: Commonwealth of Australia (2013), GPC (2016)

The National Pollutant Inventory (NPI) provides publicly available information on air, land and water pollution emissions from industries across Australia. Table 3.17 outlines the industries and associated contaminant emissions to water that have been recorded for Gladstone from 1998 to 2015, illustrating the cumulative stresses on Port Curtis waters over time. The most recent data for Gladstone states 22 reportable chemical compounds were discharged by Gladstone facilities in 2014 to 2015 with the greatest volume of inputs from fluoride compounds (158,870kg/year) from basic non-ferrous metal manufacturing (Department of the Environment 2016).

Unlicensed sources of discharge in the Port may include waste from charter and recreational vessels. These discharges can be the source of contaminants such as nutrients and heavy metals which can accumulate in sediments.

The potential for groundwater contamination from smaller industries such as petrol stations and landfill sites also exists. Impacts on the Port's waters and estuaries from these sources are dependent on the location and scale of contamination (GPC 2012).

Industrial incidents may potentially influence water quality in the Port of Gladstone. A number of industrial incidents have been recorded in the Gladstone region, including the release of cyanide contaminated water, the release of caustic aerosol spray containing sodium hydroxide, ethylene leaks and waste oil and diesel spills (Flint et al. 2015).

Table 3.17 Gladstone industrial facilities contaminant emissions to water recorded from 1998 to 2015

Contaminant	Basic chemical manufacturing	Basic non-ferrous metal manufacturing	Electricity generation	Mineral, metal and chemical wholesaling	Oil and gas extraction	Water supply, sewerage and drainage services	Water transport support services
Ammonia (total)	●						
Antimony and compounds		●					
Arsenic and compounds	●	●	●		●		●
Benzene				●			
Beryllium and compounds		●	●				
Cadmium and compounds	●	●	●				
Chlorine and compounds	●						
Chromium (III) compounds	●	●	●				●
Chromium (VI) compounds		●	●				
Cobalt and compounds		●					
Copper and compounds	●	●	●		●		●
Cumene (1-methylethylbenzene)				●			
Cyanide (inorganic) compounds	●			●			
Cyclohexane				●			
Ethylbenzene				●			
Fluoride compounds		●			●		
Lead and compounds	●	●	●		●		●
Manganese and compounds		●	●		●		
Mercury and compounds	●	●	●		●		●
n-Hexane				●			
Nickel and compounds	●	●	●		●		●
Particulate Matter 10.0 um							●
Polycyclic aromatic hydrocarbons (PAHs)		●			●		
Styrene (ethenylbenzene)				●			
Toluene (methylbenzene)				●			
Total Nitrogen	●	●				●	
Total Phosphorus	●	●				●	
Total Volatile Organic Compounds				●			
Xylenes (individual or mixed isomers)				●			
Zinc and compounds	●	●	●		●		●

Source: Department of the Environment (2016) NPI

3.8.2 Land use and catchment runoff

The main catchments that discharge sedimentary material to Port Curtis are the Boyne and Calliope Rivers. The Fitzroy River may also contribute some flows to the Port (via The Narrows) under some conditions (Hertzfeld et al. 2004). These catchments are a potential source of contaminants such as pesticides, herbicides and nutrients.

While the Boyne River and Calliope River catchments are relatively small and do not contain large areas of intensive agriculture, significant land use changes since European settlement have resulted in increases in the nutrient and sediment loads in Port Curtis (Commonwealth of Australia 2013). The land use in both catchments is largely dominated by grazing and as a result the majority of sediment loads are generated from these areas (Coughlin 2016). An assessment of Australian catchments, rivers and estuarine systems completed by the CRC and CSIRO (Norris et al. 2001) describes the Boyne River as being in low-moderate condition with highly modified hydrology and riparian zones, and is severely modified due to the presence of flow barriers. The Calliope River was assessed as being relatively unmodified with water quality having had some change from its natural state (Norris et al. 2001).

Urban stormwater discharges have the potential to carry increased nutrients, heavy metals, suspended solids and hydrocarbons. Stormwater can also contain other gross-pollutant waste, including polystyrene foam, plastic cups, bags and bottles (GPC 2012). No estimate of the potential impact that stormwater may be having on the Port of Gladstone is currently available (Commonwealth of Australia 2013).

When waste enters the marine environment it becomes marine debris and can have an adverse impact on water quality. Marine debris recorded in the Gladstone region originates from local land sources, stormwater, commercial shipping and fishing activities. Debris surveys conducted at Gladstone beaches, including Chinaman Beach, Fishermans Beach, Facing Islands and Rodds Peninsula in 2014 recorded 311.7kg of debris (Flint et al. 2015).

The Calliope River Sewage Treatment Plant treats approximately 97% of Gladstone's sewage with the remainder treated at the South Trees Sewage Treatment Plant. Both plants treat sewage to secondary standard before being recycled (Gladstone Regional Council 2013). From 2002 treated effluent was no longer discharged directly to the Calliope estuary from the Calliope River Sewage Treatment Plant with the majority of water diverted for reuse at the Queensland Alumina Ltd (QAL) refinery. Nutrient and sediment loads associated with wastewater treatment have been included in the National Pollutant Inventory data. All new housing developments must implement water sensitive urban design methodology in accordance with the Queensland Government's Urban Stormwater Quality Planning Guidelines 2010 (Commonwealth of Australia 2013).

The main water storage in the area, Awoonga Dam, has a capacity of 250,000ML. Awoonga Dam has overflowed several times since it was raised in 2002, the first time being in December 2010 (Commonwealth of Australia 2013).

Recreational and commercial fishing activities have a potential to impact on water quality within Port Curtis. The use of 2-stroke carburettor outboard engine-powered vessels commonly used by recreational fishers and boaters can cause measurable water quality impacts in areas of high use (for example near boat ramps, in estuaries and near-shore environments). Commercial fishing vessels may also emit toxins, including petrochemicals and anti-fouling chemicals into the marine environment (Flint et al. 2015).

Vessel incidents have the potential to cause stored garbage and toxicants to enter the marine environment. The most commonly reported marine vessel incidents in Gladstone in 2013 were unintentional groundings, collisions with a fixed object and collisions between ships (Flint et al. 2015).

Additional shipping activities which may have an impact on water quality include:

- Ship movements, including:
 - Propeller wash and berthing settlement (resuspension of sediments)

- Petrochemical emissions
- Shipping incidents and grounding, including oil spills, hazardous material spills and waste
- Marine debris (dumping/losing garbage at sea)
- Discharge of ballast water
- Use of anti-fouling paints.

Wharf facilities can be a source of water quality contamination through spills and wash down during and after loading and unloading freight. There are 20 operational wharves and six anchorages within the Port of Gladstone. The wharves and anchorage facilities are serviced by waste disposal and sterilisation services (Flint et al. 2015).

3.8.3 Oil spills

Due to the nature of shipping activity and surrounding industry in Port Curtis, oil spills have the potential to occur and to impact on the water quality of surrounding sensitive marine environments.

In January 2006, an incident involving the bulk carrier *Global Peace* saw 25t of heavy fuel oil spilt into the Port of Gladstone at the RG Tanna Coal Terminal (RGCT) loading facility (GPC 2012). This event triggered a spill response clean-up procedure along with short and long term monitoring programs at surrounding marine, coastal and intertidal environments.

Other notable oil spills affecting the Port of Gladstone include a land-based spill of 1,000L of diesel in 2009, and a ship-based spill of 1,500L of sewage and grey water in 2012. Small amounts of diesel and hydraulic fluid are the most frequent spills from both land and ship sources (Flint et al. 2015).

While the risk of a significant oil spill in the Port is small, a number of activities that regularly occur in the Port do present a risk to the water quality of Port Curtis from smaller potential spills. These activities include:

- Large trading vessels entering and leaving the Port via designated shipping channels
- Oil product tankers discharging oil products at South Trees and Auckland Point wharves
- Chemical tankers discharging caustic soda at South Trees Wharf, Fisherman's Landing #2 Berth and Bulk Liquid Ammonia at Fisherman's Landing #5 Berth
- Large trading vessels calling to load and unload bunkers
- Smaller commercial and recreational watercraft using the marina.

A MSQ analysis of oil spill risk in the Port of Gladstone outlined the main risk factors as land-based spills, frequent small spills, refuelling activities, and navigational hazards in the Port (DTMR 2013).

3.9 Potential impacts of dredging activity

3.9.1 Overview

Although the Port of Gladstone is a natural deep water port with a relatively large tidal range, capital and maintenance dredging is undertaken to accommodate new industries, improve vessel movement efficiency, and maintain existing shipping channels.

Dredging and material placement have the potential to change the physical and chemical environment, and affect the biological values of an area, through both direct and indirect potential impacts. A 2015 report prepared by an independent panel of experts and published by GBRMPA, provided a synthesis of the current knowledge of the effects of dredging and material placement on the physicochemical environment and the biological values of the GBRWHA. Dredging activities and related pressures identified in the synthesis report are outlined in Table 3.18. Many of these effects are context dependent and will differ between locations, types and extent of dredging, and sediment placement activities.

Table 3.18 Dredging activities and related pressures

Phase	Activity/process	Pressures
Dredging	Duplication of shipping channels and dredging of barge access channel	■ Removal of benthos and substrate (direct) ■ Suspended sediments: – Increased turbidity and reduced light – Sediment deposition ■ Bathymetric and consequent hydrodynamic changes ■ Underwater noise ■ Chemical effects released from sediment: – Nutrients, organic matter – Contaminants, if present
Material placement (immediate effects)	Dredged material unloading and placement in designated reclamation areas	■ Burial of habitats (direct) ■ Suspended sediments: – Increased turbidity and reduced light – Sediment deposition ■ Bathymetric and consequent hydrodynamic changes ■ Chemical effects released from sediment: – Nutrients, organic matter – Contaminants, if present
Sediment dynamics (intermediate and long term)	■ Resuspension ■ Transport ■ Consolidation, armouring	■ Suspended sediments – Increased turbidity and reduced light – Sediment deposition ■ Chemical effects released from sediment: – Nutrients, organic matter – Contaminants, if present

Source: Adapted from McCook et al. (2015)

3.9.2 Capital dredging – Western Basin Dredging and Disposal Project

3.9.2.1 Project overview

The WBDDP (Stage 1A) was a major capital dredging project undertaken by GPC from May 2011 to September 2013. It was declared a significant project by the Coordinator-General (CG) on 24 April 2009 and approved by the CG in July 2010, and the DoEE in October 2010 with conditions (Ref: EPBC 2009/4904).

The project was required to facilitate safe and efficient shipping access to the emerging LNG industry located on Curtis Island. Stage 1A of the project involved dredging approximately 25Mm³ of material from the seabed of the Western Basin area of the Port of Gladstone for the deepening and widening of existing channels and swing basins, as well as the creation of new channels, swing basins and berth pockets. Placement of dredged material was split between the WB reclamation area adjacent to Fisherman's Landing (onshore) and the East Banks DMPA (offshore).

Several management plans, including a Dredge Management Plan (DMP) and WQMP were prepared for the WBDDP to address the requirements of the CG Report and *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) controlled action approval. These plans were approved by the Queensland and Commonwealth Governments prior to implementation.

The WBDDP also saw the establishment of a Dredge Technical Reference Panel (DTRP), as a result of an EPBC Act condition of approval. The DTRP was established to advise, review and oversee all aspects of the environmental monitoring for the WBDDP. This independent panel consisted of industry experts in dredging, seagrass, benthic life, water quality, along with representatives from GPC and the Queensland Government.

A comprehensive monitoring program for water quality and BPAR during dredging began in April 2012 and included 16 water quality sites, including compliance monitoring sites, supplementary monitoring sites and reference sites. Water quality data was collected every 15 minutes and transmitted via telemetry for parameters, including turbidity, BPAR and TSS, along with routine grab sampling for laboratory analysis of nutrients and metals. Water quality monitoring continued until November 2013, two months after the completion of Stage 1A dredging.

3.9.2.2 Western Basin Dredging and Disposal Project Water Quality Management Plan

The initial WQMP was developed with a focus on turbidity as an indicator of water quality and the protection of key environmentally sensitive locations (e.g. seagrass meadows). Water quality monitoring sites were then established at the predicted (modelled) areas of dredging plume impact and at environmentally sensitive locations. Turbidity trigger values for the wet and dry seasons were established at each monitoring site, with corresponding response procedures, including internal and external reporting. These trigger values were based on the exponentially weighted moving average (EWMA) of turbidity, and were derived from data available in February 2011. At the time some sites had either no data or incomplete background existing baseline data available, therefore 'interim' trigger values were estimated using information available at neighbouring sites. More sophisticated methods were not employed for this task given that these were interim values and due to be replaced by empirical estimates once the supporting data had been collected (Environmetrics Australia 2011a; Environmetrics Australia 2011b).

Prior to dredging, 'interim' trigger values in the WQMP were approved by Commonwealth and State regulatory agencies. As a result of interim turbidity trigger values being established with insufficient background data, these trigger values did not account for the natural variability of turbidity in Port Curtis. Under normal conditions, inshore turbidity levels are found to be highly influenced by the tidal regime. At Outer Harbour and coastal water locations these usually exhibit low, stable turbidity levels, with some tidal influence evident. Historical monitoring has indicated that the Outer Harbour location is more exposed to higher wind speeds, and less influenced by the tidal regime, than the Inner Harbour location and relatively high turbidity at this location was recorded during the high wind periods. Rainfall and flooding during the wet season are also natural events that can influence the turbidity of water, particularly at inshore areas (e.g. Western Basin, Inner Harbour and Outer Harbour) due to catchment runoff.

Due to natural variations, several exceedances of license trigger values were recorded during dredging works, irrespective of turbidity generated by the dredged activity. Despite a consensus from the DTRP, the process of revising the interim trigger values in the WQMP to account for natural variations in turbidity, was not easily accomplished and was looked upon unfavourably by various stakeholders. Triggers for two compliance water quality monitoring sites were amended in 2012 based on recommendations from the DTRP.

3.9.2.3 Development of light-based trigger values

As per the CG Report conditions for the WBDDP, a move towards more ecologically relevant trigger values based on established seagrass light requirements rather than background turbidity was required. The use of the adaptive light-based seagrass monitoring triggers rather than turbidity triggers is generally deemed to be more effective at protecting seagrass than using a surrogate measure based on turbidity (Commonwealth of Australia 2013). Turbidity and BPAR data, collected as part of the WQMP, was used to develop a transition to light-based compliance monitoring.

The seagrass meadows in Port Curtis and Rodds Bay are of regional significance as they are the only known major areas of seagrass between Hervey Bay (170km south) and Shoalwater Bay (170km north) (Sobtzick et al. 2013). A light-based management approach was therefore used to protect these species from dredging plume turbidity impacts associated with the WBDDP. The WQMP and trigger levels were based on findings from two years of seagrass research in Port Curtis, outlined in the DAFF publication *Development of a Light-Based Seagrass Management Approach for the Gladstone Western Basin Dredging Program* (Chartrand et al. 2012), which established the required light levels for Port Curtis seagrass species, namely *Zostera muelleri* ssp. *capricorni*.

The use of light attenuation trigger values in conjunction with turbidity trigger values was adopted in the WQMP as an additional reference tool for guiding dredging operations, in the instances of turbidity exceedances. This meant if turbidity trigger values were exceeded, BPAR results at seagrass meadows could also be assessed to determine the level of risk to the seagrass species.

3.9.2.4 Independent review of the Port of Gladstone

In June 2012, following concerns about the health of the Port of Gladstone, the World Heritage Committee (WHC) issued a decision relating to the state of conservation of the Great Barrier Reef World Heritage Property and requested that the Australian Government undertake an independent review of the management arrangements for Port of Gladstone to allow the optimisation of port development and operation in the Port and on Curtis Island, consistent with the highest internationally recognised standards for best practice commensurate with iconic World Heritage status.

The role of the independent review, was to examine and report on the management arrangements for the Port of Gladstone, and to advise the Minister for Sustainability, Environment, Water, Population and Communities (now Minister for Environment and Energy) on other relevant matters to inform decision-making under the EPBC Act. The review considered various publicly available information resources, interviews with various stakeholders, and called on additional expert advice where required.

The health of fish and the water quality of the Port of Gladstone in 2011 was raised in a large number of submissions as one of the major environmental concerns. The potential impacts of dredging operations from the WBDDP in relation to observed fish illness were also raised. These concerns related to the potential for mobilisation of contaminants from dredged sediments to affect marine organisms, including commercial fishing species.

The independent review recognised that the Port of Gladstone is one of the most studied ports in Australia and the Port and its industry partners have invested in and used advanced environmental science and monitoring to inform decision making. While information gaps exist, these gaps are not only unique to Gladstone and steps have been taken to correct many of them. While there is substantial monitoring in the Port, the independent review notes that community confidence in the science implemented by the Port, industry and governments, appeared to be very low.

Key findings and recommendations identified in the independent review (i.e. Chapter 5 Environmental concerns and performance) are listed in Table 3.19.

Table 3.19 Port of Gladstone independent review key findings for environmental concerns and performance

Number	Finding/recommendation
Finding 7	The ANZECC Guidelines contain a suitable framework for determining the species protection guideline trigger levels for toxicants in water in the Port of Gladstone and have been appropriately applied
Finding 8	The <i>National Assessment Guidelines for Dredging 2009</i> (NAGD) contain a robust framework for determining the suitability for ocean disposal of dredged material from the Port of Gladstone
Finding 9	Sediment sampling and analysis in the Port of Gladstone were undertaken in accordance with the NAGD and the data showed that the sediments to be dredged were compliant with the requirements of the NAGD for ocean disposal (i.e. all contaminants were below the 95 per cent upper confidence level of relevant Screening Levels)
Finding 10	Dredging and disposal of potential acid sulfate soils (PASS) containing sediments in the marine environment are unlikely to result in either significant oxidation of this material, acid production, or release of significant quantities of heavy metals to the water column
Finding 11	There is no clear single cause identified for the fish health issues observed in the Port of Gladstone in 2011. They are likely to be the result of multiple pressures, in particular extreme weather events and associated overcrowding from fish that moved into the area after overspilling Awoonga Dam.
Recommendation 13	That the Queensland Government continue to address and respond to the recommendations of the Fish Health Panel, specifically that future studies be undertaken to understand cause-effect relationships of fish health and environmental factors.
Recommendation 14	That proponents of developments within the Port of Gladstone ensure that any voluntary independent audits are conducted consistent with best practice standards and seek to obtain the department's agreement to the criteria.
Recommendation 15	That all confirmed cases of non-compliance be publicly announced on both the department's and proponent's website along with details of any remedial actions.

Table note:

Responses to how the Channel Duplication Project will address these recommendations will be outlined in Appendix D.

Source: Commonwealth of Australia (2013)

3.9.2.5 Independent review of the bund wall at the Port of Gladstone

Between June 2011 and July 2012, during the WBDDP, events relating to the performance of the reclamation area bund wall occurred. The Gladstone bund wall independent review was commissioned by the Commonwealth Government to examine and report on information relevant to the design, construction and functioning of the outer bund wall of the WB reclamation area and to consider the adequacy of monitoring requirements.

The review panel found that aspects of the design and construction of the bund wall were not consistent with industry best practice. Inadequate restraint of a geotextile liner, piping of water and sediment through paleochannels under the wall and the erosion of mud outside the wall all contributed to changes in turbidity in the vicinity of the bund wall. Key findings and recommendations of the review in terms of environmental monitoring are outlined in Table 3.20.

Table 3.20 Bund wall independent review key findings for monitoring requirements and operations

Number	Finding/recommendation
Finding 10	Although there are some differences between the Australian and Queensland Government conditions of approval, the two sets of approval conditions with respect to water quality monitoring are complementary and provided an objective basis to manage construction and dredging activities.
Finding 11	A single water quality management plan was designed and prepared to comply with Australian and Queensland Government conditions of approval. The Water Quality Management Plan for the WBDDP did not meet best practice, as it failed to include all updated trigger levels.
Finding 12	The location of low, medium and high impact zones could not be easily determined, in part due to differences in some definitions between the Australian and Queensland Governments
Finding 13	The status of the approved Water Quality Management Plan and its subsequent revisions was not clearly documented and then effectively communicated to relevant advisory bodies (e.g. the Dredge Technical Reference Panel) and the general public.
Finding 14	The baseline water quality datasets do not fully meet ANZECC guidelines (i.e. two full dry and wet seasons of monitoring to establish a baseline) with dry season data being available at only three of the six sites; however, what is available does provide a useful baseline.
Finding 15	The monitoring framework underpinning the Water Quality Management Plan is consistent with the Australian and Queensland Government conditions of approval.
Finding 16	The development and utilisation of a light attenuation trigger for the low-impact monitoring sites is considered best practice; however, this was poorly implemented in relation to the overall Water Quality Management Plan and poorly communicated to the general public.
Finding 17	Significant community misunderstanding exists as to the expected impacts on water quality across the low and medium/high impact zones.
Finding 18	The processes for initially determining and subsequently modifying the boundaries of the low to medium/high-impact zone were poorly documented.
Finding 19	The location of monitoring sites was inadequate to provide detailed analysis of changes in turbidity at the scale of individual projects.
Finding 20	No compliance monitoring sites existed to identify and then assist in managing discharge from the bund wall.
Finding 21	The Port Curtis Integrated Monitoring Program was not designed for identifying and managing the consequences arising from dredging generally and the bund wall specifically.
Finding 22	While the use of reference sites to provide additional information to assist in decision making is good practice, in Gladstone Harbour the methods for evaluating possible non-dredging related causes of the turbidity increases were only generally described and qualitative, thereby limiting their effectiveness.
Finding 23	Through voluntary monitoring activities Gladstone Ports Corporation did obtain additional datasets on harbour water quality during the construction of the bund. Gladstone Ports Corporation was not under any legal obligation to make these data public.
Finding 24	The movement of site C3 was necessary given the bund construction and had no bearing on management decisions. No silt curtains were used along the north-eastern wall; inoperative dredge pipes were mistaken by some members of the community for silt curtains.
Finding 25	The effectiveness of monitoring would have been improved by including more sites in the low-impact zone.

Number	Finding/recommendation
Finding 26	Specific conditions for monitoring around the bund wall were inadequate and conditions only called for management responses to exceedances in the low-impact zone
Finding 27	The roles of the co-existing conditions for monitoring associated with the WBDDP, Queensland Government monitoring activity and the voluntary Port Curtis Integrated Monitoring Program are not well understood by the community.
Recommendation 5	The Australian and Queensland Governments should endeavour to align their respective Conditions of Approval to the maximum extent possible, particularly in terms of defining the extent, severity and duration of acceptable impacts and stating where no impacts are acceptable.
Recommendation 6	Future water quality management plans should aim to address all condition/permit requirements within a single internally consistent document. Where this is not feasible or practical, plans should explicitly explain the relationships between the different approvals/permits and how and where they are addressed.
Recommendation 7	The Australian and Queensland governments and project proponents should ensure that the status of water quality management plans and any revisions therein are effectively and efficiently managed and communicated to relevant advisory bodies and the general public.
Recommendation 8	High-quality background environmental data should be recognised as critical environmental infrastructure and its acquisition and maintenance be a high priority for the Australian and Queensland governments.
Recommendation 9	Consideration should be given by the Australian and Queensland governments to the development of spring and neap tide criteria in tropical coastal systems, either as a replacement for the seasonal criteria or to provide an additional level of assurance.
Recommendation 10	Governments and proponents should clearly communicate the location and purpose of water quality monitoring sites to the general public.
Recommendation 11	For large and complex developments in sensitive marine environments such as Gladstone Harbour, governments and proponents should implement a single integrated monitoring framework that encapsulates reference, long term and management monitoring sites with clear reporting requirements and decision pathways.

Table note:

Responses to how the Channel Duplication Project will address recommendations will be outlined in Appendix D.

Source: Commonwealth of Australia (2014)

3.9.3 Maintenance dredging

3.9.3.1 Maintenance dredging campaigns

Maintenance dredging is generally undertaken annually in Port of Gladstone channels, berths, swing basins and the Gladstone Marina to remove sedimentation resulting from littoral drift, sediment laden stormwater runoff/flooding and tidal currents, as well as to maintain declared depths for commercial shipping access. Maintenance dredging is a legislated activity to ensure Queensland's trade arteries are kept open and forms a routine part of GPC's operation of the Port having been undertaken almost annually since the early 1990s (GPC 2014c).

Historically, within the Port of Gladstone, approximately 65% of maintenance dredging has occurred in the outer channels and approximately 35% occurring in the inner channels. Maintenance dredging projects generally produce smaller volumes of dredged material than capital dredging. From the mid-1990s to 2006, approximately 100,000m³ of maintenance dredging was carried out annually within the Port of Gladstone. Currently the average annual maintenance dredge volume is about 150,000m³.

Offshore placement of dredged material at the Port of Gladstone has historically occurred within the existing East Banks DMPA, an area of approximately 1,050ha located within Port limits and outside the GBRMP. Dredged material placement at this location has occurred in association with the Port's annual maintenance dredging.

Offshore dredged material placement is a regulated activity and is undertaken in accordance with the statutory obligations outlined in both Commonwealth and State (i.e. *Sea Dumping Act 1981*) conditions of approval.

3.9.3.2 Maintenance dredging campaigns 2014 and 2015

Maintenance dredging was undertaken in the Port of Gladstone in 2014 (during selected dates in February, March and July) and 2015 (between 4 June and 18 June). Water quality monitoring was undertaken for these maintenance dredging campaigns, which is required under Commonwealth and State regulatory approvals conditions, during pre-dredging, dredging and post dredging periods.

Monitoring programs for maintenance dredging campaigns are established through a process of hydrodynamic modelling and validation through plume monitoring. This enables accurate impact hypotheses to be made which the water quality monitoring program then tests. Particular focus is given to turbidity and the impact on BPAR due to the location of seagrass meadows in proximity to the areas to be dredged. The objectives of the maintenance dredging monitoring programs are to:

- Assess potential impacts of dredging through monitoring Port water quality, particularly turbidity, metals and tributyltin
- Assess potential impacts of offshore dredged material placement through monitoring offshore water quality, particularly turbidity downstream of the East Banks DMPA
- Assess the potential for dredging turbidity plumes to travel north into The Narrows.

Results from the recent maintenance dredging monitoring reports conclude that the effect of maintenance dredging on turbidity levels was not detected at monitored seagrass meadows.

Changes in turbidity were assessed at all sites (Inner Harbour areas and the East Banks DMPA) in relation to dredging activities, tidal and wind influences. A strong correlation was noted at all sites between turbidity, BPAR and natural environmental processes, such as spring tides, medium to strong winds and available natural light. Turbidity levels at Western Basin and Mid Harbour locations were primarily influenced by the tidal fluctuations associated with the lunar phases, with highest turbidity during the new moon spring tide in mid-June, although P5 turbidity was also likely impacted by high winds.

Metals and tributyltin results did not exceed the 99% trigger for pristine environments, indicating that dredging activities did not have a measurable impact on metals or tributyltin mobilisation in the water column.

The effects of maintenance dredging on turbidity levels were not discernible and were likely to be very small or very localised (at monitored seagrass meadows) confirming that the Port maintenance dredging is unlikely to influence turbidity to an extent that will result in environmental harm. The Port Maintenance dredging monitoring programs support previous findings that changes in turbidity in Port Curtis are largely driven by the normal tidal range with wind and wave action being the other major drivers, particularly at offshore monitoring sites (GPC 2014c; GPC 2015).

3.9.3.3 Maintenance dredging campaigns 2017 and 2018

Maintenance dredging was also undertaken in the Port of Gladstone in 2017 (during selected dates between August to October 2017) and in 2018 (between 14 November to 16 December 2018). As with previous campaigns, water quality monitoring was undertaken as required under Commonwealth and State regulatory approvals conditions, during pre-dredging, dredging and post dredging periods.

Measured turbidity and BPAR were within ranges of those historically recorded for the monitoring sites during baseline (or non-dredging periods) and previous dredging programs. The overall driving factors of changes in measured turbidity and BPAR appeared to be natural influences such as tidal phases, wind speeds and overall light availability. No exceedances of the 95% species protection AWQG trigger values were evident for dissolved metals or tributyltin. Maintenance dredging operations did not appear to have an effect on measured contaminant concentrations (VE 2017; 2018).

3.10 Port Curtis water quality data collation summary

Given the broad range of stakeholders in the community, the industrial growth and Port expansion over the last 50 years, and the increasing population of the region, water quality is one of the key indicators for the health of Port Curtis. The Port is one of the most studied ports in Australia, with studies relating to water quality in Port Curtis dating back to the 1970s.

The objective of this data collation is to address EIS requirements to describe the existing water quality environment for Port Curtis, with a view to understanding historic water quality conditions over periods of urban and industrial expansion in the Gladstone area. Understanding the potential impacts that Gladstone development and an operating commercial Port have had on the water quality of Port Curtis gives an indication of the potential baseline 'creep' which may have occurred over the past 30 years. This context is important when reporting on 'baseline' water quality results collected for the Project in 2014/2015.

This report has been prepared with information from a variety of available information sources, including desktop and field monitoring programs. An independent review of water quality data in Port Curtis and Port Alma by Hale (2013) states there is a large body of water quality data and information for the Port Curtis region and that there are few, if any water quality/information gaps for the study area.

3.10.1 Natural influences

3.10.1.1 Climate

For details on the climate in the Gladstone region refer to Section 3.7.2 and Project EIS (Chapter 11 (climate and climate change assessment)).

3.10.1.2 Hydrodynamics

The water quality of Port Curtis has been shown to be strongly correlated with tidal state and associated bedload resuspension. The Port has a large tidal range from low to high, around 4m during neap tide periods and around 1m during spring tides (Herzfeld et al. 2004). The Port experiences a neap-spring tide cycle over a period of approximately 14 days with the associated tidal regime inducing high current velocities in the main channel (Herzfeld et al. 2004). The region is therefore commonly described as a naturally turbid environment.

The waters of Port Curtis are generally well mixed both vertically and horizontally. The flushing time (i.e. the time for total mass of material to decrease to a third of its original mass) for the estuary is 19 days (Herzfeld et al. 2004). This reduced flushing time is likely to contribute to the anomalous bioaccumulation of some metals in biota of Port Curtis (Andersen et al. 2005).

The estuary receives freshwater flows from the Boyne and Calliope Rivers, along with some influence through The Narrows from the Fitzroy River. The Port is a well-connected estuary which allows dissolved material to be dispersed evenly, although material does not as readily leave the estuary to the offshore environment (Herzfeld et al. 2004).

3.10.2 Physico-chemical parameters

Salinity, temperature and DO in Port Curtis have been shown to be influenced by climate, and follow seasonal as well as longer term climatic cycles.

3.10.2.1 Turbidity

Port Curtis is commonly described as being a naturally turbid environment with turbidity levels highly variable both temporally and spatially, with previous studies often recording levels above the QWQG and moderately below the AWQG (Hale 2013; GPC 2012; DERM 2011; (VE 2011a); GHD 2009b). Previous studies show that turbidity in Port Curtis generally ranges from 0 to 20NTU with the potential to increase up to and above 50NTU during the wet season (DERM 2011; GPC 2012; (VE 2011a)).

Turbidity levels in this area are influenced by a combination of season, wind speed, wind direction and tidal range and/or tidal height, as well as catchment runoff.

Turbidity levels are heavily influenced by the spring and neap tide cycle with turbidity during spring tide conditions recorded as two to four times those in neap tide conditions (GHD 2009a). There is also a distinct difference in turbidity levels between ebb and flood tides, with ebb tides typically containing increased turbidity levels and flood tides with clearer waters (Herzfeld et al. 2004). Several turbidity data sets clearly illustrate the relationship between turbidity levels and tidal cycles/range/height (GPC 2014c; GPC 2012; Herzfeld et al. 2004).

Turbidity at the surface is generally lower than at the bottom of the water column most likely due to bottom sediment resuspension. Turbidity in the Outer Harbour and coastal waters can be influenced by benthic sediments being resuspended during strong winds and elevated wave heights. Sediment concentrations in the water column, particularly in the inshore areas are influenced by two natural environmental variables; tidal state current speeds that induce resuspension of bottom sediments, and wet season freshwater inflows from the Port Curtis and Fitzroy (during significant rain events) catchments (GHD 2009a).

Previous datasets have demonstrated that high inflow events have coincided with elevated turbidity, particularly in 2003 and 2008 and more recently in 2010-2011, and 2013 (Hale 2013; Holmes et al. 2013). Turbidity levels in the harbour have commonly exceed 50NTU, and beyond 100NTU during natural events (DERM 2011; GHD 2009b; Vision Environment 2011).

A long term dataset for turbidity recorded at Clinton Wharf showed a natural variation in turbidity which is reflected in Figure 3.12 (GHD 2009a). Turbidity levels generally ranged between 0 to 20NTU but there were regular increases between 20 and 40NTU during February/March 2004 and 2005.

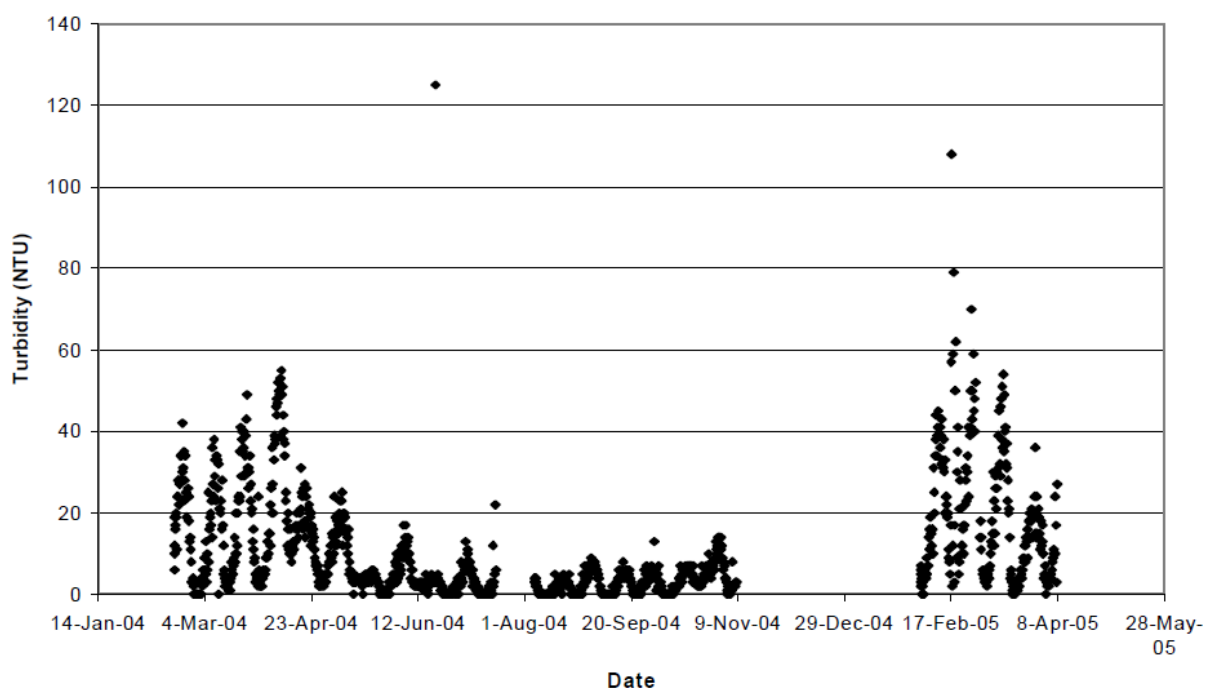


Figure 3.12 Long term turbidity at Clinton Wharf RG Tanna Coal Terminal (February 2004 to April 2005)

Source: GPC (2012)

Peaks of up to 125 NTU were also recorded for short periods and are likely from natural resuspension of sediments by tidal currents (GPC 2012).

Data outlined in the DERM (2011) report *Port Curtis and Tributaries Comparison of Current and Historical Water Quality*, shows the data for the Calliope River (refer Figure 3.13) generally reflects the same trends as the shorter term datasets from within Port Curtis, with turbidity ranging from 0 to 50NTU, with occasional spikes relating to spring tides and rainfall events (DERM 2011).

DERM (2011) analysed long term datasets for the Boyne River and Calliope River estuaries (1994 to 2011) and recent turbidity data for Port Curtis (2010 to 2011). Turbidity in the Boyne River estuary was highest in 1995 during a flood event. No subsequent event to date has produced such high turbidity levels at this site. The Calliope River is generally a more turbid estuary than the Boyne River. The highest turbidity recorded in the Calliope River from 1994 to 2011 was in February 2008.

Turbidity data from Port Curtis shows the highest turbidity levels in May to October 2010. Turbidity in 2011 is not as high as in the previous year. During the flood in 2011, turbidity was temporarily elevated and all the high values represent sampling from 13 December 2010, at the peak of the flood event.

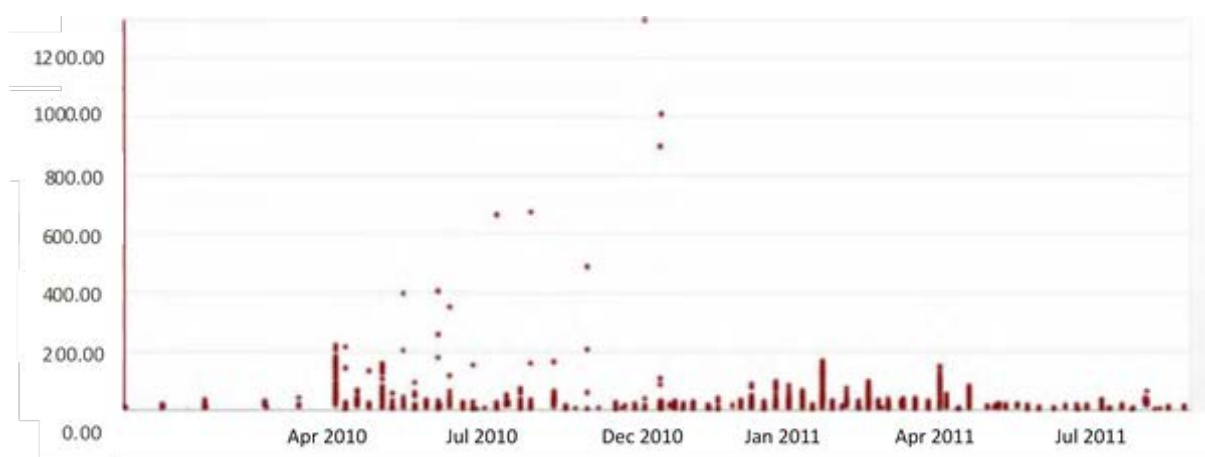


Figure 3.13 Port of Gladstone – All Depths – All DERM Sites – Turbidity (NTU)

Figure notes:

1. Minimum: 0.1 (multiple dates)
Maximum: 1,329.5 (4 October 2010)

Source: DERM (2011)

3.10.2.2 Salinity

Salinity levels in Port Curtis and The Narrows are generally close to ocean seawater (35.5g/L) but can range from 34g/L to 39g/L, depending on influences such as freshwater influx, evaporative losses and limited discharge to coastal waters (Apte et al. 2005; GPC 2012). Dry season salinity can be significantly higher than that in the wet season, although this difference is much more present in inshore areas, compared to Outer Harbour and coastal which may not show any seasonal differences.

Slightly reduced salinity levels tend to be a feature of The Narrows and the major rivers and creeks, particularly following periods of high rainfall. On a number of occasions, DERM (2011a) reported salinity results of 0g/L in sites in the Calliope and Boyne River estuaries, reflecting the impact of heavy rainfall and flooding on salinity levels. Recovery to near ocean salinity levels may take two or three weeks after freshwater runoff has ceased. During this recovery period, there can be marked vertical stratification in the streams as a result of a salt water wedge propagating upstream (freshwater floating above saltwater). However, due to the mixing nature of the tides, this feature is limited to partially enclosed estuaries, rivers and creeks, and is not typically seen further offshore (GPC 2012).

The Outer Harbour zone and open coastal waters experience less catchment runoff and more oceanic mixing with a conductivity value of at most 7mS/cm lower than around Inner Harbour zones (VE 2010b).

3.10.2.3 Temperature

Water temperature throughout the estuaries and Port Curtis is relatively uniform. The estuary currents and level of natural turbulence result in a reasonably well-mixed water column in the deeper channels, however, shallower waters over the tidal mud flats may experience less mixing and be subject to higher water temperatures (GPC 2012). Monitoring undertaken in shallower areas in the Inner Harbour in 2009 reported temperatures almost always homogeneous through the water column at each monitored station. Exceptions to this were two sites that were reported to have bottom waters 0.2 to 0.5°C cooler than the mid and near surface waters (GHD 2009b). Temperature in the Calliope River tended to be between 2 to 4°C warmer than the majority of Port Curtis sites, which was attributed to the hot water discharge from the Gladstone Power Station. This was a consistent finding over six years of monitoring (VE 2010b).

In terms of seasonal differences, PCIMP describes that on average, the temperatures tended to be between 9 to 11°C cooler in July 2008 and 2010 than in January 2010. Across the Port, coolest temperatures have been recorded in upper Boat Creek in the 2010 winter program, as well as during summer 2009/2010 and winter 2005, 2006, 2007 and 2008. This is in contrast to the warmer temperatures experienced in the upper estuarine areas (VE 2010b).

Generally the typical temperature cycle experienced in the area shows cooling over a four month period from April to July before heating up again from September (DERM 2011). Long term data recorded by DERM in the Calliope River and Boyne River recorded a minimum of 15.8°C (July 1996) and maximum of 33.5°C (January 2004) (DERM 2011).

From 1993 to 2012 mean and median dry and wet season water temperatures were approximately 24.5°C and 28°C respectively and average water temperatures have not changed despite large variation in rainfall over this same time (Hale 2013).

3.10.2.4 Dissolved oxygen

Clean surface waters are normally saturated with DO and are reflected in the QWQG (EHP 2009a) upper and lower guideline values of 90% and 100% saturation, respectively. Waters within the Port Curtis are generally well saturated, with values ranging between 85 to 100% saturation for sites around the Inner Harbour, and 95 to 105% saturation in coastal waters (Hale 2013). Medians (25th and 75th percentiles) were within QWQG (EHP 2009a).

A review of estuary data from 1993 to 2012 indicated that there was no evidence of temperature stratification or low dissolved oxygen concentrations in bottom waters in the Calliope estuary and that that majority of readings were within QWQG (Hale 2013). DO concentrations were lower at enclosed coastal waters sites, compared to those offshore, perhaps due to increased river influences and organic material around the Inner Harbour (Hale 2013).

DO readings collected during the WBDDP monitoring identified a 30% decrease in DO to 70-80% in Port Curtis during the January 2013 flood event. This decrease appeared less evident at coastal monitoring sites (VE 2013). Similarly DO readings at The Narrows and South Trees Inlet during the Autumn 2013 PCIMP monitoring event were below guidelines most likely due to the large amount of organic matter in the system due to post flood deposition (PCIMP 2013).

3.10.2.5 pH

pH data in Port Curtis has historically shown to be consistent with typical sea water values (around pH 8.2). Estuarine waters have the potential to exhibit a lower pH due to the influence of terrestrial inputs, as evidenced in Port Curtis pH data which has been recorded as generally ranging from 7.7 in estuarine areas to 8.1 in the surrounding oceanic waters (PCIMP 2013; Storey et al. 2007; Vision Environment 2011).

Lower pH and higher turbidity levels were noted by PCIMP in the shallow mangrove lined upper estuaries (Storey et al. 2007). pH is relatively uniform with depth, with evidence of only slight thermal stratification (WBM 2008). Water column pH is lowest in The Narrows region most likely related to acid inputs from the adjacent mangrove regions (Apte et al. 2005).

Daily data collected from 2009 to 2012 indicates pH remains similar between wet and dry seasons with pH more variable in upper estuarine sites due to freshwater pulses (Hale 2013; PCIMP 2013). This trend was observed in data collected during the January 2013 flood event, with pH dropping to as low as 6.0 in The Narrows and between 7.0 and 7.5 in the Inner Harbour (VE 2013c).

pH is consistently recorded within water quality guidelines suggesting Port Curtis has a good buffering capacity likely associated with the large tidal ranges allowing greater turnover and mixing of fresh and seawater (Hale 2013; PCIMP 2013; Storey et al. 2007; (VE 2011b); GPC 2014c).

3.10.3 Metals

Numerous studies into trace metal distributions in Port Curtis have demonstrated that the majority of metals concentrations found in samples fall below the relevant guidelines for estuarine and coastal waters, or below the laboratory LOR. This is highlighted in studies published by the CSIRO, the Queensland government, and independent investigations, such as Apte et al. (2006), Angel et al. (2012), DERM (2011), Hale (2013) and PCIMP (2013).

Based on results collected in 2001 to 2002, Apte et al. (2006) stated that trace metal distributions in Port Curtis *'are likely to reflect a subtle mixture of metal inputs, including industrial and other anthropogenic discharges, inputs from unidentified sources in The Narrows and the Fitzroy River plume'* and that *"trace metal inputs to Port Curtis which contribute to the observed dissolved metal concentrations are most likely to be delivered in solution form and not by release of metals from particulates"* (Apte et al. 2005).

The presence of total and dissolved metals in Port Curtis has been found to demonstrate seasonal patterns with higher metals concentrations (compared to reference sites) found in samples collected around estuarine and harbour zones within summer/autumn compared to winter/spring (PCIMP 2013; VE 2013c). At this time of year Port Curtis can experience lower salinity and higher turbidity due to increased runoff. This is particularly evident following significant rain events in Gladstone, such as on the 26 to 28 January 2013, and during December 2010 (VE 2013c). Higher contaminants loads are associated with this runoff and increased turbidity plumes, particularly in the Inner Harbour zones compared to coastal waters. In January 2010, a study by Vision Environment (VE 2010b) highlighted the correlation between the concentration of total iron, aluminium, chromium, cobalt, lead, nickel and turbidity, suggesting that these metals were bound to sediments and other particles within the water column.

Several studies of dissolved metals concentrations in Port Curtis have also demonstrated a clear spatial gradient, with lower concentrations of dissolved metals present in samples collected in coastal waters and higher concentrations found in samples from the Inner Harbour, Western Basin and The Narrows zones (Hale 2013; Angel 2013; Apte et al. 2005). Apte et al. (2005) found the samples from Calliope River contained the highest metals concentrations compared to harbour zones with the exception of TBT which was highest in the Gladstone Marina (GPC 2014d).

Metals that have historically been detected in water samples from Port Curtis include (but are not restricted to) aluminium, arsenic, cadmium, cobalt, copper, iron, manganese, nickel, molybdenum, and zinc, which occasionally exceed adopted guidelines (generally AWQG for slightly to moderately disturbed ecosystems (ANZECC/ARMCANZ 2000a)).

Historically water quality monitoring programs in 2001, 2003, 2004 and 2012 have detected dissolved metal concentrations within ANZECC/ARMCANZ (2000a) guidelines for all metals tested at all sites (Apte et al. 2005; Angel et al. 2010), although TBT exceeded the guidelines at five of the seven sites tested in 2001 (GPC 2014c; Apte et al. 2005).

Other studies such as that undertaken by the DERM in 2011 found of the 28 dissolved metals and metalloids analysed from 37 sites across Port Curtis, aluminium (six sites), copper (three sites) and total chromium (two sites) exceeded ANZECC/ARMCANZ (2000a) trigger values for slightly to moderately disturbed ecosystems (DERM 2011). PCIMP quarterly monitoring from mid-2012 to mid-2013 also found that of the 20 dissolved metals and metalloids analysed from 54 sites, ANZECC 95% trigger values were exceeded for dissolved copper (four sites) and silver (one site) only (PCIMP 2013; GPC 2014d).

Angel et al. (2012) (CSIRO) reported that dissolved copper levels, while within guidelines had increased from 2003/04 to 2011 and that dissolved aluminium concentrations were above the ANZECC/ARMCANZ (2000a) environmental concern level (ECL) of 0.5µg/L at the majority of sites sampled, although it is acknowledged that this is a highly conservative ECL value based on very limited toxicity data (Angel et al. 2012). Water quality data reviews by BMT WBM (2009a) state that aluminium and iron concentrations can be significantly higher in the water of the harbour zones, compared to oceanic seawater, while Arango et al. (2013) (DSITIA) found elevated aluminium, iron and copper in waterways during overtopping of Awoonga Dam in January 2013.

Despite the large amount of industrial and shipping activity in Port Curtis, it is generally accepted by organisations such as the CSIRO, and that Port Curtis compares favourably with other industrialised harbours around the world in regards to the relatively low metal concentrations of some dissolved metals concentrations (Angel et al. 2012; EHP 2013), and that concentrations of dissolved metals in Port Curtis are low indicating a low risk to ecological values (Hale 2013). Further, results for Port Curtis water quality and metals concentrations, are typical of the waters of other tropical estuaries.

In regards to dredging, studies undertaken during the WBDDP by DERM, CSIRO and GPC also concluded that dissolved metal concentrations in Port Curtis were of a low risk to ecological values (Angel et al. 2012; DERM 2011b; Hale 2013).

3.10.4 Nutrients

Significant land use changes have occurred in the Boyne River and Calliope River catchments since European settlement and catchment inputs and run-off is a major source of nutrients in Port Curtis, and coastal marine waters in general (Commonwealth of Australia 2013). Industrial source discharges and sewage from vessels may also contribute additional nutrient loads to the Port. Increases in the nutrient and sediment loads have been reported in the Port of Gladstone (Commonwealth of Australia 2013), however nutrient, total organic carbon and biochemical oxygen demand concentrations appear generally low and consistent with high quality estuarine water (WBM 1999). Low chlorophyll a concentrations were noted throughout Port Curtis (Dekker & Phinn 2005 cited in BMT WBM 2009b). A trend of increased nutrients in the Calliope estuary was observed from late 2009 onwards coinciding with the increase in wet conditions from mid-2008 (Hale 2013).

The *PCIMP Ecosystem Health Report Card* (2007) results showed that concentrations of TP exceeded the AWQG (ANZECC/ARMCANZ 2000a), with some individual values in the estuarine and oceanic reference sites being up to 2.8 times the guideline. However, only a small proportion of this phosphorous was shown to be biologically available. In contrast, concentrations of TN were within guidelines in all areas (Storey et al. 2007). Results from monitoring, undertaken in January 2010 (summer), found concentrations of nutrients were lower than in winter of 2008, with TP being below detection limits in some cases and TN being detectable, but in lower concentrations than was recorded in the winter 2008 monitoring event (VE 2010b).

The *2011 PCIMP Ecosystem Health Report Card* reported that there were some elevations in nutrient concentrations at upper creek and estuary sites, but these were generally within acceptable levels and were organic in nature, and therefore not readily taken up by organisms (VE 2011a). Elevated TP concentrations were again recorded at oceanic reference sites, however, this is thought to be due to natural geology (VE 2011a).

The source of nutrients may either be anthropogenic or geological, however, it is likely that catchment runoff contributes to elevated levels during rainfall events. In contrast to coastal nutrient levels, oceanic waters typically contain lower levels of nutrients due to distance from the coastline and tidal mixing (Storey et al. 2007).

PCIMP results for 2012/2013 showed TP, orthophosphate, nitrate-nitrite, TN and ammonia concentrations were all found to exceed guidelines at some sites during monitoring (PCIMP 2013).

A review of nutrient data (rivers 1993-2012, Port Curtis WBDDP 2009-2012) identified a spatial gradient in nutrient concentrations from Inner Harbour and surrounding zones (higher) to coastal waters (lower) indicating the influence of river discharges into Port Curtis (Hale 2013). Overall concentrations of TN, ammonium, and orthophosphate were within adopted guidelines, while water quality guidelines for nitrate-nitrite and TP were exceeded at some inshore sites (GPC 2014c).

3.10.5 Other contaminants

Compared to metals and metalloids, there is comparatively little information on other contaminants in the waters of Port Curtis (Hale 2013). Contaminants from urban and industrial sources entering Port Curtis may include manufactured organic compounds including surfactants, oils, grease, hydrocarbons, cleaning solvents, and to a lesser degree pesticides and other agricultural chemicals (GPC 2012).

Analysis of a variety of organic compounds (e.g. TBT, total petroleum hydrocarbons (TPH)) in the Inner Harbour and surrounds in 2009 showed that the majority of compounds were below the respective AWQG (ANZECC/ARMCANZ 2000a) and QWQG (EHP 2009a) guideline values and/or LORs (GHD 2009c).

Apte et al. (2005) states that results from investigations in 2001 and 2002 show concentrations of TBT in the water column were above ANZECC and ARMCANZ (2000a) trigger values in five out of seven samples. This was raised as a concern on ecological health at the time, although subsequent reviews of sediment sampling results in Port Curtis have identified TBT below guideline values (EHP 2012; Hale 2013). This indicates the ban on TBT associated antifouling paints in Australian ports from 1989 has had some effect.

A review of sediment sample results undertaken by EHP in 2012, indicated that in over 400 sediment samples collected in Port Curtis over a number of programs, along with TBT, the following contaminants were also within sediment quality guidelines: PAHs; Benzene, Toluene, Ethyl Benzene, Xylenes (BTEX); TPH; organophosphate pesticides (OPs); organochlorine pesticides (OCs); triazines, carbamates; pronamide; phenoxyacetic acids; PCBs; semi-volatiles; hexachlorobenzene (HCB); and other halogenated hydrocarbons; radionuclides and explosives (EHP 2012; Hale 2013). This indicates a low risk and suggests that sampling of the water column for these contaminants is not a high priority (Hale 2013).

3.11 Future Port expansion and management of water quality

3.11.1 Port master planning

3.11.1.1 Background

The area of Gladstone and Port Curtis has seen extensive industrial and urban development over the past 50 years. The Port of Gladstone is the fifth largest multi-commodity port in Australia and the world's fourth largest coal exporting terminal. This substantial growth in industry and population in the region has resulted in a change to the water quality of Port Curtis, generally attributed to the impacts of urban, industrial and agricultural runoff, operational industry discharges, shipping and dredging. The effects of natural events such as cyclones, hydrodynamics, and rainfall/runoff on the environment of Port Curtis also play a significant role in impacting on the water quality within the Port.

The Port of Gladstone's operation as an established industrial port exceeds 50 years (pre-dating World Heritage listing in 1981). The Port of Gladstone is one of four nominated priority ports in Queensland identified under the *Sustainable Ports Development Act 2015* (Qld) (Ports Act)

Under the Ports Act, the Queensland Government is delivering master planning for the priority ports to meet its commitment under the *Reef 2050 Long-Term Sustainability Plan* (Reef 2050). Priority port master planning has a timeframe up to 2050 to align with Reef 2050.

Through port master planning, the Queensland Government seeks to appropriately manage the land and marine areas needed for the effective development and operations of each of the priority ports, while ensuring that the OUV of the GBRWHA is protected and managed as part of an intrinsic consideration in port development, management and governance..

Specifically for the purposes of ensuring the protection of Queensland's environmental assets, the Ports Act includes provisions which:

- *Restrict new port development in and adjoining the GBRWHA to within existing port limits and outside of Commonwealth and the State marine parks*
- *Prohibit capital dredging for the development of new port facilities or the expansion of existing port facilities where proposed outside of the declared Priority Port Development Areas (PPDAs) of Gladstone, Abbot Point, Townsville and Hay Point/Mackay*
- *Prohibit the sea-based disposal of port-related capital dredge spoil material within the GBRWHA*
- *Mandate that capital dredge material generated at priority ports be beneficially reused or disposed of on land where it is environmentally safe to do so.*

3.11.1.2 Relevance to Project

The Port of Gladstone is a declared priority port under the Ports Act and in late 2018, the Master plan for the priority Port of Gladstone 2018 was released by the Queensland Government. The Gladstone port master planning process is currently ongoing, with the requirement now being to prepare and implement a port overlay (the regulatory instrument that implements the master plan over the master planned area).

The Master plan for the priority Port of Gladstone 2018 outlines the strategic vision, objectives and desired outcomes for the Port and the land and marine areas vital for its future development (the master planned area). The Master plan takes into consideration state interests associated with the Port, including managing port-related development, economic, community or environmental interests. The Master plan includes an environmental management framework which identifies and maps environmental values, and states the objectives and measures to avoid, mitigate and/or offset impacts from Port operations and development consistent with the principles of ecologically sustainable development. Through the Master plan, the Queensland Government will seek to ensure that the Outstanding Universal Value (OUV) of the GBRWHA is an intrinsic consideration in managing Port-related development (DTMR 2018).

3.11.2 Independent review into the Port of Gladstone

The independent review into the Port of Gladstone prepared by the Commonwealth of Australia (2013) states that given that the Port of Gladstone lies within the GBRWHA management, the Port should ensure a higher environmental protection level than may otherwise be required. However, it is a working Port that pre-existed the World Heritage listing and it would not be reasonable to expect it to be managed as a pristine area of high conservation value. Continued management of the Port as a slightly to moderately disturbed ecosystem is consistent with maintaining the OUV of the GBRWHA expressed in the Port (Commonwealth of Australia 2013).

The independent review of the WB reclamation area bund wall (Commonwealth of Australia 2014) identified several recommendations for GPC and government agencies to consider in terms of environmental management and dredging projects in Gladstone. Key recommendations pertaining to water quality include:

- High-quality background environmental data should be recognised as critical environmental infrastructure and its acquisition and maintenance be a high priority for the Australian and Queensland governments
- Consideration should be given by the Australian and Queensland governments to the development of spring and neap tide criteria in tropical coastal systems, either as a replacement for the seasonal criteria or to provide an additional level of assurance
- For large and complex developments in sensitive marine environments such as Port Curtis, governments and proponents should implement a single integrated monitoring framework that encapsulates reference, long term and management monitoring sites with clear reporting requirements and decision pathways.

The Project has incorporated the key findings and recommendations into the development of the EIS baseline data monitoring program, dredging and reclamation concept design, impact assessment and the development of management plans. Responses to how the Project will address recommendations outlined in the Independent Review of the Port of Gladstone (Commonwealth of Australia 2013) and the Independent Review of the Bund Wall at the Port of Gladstone (Commonwealth of Australia 2014) are outlined in Appendix D of the EIS.

4 Project baseline water quality data collection

4.1 Scope of baseline study

This section addresses relevant aspects and requirements of the Queensland Government issued EIS ToR and the Commonwealth DoE EIS guidelines relating to the water quality of coastal waters potentially affected by Project activities. The general ToR and EIS guideline items include:

- Providing baseline information on the water quality of coastal waters incorporating seasonal and tidal variation, including information (but not limited to) biological and physicochemical water quality parameters and toxicants
- Discuss the interaction of freshwater flows with coastal waters and the significance of this in relation to marine flora and fauna adjacent to Project activity areas, and consider the variability associated with local wind climate, seasonal factors, freshwater flows and extreme events when determining baseline values.

This section presents the results of the Project EIS baseline water quality monitoring program and supplementary water quality data recorded by PCIMP from 2012 to 2017, GPC wharf analyser data (2015 to 2017) and GHHP data collected from 2014 to 2017. The Project baseline water quality monitoring program was undertaken by VE marine scientists in Port Curtis from June 2014 to July 2015 and was designed to provide baseline water quality data spatially and temporally over 13 months, during a period of no capital dredging works over both wet and dry seasonal conditions. The water quality conditions recorded in the potential Project impact area are described and assessed to facilitate a risk and compliance based assessment of potential impacts during Project activities.

The full Baseline Water Quality Monitoring Report (VE 2015) can be found in Appendix B.

4.2 Statutory framework

The report has been prepared with consideration of the legislation summarised below.

4.2.1 Environmental Protection Act 1994 and Environmental Protection (Water) Policy 2009

4.2.1.1 Environmental Protection Act 1994

The object of the *Environmental Protection Act 1994* (EP Act) is to protect Queensland's environment while allowing for development that improves the total quality of life, both now and in the future, in a way that maintains the ecological processes on which life depends. The EP Act, which is administered by EHP, seeks to achieve this by an integrated management system that is consistent with ecologically sustainable development.

Section 319 of the EP Act establishes a 'general environmental duty' to prevent and minimise environmental harm which states:

A person must not carry out any activity that causes or is likely to cause environmental harm unless all reasonable and practicable measures have been taken to prevent or avoid harm from an activity.

Under the Act, 'environmental harm' and 'environmental nuisance' are defined as:

- *Environmental harm is any adverse effect or potential adverse effect (whether temporary or permanent and of whatever magnitude, duration or frequency) on an environmental value, and includes environmental nuisance. Environmental harm may be caused by an activity—*
 - (a) *whether the harm is a direct or indirect result of the activity; or*
 - (b) *whether the harm results from the activity alone or from the combined effects of the activity and other activities or factors.*
- *Environmental nuisance is unreasonable interference or likely interference with an environmental value caused by:*
 - (a) *aerosols, fumes, light, noise, odour, particles or smoke*
 - (b) *an unhealthy, offensive or unsightly condition because of contamination*
 - (c) *another way prescribed by regulation*

Under the EP Act, the *Environmental Protection (Water) Policy 2009* (EPP Water) provides the framework for developing environmental value (EVs), management goals and water quality objectives (WQOs) for Queensland waters.

4.2.1.2 Environmental Protection (Water) Policy 2009

The *Environmental Protection (Water) Policy 2009* (EPP (Water)) is subordinate legislation that supports the EP Act. The purpose of this policy is to achieve the objectives of the EP Act in relation to Queensland waters. As stated in the EPP (Water) Part 2:

The purpose of this policy is achieved by—

- (a) *identifying environmental values and management goals for Queensland waters; and*
- (b) *stating water quality guidelines and water quality objectives to enhance or protect the environmental values; and*
- (c) *providing a framework for making consistent, equitable and informed decisions about Queensland waters; and*
- (d) *monitoring and reporting on the condition of Queensland waters.*

Environmental values

The EP Act, Section 9 defines EVs as:

- (a) *a quality or physical characteristic of the environment that is conducive to ecological health or public amenity or safety; or*
- (b) *another quality of the environment identified and declared to be an environmental value under an environmental protection policy or regulation.*

DES describes EVs for Queensland waters as:

The qualities that make water suitable for supporting aquatic ecosystems and human use. These EVs need to be protected from the effects of habitat alteration, waste releases, contaminated runoff and changed flows to ensure healthy aquatic ecosystems and waterways are safe for community use. All tidal and non-tidal waters, including wetlands, lakes and groundwater have EVs. Aquatic ecosystem health is an environmental value of all Queensland waters (EHP 2014a).

Water quality objectives

WQOs are long term goals for water quality management. They are measures, levels or narrative statements of particular indicators of water quality (such as salinity or turbidity) that protect EVs. They define what the water quality should be to protect the EVs, after consideration of the socio-economic assessment of protecting the water quality.

WQOs are defined for a range of physical indicators (e.g. turbidity, suspended sediment and temperature), chemical indicators (e.g. oxygen demand and toxicants), biological indicators (e.g. macroinvertebrates and fish), pathogens, and measures of waterway condition (e.g. erosion and riparian vegetation extent and condition).

Indicators and water quality guidelines for an EV are decided under the EPP (Water) according to (in order of preference):

- Site-specific scientific studies
- The Queensland Water Quality Guidelines (QWQG) (EHP 2009a)
- The AWQG for fresh and marine water (ANZECC/ARMCANZ 2000a)
- Other documents published by recognised entities

Section 4.6 outlines the EVs and WQOs developed for waters of the Port Curtis Region.

4.3 Water quality guidelines

Water quality guidelines are quantitative measures or statements for indicators that protect a stated EV. An overview of the applicable water quality guidelines for the Project is provided below.

4.3.1 Australian Water Quality Guidelines for Fresh and Marine Waters

The Australian Water Quality Guidelines for fresh and marine waters were developed by the Australian and New Zealand Environment and Conservation Council (ANZECC) and Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ) in 2000.

The AWQG have been prepared under the auspices of Australia's NWQMS. They provide government, industry, consultants and community groups with a sound set of tools that will enable the assessment and management of ambient water quality in a wide range of water resource types, and according to designated environmental values.

The guidelines provide values or descriptive statements for different indicators to protect both aquatic ecosystems and human uses of waters (e.g. primary recreation, human drinking water, agriculture, stock watering). The default water types outlined in the AWQG are generic in their characterisation and consequently, the direct application of the default AWQG values may not necessarily reflect local water types or water quality characteristics. The AWQG recommends that, where applicable, locally relevant guidelines be adopted (refer Section 4.6 for EVs and WQOs for waters of the Port Curtis Region).

4.3.2 Queensland Water Quality Guidelines

The QWQG (EHP 2009a) are intended to address the need for local guidelines as identified in the AWQG guidelines by:

- Providing guideline values (numbers) that are tailored to Queensland regions and water types
- Providing a process/framework for deriving and applying local guidelines for waters in Queensland (i.e. more specific guidelines than those in the AWQG).

The QWQG provide a mechanism for recognising and protecting local Queensland waters and are not mandatory legislative standards or WQOs. It is important to note that WQOs are generally reserved for the waters' schedule in the EPP Water.

4.3.3 Water quality guidelines for the Great Barrier Reef Marine Park

The Water Quality Guidelines for the Great Barrier Reef Marine Park (GBRWQG) are administered by the Great Barrier Reef Marine Park Authority (GBRMPA) and address the AWQG processes of defining EVs and WQOs for local conditions. The guidelines describe the concentrations and trigger values for sediment, nutrients and pesticides that have been established as necessary for the protection and maintenance of marine species, and ecosystem health of the Great Barrier Reef.

The guidelines have been established to support initiatives, including the Commonwealth Government's Reef Rescue Plan, Reef Water Quality Protection Plan, Coastal Catchment Initiative, NWQMS, the Queensland Wetlands Program and the EPP (Water).

The majority of the Port of Gladstone is located outside the GBRMP, however it is located within the GBRWHA (refer Section 4.6.1). Some baseline water quality monitoring sites for the Project water quality assessment were located within the GBRMP. Ongoing consultation has been undertaken with GBRMPA throughout the scoping, planning and investigative stages of the Project EIS.

4.4 Water quality guidelines and management intent for waters

The AWQG and QWQG outline how the aquatic ecosystem EV can be subdivided into different levels of protection, depending on condition. For the aquatic ecosystem EV there are three levels of aquatic ecosystem protection according to their ecological condition, in accordance with the framework outlined in the National Water Quality Management Strategy (NWQMS). These include high ecological value (HEV), slightly to moderately disturbed (SMD) and highly disturbed (HD) waters. The management definitions for aquatic ecosystem conditions are outlined in Table 4.1.

Table 4.1 Definitions of aquatic ecosystem condition

Ecosystem condition	Definition
Level 1 HEV ecosystems	These are effectively unmodified or other highly valued systems, typically (but not always) occurring in national parks, conservation reserves or in remote and/or inaccessible locations. While there are no aquatic ecosystems in Australia and New Zealand that are entirely without some human influence, the ecological integrity of high conservation/ecological-value systems is regarded as intact (ANZECC 2000a).
Level 2 SMD ecosystems	Ecosystems in which aquatic biological diversity may have been adversely affected to a relatively small but measurable degree by human activity. The biological communities remain in a healthy condition and ecosystem integrity is largely retained. Typically, freshwater systems would have slightly to moderately cleared catchments and/or reasonably intact riparian vegetation; marine systems would have largely intact habitats and associated biological communities. Slightly to moderately disturbed systems could include rural streams receiving runoff from land disturbed to varying degrees by grazing or pastoralism, or marine ecosystems lying immediately adjacent to metropolitan areas (ANZECC 2000a).
Level 3 Highly disturbed (HD) ecosystems	These are measurably degraded ecosystems of lower ecological value. Examples of highly disturbed systems would be some shipping ports and sections of harbours serving coastal cities, urban streams receiving road and stormwater runoff, or rural streams receiving runoff from intensive horticulture. The third ecosystem condition recognises that degraded aquatic ecosystems still retain, or after rehabilitation may have, ecological or conservation values, but for practical reasons it may not be feasible to return them to slightly to moderately disturbed condition (ANZECC 2000a).

Source: ANZECC ARMCANZ (2000a)

4.5 Deriving local water quality guideline values

Where locally relevant water quality guidelines are to be adopted, the QWQG state the method for deriving local water quality guidelines for aquatic ecosystems. There are two approaches:

- Direct measurement of biological impacts - guideline values are based on the results of direct testing of the impacts of a stressor (e.g. a toxicant) on a target organism (usually by scientific studies).
- Acceptable departure from reference condition - guideline values are based on the premise that some small departure from reference condition is acceptable. This is suitable for biological condition indicators and also for indirect stressor indicators such as nutrients. This approach requires a good knowledge of reference condition and a value judgement on the extent of an acceptable departure.

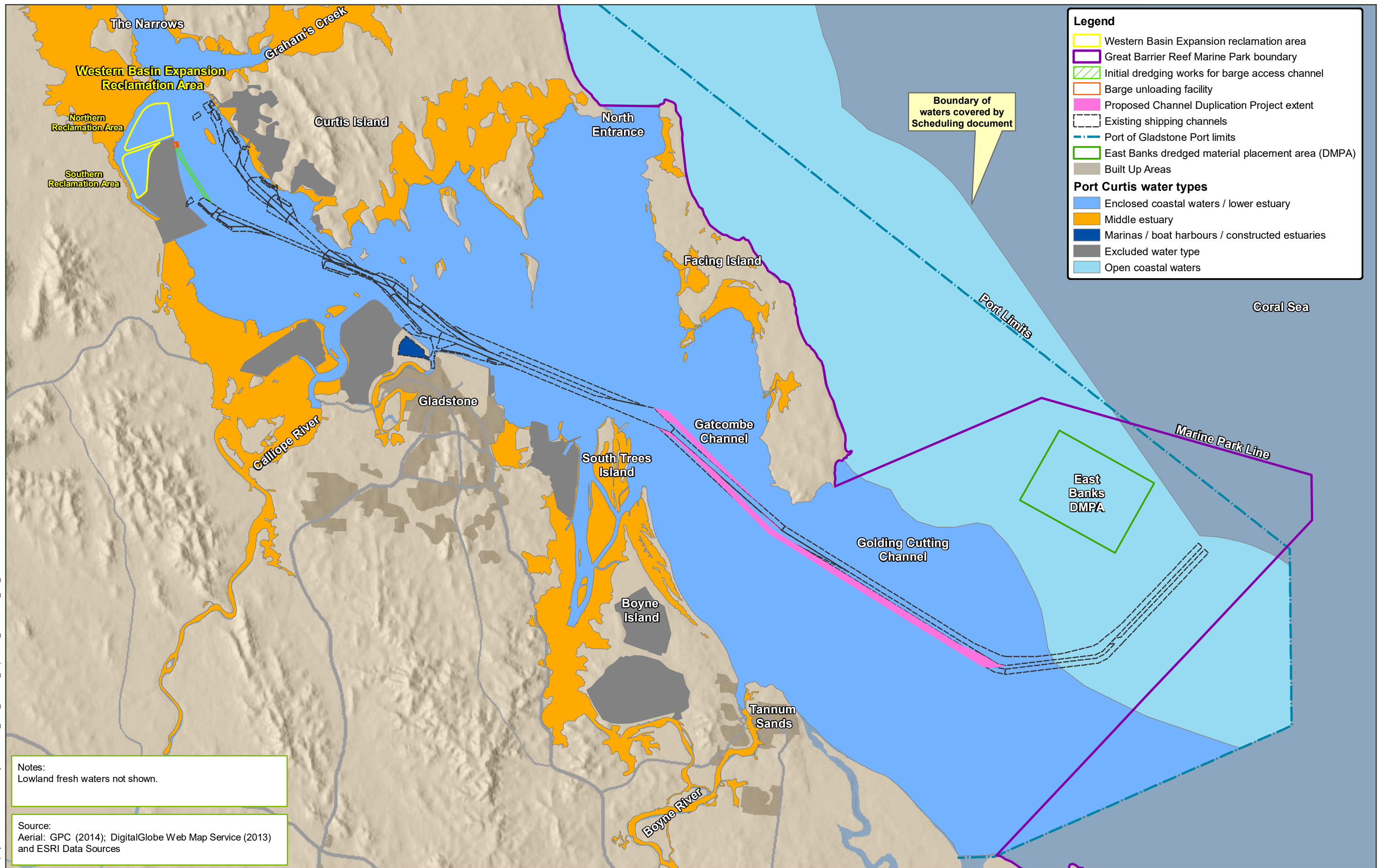
4.6 Curtis Island, Calliope River and Boyne River Basins Environmental Values and Water Quality Objectives

Local physicochemical water quality guidelines for the protection of the 'aquatic ecosystem' environmental value in waters of the Capricorn-Curtis Coast region were developed, as part of the Capricorn-Curtis Coast EVs project, undertaken by the Queensland Government in collaboration with Fitzroy Basin Association, pursuant to the EPP (Water). Waters covered by the report lie east of the Fitzroy Basin, and extend from the Styx Basin in the north to the Boyne Basin in the south, including Curtis Island and the Port of Gladstone and includes fresh, estuarine and coastal/marine waters to the limit of Queensland waters (refer Figure 4.1).

Developed by the (former) Queensland Department of Science, Information Technology, Innovation and the Arts (DSITIA), the *Report on draft aquatic ecosystem water quality guidelines for the Capricorn Curtis Coast* (draft), outlines the process of developing localised physicochemical aquatic ecosystem water quality guidelines for the Capricorn-Curtis coast study area, using the best available water quality data. This project used a reference site approach to develop the sub-regional guidelines. The approach taken for these guidelines is similar to that taken for the Fitzroy Basin (Jones and Moss 2011), but with greater emphasis on coastal and marine waters (DSITIA 2014). The *Draft environmental values and water quality guidelines: Fitzroy Basin fresh, estuarine and marine waters, including Keppel Bay* was published in March 2017 by DSITIA, however this report does not include any amendments or changes to environmental values or water quality objectives for the fresh or estuarine waters of the Capricorn-Curtis coast basins, or waters of Gladstone Harbour so this report will not be referred to again.

EVs and WQOs for waters in the Curtis Island, Calliope River and Boyne River Basins, Port of Gladstone, The Narrows and adjacent coastal waters (refer Appendix A), are included in Schedule 1 of the EPP (Water), outlined in the following documents:

- *Schedule 1: Document – Curtis Island, Calliope River and Boyne River Basins Environmental Values and Water Quality Objectives* (EHP 2014b)
- *Schedule 1 – Plan WQ1312 – Gladstone Harbour and the Narrows plan* (EHP 2014c).



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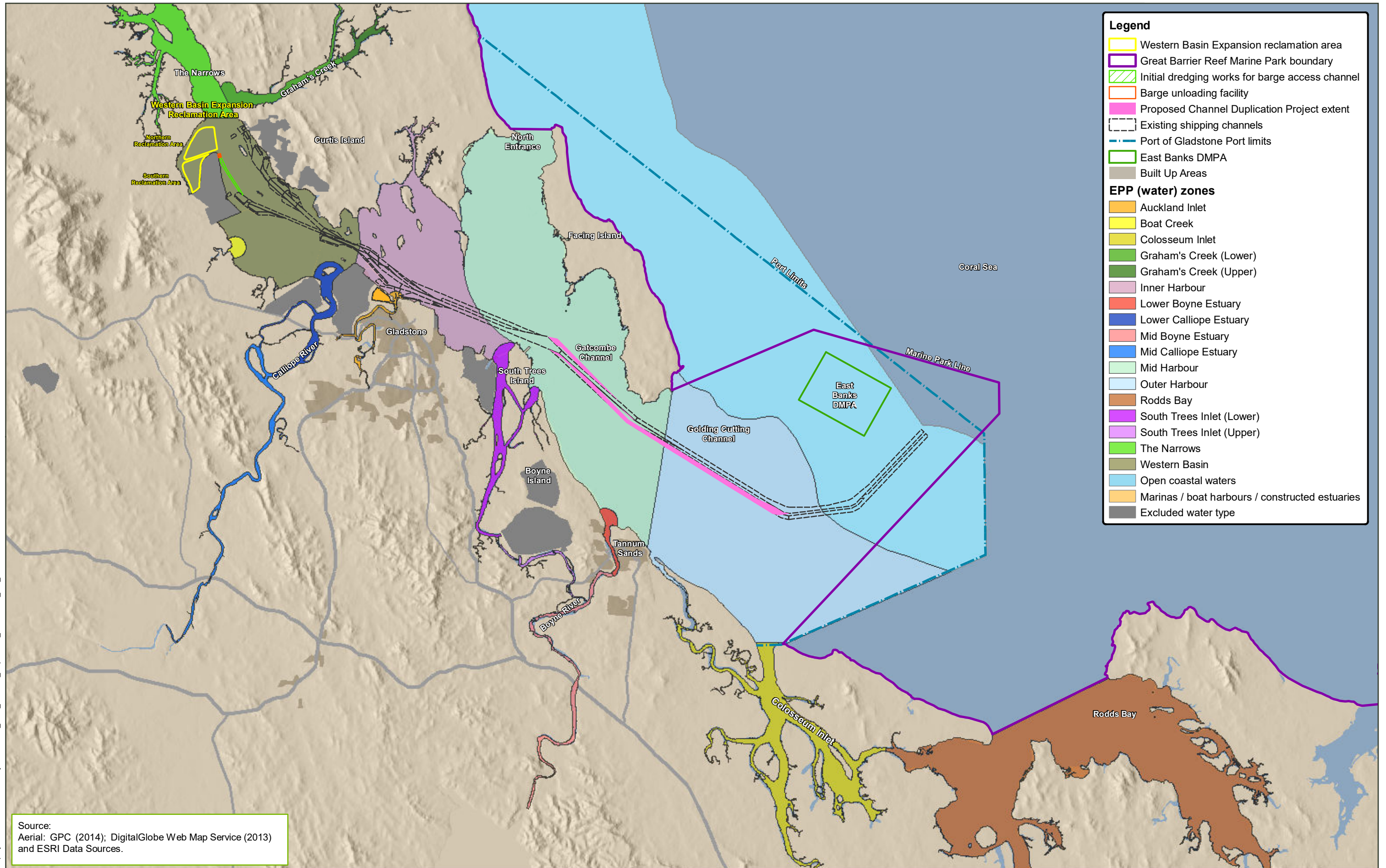


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Figure 4.1: EPP (water) Port Curtis marine estuarine water types



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Figure 4.2: EPP (water) zones for Port Curtis, The Narrows and adjacent coastal waters

Table 4.2 outlines the EVs that have been assigned to waters in the Port of Gladstone. WQOs for the protection of the aquatic ecosystem EV are outlined in Table 4.3 to Table 4.5 and Plan WQ1312 in Appendix A. WQOs have been derived for both baseflow and event flow in Gladstone Harbour and The Narrows. The WQOs that baseline results have been compared to in this report apply to baseflow conditions only. Schedule 1 of the EPP (Water) outlines the WQOs which apply during event flows, relative to peak discharges at the Castlehope gauging station (132001A). Time periods after which baseflow WQOs are to be applied to waters, following an event, are also outlined in Schedule 1 (EHP 2014).

Appendix A contains further information on EVs and WQOs for the Port of Gladstone.

Table 4.2 Environmental values for Port of Gladstone, The Narrows, and adjacent coastal waters

Zone	Water type	Environmental value							
		Aquatic ecosystems	Human consumer	Primary recreation	Secondary recreation	Visual recreation	Drinking water ¹	Industrial use	Cultural and spiritual values
The Narrows ²	Enclosed coastal/Lower estuary	●	●		●	●			●
Western Basin	Enclosed coastal/Lower estuary	●	●	●		●		●	●
Inner harbour	Enclosed coastal/Lower estuary	●	●	●	●	●	●	●	●
Mid harbour	Enclosed coastal/Lower estuary	●	●	●	●	●	●	●	●
Outer harbour	Enclosed coastal/Lower estuary	●	●	●	●	●	●	●	●
Coastal waters outside Port of Gladstone ³	Open coastal waters	●	●	●	●	●	●		●

Table notes:

1. Waters in which desalination for drinking water may apply
2. The Narrows (north of Graham's Creek), Deception Creek, East Balaclava Island, Connor Creek and Kamiesh Passage (estuarine reaches)
3. Coastal waters outside Port of Gladstone east and south of Facing Island (to southern limits of the Port)

Source: EHP (2014b)

Table 4.3 Water quality objectives (nutrients) to protect aquatic ecosystem environmental value under baseflow conditions (peak discharge < 100m³/sec)

Parameter	WQO	Zone and level of protection					
		The Narrows HEV	Western Basin MD	Inner harbour MD	Mid harbour MD	Outer harbour MD	Open coastal waters adjacent to Gladstone SMD
Ammonium Nitrate (µg/L)	20 th %ile	3	3	3	3	3	-
	50 th %ile	3	3	3	3	4	-
	80 th %ile	10	8	10	12	5	< 3
Oxide N (µg/L)	20 th %ile	2	1	2	1	1	-
	50 th %ile	3	4	5	3	3	-
	80 th %ile	9	16	12	9	6	< 1
PN (µg/L)	Annual mean	-	-	-	-	-	≤ 20
Total Dissolved N (µg/L)	80 th %ile	-	-	-	-	-	< 70
Total N (µg/L)	20 th %ile	140	145	130	110	115	-
	50 th %ile	170	170	160	135	130	-
	80 th %ile	220	210	220	200	170	< 100
FRP (µg/L)	20 th %ile	3	1	1	1	1	-
	50 th %ile	3	3	3	2	1	-
	80 th %ile	7	7	6	3	3	< 1
Partic P (µg/L)	Annual mean	-	-	-	-	-	≤ 2.8
Total Diss P (µg/L)	80 th %ile	-	-	-	-	-	< 6
Total P (µg/L)	20 th %ile	15	14	15	9	9	-
	50 th %ile	20	18	21	14	13	-
	80 th %ile	29	29	33	23	21	< 8
Chl-a (µg/L)	Annual mean	-	-	-	-	-	≤ 0.45
	20 th %ile	0.5	0.5	0.5	0.5	0.5	-
	50 th %ile	1.0	1.0	1.0	1.0	1.0	-
	80 th %ile	20	2.0	2.0	2.0	2.0	-

Table notes:

WQOs for indicators are shown as 20th, 50th and 80th percentiles, lower and upper limits (20th/80th percentiles, e.g. pH), or as a single values (median or 80th percentile) (e.g. < 15)

Source: EHP (2014b)

Table 4.4 Water quality objectives (physicochemical) to protect aquatic ecosystem environmental value under baseflow conditions (peak discharge < 100m³/sec)

Parameter	WQO	Zone and level of protection					
		The Narrows HEV	Western Basin MD	Inner harbour MD	Mid harbour MD	Outer harbour MD	Open coastal waters adjacent to Gladstone SMD
DO (% sat)	20 th %ile	87	91	93	94	94	95
	50 th %ile	92	96	96	97	97	-
	80 th %ile	95	100	98	101	100	105
Turbidity (NTU) Dry (May-Oct)	20 th %ile	4	4	4	2	1	-
	50 th %ile	7	8	8	4	3	-
	80 th %ile	12	17	17	7	6	-
Turbidity (NTU) Wet (Nov-Apr)	20 th %ile	8	7	7	4	2	-
	50 th %ile	15	13	13	9	7	-
	80 th %ile	30	29	29	16	13	-
Secchi (m)	Annual mean	-	-	-	-	-	≥ 10
pH (< 40 mS/cm)	20 th %ile	7.2	7.2	7.2	7.2	8.0	8.1
	50 th %ile	-	-	-	-	8.1	-
	80 th %ile	8.2	8.2	8.2	8.2	8.2	8.4
pH (>40 mS/cm)	20 th %ile	8	7.4	7.4	7.4	-	-
	50 th %ile	15	-	-	-	-	-
	80 th %ile	30	8.3	8.3	8.3	-	-
TSS (mg/L)	Annual mean	-	-	-	-	-	≤ 2
Silicate (µg/L)	80 th %ile	-	-	-	-	-	> 60
Temperature (°C)	-	-	-	-	-	-	Increases of no more than 1°C above long term (20 year) average maximum

Table notes:

WQOs for indicators are shown as 20th, 50th and 80th percentiles, lower and upper limits (20th/80th percentiles, e.g. pH), or as single values (median or 80th percentile (e.g. < 15))

Source: EHP (2014b)

Table 4.5 Water quality objectives (toxicants) to protect aquatic ecosystem environmental value under baseflow conditions (peak discharge < 100m³/sec)

Metal/toxicant	Water quality objectives for marine waters, SMD (95% species protection unless specified) (µg/L)
Aluminium	24 (MD waters – 95%) 2.1 (HEV/SD waters – 99%)
Arsenic (AsIII)	Insufficient data (ID)
Arsenic (asV)	ID
Cadmium	0.7 (99%)
Chromium (CrIII)	27.4
Chromium (CrVI)	4.4
Copper	1.3
Cyanide	4
Gallium	ID
Lead	4.4
Molybdenum	ID
Nickel	7 (99%)
Zinc	15
Other toxicants	Refer to AWQG Volume 1 Section 3.4—‘water quality guidelines for toxicants’ (including Tables 3.4.1 and 3.4.2, and Figure 3.4.1), and AWQG Volume 2 (Section 8, including Section 8.3.4.4 on application in estuarine waters). AWQG values for the MD level of protection typically correspond to protection of 95% species (in a small number of cases where bioaccumulation may occur, the AWQG recommends 99% species protection level)
Pesticides	As per GBRWQG and AWQG, to protect marine species at the HEV level of protection (except where noted)

Table note:

ID = Values to be updated in guidelines when available.

Source: EHP (2014b)

4.6.1 Great Barrier Reef World Heritage Area and Outstanding Universal Value

The GBRWHA was inscribed on the World Heritage List in 1981. The Port of Gladstone Port limits lie within the GBRWHA and partially within the GBRMP (refer Figure 1.1). Facing Island and Curtis Island are also located within the GBRWHA, as are many of the other smaller islands within the Port. Gladstone and other Queensland ports have operated for many decades prior to inscription of the Great Barrier Reef on the World Heritage List in 1981.

The GBRWHA was inscribed on the World Heritage List for all four of the natural heritage criteria established in a nomination document prepared in accordance with the *1978 World Heritage Operational Guidelines* (the Operational Guidelines). The nomination addressed the holistic and interconnected nature of the OUV of the very large complex coastal marine ecosystem. At the time, substantial areas were unsurveyed and while the nomination provided a broad description and inventory of the natural and cultural heritage at the broad ecosystem scale, nomination documents were not required to identify values at any greater level of specificity (Commonwealth of Australia 2013).

The area was nominated on the basis of management for conservation and reasonable multiple use through the *Great Barrier Reef Marine Park Act 1975* and associated arrangements with the Queensland Government with respect to day-to-day management.

In 2012, the World Heritage Committee (WHC) adopted a retrospective *Statement of Outstanding Universal Value for the Great Barrier Reef World Heritage Area*, which Australia had prepared. The 2012 *Statement of Outstanding Universal Value for the Great Barrier Reef World Heritage Area* is now the primary reference point for monitoring and reporting to the WHC, although other technical documents are also referenced.

The 2012 *Statement of Outstanding Universal Value for the Great Barrier Reef World Heritage Area* establishes that the GBRWHA meets all four natural heritage criteria of the current Operational Guidelines, each of which are present within the Port of Gladstone:

- Criterion vii – aesthetic values and superlative natural phenomena
- Criterion viii – ongoing geological processes
- Criterion ix – ecological and biological processes
- Criterion x – biodiversity conservation.

4.7 Baseline water quality program methodology

4.7.1 Monitoring locations and rationale

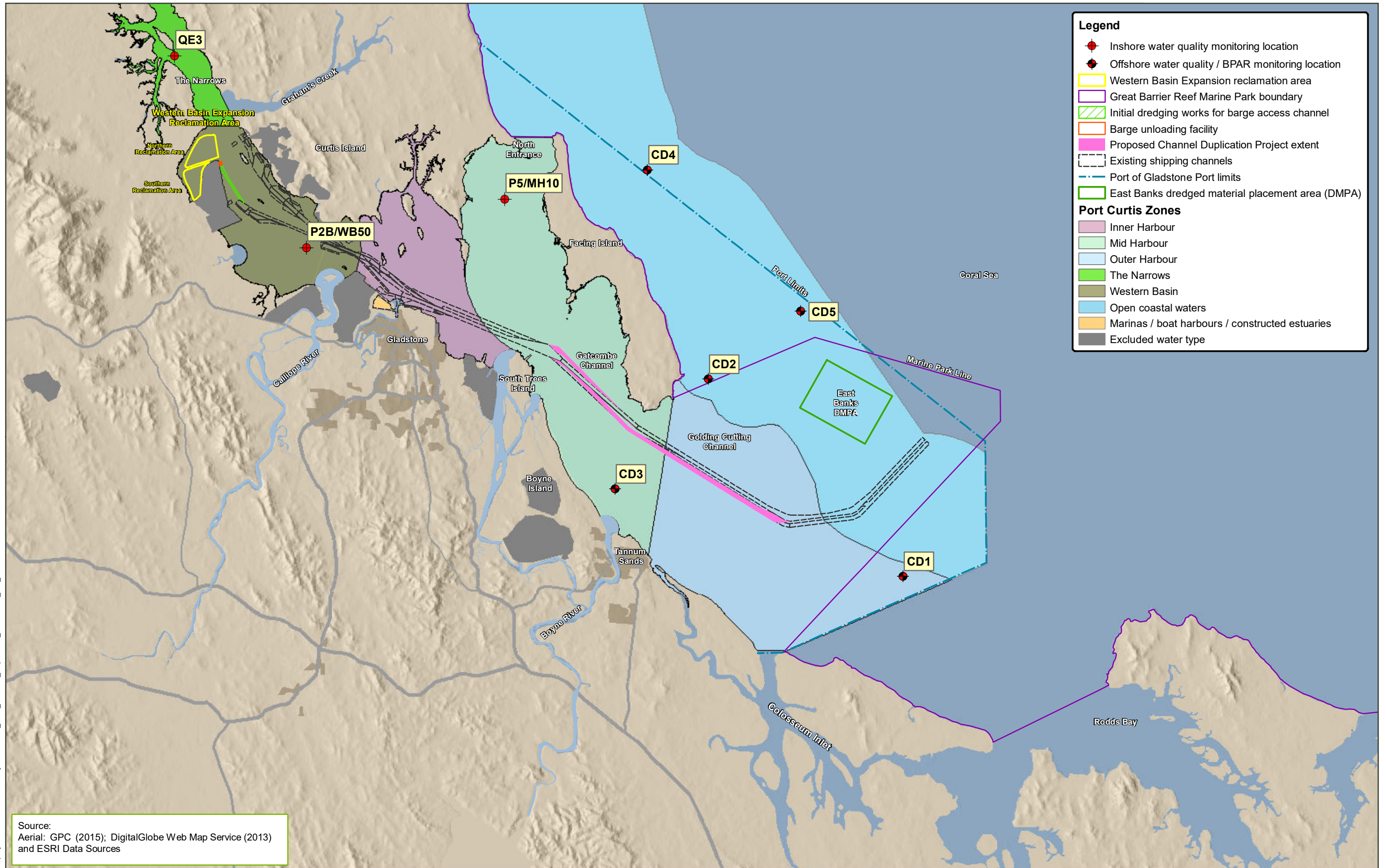
Eight water quality monitoring sites, spanning from The Narrows to open coastal waters east and south of Facing Island, were selected in 2014 BPAR as part of a Project EIS baseline data collection strategy in consultation with Commonwealth and State regulatory agencies (i.e. DoE, GBRMPA, EHP and DSITIA). These monitoring sites are outlined in Table 4.6 and illustrated in Figure 4.3. All monitoring locations were selected to provide data to characterise the current baseline water quality of Port Curtis, with the potential for these sites to transition into compliance and reference monitoring sites during dredging works. The location of monitoring sites may be reviewed following the finalisation of hydrodynamic plume modelling, to ensure that they are best placed to determine potential water quality impacts during construction.

Water quality monitoring sites were spread across a wide area throughout Port Curtis and the factors influencing the background conditions at the surface and seabed varied between some sites. During the design of the baseline monitoring strategy water quality monitoring sites were split into two groups: 'inshore' (i.e. CD1, CD2, CD3, CD4 and CD5) and 'offshore' (i.e. P5/MH30, P2B/WB50 and QE3) (refer Figure 4.3) based on historical water quality data and knowledge of background environmental influences on Port Curtis waters.

Inshore sites were generally characterised by a shallow environment (approximately 5 metres depth), highly tidally influenced with a large tidal run (approximately 0.4 metres per second). Historical depth profiling confirms the water column is well-mixed at these inshore sites with sub-surface measurements being similar to those above benthos, including little to no stratification during rain events. This data was collected and confirmed during the WBDDP water quality sampling undertaken by Vision Environment.

Offshore sites were generally characterised by a deeper water environment (generally > 15m) highly influenced by wind and wave action.

While site CD3 was grouped among the offshore sites for the purposes of this monitoring program, it was noted that that location of CD3 exhibits both inshore and offshore characteristics (CD3 lies within the Mid Harbour zone, close to the Outer Harbour zone boundary). Scientists from Vision Environment consider that this site exhibited characteristics closer to the offshore environment, when compared to the characteristics and influences of sites further inshore of the estuary (e.g. P2B/WB50 and P5/MH10). This was based on historical water quality data collected at nearby PCIMP monitoring site MH60. A discussion on the monitoring results and the influences on background water quality at each monitoring site are outline in Section 4.8.



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Figure 4.3: Baseline water quality monitoring locations

Baseline water quality monitoring locations (CD1 to CD5, P2B/WB50, and P5/MH30) (refer Figure 4.3) were determined in April 2014 based on preliminary hydrodynamic modelling undertaken by BMT WBM for the Project dredging activity. Modelling was used to generate a composite plot that provided a semi-quantitative indication of potential plume dispersion under a number of given dredging and material placement scenarios and assumptions (BMT WBM 2014). This modelling predicted that plumes will potentially impact areas of Port Curtis, including The Narrows, Western Basin, Inner Harbour, Mid Harbour, Outer Harbour, and open coastal waters, including waters of the GBRMPA, to the north, northeast and south. Subsequent option assessment and analysis was undertaken as part of the Supplementary Dredged Material Placement Options Investigation (DMPOI). This investigation identified the WBE reclamation area as the preferred DMPA to be included in the detailed impact assessment.

Table 4.6 Project baseline water quality monitoring sites

Grouping ¹	Monitoring site name	Location (WGS84)	Zone ²	Location description	Monitoring period
Offshore	CD1	S23 57.469 E151 30.115	Open coastal waters	Adjacent to Seal Rocks	June 2014 to July 2015
	CD2	S23 52.017 E151 24.380	Open coastal waters	Off East Point off Facing Island	June 2014 to July 2015
	CD3	S23 54.989 E151 21.569	Mid Harbour ³	Located outside the mouth of the Boyne River	June 2014 to July 2015
	CD4	S23 46.269 E151 22.639	Open coastal waters	Off the eastern side of Facing Island, adjacent to Pearl Ledge	June 2014 to July 2015
	CD5	S23 50.187 E151 27.153	Open coastal waters	Off the eastern side of Facing Island, 3km northwest of East Banks DMPA	June 2014 to July 2015
Inshore	P5/MH10	S23 47.029 E151 18.388	Mid Harbour ³	Adjacent to Pelican Banks seagrass meadows	June 2014 to July 2015
	P2B/WB50	S23 48.289 E151 12.547	Western Basin	Outside the mouth of the Calliope River	June 2014 to July 2015
	QE3	S23 42.965, E151 08.574	The Narrows	Adjacent to Worthington Island in The Narrows	January 2014 to July 2014

Table notes:

- 1 Type refers to the general term used to group the Project EIS water quality monitoring sites
- 2 Water zones in accordance with EPP (Water) Schedule 1 – Plan WQ1312 (EHP 2014c)
- 3 While CD3 and P5/MH10 were both located in the Mid Harbour Zone they were grouped as ‘inshore’ and ‘offshore’, respectively. CD3 was located close to the edge of the Mid Harbour and Outer Harbour Zone boundaries and baseline water quality appeared to show more wind and wave influences. Conversely P5/MH10 was located in a more enclosed coastal location showing a more tidally influenced, well-mixed water column.

Due to multiple dredged material placement options and the geographic spread of the Project activities, there are a number of potential multiple impact sources, and no clear gradient of impact able to be discerned for those impacts. A cumulative impact monitoring approach was therefore adopted with water quality sites located:

- Within the direct impact areas (e.g. areas to be dredged, DMPAs)
- Within potential indirect impact areas (e.g. outside of the areas of direct impact)
- In the vicinity of sensitive receptors (e.g. seagrass meadows and/or coral reefs).

The locations of these monitoring sites are also designed to facilitate a Before-After, Control-Impact (BACI) or Beyond-BACI experimental design. Temporally and spatially replicated BACI designs can be used to assess effects of dredging and dredged material placement on communities at the area to be dredged, DMPAs and at near-field potential impact locations.

4.7.1.1 CD1 and CD2

Both monitoring sites CD1 and CD2 are considered near-field for the area to be dredged, in addition to being within the 95th percentile of modelled plumes for the East Banks Expansion DMPA option and 50th percentile for the West Banks Island and Port Central Expansion DMPA options.

Hydrodynamic modelling predicts impacts into the GBRMP boundaries at the 50th percentile, thus monitoring of the northern, eastern and southern boundaries of the GBRMP was undertaken. CD1 and CD2 were located within the GBRMP (within Port limits) and adjacent to sensitive habitats including seagrass meadows and reef communities. These sites have the potential to act as sentinel management sites during dredging works. Project EIS marine ecology surveys have also occurred at these two locations (refer *Project Ecology Technical Report* (Aurecon 2019a)).

4.7.1.2 CD3

Monitoring site CD3 was located southwest of the West Banks Island DMPA option adjacent to intertidal and subtidal seagrass habitats. The site was established to provide an indication of flood event flows from the Boyne River.

Monitoring site CD3 was within the 95th percentile of modelled plumes for the East Banks Expansion DMPA option, and the 50th percentile for West Banks Island and Port Central Expansion DMPA options. It also serves as a near-field site for the Project area to be dredged.

Additionally, this site was located in the vicinity of PCIMP water quality monitoring site MH60 which has been monitored at least annually (not continuously) for a range of parameters from 2006 to current, providing additional baseline information.

4.7.1.3 CD4

Monitoring site CD4 was located within the GBRMP boundary and outside Port limits. CD4 was positioned to be outside of the preliminary predicted plume modelling of direct dredging activities, although modelling of natural resuspension of sediments and potential impacts to this site was not validated at the time of establishment. It is anticipated that any impacts from resuspension of sediments to this site would be minor. CD4 was located adjacent to comparable sensitive seagrass and coral habitats at similar depths to those at potentially impacted sites.

CD4 was also located near previous water quality monitoring site SGM2, used during the WBDDP water quality monitoring. CD4 was within the deep water seagrass meadows (mapped in November 2013 and 2014) and adjacent to permanent seagrass transect blocks (refer *Project Ecology Technical Report* (Aurecon 2019a)).

In order to complete the requirements of a BACI design, site CD4 not only provided a far-field monitoring site, but a reference location for water quality in Outer Harbour and open coastal waters zones (located near Project EIS seagrass and macroinvertebrate survey locations), as detailed in *Project Ecology and Matters of National Environmental Significance Technical Report* (Aurecon 2016a).

4.7.1.4 CD5

Monitoring site CD5 was located immediately north of the East Banks Expansion DMPA option. It acts as a far-field site for the Channel Duplication area to be dredged, and was within the 95th percentile of modelled plumes for the East Banks Expansion DMPA option. Although some plume dispersion at the East Banks Expansion DMPA option occurs in a northeasterly direction, water quality monitoring sites could not be located in this area due to the position of Port anchorage and pilotage areas.

4.7.1.5 P5/MH10

Monitoring site P5 was established as a water quality monitoring site for the WBDDP WQMP. Site P5 was renamed to MH10 to align with the new Port Curtis zoning for environmental monitoring programs such as PCIMP, Gladstone Healthy Harbour Partnership and EHP/DSITIA monitoring. It has therefore been labelled P5/MH10 for this assessment. While the requirements for water quality monitoring under the WQMP concluded in November 2013, water quality monitoring at site P5/MH10 continued up until the beginning of the Channel Duplication Project EIS baseline water quality monitoring program in June 2014 (refer Appendix B Table 6.1).

Site P5/MH10 was within the 95th percentile plume modelling for both the Port Central Expansion DMPA and West Banks Island DMPA options, and was the only water quality site designed to monitor potential plume dispersion through the north entrance, between Curtis Island and Facing Island, which has the capacity to affect the eastern side of Curtis Island. P5/MH10 may also capture potential impacts from plumes associated with dredged material placement in the WBE reclamation area.

P5/MH10 was located in the Mid Harbour adjacent to some of the most important seagrass meadows in Gladstone, located at Pelican Banks. The Pelican Banks seagrass meadows are monitored as part of the Port Curtis long term seagrass monitoring program, which includes BPAR monitoring (refer *Project Ecology Technical Report* (Aurecon 2019a)). Monitoring water quality at site P5/MH10, along with sedimentation rates, will assist in the continuation of defining the relationship between TSS, PAR and turbidity (NTU).

4.7.1.6 P2B/WB50

Monitoring site P2B/WB50 was located in the Western Basin area of Port Curtis, adjacent to the mouth of the Calliope River, the WICT and the Wiggins Island seagrass meadows. Monitoring at P2B/WB50 was designed to capture impacts from natural flow events from the Calliope River, the Port's largest catchment.

Site P2B formed part of the WBDDP WQMP as a compliance site during dredging works. It is a well-studied monitoring location with water quality data dating back to 2009. P2B was renamed to WB50 in 2014 as part of the new Port Curtis zoning. It has therefore been labelled P2B/WB50 for this assessment. P2B/WB50 was located within the 95th percentile of predicted plume modelling for both the West Banks Island DMPA and Port Central Expansion DMPA options. The site was also designed to monitor potential impacts in The Narrows conservation area, from the dredging works and dredged material placement activities, at the WBE reclamation area.

4.7.1.7 QE3

Monitoring site QE3 was located in The Narrows and was designed to capture potential impacts from dredged material placement activities at the WB and WBE reclamation areas.

Site QE3 formed part of the WBDDP WQMP as a compliance site for The Narrows Crossing during dredging works. It is a well-studied monitoring site with water quality data dating back to 2010. Baseline monitoring at QE3 began in January 2015.

4.7.2 Baseline water quality monitoring program methods

Baseline water quality monitoring was undertaken by marine scientists from VE over a 13 month period from 1 June 2014 to 5 July 2015. Table 4.7 outlines the methods utilised for collecting water quality data, light, and sedimentation during the Project EIS baseline monitoring period.

Table 4.7 Summary of Project EIS baseline water quality, light and sedimentation monitoring at all sites

Data type	Parameters	Method	Frequency
Water quality	- Turbidity - Temperature - pH - Conductivity - DO	Water quality telemetry and remote loggers: - Dual surface Aqualab DS5X water quality sonde - Dual benthic Aqualab DS5X water quality sonde (CD1 to CD5 only)	Logged every 15 minutes
	- Turbidity - Temperature - pH - Conductivity - DO	In situ depth profiling - YSI 6820 multi-parameter water quality meter	Monthly
	TSS	Water sampling - Van Dorn sampler	Monthly
	- Metals/metalloids - Nutrients - Chlorophyll a	Water sampling - Perspex pole sampler	Monthly (or weekly if pH is outside release limits)
	Organic contaminants	Water sampling - Perspex pole sampler	Quarterly
Light	BPAR	BPAR telemetry and remote loggers: dual LI-COR LI192SA Underwater Quantum Sensors	Logged every 15 minutes
	Light attenuation	In situ depth profiling - LI-COR LI192SA Underwater Quantum Sensor	Monthly
Sedimentation	Sedimentation rate	Acoustic altimeters	Logged every 15 minutes

4.7.2.1 Water quality loggers

The offshore monitoring area (containing monitoring sites CD1 to CD5) is a deep water (generally > 10m) oceanic environment with turbidity being highly driven by wind speeds and wave heights, causing resuspension of material from the seabed. Both benthic and surface water quality loggers were concurrently utilised at these sites. The use of surface water quality loggers only may not have been sufficient to detect all resuspension events.

The inshore monitoring area (containing monitoring sites QE3, P2B/WB50 and P5/MH10) is a shallow environment (average ~5m depth at monitoring sites), highly tidally influenced and with a large tidal run (~0.4m/s). Historical depth profiling confirms the water column is well mixed at these sites with sub-surface measurements being similar to those above seabed, including little to no stratification after rain events (VE 2013a). Therefore only sub-surface water quality loggers were required at inshore sites.

Surface and benthic water quality loggers recorded turbidity (NTU), temperature (°C), pH, conductivity (mS/cm) and DO (% saturation). Measurement of BPAR was also undertaken as part of the Project EIS baseline water quality monitoring program to determine the light environment at subtidal seagrass and coral habitats at all offshore sites. This relationship is reported further in the Project *Ecology Technical Report* (Aurecon 2019a).

For surface water quality logging, two Aqualab® DS5X sondes, each encased in a copper sheathed cage, were placed into secured, antifouled PVC tubes, which were inserted into the base of a modified special marker buoy at each site. Telemetered loggers were attached to solar powered telemetry units installed within the modified special marker buoy. Parameters were logged every 15 minutes and data transferred via telemetry to the VE cloud database every 30 minutes. The self-cleaning unit was set to wipe the probes prior to each data log. All loggers were scheduled to be exchanged fortnightly or as required based on examination of real-time data.

For the benthic loggers, two loggers were secured into a benthic frame, recording parameters approximately 1m above the seabed and transmitting data to the surface telemetry unit via an umbilical. Due to unforeseen frequent interruptions of the benthic logging and transmission during major storm events in the wet season, autonomous benthic loggers were utilised from February 2015 until the end of the baseline monitoring period in July 2015. Loggers were placed in the benthic frame and were programmed to log every 15 minutes, with data recorded within the sonde. Sondes were exchanged each fortnight and the recorded data downloaded.

Calibration

Each logger was calibrated and tested prior to deployment. Turbidity sensor calibration was adjusted for seasonal changes between cooler autumn/winter conditions and the warmer, more turbid spring/summer conditions.

Calibration methodology included two-point calibrations for turbidity (1 and 20NTU), conductivity (0 and 56.9mS/cm), pH (7 and 10), in addition to a one-point calibration for DO (100% saturation at ambient atmospheric pressure). Post-calibration testing involved a logtest of turbidity in a 10NTU solution logging at 5 minute intervals for a one to two hour period. Turbidity values at 10NTU ± 1NTU during the logtest were considered acceptable.

Data management

All physicochemical data were uploaded to a cloud database either automatically for real-time data or manually for autonomous data. Management and validation of water quality logger data were undertaken as per protocols developed and peer reviewed during the three year WBDDP, and The Narrows Crossing Project (VE 2013b). A data deconfounding process was undertaken to filter out erroneous raw data for validation and quality assurance/quality control (QA/QC) review.

A Self-Monitoring Algorithm in Real Time (SMART) was developed as an initial automatic data deconfounding process in order to filter out erroneous raw real time data from multiple instruments, to provide a more accurate and instantly usable real time data set. Following automated deconfounding, SMART data were manually validated and reissued for final reporting after having undergone QA/QC review. In most cases, the SMART data did not need altering. However, there were some instances where data were moved incorrectly, in which case it was inserted back into the dataset. A summary of how erroneous data were identified in the dataset for each parameter is outlined in the *Channel Duplication Baseline Water Quality Monitoring Report* (refer Appendix B Section 2.2.2). All raw datasets were retained in accordance with VE's Health, Safety, Environment and Quality (HSEQ) Management System (MS) protocols (VE 2015).

The mean validated data retention across the 13 month baseline monitoring period for water quality loggers ranged between 83 and 98% per site (refer Table 4.8). Monthly validated data retention ranged up to 100% indicating a very high data retention rate. Episodes of data loss were generally rectified within a 72 hour period.

Table 4.8 Mean validated (useable) data retention rate for water quality monitoring loggers

Site	Validated (usable) data retention rate (%)	
	Surface	Benthic
QE3	95	-
P2B/WB50	97	-
P5/MH10	96	-
CD1	96	92
CD2	98	83
CD3	93	94
CD4	94	84
CD5	89	88

Data analysis

Monthly and seasonal (wet season: 1 November to 30 April; dry season: 1 May to 31 October, as per EHP 2014b and DSITIA 2014) statistics were calculated for each site, including means, standard errors, ranges and percentiles. When plotting results a smoothing technique was applied. The 6 hourly EWMA, utilised as part of the WBDDP water quality monitoring program, was also plotted.

One and two-way analyses of variance ($p < 0.05$, 95% confidence intervals) were used to determine statistical differences in water quality parameters among sites, depth (surface and seabed), and seasons (wet season and dry season). Data were tested for homogeneity of variance and normality. Significance levels were increased ($p < 0.01$, 99% confidence intervals) where data did not meet that criterion (Underwood 1997; O'Neill 2000). In order to determine where significant differences among the four locations were, Fisher's Least Significant Difference (LSD) Post hoc tests were used to elucidate any differences among sites. Linear regressions were performed between surface and benthic turbidity to determine whether they varied similarly.

4.7.3 Benthic photosynthetically active radiation

Telemetered BPAR units were located at the five offshore sites (CD1 to CD5). BPAR was recorded using dual LI-COR® LI192SA Underwater Quantum Sensors which were attached to the benthic frame running concurrently with the dual benthic data loggers. BPAR was logged every 15 minutes (averaged from 1 minute readings) with data transferred to a cloud database every 30 minutes. Wiper units were also attached to the frames and set to clean the PAR sensors every 15 minutes. Data were transferred to the surface telemetry unit via an umbilical. Similar to the water quality loggers, autonomous PAR loggers (Odyssey® submersible photosynthetic irradiance recording system with self-cleaning wipers) were utilised from January 2015 until the end of monitoring in July 2015, and loggers were exchanged each fortnight and the recorded data downloaded.

The availability of light at the benthos can be influenced by natural variables such as the daily light integral (i.e. ambient PAR). In order to record changes and fluctuations in daily ambient PAR (e.g. reductions in light due to cloud cover), a telemetered light sensor was stationed at the VE base (VB) in Gladstone as a 'control' site. Management of BPAR logger data was undertaken as per VE HSEQ MS protocols (VE 2013d) detailed in Appendix B, Section 2.3.2.

4.7.4 Sedimentation

The resuspension of sediments due to natural and anthropogenic influences, such as dredging related activities have the potential to not only cause a reduction of light and therefore decrease in primary productivity, but also the smothering of benthic habitats, such as seagrass meadows and coral. The ecological significance of resuspension includes impact on cycling of nutrients and contaminants. Although traditional instruments such as sediment traps measure the downward flux of sediment particles over any given time, it is also important to measure the net flux or bed level change (i.e. whether there is overall deposition or erosion of sediments over a given time). The traditional sediment trap method assumes all captured particles are permanently deposited, whereas in reality, the majority of particles are transient. Benthic habitats may be tolerant to short term temporary deposition periods, however long term deposition can cause smothering and habitat stress. Therefore, it is more important to determine the actual bed level change over time.

Sedimentation rates were measured at all eight monitoring sites using fixed deployment acoustic altimeters. Increased sediment resuspension can be influenced by an increase in wave energy as a result of increased wind speeds, or stronger currents as a result of higher tidal ranges. One of three outcomes may occur during such an event: deposition of sediment from another location, movement of sediment to another location, or resuspension with no net change. Two forms of information are provided by the altimeters:

- Instantaneous sediment flux or the amount of sediment movement and resuspension occurring at a set point in time
- Net cumulative change in bed level over a given period.

The 'ALTUS' altimeter is an autonomous instrument that obtains very high precision bed level measurements (mm scale) every 15 minutes, using a high frequency acoustic sensor and an inbuilt data logging device.

Altimeters were positioned between 300 and 700mm above the seabed at each site. Wipers were also installed to eliminate transducer interference caused by fouling. Distance to seabed data were recorded on four separate channels, each with unique detection threshold settings (i.e. 11%, 23%, 39% and 70%). Threshold 1 (11%) was considered most useful in measurement of a non-homogenous medium such as found in Port Curtis (mix of silt, sand and gravel sediment fractions). Additional channels measured depth using an inbuilt pressure sensor to aid in data interpretation, and max echo to aid in data validation. Altimeters were downloaded and exchanged on a monthly basis, or when diving conditions permitted. Data were analysed and validated by VE. Management of altimeter data was undertaken as per VE HSEQ MS protocols (VE 2015) and is detailed further in Appendix B, Section 2.4.2.

As non-homogenous sediment dominates the seabed in Port Curtis, Threshold 1 altitude data were used to analyse surficial sediment deposition and erosion. Instantaneous sediment change (change from the reading 15 minutes prior) was calculated, as well as cumulative sediment change (calculated every 24 hours) per deployment period.

As the instruments were continuous but not telemetered, faults could not be identified and rectified until retrieval of the self-loggers. Overall, across the 13 month period, validated data were captured on between 61 to 90% of monitoring days. This value is lower than telemetered validated data retention for the water quality loggers (average > 92% across all sites (surface and benthic)). Data gaps which occurred at each site were due to barnacle encrustation, movement of the unit during storm or rain events, in addition to external interference to the beam from marine organisms.

4.7.5 In situ physicochemical profiling

Physicochemical parameters (i.e. temperature, conductivity, pH, DO and turbidity) were also measured in situ from a boat at each monitoring site using a YSI® 6820 multi-parameter water quality meter. The water quality metre was slowly lowered through the water column from the surface to the seabed, with triplicate sub-surface readings (0.5m depth) recorded at each site.

4.7.6 Light attenuation

Down-welling PAR, measured in micromoles per square metre per second ($\mu\text{mol}/\text{m}^2/\text{s}$), was measured in situ from a boat through the water column at 0.5m depth intervals using a LI-COR® LI192SA Underwater Quantum Sensor in a lowering frame and a LI-189 Quantum Radiometer Photometer until light was $< 10\mu\text{mol}/\text{m}^2/\text{s}$. The vertical light attenuation coefficient (K_d) was calculated in order to compare light attenuation through the water column at different sites and on different sampling occasions.

4.7.7 Water sample collection

Monthly collection of water samples for analysis was done concurrently with discrete physicochemical measurements at each monitoring site. Sampling was undertaken in accordance with VE HSEQ MS protocols (VE 2013d), which were derived from worldwide authorities, including:

- Australian and New Zealand Standards for water quality sampling AS/NZS 5667 (Standards Australia 1998a; Standards Australia 1998b; Standards Australia 1998c; Standards Australia 1998d)
- American Public Health Association (APHA) Standard Methods for the Examination of Water and Wastewater (APHA 2005)
- Australian and New Zealand Water Quality Guidelines (ANZECC 1992; ANZECC 1998; ANZECC/ARMCANZ 2000a)
- Queensland Water Quality Guidelines (EHP 2009a)
- EHP Monitoring and Sampling Manual (EHP 2009b).

Samples were collected and analysed monthly for TSS and metals/metalloids, while organic contaminants were analysed quarterly. Samples were collected using pre-acid washed Nalgene bottles in a Perspex pole sampler at the sub-surface (0.5m depth). At the five offshore sites, additional TSS samples were collected at mid-column and above seabed, using a Van Dorn sampler. Water samples were collected in laboratory supplied containers. Samples which required filtration (dissolved metals/metalloids and nutrients) were filtered, in situ, through a $0.45\mu\text{m}$ sterile surfactant free cellulose acetate membrane syringe filter (refer Appendix B Section 2.5.3 for additional methodology).

Duplicate water samples for all parameters were collected at 10% of sites as per established protocols (VE 2015), with a field and laboratory blank collected per sampling day. Analytical laboratory quality control (QC) measures included laboratory duplicates, laboratory blanks, analysis of certified reference material and matrix spikes. Management of sample data was undertaken as per VE HSEQ MS protocols (VE 2015) and is detailed further in Appendix B, Section 2.5.4.

4.8 Baseline water quality monitoring results

This section provides a summary of the Project EIS baseline water quality, BPAR, and sedimentation data presented in the Project *Baseline Water Quality Monitoring Report* prepared by VE (refer Appendix B Section 3). Statistical analyses have been presented to identify temporal, spatial and seasonal trends, and water quality results have been compared against relevant guidelines for reference.

Historically, water quality monitoring data from Port Curtis has been compared to QWQG and AWQG. While the AWQG include aquatic ecosystem water quality guideline values for broad water regions and water types, it recommends that wherever possible, local guidelines should be developed. DSITIA and EHP have therefore developed EVs and developed local WQOs for the Capricorn-Curtis Coast region via a process of stakeholder consultation and analysis of available water quality data (DSITIA 2014; EHP 2014b).

Schedule 1 of the EPP (Water) lists the EVs and WQOs for Queensland waters, including those for Curtis Island, Calliope River and Boyne River Basins (Basins 131, 132 and 133, including all waters of Gladstone Harbour, The Narrows, Curtis Island, Calliope River and Boyne River Basins, and adjacent coastal waters) (EHP 2014b). Plan WQ1312 of Schedule 1 of the EPP (Water) also outlines water types and zones along with EVs and the current management intent of these waters (refer Appendix A).

WQOs are numerical concentration levels or narrative statements of indicators established for receiving waters to support and protect the designated EVs for those waters (DSITIA 2014). WQOs are long term goals for water quality management and are used to help set development conditions, influence local government planning schemes and underpin report card grades for ecosystem health monitoring programs such as the GHHP and other similar programs (DSITIA 2014).

For the purposes of this EIS technical report, water quality results, which represent ambient baseline conditions across eight sites in Port Curtis from June 2014 to July 2015, have been compared against WQOs for reference purposes only as the EIS baseline data have the potential to be utilised in refining the WQOs. Where there is no local WQO provided, results have been compared against QWQG and AWQG as a default (EHP 2014b). Baseline water quality data collected for the Project has the potential to be used in the development of Project specific water quality triggers, to be implemented during dredging and dredged material placement works, taking into account the assigned EHP WQOs.

EHP (2014b) states that the median water quality value should be compared against the WQO, when multiple WQOs are provided (e.g. 20th, 50th and 80th percentile values). However, when only a single WQO value is provided, such as for most parameters in the coastal waters area, these should be compared to the mean value. Given a mix of multiple areas have been monitored in this Project, for ease of comparison both the mean and median values for results have been used to compare against WQOs at all sites.

WQOs have been derived for both baseflow and event flow in Gladstone Harbour and The Narrows. The WQOs that baseline results have been compared to in this report apply to baseflow conditions only. Schedule 1 of the EPP (Water) outlines the WQOs which apply during event flows, relative to peak discharges at the Castlehope gauging station (132001A). Time periods after which baseflow WQOs are to be applied to waters, following an event, are also outlined in EPP (Water) Schedule 1 (EHP 2014b).

4.8.1 Climatic conditions

During the 13 month baseline monitoring period from 1 June 2014 to 4 July 2015, approximately 849mm of rainfall was recorded in Gladstone (BoM 2015b) (refer Table 4.9, Figure 4.4), slightly below the average annual rainfall (1957 to 2015) of 889mm recorded at the Gladstone Radar (station 039123) (BoM 2015a). Overall > 100mm of rainfall was recorded per month during the wet season months of December 2014 (155mm), January 2015 (249mm) and February 2015 (128mm), while < 50mm per month was recorded from June to November 2014, and March, May and June 2015 (BoM 2015b).

In mid-February 2015 severe Tropical Cyclone Marcia made landfall as a category five system in Central Queensland near Shoalwater Bay to the north of Gladstone, bringing almost 100mm of rainfall over a three day period to the Gladstone area. Wave heights were also considerably higher than typical at this time (2.1 significant wave height (Hsig)), compared to 0.4 to 0.9 Hsig (20th to 80th percentile range) recorded throughout the monitoring period (refer Figure 4.4). Inshore winds generally ranged between 0 and 40km/hr, with the highest winds of the monitoring period experienced on 20 February 2015, with gusts of up to 89km/hr recorded (BoM 2015b).

Overall, ambient air temperature ranged from 12.9°C in July 2014 (mean minimum temperature) to 32.3°C in February 2015 (mean maximum temperature), a slightly wider range than historical averages of 13.4°C to 31.3°C (BoM 2015b). Spring tides associated with the new and full moon periods generally occurred bimonthly, alternating with neap tide periods. The highest tidal range of the monitoring period occurred on 19 February 2015 (4.44m), just prior to the landfall of Tropical Cyclone Marcia.

Table 4.9 Monthly rainfall recorded at Gladstone during baseline monitoring period compared to long term averages

Month	Rainfall (mm)	
	Baseline period (2014 to 2015)	Long term average (1957 to 2015)
June	9.8	37.5
July	2.0	33.5
August	36.0	32.0
September	49.2	26.9
October	14.2	58.0
November	30.0	70.6
December	155.2	128.4
January	248.8	153.5
February	127.8	144.6
March	36.2	94.0
April	57.4	49.0
May	33.0	57.4
June	49.6	37.5

Source: BoM (2015a)

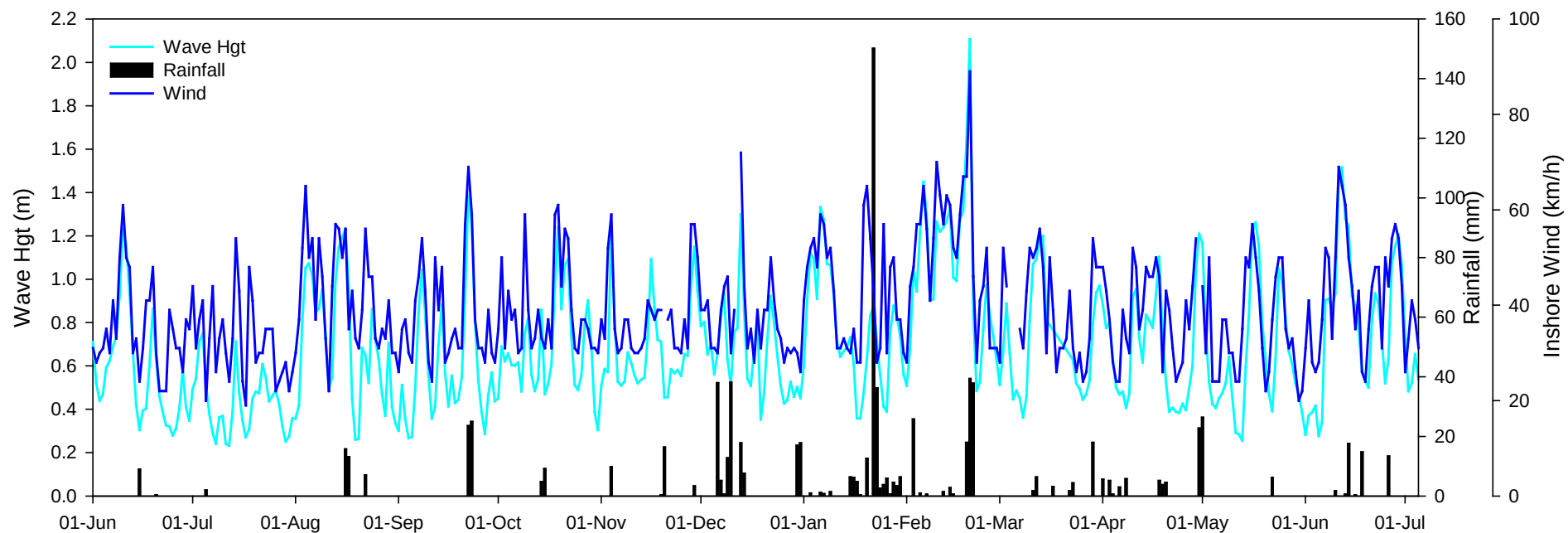


Figure 4.4 Rainfall, wave height and inshore wind at Port Curtis during the monitoring period (1 June 2014 to 4 July 2015)

Source: BoM (2015a)

4.8.2 Turbidity

Surface and benthic turbidity results from the baseline monitoring period are outlined in Table 4.10.

Table 4.10 Turbidity results at water quality loggers (June 2014 to July 2015)

Site	Statistic	Dry season turbidity (NTU)			Wet season turbidity (NTU)		
		Surface	Benthic	WQOs	Surface	Benthic	WQOs
QE3 ²	Mean $\pm$ se	7.0 $\pm$ 0.0	-	-	8.3 $\pm$ 0.1	-	-
	Range	< 1 to 77	-	-	< 1 to 520	-	-
	20 th %ile	3.8	-	4	1.1	-	8
	50 th %ile	7.3	-	7	3.8	-	15
	80 th %ile	9.4	-	12	9.9	-	30
P2B/WB50	Mean $\pm$ se	9.0 $\pm$ 0.1	-	-	7.2 $\pm$ 0.1	-	-
	Range	< 1 to 138	-	-	< 1 to 101	-	-
	20 th %ile	4.0	-	4	2.1	-	7
	50 th %ile	6.7	-	8	5.3	-	13
	80 th %ile	13	-	17	11	-	29
P5/MH10	Mean $\pm$ se	4.3 $\pm$ 0.0	-	-	4.7 $\pm$ 0.0	-	-
	Range	< 1 to 44	-	-	< 1 to 98	-	-
	20 th %ile	1.8	-	2	1.1	-	4
	50 th %ile	3.3	-	4	3.3	-	9
	80 th %ile	5.9	-	7	6.6	-	16
CD1	Mean $\pm$ se	1.5 $\pm$ 0.0	3.3 $\pm$ 0.0	-	1.9 $\pm$ 0.0	5.2 $\pm$ 0.2	-
	Range	< 1 to 29	< 1 to 142	-	< 1 to 37	< 1 to 130	-
	20 th %ile	<1	<1	1	<1	<1	2
	50 th %ile	<1	1.9	3	1.4	2.2	7
	80 th %ile	2.3	4.7	6	3.1	6.4	13
CD2	Mean $\pm$ se	2.3 $\pm$ 0.0	4.5 $\pm$ 0.0	< 1	2.0 $\pm$ 0.0	7.2 $\pm$ 0.1	< 2
	Range	< 1 to 25	< 1 to 104	-	< 1 to 201	< 1 to 250	-
	20 th %ile	<1	1.6	-	<1	1.9	-
	50 th %ile	1.9	3.3	-	1.3	4.9	-
	80 th %ile	3.7	6.7	-	3.3	9.8	-
CD3	Mean $\pm$ se	4.1 $\pm$ 0.0	5.7 $\pm$ 0.0	-	3.1 $\pm$ 0.1	6.7 $\pm$ 0.1	-
	Range	< 1 to 42	< 1 to 110	-	< 1 to 40	< 1 to 313	-
	20 th %ile	1.1	1.0	2	<1	<1	4
	50 th %ile	3.2	3.9	4	2.5	3.7	9
	80 th %ile	6.9	8.9	7	4.9	11	16

Site	Statistic	Dry season turbidity (NTU)			Wet season turbidity (NTU)		
		Surface	Benthic	WQOs	Surface	Benthic	WQOs
CD4	Mean $\pm$ se	1.0 $\pm$ 0.0	4.0 $\pm$ 0.0	< 1	1.5 $\pm$ 0.0	2.5 $\pm$ 0.0	< 2
	Range	< 1 to 35	< 1 to 173	-	< 1 to 13	< 1 to 44	-
	20 th %ile	< 1	<1	-	<1	<1	-
	50 th %ile	< 1	<1	-	1.0	<1	-
	80 th %ile	1.7	6.0	-	2.6	4.9	-
CD5	Mean $\pm$ se	<1	1.7 $\pm$ 0.0	< 1	1.8 $\pm$ 0.0	3.0 $\pm$ 0.0	< 2
	Range	< 1 to 17	< 1 to 98		< 1 to 43	< 1 to 127	
	20 th %ile	<1	<1	-	<1	<1	-
	50 th %ile	<1	<1	-	<1	<1	-
	80 th %ile	1.5	2.1	-	2.0	3.9	-

Table notes:

1. N = 7,858 to 20,773
2. WQOs Source: Curtis Island, Calliope River and Boyne River Basins EVs and WQOs (EHP 2014b)
3. QE3 results collected from January 2015 to July 2015
4. Statistics listed include 20th, 50th (median) and 80th percentiles

4.8.2.1 Inshore turbidity

Turbidity results from inshore sites (i.e. P5/MH30, P2B/WB50 QE3) indicated:

- Surface turbidity was significantly higher at inshore sites (i.e. P2B/WB50, QE3 and P5/MH30) than at offshore sites (CD1 to CD5) with the highest turbidity results recorded during spring tides
- Of the three inshore sites, P2B/WB50 and QE3 recorded consistently higher turbidity values during both wet (P2B/WB50 median 3.8NTU, QE3 median 5.3NTU) and dry (P2B/WB50 median 6.7 and QE3 median 7.3NTU) seasons than site P5/MH10 (median 3.3NTU over both seasons). This is most likely due to their locations in the inner estuarine Port Curtis, compared to P5/MH10, located close to the North Entrance between Curtis Island and Facing Island, which has a more oceanic influence.
- Sites QE3 and P5/MH10 exhibited significantly higher turbidity during the wet season than during the dry season. However, this pattern was not evident at site P2B. The loss of data at this site during Tropical Cyclone Marcia during February 2015 may have influenced this result.
- At the three inshore sites, turbidity increases were evident bimonthly during the spring tides associated with the full and new moon periods. Higher tidal ranges associated with spring tides at inshore sites permit a higher level of mixing and resuspension of particles within the water column. When tidal ranges are lower, such as during neap tides associated with the quarter moon phases, the turbidity levels tend to decrease accordingly (refer plots in Appendix B Section 3.2.1).
- The three inshore sites are located in different water quality zones under the EPP (Water) (EHP 2014b): The Narrows (QE3), Western Basin (P2B/WB50), and Mid Harbour (P5/MH10) and each have varying WQOs
- QE3 20th, 50th and 80th percentile values were equal to or below their corresponding WQO values, with median turbidity values also equal to or lower than the 50th percentile WQO
- Both P2B/WB50 and P5/MH10 20th, 50th and 80th dry season and wet season percentile values were slightly lower than the 20th, 50th and 80th percentile WQOs
- Results from the 13 month monitoring period indicate inshore turbidity trends were comparable to the studies used to calculate the WQOs for aquatic ecosystems in Port Curtis (DSITIA 2014).

4.8.2.2 Offshore turbidity

Turbidity results from offshore sites (i.e. CD1 to CD5) indicated:

- Benthic turbidity at each offshore site was significantly higher than surface turbidity most likely due to the proximity of the loggers to the benthic sediment. The offshore benthic sediments tended to be resuspended during strong winds and elevated wave heights.
- Turbidity at the majority of offshore sites also tended to be significantly higher during the wet season than during the dry season
- When comparing turbidity results across the offshore sites, CD2 and CD3 surface and benthic results exhibited the highest turbidity values during both the wet season (mean 2.2 to 7.3NTU) and dry season (mean 2.3 to 5.7NTU). Higher turbidity at CD2 and CD3 is likely to be due to CD2's location closer to land masses in Port Curtis (i.e. more influenced by lunar and tidal cycles) (refer Figure 4.3) and CD3's location closer to the main land and the Boyne River (i.e. more influence by rain events) in comparatively shallower depths
- CD3, located at the mouth of the Boyne River, tended to display more elevated benthic turbidity for several weeks during increased wind speed events following Tropical Cyclone Marcia in mid-February 2015. It is likely that fine sediments washed down from the Boyne River were being easily resuspended during these events.
- Lowest turbidity values were evident at CD1, CD4 and CD5, particularly during the dry season (CD4 mean < 1 to 4.0NTU). Turbidity at CD4 and CD5 (the deepest sites) and CD1 was primarily related to wind events. Although CD1 is the third shallowest offshore site (depth < 9m), it is also located the furthest from any anthropogenic and estuarine influences.
- The offshore monitoring sites were situated in three different water quality zones under the EPP (Water) (EHP 2014c): Outer Harbour (CD1), Mid Harbour (CD3), and coastal waters outside Gladstone Harbour (i.e. CD2, CD4 and CD5) (refer Figure 4.2)
- Median turbidity at CD1 during the wet and dry season ranged between 20th and 50th percentile WQOs
- Similarly, CD3 median wet and dry season turbidity ranged between the 20th and 50th percentile WQOs
- For CD4 and CD5 only mean surface turbidity during the wet and dry season were below assigned WQOs
- Mean CD2 turbidity results were all above the assigned WQOs.

4.8.2.3 Influence of natural events on turbidity

The advent of severe Tropical Cyclone Marcia in Central Queensland around 20 February 2015 resulted in short term elevated turbidity at the offshore sites (CD1 to CD5) and at P5/MH10. Turbidity at the Mid Harbour site of P5/MH10 has historically been found to be influenced by increased wind, in addition to tidal phases (VE 2013b). Generally these types of events are acute in nature resulting in a rapid but short-lived elevation in turbidity, particularly when wind rather than rainfall is the driving factor, as observed with Tropical Cyclone Marcia. Benthic EWMA turbidity values at sites CD1, CD2, CD3 and CD5 were greater than 50 NTU on 20 February and 21 February 2015, however raw values were consistently over 200NTU at CD1, one of the shallower and most exposed monitoring sites. Surface turbidity peaks were not as high or variable, with values ranging from approximately 20NTU up to 100NTU during the same period. A return to lower turbidity values (<10NTU) occurred by 24 February at all sites. The inshore sites also exhibited an increase in turbidity (EWMA > 30NTU) with the advent of Tropical Cyclone Marcia, although high rainfall (~100mm) and spring tides which occurred concurrently with this event, are likely to have been instrumental in this (refer Appendix B Section 3.2.1 for turbidity plots for each monitoring site).

Major rain events recorded in Gladstone such as during mid to late January 2015 (> 200mm) (BoM 2015b) were shown to be more influential on turbidity at the inshore sites than high wind speeds. Short term peaks in turbidity were particularly evident at QE3 (EWMA approximately 68NTU) following significant rain events as evidenced in mid-January and mid-February 2015. This is likely due to QE3 being exposed to flood peaks which traverse down The Narrows from the Fitzroy River and surrounding catchments. This is a historical pattern which has been observed previously, particularly when higher rainfall is experienced in the Fitzroy River catchment (VE 2013a).

P2B/WB50 has also historically displayed post flood peaks in turbidity due to the proximity of the site to the mouth of the Calliope River (refer Figure 4.3). During mid-January and mid-February 2015 both sites exhibited concurrent declines in other physicochemical parameters such as conductivity (20mS/cm at QE3) and DO (<70% at QE3), which are also generally associated with large fresh water flows. These physicochemical parameters are discussed further in the sections below and in the *Project Baseline Water Quality Report* in Appendix B Section 4.5.2.

4.8.3 Temperature

During the monitoring period, temperature at all sites exhibited a clear seasonal pattern, associated with ambient temperatures (refer Table 4.11). As expected, temperature at all sites was significantly higher during the wet season than during the dry season, paralleling ambient air conditions. Of note were the small immediate decreases in temperature associated with rainfall events which were less evident at the deepest sites CD4 and CD5 further offshore. No WQOs are assigned for temperature.

Table 4.11 Baseline seasonal temperature (1 June 2014 to 4 July 2015)

Site	Statistic	Dry season temperature (°C)		Wet season temperature (°C)	
		Surface	Benthic	Surface	Benthic
QE3 ¹	Mean ± se	20.8 ± 0.0	-	27.6 ± 0.0	-
	Median	20.6	-	28.0	-
P2B/WB50	Mean ± se	21.2 ± 0.0	-	27.8 ± 0.0	-
	Median	20.8	-	28.1	-
P5/MH10	Mean ± se	21.0 ± 0.0	-	27.4 ± 0.0	-
	Median	20.7	-	27.6	-
CD1	Mean ± se	21.4 ± 0.0	21.3 ± 0.0	27.3 ± 0.0	27.2 ± 0.0
	Median	20.9	20.8	27.6	27.4
CD2	Mean ± se	21.1 ± 0.0	21.1 ± 0.0	27.3 ± 0.0	27.4 ± 0.0
	Median	20.9	20.8	27.5	27.7
CD3	Mean ± se	20.9 ± 0.0	20.9 ± 0.0	27.6 ± 0.0	27.6 ± 0.0
	Median	20.5	20.5	27.9	27.8
CD4	Mean ± se	21.4 ± 0.0	21.2 ± 0.0	27.4 ± 0.0	27.2 ± 0.0
	Median	21.2	21.0	27.6	27.4
CD5	Mean ± se	21.3 ± 0.0	21.2 ± 0.0	27.2 ± 0.0	27.1 ± 0.0
	Median	21.2	21.1	27.4	27.4

Table notes:

1 N = 8,636 to 20,823

2 QE3 results collected from January 2015 to July 2015

4.8.4 pH

The pH at each site tended to remain reasonably consistent throughout the monitoring period (refer Table 4.12). While consistently lower pH was evident at inshore site QE3, typical of estuarine environments, only minor differences were evident between remaining sites. Benthic and surface pH at each site suggested a well-mixed water column at offshore sites. Tidal fluctuations in pH were also evident at QE3, while P2B/WB50, P5/MH10 and CD3 demonstrated this pattern to a lesser extent and generally only after significant rain events recorded in January and February 2015. All mean seasonal pH values were within their appropriate WQO range (EHP 2014b).

Table 4.12 Baseline seasonal pH (1 June 2014 to 4 July 2015)

Site	Statistic	Dry season		Wet season		WQOs (range) ¹
		Surface	Benthic	Surface	Benthic	
QE3 ²	Mean ± se	8.0 ± 0.0	-	7.8 ± 0.0	-	7.4 to 8.3
	Median	8.0	-	7.8	-	
P2B/WB50	Mean ± se	8.0 ± 0.0	-	8.0 ± 0.0	-	7.4 to 8.3
	Median	8.0	-	8.0	-	
P5/MH10	Mean ± se	8.1 ± 0.0	-	8.1 ± 0.0	-	7.4 to 8.3
	Median	8.1	-	8.1	-	-
CD1	Mean ± se	8.2 ± 0.0	8.1 ± 0.0	8.2 ± 0.0	8.2 ± 0.0	8.0 to 8.2
	Median	8.2	8.1	8.1	8.2	-
CD2	Mean ± se	8.2 ± 0.0	8.2 ± 0.0	8.2 ± 0.0	8.2 ± 0.0	8.1 to 8.4
	Median	8.2	8.2	8.2	8.2	-
CD3	Mean ± se	8.2 ± 0.0	8.2 ± 0.0	8.1 ± 0.0	8.1 ± 0.0	7.4 to 8.3
	Median	8.2	8.2	8.1	8.1	-
CD4	Mean ± se	8.2 ± 0.0	8.2 ± 0.0	8.2 ± 0.0	8.2 ± 0.0	8.1 to 8.4
	Median	8.2	8.2	8.2	8.2	-
CD5	Mean ± se	8.2 ± 0.0	8.2 ± 0.0	8.2 ± 0.0	8.1 ± 0.0	8.1 to 8.4
	Median	8.2	8.3	8.2	8.1	-

Table notes:

1 N = 8,636 to 20,229

2 WQOs Source: Curtis Island, Calliope River and Boyne River Basins Environmental Values and Water Quality Objectives (EHP 2014b) WQOs are upper and lower limits (20th to 80th percentiles)

3 QE3 results collected from January 2015 to July 2015

4.8.5 Conductivity

Conductivity results for the baseline monitoring period are outlined in Table 4.13.

Table 4.13 Baseline seasonal conductivity (1 June 2014 to 4 July 2015)

Site	Statistic	Dry season (mS/cm)		Wet season (mS/cm)	
		Surface	Benthic	Surface	Benthic
QE3 ¹	Mean ± se	51.4 ± 0.0	-	45.3 ± 0.0	-
	Median	51.0	-	47.5	-
P2B/WB50	Mean ± se	53.2 ± 0.0	-	49.7 ± 0.0	-
	Median	53.0	-	51.0	-
P5/MH10	Mean ± se	53.5 ± 0.0	-	52.4 ± 0.0	-
	Median	53.5	-	52.5	-

Site	Statistic	Dry season (mS/cm)		Wet season (mS/cm)	
		Surface	Benthic	Surface	Benthic
CD1	Mean $\pm$ se	53.1 $\pm$ 0.0	53.9 $\pm$ 0.0	54.3 $\pm$ 0.0	54.1 $\pm$ 0.0
	Median	53.0	54.0	54.0	54.2
CD2	Mean $\pm$ se	53.3 $\pm$ 0.0	53.4 $\pm$ 0.0	53.1 $\pm$ 0.0	54.1 $\pm$ 0.0
	Median	53.0	53.5	53.5	53.9
CD3	Mean $\pm$ se	52.5 $\pm$ 0.0	53.9 $\pm$ 0.0	51.3 $\pm$ 0.0	52.9 $\pm$ 0.0
	Median	52.5	53.5	52.5	53.5
CD4	Mean $\pm$ se	53.4 $\pm$ 0.0	52.8 $\pm$ 0.0	53.5 $\pm$ 0.0	54.1 $\pm$ 0.0
	Median	53.5	53.0	53.5	54.5
CD5	Mean $\pm$ se	53.1 $\pm$ 0.0	53.1 $\pm$ 0.0	54.1 $\pm$ 0.0	54.5 $\pm$ 0.0
	Median	53.0	53.5	54.0	54.7

Table notes:

1 N = 8,635 to 20,831

2 QE3 results collected from January 2015 to July 2015

Conductivity tended to remain stable except for during and after large rainfall events (e.g. in January and February 2015), which resulted in noticeable decreases particularly at inshore sites and CD3, and to a lesser extent at site CD2 (refer Table 4.13). During mid-January and mid-February 2015, rainfall events (> 100mm) resulted in conductivity levels < 20mS/cm at inshore sites QE3 and P2B/WB50, < 40mS/cm at P5/MH10, and < 10mS/cm at CD3 (surface). Values were not as low as those recorded after the January 2013 flood event (820mm over a four day period), where values < 5mS/cm (technically considered freshwater), were recorded at all inshore sites, which were being monitored as part of the WBDDP at the time. Conductivity of 0mS/cm was also recorded at site P2B/WB50 for short periods during the 2013 event (VE 2013c).

Recovery to almost typical dry season background conditions after the January and February 2015 rain events, did not occur at these sites until April 2015. At CD3, surface conductivity during these times was considerably lower than benthic conductivity with pronounced tidal fluctuations, indicating vertical stratification of the water column and the presence of a surface layer of freshwater outflow from the Boyne River on outgoing tides. Apart from these occasions, only minor differences were evident between mean values calculated for surface and benthic loggers ($\leq$ 1.6mS/cm). No WQOs are assigned for conductivity.

4.8.6 Dissolved oxygen

Surface and benthic DO results for the baseline monitoring period are outlined in Table 4.14.

Table 4.14 Baseline seasonal dissolved oxygen (1 June 2014 to 4 July 2015)

Site	Statistic	Dry season (% saturation)		Wet season (% saturation)		WQOs ¹
		Surface	Benthic	Surface	Benthic	
QE3	Mean $\pm$ se	93 $\pm$ 0	-	88 $\pm$ 0	-	-
	20 th %ile	-	-	-	-	87
	50 th %ile	93	-	88	-	92
	80 th %ile	-	-	-	-	95
P2B/WB50	Mean $\pm$ se	97 $\pm$ 0	-	96 $\pm$ 0	-	-
	20 th %ile	-	-	-	-	91
	50 th %ile	97	-	96	-	96
	80 th %ile	-	-	-	-	100

Site	Statistic	Dry season (% saturation)		Wet season (% saturation)		WQOs ¹
		Surface	Benthic	Surface	Benthic	
P5/MH10	Mean $\pm$ se	100 $\pm$ 0	-	101 $\pm$ 0	-	-
	20 th %ile	-	-	-	-	94
	50 th %ile	100	-	99	-	97
	80 th %ile	-	-	-	-	101
CD1	Mean $\pm$ se	100 $\pm$ 0	100 $\pm$ 0	101 $\pm$ 0	99 $\pm$ 0	-
	20 th %ile	-	-	-	-	94
	50 th %ile	100	100	101	99	97
	80 th %ile	-	-	-	-	100
CD2	Mean $\pm$ se	100 $\pm$ 0	100 $\pm$ 0	101 $\pm$ 0	101 $\pm$ 0	-
	20 th %ile	-	-	-	-	95
	50 th %ile	100	100	100	101	-
	80 th %ile	-	-	-	-	105
CD3	Mean $\pm$ se	100 $\pm$ 0	100 $\pm$ 0	100 $\pm$ 0	99 $\pm$ 0	-
	20 th %ile	-	-	-	-	94
	50 th %ile	99	99	100	99	97
	80 th %ile	-	-	-	-	101
CD4	Mean $\pm$ se	100 $\pm$ 0	100 $\pm$ 0	101 $\pm$ 0	100 $\pm$ 0	-
	20 th %ile	-	-	-	-	95
	50 th %ile	100	99	101	100	-
	80 th %ile	-	-	-	-	105
CD5	Mean $\pm$ se	101 $\pm$ 0	100 $\pm$ 0	102 $\pm$ 0	100 $\pm$ 0	-
	20 th %ile	-	-	-	-	95
	50 th %ile	101	99	102	100	-
	80 th %ile	-	-	-	-	105

Table notes:

1. N = 8,636 to 20,832
2. QE3 results collected from January 2015 to July 2015
3. WQOs Source: Curtis Island, Calliope River and Boyne River Basins EVs and WQOs (EHP 2014b) WQO values for CD2, CD4 and CD5 indicate the 20th to 80th percentile value range

DO levels tended to display reasonably consistent patterns throughout the baseline monitoring period, with little difference between median dry and wet season values for each site. The following DO trends were observed across the sites:

- Across the sites, mean QE3 and P2B/WB50 DO levels were lower than offshore sites by between 3 to 12%, a spatial pattern which has been recorded previously in Port Curtis (VE 2013b). Only minor differences were evident between mean values for surface and benthic loggers ($\leq$ 3% saturation).
- All mean surface and benthic DO concentrations for sites CD2, CD4 and CD5 in coastal waters outside Gladstone Harbour were within the assigned WQO range
- For all other sites, median surface and benthic DO concentrations for the wet season and dry season were slightly above or equal their 50th percentile WQO except for QE3 surface
- Immediate decreases in DO were correlated to rainfall events in mid-January and mid-February 2015, particularly evident at inshore sites QE3 and P2B/WB50 where declines to $< 70\%$ and $< 80\%$ saturation, respectively, were recorded. Declines were also evident at site CD3 which were particularly pronounced and persistent at the seabed, and were directly related to tidal flows.

- Diurnal patterns were evident at all sites but were most pronounced at the inshore sites of QE3, P2B/WB50 and P5/MH10. Diurnal patterns are likely to be due to plant (e.g. algae) photosynthesis and respiration, and were particularly noticeable at site P5/MH10 (which is adjacent to large seagrass meadows at Pelican Banks) and QE3 in The Narrows (which is a mangrove dominated environment).
- Immediate declines after rain events in mid-January and mid-February 2015 were often followed by more pronounced diurnal patterns with peaks of DO > 120% recorded at P5/MH10. These patterns suggest post rain event increases in photosynthetic activity generally associated with algal blooms, due to the break-down of stormwater introduced detritus which can increase nutrients and therefore stimulate algal growth.
- Intermittent seasonal increases in DO were sometimes evident at offshore sites and often coincided with visual confirmation of algal blooms, during vessel sampling.

4.8.7 Sedimentation

Several external environmental factors were found to influence sediment flux with effects varying depending on the location of the site either inshore or offshore. The below trends in sedimentation rates were observed from the deployment of acoustic altimeters at each monitoring site over the baseline monitoring period (refer Appendix B Section 3.3 for individual site sedimentation plots).

4.8.7.1 Instantaneous bed level change - inshore

- Increases in sediment flux at inshore sites (i.e. QE3, P2B/WB50 and P5/MH10) were associated with significant rain events over January and February 2015, as well as with spring tides coinciding with elevated turbidity and higher sediment resuspension (refer Figures 3.28 to 3.30 in Appendix B for detailed inshore sedimentation plots).
- During Tropical Cyclone Marcia in mid-February 2015, sedimentation data could only be captured at site QE3. At site QE3 increased turbidity (EWMA ~ 70NTU and 40NTU, during rain events in mid-January and mid-February 2015, respectively) generated increased sediment resuspension. Instantaneous bed level change up to ~ 30mm either positively or negatively from the point of origin at deployment (base point) was recorded in January 2015 at QE3, and this was followed by a period of cumulative bed level deposition of up to ~ 30mm.
- Although turbidity only reached approximately 10NTU at P5/MH10 during the rain event in mid-January 2015, increased sediment resuspension was also observed and this was followed by a period of erosion of > 20mm for the remainder of the deployment period. At P2B/WB50 despite an increase in turbidity of up to 40NTU in mid-January 2015, measurements remained fairly static with only slight erosion over the deployment period, most likely due to increased freshwater flows.
- For the inshore sites, spring tides coinciding with elevated turbidity also generated more dynamic bed level flux.
- Apart from the two major rain events in January and February 2015, one additional occasion of higher instantaneous sediment change was evident at QE3 in February, coinciding with a period of elevated turbidity associated with the higher spring tide in early February.
- Consistent tidal patterns were particularly evident at P2B/WB50 over the 13 month deployment, with more volatile bed level changes coinciding with the higher turbidity recorded during the majority of spring tides. A threshold value of surface turbidity EWMA > 15NTU at P2B/WB50 appeared to generate an altered bed level state. The spring tide of the 11 August 2014 generated sediment flux up to ~ 50mm from base point and resulted in cumulative erosion up to 20mm during the deployment period.

- In comparison to P2B/WB50, sediment flux at P5/MH10 was lower and sediment movement occurred less frequently, even during spring tides or high wind events. During the dry season deployment, turbidity at both QE3 and P5/MH10 remained reasonably stable, as did overall sediment flux which tended to mostly fluctuate around a fixed point.

4.8.7.2 Cumulative bed level change - inshore

- Initial deployment periods in June and July 2014 resulted in deposition at most inshore sites (refer Figure 4.5), but this may have been an artefact of sinking of the deployment frame, and therefore data during this time prior to fixed stake deployment should be treated with caution.
- At site QE3, all three deployment periods during the wet season exhibited a net accumulation of sediment (range between ~ 12mm and 30mm). In contrast, the one deployment period during the dry season (May to July 2015) exhibited slight, gradual erosion over the deployment period, with sediment levels ~ 4mm lower at the end of the 66 day deployment.
- Of the 13 deployment periods at P2B/WB50, erosion and deposition occurred fairly evenly (refer Figure 4.5). No clear seasonal pattern was apparent, with periods of erosion interspersed with periods of deposition. The most evident cumulative deposition of ~ 50mm was recorded during May and June 2015, although no clear environmental trigger for this was apparent.
- A similar pattern was observed at P5/MH10 but with bed level deviating generally consistently from a fixed point. While no clear seasonal pattern was evident, highest erosion rates for any one deployment (up to 21mm) occurred from December 2014 to February 2015, where wave heights and winds speeds were generally at their highest during the baseline monitoring period.

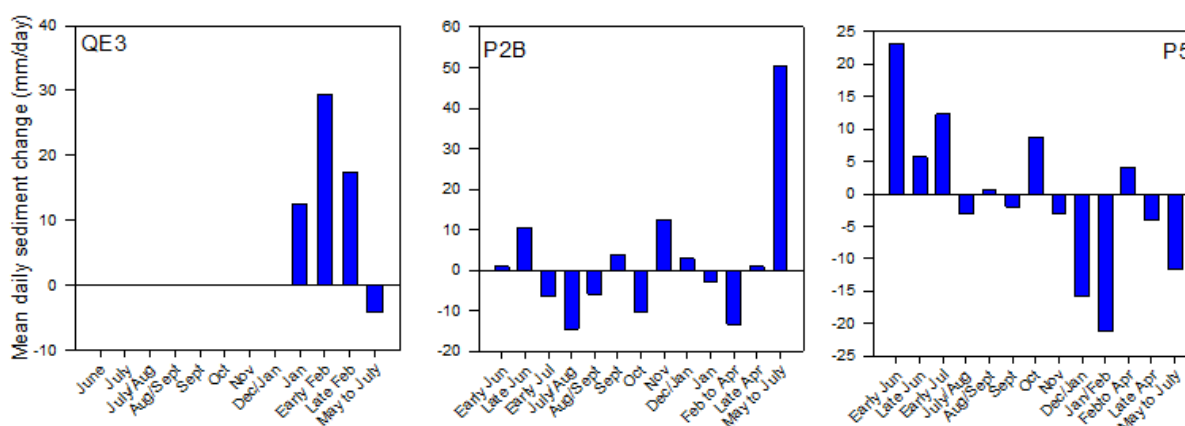


Figure 4.5 Cumulative bed level change - inshore monitoring sites

4.8.7.3 Instantaneous bed level change – offshore

- Between the offshore sites, the driving factors for sediment resuspension at the furthest offshore sites (i.e. CD1, CD4 and CD5) appeared to be wind speed and wave heights. At those sites closer to land (i.e. CD2 and CD3) tidal influences appeared more evident (refer Figures 3.31 to 3.35 in Appendix B for detailed offshore sedimentation plots).
- Instantaneous bed level change paralleled turbidity particularly at CD2, with a higher level of instantaneous sediment change during each spring tide period. This tended to be the dominant overall pattern at CD2 overriding wind speed events, with instantaneous bed level measurements regularly ranging up to ~ 50mm either positively or negatively from the base point at CD2. A similar pattern occurred at CD3, however instantaneous bed level change generally only fluctuated within 20mm of the fixed point.

- At CD1 benthic turbidity remained relatively low during the majority of the 13 month monitoring period and as such, instantaneous bed level change also remained stable during these periods. However, similar to P2B/WB50, when turbidity > 15NTU was recorded during periods of elevated wave height, instantaneous sediment flux increased, including in August and October 2014, and to a lesser extent June 2015. Instantaneous bed level measurements ranged up to 15mm either positively or negatively from the base point at CD1 during these occasions.
- Over the 13 month deployment period, sites CD4 and CD5 were less dynamic in terms of instantaneous bed level change compared to other offshore sites, most likely due to their deeper locations. Both sites captured data through the advent of Tropical Cyclone Marcia and it was during this period that the highest sediment flux for CD5 was recorded.
- Elevated turbidity (EWMA > 45NTU) generated instantaneous bed level change up to 30mm either positively or negatively from the base point at CD5. At CD4 sediment flux was not as elevated, with instantaneous bed level change up to 20mm either positively or negatively from the base point.

4.8.7.4 Cumulative bed level change - offshore

Cumulative bed level change at offshore sites per deployment period has been plotted in Figure 4.6. The following trends were observed over the baseline monitoring period:

- Sediment flux appeared to be driven by lunar phases and/or wave heights, but not all resuspension events resulted in cumulative bed level change. In some cases bed level fluctuated around a fixed mean, whereas in other cases there was measured deposition or erosion. Wind direction and its influence on sediment flux, which results in deposition or erosion, appeared to be a major factor in bed level change during the baseline monitoring period.
- Following the period of initial deposition, cumulative erosion occurred for the majority of deployment periods at CD1, CD2, CD4 and CD5. This was most apparent at CD2 with up to 63mm of cumulative erosion recorded in any one deployment period (March to April 2015). Maximum cumulative erosion only reached ~ 13, 20 and 12mm at CD1, CD4 and CD5, respectively.
- Compared to other offshore sites, bed level at CD2 fluctuated greatly, demonstrating the overall result of the highly volatile sediment flux recorded at this site. Sediment erosion rates at CD2 were generally up to three fold higher than those recorded at all other sites and were highest during the March/April 2015 deployment, post Tropical Cyclone Marcia.
- In contrast to all other sites, almost all deployment periods at CD3 resulted in deposition. Apart from the initial deployment periods, cumulative net deposition up to 28mm was recorded for any one deployment period. Highest deposition occurred during the rain events of mid-January and mid-February 2015. This is expected considering this site's location at the mouth of the Boyne River and associated siltation impacts.
- Wind direction was also highly influential in determining the extent of sediment flux at the offshore sites and net bed level change, whether accretion or erosion, for example, both CD4 and CD5 demonstrated a period of erosion for several days prior to landfall of Tropical Cyclone Marcia in February 2015, corresponding with increasing wind speeds in an east-southeast direction (refer Figures 3.33 and 3.34 in Appendix B Section 3.3). During the landfall of Tropical Cyclone Marcia on 22 February 2015 and with wind direction rapidly changing to a westerly direction, rapid erosion continued, with up to 24mm recorded at CD4, which created a new stable baseline until the end of the deployment period in early April 2015.

- In contrast rapid deposition up to ~20mm was recorded at CD5 from 21 to 23 February 2015, post Tropical Cyclone Marcia. Data were only able to be captured for some of this period during the passing of Tropical Cyclone Marcia at CD2, but erosion followed by a short period of deposition, was recorded at this site before unit disruption. The differences may be related to the location of CD2 and CD4 north of the harbour entrance, East Banks DMPA and outer anchorage, whereas CD4 is located to the north and exposed to more open prevailing currents. On retrieval after Tropical Cyclone Marcia, the CD2 altimeter buoy, mooring and stake with altimeter, were found approximately 2km from its deployed location, indicating strong water movement through the area during this period.

Due to the altimeters measuring at a fixed point, with each new deployment after data retrieval, a new fixed base level was established. Due to missing data, net cumulative bed level change for the 13 month monitoring period could not be calculated. However cumulative sediment change for each particular deployment period, which assisted to identify trends, was able to be calculated. Thus longer term deployments were more beneficial in capturing cumulative changes through lunar cycles and extreme meteorological events. Although increased sediment flux corresponded with increases in turbidity, there appeared to be a critical minimum threshold (e.g. EWMA > 10 NTU offshore and > 15 NTU inshore) of turbidity for this to occur in some cases.

Bed level flux appeared to be driven by lunar phases and/or wave heights, but not all resuspension events resulted in cumulative bed level change. In some cases bed level fluctuated around a fixed mean, whereas in other cases there was measured deposition or erosion. Wind direction and its influence on bed level flux, which results in deposition or erosion, appeared to be a major factor in bed level change during the baseline monitoring period, particularly at offshore sites.

The GBRMPA has set a sedimentation trigger value at a maximum annual deposition of 3 milligrams per square centimetre per day ($\text{mg}/\text{cm}^2/\text{day}$) and a daily maximum of $15\text{mg}/\text{cm}^2/\text{day}$ in the *Water Quality Guidelines for the Great Barrier Reef* (GBRMPA 2010). However, these are low confidence values based on limited field studies, which have examined the effects of sediments settling on a few coral species. The trigger value is expected to guard against excessive coral recruit mortality (GBRMPA 2010). However, values were derived using different instrumentation, including traditional sediment traps (De'ath and Fabricius 2008) which measure downward flux only and cannot be compared to altimeter values (which measure cumulative bed level change in mm, which includes resuspension).

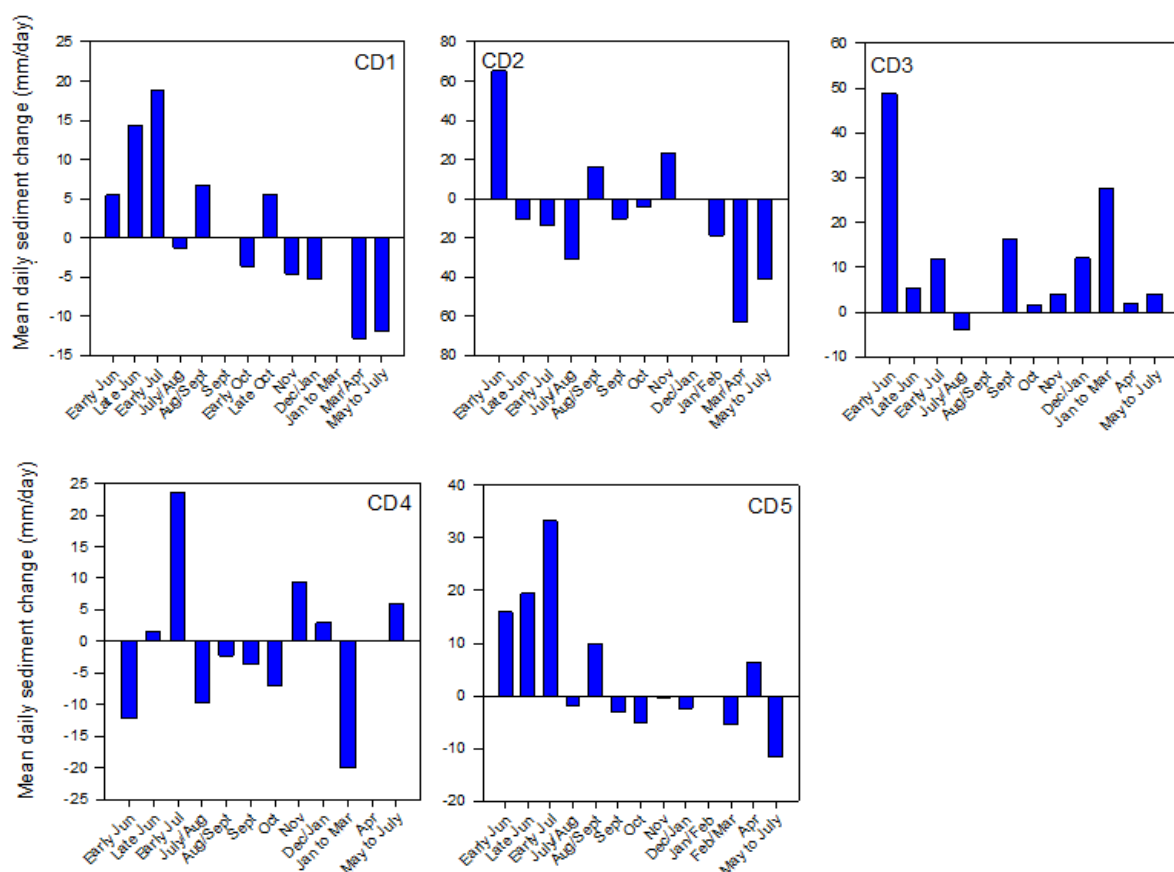


Figure 4.6 Cumulative bed level change – offshore monitoring sites

4.8.8 Benthic Photosynthetically Active Radiation

BPAR results recorded in moles per metre square per day ($\text{mol/m}^2/\text{day}$) at monitoring sites during the baseline data collection period are outlined in Table 4.15. Ambient PAR representing the daily light integral was recorded at VE Base (VB) and is outlined in Table 4.16. The baseline report in Appendix B Section 3.4 contains BPAR plots with turbidity for individual sites.

Table 4.15 Baseline seasonal BPAR (1 June 2014 to 4 July 2015)

Site	Statistic	Dry season TDP ($\text{mol/m}^2/\text{day}$)	Wet season TDP ($\text{mol/m}^2/\text{day}$)
CD1	Mean $\pm$ se	2.6 ± 0.2	1.4 ± 0.1
	Median	1.6	0.7
	Range	0.0 to 10.9	0.0 to 7.0
CD2	Mean $\pm$ se	1.4 ± 0.1	0.9 ± 0.1
	Median	0.9	0.4
	Range	0.0 to 7.3	0.0 to 8.8
CD3	Mean $\pm$ se	0.9 ± 0.1	0.6 ± 0.1
	Median	0.2	0.2
	Range	0.0 to 8.6	0.0 to 6.1
CD4	Mean $\pm$ se	1.0 ± 0.1	0.7 ± 0.1
	Median	0.7	0.4
	Range	0.0 to 5.3	0.0 to 3.3

Site	Statistic	Dry season TDP (mol/m ² /day)	Wet season TDP (mol/m ² /day)
CD5	Mean ± se	1.3 ± 0.1	0.5 ± 0.1
	Median	0.9	0.3
	Range	0.0 to 5.7	0.0 to 4.4

Table note:

1. N = 167 to 218

Table 4.16 Baseline seasonal ambient PAR (1 June 2014 to 4 July 2015)

Site	Statistic	Dry season PAR (mol/m ² /day)	Wet season PAR (mol/m ² /day)
VB	Mean ± se	37.9 ± 0.8	51.1 ± 0.9
	Median	36.0	54.3
	Range	9.1 to 59.5	6.4 to 67.5

Table notes:

1. N = 167 to 218

4.8.9 Benthic Photosynthetically Active Radiation and seagrass seasonality

BPAR results recorded at monitoring sites have also been calculated according to the two generalised seasons that have been distinguished for local Port Curtis seagrass species, the growing season (July to January) and the senescent (February to June). The growing seasons typifies seagrass' natural increase in biomass and distribution as ideal growth conditions provide a period of opportunistic expansion; and the senescent season sees seagrasses typically retract and rely more on stores or seeds to get through wet season conditions, including flooding and poor water quality (Chartrand et al. 2012).

Table 4.17 Baseline BPAR during seagrass seasons (1 June 2014 to 4 July 2015)

Site	Statistic	Growing season TDP (mol/m ² /day)	Senescent season TDP (mol/m ² /day)
CD1	Mean ± se	2.8 ± 0.1	1.1 ± 0.1
	Median	1.8	0.7
	Range	0.0 to 10.9	0.0 to 5.1
CD2	Mean ± se	1.7 ± 0.1	0.7 ± 0.1
	Median	1.1	0.3
	Range	0.0 to 8.8	0.0 to 3.3
CD3	Mean ± se	1.2 ± 0.1	0.4 ± 0.0
	Median	0.3	0.1
	Range	0.0 to 8.6	0.0 to 2.8
CD4	Mean ± se	1.3 ± 0.1	0.4 ± 0.0
	Median	1.1	0.3
	Range	0.0 to 5.3	0.0 to 1.8
CD5	Mean ± se	1.3 ± 0.1	0.4 ± 0.0
	Median	0.9	0.1
	Range	0.0 to 5.7	0.0 to 2.1

Table note:

N = 167 to 218

Table 4.18 Baseline ambient PAR during seagrass seasons (1 June 2014 to 4 July 2015)

Site	Statistic	Growing season TDP (mol/m ² /day)	Senescent season TDP (mol/m ² /day)
VB	Mean ± se	47.6 ± 0.9	39.3 ± 0.9
	Median	49.3	38.3
	Range	9.1 to 67.5	6.4 to 64.0

Table notes:

N = 167 to 218

JCU inshore BPAR results to be analysed and inserted in similar format as VE

The BPAR trends below were observed across the five BPAR monitoring sites, as well as the 'control' ambient PAR site (VB):

- The mean ambient PAR recorded at VB was higher during the wet season (51.1mol/m²/day) than during the dry season (37.9mol/m²/day), most likely due to the increased daylight hours experienced during the wet season.
- Ambient PAR results highlight the ideal seagrass growth conditions during the growing season (47.6mol/m²/day) versus the senescent season (39.3mol/m²/day). Mean BPAR was recorded higher at each site during the growing season versus the senescent season.
- All five monitoring sites exhibited significant seasonal variation ($p < 0.05$), however, in contrast, dry season BPAR at these sites was found to be significantly higher than wet season BPAR, despite lower ambient PAR, indicating ambient light was not the only driving factor influencing BPAR at these sites. This is supported by the lack of significant linear regressions in the data between ambient PAR and BPAR at CD1, CD2 and CD5.
- Significant but weak linear regressions were evident in the data between turbidity and BPAR at each site, with BPAR decreasing as turbidity increased
- Across the monitoring sites, CD1 and CD2 recorded significantly higher mean BPAR (1.0 to 2.3mol/m²/day), than CD3, CD4 and CD5 (0.7 to 1.1mol/m²/day). CD1 and CD2 were located at shallower depths (~ 6 to 9m) than CD4 and CD5 (~ 16 to 18m) and therefore light would not have been attenuated as much prior to reaching the benthic logger
- CD3 was located at a similar depth to CD1 and CD2 (~ 7m) but experienced overall higher benthic turbidity during the dry season. In addition, TSS concentrations (refer Section 4.8.10) were found to be uniform through the water column for CD3, indicating elevated turbidity was not entirely restricted to the seabed as it may have been for other offshore sites, thus resulting in greater light attenuation. The location of CD3 adjacent to the Boyne River mouth would predispose this location to a lower light regime.

The relationship between BPAR and Port Curtis sensitive ecological receptors, such as seagrass species, is further analysed in the *Project Ecology Technical Report* (Aurecon 2019a).

4.8.10 Total suspended solids

TSS sample results are outlined in Table 4.19. Monthly samples were collected at three depths in the water column at the five offshore sites (sub-surface, mid column and 1m above the seabed (benthic)). At the three inshore sites TSS samples were collected at the sub-surface only due to the well-mixed water column.

Table 4.19 Baseline total suspended solids sample concentrations

Site	Sample depth	Dry season (mg/L)		Wet season (mg/L)		WQOs (mg/L)
		Mean $\pm$ se	Median	Mean $\pm$ se	Median	
QE3	Surface	7.0 $\pm$ 3.0	7.0	8.5 $\pm$ 2.7	7.0	20
P2B/WB50	Surface	15.7 $\pm$ 6.1	9.0	8.3 $\pm$ 2.2	8.0	20
P5/MH10	Surface	4.9 $\pm$ 2.3	2.0	6.0 $\pm$ 2.1	5.0	20
CD1	Surface	2.0 $\pm$ 1.0	<2	<2	<2	1
	Mid	2.6 $\pm$ 0.6	3.0	<2	<2	-
	Benthic	2.9 $\pm$ 1.0	2.0	4.7 $\pm$ 1.3	5.5	-
CD2	Surface	<2		2.5 $\pm$ 0.6	2.0	2
	Mid	3.1 $\pm$ 0.7	3.0	3.2 $\pm$ 1.4	<2	-
	Benthic	3.4 $\pm$ 1.0	3.0	8.2 $\pm$ 3.6	5.5	-
CD3	Surface	7.6 $\pm$ 4.2	2.0	3.7 $\pm$ 0.9	3.5	1
	Mid	8.0 $\pm$ 3.0	5.0	4.3 $\pm$ 1.0	4.5	-
	Benthic	7.4 $\pm$ 3.2	4.0	14.2 $\pm$ 4.6	9.5	-
CD4	Surface	<2	<2	<2	<2	2
	Mid	<2	<2	<2	<2	-
	Benthic	<2	<2	4.3 $\pm$ 1.4	3.5	-
CD5	Surface	<2	<2	<2	<2	2
	Mid	<2	<2	2.0 $\pm$ 0.7	<2	-
	Benthic	2.4 $\pm$ 1.3	<2	3.2 $\pm$ 0.9	3.0	-

Table notes:

1. N = 3 to 7
2. CD2, CD4 and CD5 use TSS WQOs for open coastal waters outside Gladstone Harbour (EHP 2014b)
3. CD1 and CD3 use TSS guidelines for Marine Open Coastal guidelines from QWQG Central Coast Queensland Region (EHP 2009a) in lieu of specified TSS for Outer Harbour and Mid Harbour
4. QE3, P2B/WB50 and P5/MH30 use TSS guidelines for Mid-Estuarine and Tidal Canals, Constructed Estuaries, Marinas and Boat Harbours (EHP 2009a) in lieu of specified TSS for The Narrows, Western Basin and Mid Harbour

The TSS trends below were observed from monthly sample results collected across the eight monitoring sites during the baseline monitoring period:

- TSS concentrations paralleled the spatial patterns exhibited by turbidity measured by both continuous loggers (refer Table 4.10) and depth-profiling (refer Appendix B Table 6.1). A significant ($p < 0.05$) linear regression was evident between TSS results and depth-profiled turbidity measured concurrently ($r^2 = 0.87$) (refer Appendix B Figure 6.4). This indicates that as TSS increased, so did turbidity. As TSS was only sampled and analysed monthly, values are highly variable depending on the timing of sampling coinciding with spring or neap tides, and/or rainfall events, with sampling during spring tides resulting in higher TSS concentrations.
- Surface TSS was significantly higher in samples from site P2B/WB50 (mean 8.3 to 15.7mg/L) than at all other sites (mean < 2 to 7.6mg/L), with no significant seasonal variation found, which was a similar finding to that of surface logger turbidity results (refer Section 4.8.2.1). Samples from sites QE3 and P5/MH10 exhibited intermediate TSS concentrations (5.2 to 10mg/L) which were similar to the majority of offshore surface sample TSS concentrations.
- Among the offshore sites (with the exception of CD3), concentrations of TSS in samples collected at benthic layers (< 2 to 8.2mg/L) were significantly higher than concentrations of TSS in samples collected at the surface and mid-level of the water column (< 2 to 3.2mg/L). Results paralleled those of turbidity, with higher benthic compared to surface turbidity. No significant difference in TSS concentrations was evident in samples collected from different depths at site CD3 in either the wet season or dry season, indicating a well-mixed water column.

- Inshore TSS sample concentrations were compared to QWQG (EHP 2009a), with mean seasonal sample concentrations from all inshore sites lower than the WQO of 20mg/L
- Given the relatively low WQOs for all offshore sites (1mg/L for CD1 and CD3, and 2mg/L for CD2, CD4 and CD5), TSS concentrations were above the WQO (< 2mg/L) on several occasions:
 - Samples from all depths from CD3 over both seasons
 - Samples from all depths from CD2 over both seasons except dry season surface
 - All benthic samples from CD1, CD4 and CD5
- Sampling on 2 February 2015 occurred approximately 10 days after > 200mm of rainfall was recorded for Gladstone (BoM 2015b). However these TSS results were no more elevated than other occasions suggesting rapid recovery of water clarity to background conditions. The exception was CD3, where benthic and mid-column TSS results were consistently elevated after the commencement of the wet season in December 2014, while previously being within range of other sites' results prior to this. Wind driven resuspension of sediments deposited during rain events was likely the cause.
- Light attenuation was measured monthly during depth-profiling and collection of TSS samples. Monthly values paralleled the spatial patterns exhibited by turbidity and TSS (refer Appendix B Table 6.10).

4.8.11 Nutrients

Nutrient sample results are outlined in Table 4.20 to Table 4.26.

Table 4.20 Mean seasonal phosphorus sample concentrations (June 2014 to June 2015)

Site	Statistic	Dry season (mg/L)	Wet season (mg/L)	WQOs (mg/L)
QE3	Mean $\pm$ se	17 $\pm$ 2	28 $\pm$ 5	-
	20 th %ile	-	-	15
	50 th %ile	17	28	20
	80 th %ile	-	-	29
P2B/WB50	Mean $\pm$ se	30 $\pm$ 6	26 $\pm$ 3	-
	20 th %ile	-	-	14
	50 th %ile	24	29	18
	80 th %ile	-	-	29
P5/MH10	Mean $\pm$ se	15 $\pm$ 1	18 $\pm$ 3	-
	20 th %ile	-	-	9
	50 th %ile	15	17	14
	80 th %ile	-	-	23
CD1	Mean $\pm$ se	11 $\pm$ 0	11 $\pm$ 0	-
	20 th %ile	-	-	9
	50 th %ile	11	11	13
	80 th %ile	-	-	21
CD2	Mean $\pm$ se	11 $\pm$ 1	15 $\pm$ 1	< 8
	20 th %ile	-	-	-
	50 th %ile	11	14	-
	80 th %ile	-	-	-
CD3	Mean $\pm$ se	15 $\pm$ 2	14 $\pm$ 1	-
	20 th %ile	-	-	9
	50 th %ile	12	14	14
	80 th %ile	-	-	23
CD4	Mean $\pm$ se	9 $\pm$ 1	11 $\pm$ 0	< 8
	20 th %ile	-	-	-
	50 th %ile	10	11	-
	80 th %ile	-	-	-
CD5	Mean $\pm$ se	10 $\pm$ 0	10 $\pm$ 0	< 8
	20 th %ile	-	-	-
	50 th %ile	9	10	-
	80 th %ile	-	-	-

Table notes:

1. n = 3 to 7
2. WQOs sourced from EHP (2014b)
3. QE3 results collected from January 2015 to July 2015

Table 4.21 Mean seasonal orthophosphate sample concentrations (June 2014 to June 2015)

Site	Statistic	Dry season (mg/L)	Wet season (mg/L)	WQOs (mg/L)
QE3	Mean $\pm$ se	2 $\pm$ 1	2 $\pm$ 1	-
	20 th %ile	-	-	3
	50 th %ile	2	2	3
	80 th %ile	-	-	7
P2B/WB50	Mean $\pm$ se	3 $\pm$ 0	3 $\pm$ 0	-
	20 th %ile	-	-	1
	50 th %ile	3	3	3
	80 th %ile	-	-	7
P5/MH10	Mean $\pm$ se	2 $\pm$ 0	2 $\pm$ 1	-
	20 th %ile	-	-	1
	50 th %ile	< 2	< 2	2
	80 th %ile	-	-	3
CD1	Mean $\pm$ se	< 2	< 2	-
	20 th %ile	-	-	1
	50 th %ile	< 2	< 2	1
	80 th %ile	-	-	3
CD2	Mean $\pm$ se	< 2	< 2	< 1
	20 th %ile	-	-	-
	50 th %ile	-	-	-
	80 th %ile	-	-	-
CD3	Mean $\pm$ se	< 2	< 2	< 1
	20 th %ile	-	-	-
	50 th %ile	-	-	-
	80 th %ile	-	-	-
CD4	Mean $\pm$ se	< 2	< 2	-
	20 th %ile	-	-	1
	50 th %ile	< 2	< 2	2
	80 th %ile	-	-	3
CD5	Mean $\pm$ se	< 2	< 2	< 1
	20 th %ile	-	-	-
	50 th %ile	< 2	< 2	-
	80 th %ile	-	-	-

Table notes:

1. n = 3 to 7
2. WQOs sourced from EHP (2014b)
3. QE3 results collected from January 2015 to July 2015

Table 4.22 Mean seasonal total nitrogen sample concentrations (June 2014 to June 2015)

Site	Statistic	Dry season (mg/L)	Wet season (mg/L)	WQOs (mg/L)
QE3 ²	Mean ± se	130 ± 40	213 ± 27	-
	20 th %ile	-	-	140
	50 th %ile	130	220	170
	80 th %ile	-	-	220
P2B/WB50	Mean ± se	154 ± 13	183 ± 15	-
	20 th %ile	-	-	140
	50 th %ile	160	175	170
	80 th %ile	-	-	210
P5/MH10	Mean ± se	106 ± 8	143 ± 10	-
	20 th %ile	-	-	110
	50 th %ile	100	140	135
	80 th %ile	-	-	200
CD1	Mean ± se	87 ± 7	108 ± 4	-
	20 th %ile	-	-	115
	50 th %ile	80	105	130
	80 th %ile	-	-	170
CD2	Mean ± se	89 ± 6	122 ± 5	< 100
	20 th %ile	-	-	-
	50 th %ile	90	120	-
	80 th %ile	-	-	-
CD3	Mean ± se	110 ± 5	133 ± 97	-
	20 th %ile	-	-	110
	50 th %ile	110	135	135
	80 th %ile	-	-	200
CD4	Mean ± se	82 ± 11	120 ± 12	< 100
	20 th %ile	-	-	-
	50 th %ile	90	110	-
	80 th %ile	-	-	-
CD5	Mean ± se	84 ± 5	115 ± 10	< 100
	20 th %ile	-	-	-
	50 th %ile	80	110	-
	80 th %ile	-	-	-

Table notes:

1. n = 3 to 7
2. WQOs sourced from EHP (2014b)
3. QE3 results collected from January 2015 to July 2015

Table 4.23 Mean seasonal ammonia sample concentrations (June 2014 to June 2015)

Site	Statistic	Dry season (mg/L)	Wet season (mg/L)	WQOs (mg/L)
QE3	Mean $\pm$ se	3 $\pm$ 1	5 $\pm$ 1	-
	20 th %ile	-	-	3
	50 th %ile	3	7	3
	80 th %ile	-	-	10
P2B/WB50	Mean $\pm$ se	6 $\pm$ 2	4 $\pm$ 1	-
	20 th %ile	-	-	3
	50 th %ile	4	4	3
	80 th %ile	-	-	8
P5/MH10	Mean $\pm$ se	3 $\pm$ 1	< 3	-
	20 th %ile	-	-	3
	50 th %ile	3	-	3
	80 th %ile	-	-	12
CD1	Mean $\pm$ se	< 3	< 3	-
	20 th %ile	-	-	3
	50 th %ile	< 3	< 3	4
	80 th %ile	-	-	5
CD2	Mean $\pm$ se	3 $\pm$ 1	< 3	< 3
	20 th %ile	-	-	-
	50 th %ile	< 3	< 3	-
	80 th %ile	-	-	-
CD3	Mean $\pm$ se	< 3	< 3	-
	20 th %ile	-	-	3
	50 th %ile	< 3	< 3	3
	80 th %ile	-	-	12
CD4	Mean $\pm$ se	4 $\pm$ 2	3 $\pm$ 1	< 3
	20 th %ile	-	-	-
	50 th %ile	< 3	< 3	-
	80 th %ile	-	-	-
CD5	Mean $\pm$ se	5 $\pm$ 2	< 3	< 3
	20 th %ile	-	-	-
	50 th %ile	< 3)	< 3	-
	80 th %ile	-	-	-

Table notes:

1. n = 3 to 7
2. WQOs sourced from EHP (2014b)
3. QE3 results collected from January 2015 to July 2015

Table 4.24 Mean seasonal nitrate (nitrate + nitrite) sample concentrations (June 2014 to June 2015)

Site	Statistic	Dry season (mg/L)	Wet season (mg/L)	WQOs ¹ (mg/L)
QE3 ²	Mean ± se	4 ± 3	8 ± 4	-
	20 th %ile	-	-	2
	50 th %ile	4	5	3
	80 th %ile	-	-	9
P2B/WB50	Mean ± se	5 ± 1	5 ± 1	-
	20 th %ile	-	-	1
	50 th %ile	3	4	4
	80 th %ile	-	-	16
P5/MH10	Mean ± se	2 ± 1	2 ± 0	-
	20 th %ile	-	-	1
	50 th %ile	< 2	2	3
	80 th %ile	-	-	9
CD1	Mean ± se	3 ± 1	6 ± 2	-
	20 th %ile	-	-	1
	50 th %ile	< 2	4	3
	80 th %ile	-	-	6
CD2	Mean ± se	3 ± 1	8 ± 5	< 1
	20 th %ile	-	-	-
	50 th %ile	< 2	3	-
	80 th %ile	-	-	-
CD3	Mean ± se	2 ± 1	3 ± 1	-
	20 th %ile	-	-	1
	50 th %ile	< 2	2	3
	80 th %ile	-	-	9
CD4	Mean ± se	8 ± 4	5 ± 2	< 1
	20 th %ile	-	-	-
	50 th %ile	3	4	-
	80 th %ile	-	-	-
CD5	Mean ± se	11 ± 8	3 ± 2	< 1
	20 th %ile	-	-	-
	50 th %ile	2	< 2	-
	80 th %ile	-	-	-

Table notes:

1. n = 3 to 7
2. WQOs sourced from EHP (2014b)
3. QE3 results collected from January 2015 to July 2015

Table 4.25 Mean seasonal nitrite sample concentrations (June 2014 to June 2015)

Site	Statistic	Dry season (mg/L)	Wet season (mg/L)	WQOs ¹ (mg/L)
QE3 ²	Mean ± se	< 2	< 2	-
	20 th %ile	-	-	2
	50 th %ile	< 2	< 2	3
	80 th %ile	-	-	9
P2B/WB50	Mean ± se	< 2	< 2	-
	20 th %ile	-	-	1
	50 th %ile	< 2	< 2	4
	80 th %ile	-	-	16
P5/MH10	Mean ± se	< 2	< 2	-
	20 th %ile	-	-	1
	50 th %ile	< 2	< 2	3
	80 th %ile	-	-	9
CD1	Mean ± se	< 2	< 2	-
	20 th %ile	-	-	1
	50 th %ile	< 2	< 2	3
	80 th %ile	-	-	6
CD2	Mean ± se	< 2	< 2	< 1
	20 th %ile	-	-	-
	50 th %ile	< 2	< 2	-
	80 th %ile	-	-	-
CD3	Mean ± se	< 2	< 2	-
	20 th %ile	-	-	1
	50 th %ile	< 2	< 2	3
	80 th %ile	-	-	9
CD4	Mean ± se	< 2	< 2	< 1
	20 th %ile	-	-	-
	50 th %ile	< 2	< 2	-
	80 th %ile	-	-	-
CD5	Mean ± se	3 ± 2	< 2	< 1
	20 th %ile	-	-	-
	50 th %ile	< 2	< 2	-
	80 th %ile	-	-	-

Table notes:

1. n = 3 to 7
2. WQOs sourced from EHP (2014b)
3. QE3 results collected from January 2015 to July 2015

Table 4.26 Mean seasonal chlorophyll a sample concentrations (June 2014 to June 2015)

Site	Statistic	Dry season (mg/L)	Wet season (mg/L)	WQOs (mg/L)
QE3	Mean $\pm$ se	1.2 $\pm$ 0.2	2.6 $\pm$ 0.8	-
	20 th %ile	-	-	0.5
	50 th %ile	1.2	2.7	1.0
	80 th %ile	-	-	2.0
P2B/WB50	Mean $\pm$ se	0.9 $\pm$ 0.3	2.4 $\pm$ 0.7	-
	20 th %ile	-	-	0.5
	50 th %ile	0.6	1.4	1.0
	80 th %ile	-	-	2.0
P5/MH10	Mean $\pm$ se	0.5 $\pm$ 0.1	0.9 $\pm$ 0.2	-
	20 th %ile	-	-	0.5
	50 th %ile	0.6	0.9	1.0
	80 th %ile	-	-	2.0
CD1	Mean $\pm$ se	0.4 $\pm$ 0.1	0.3 $\pm$ 0.1	-
	20 th %ile	-	-	0.5
	50 th %ile	0.3	0.3	1.0
	80 th %ile	-	-	2.0
CD2	Mean $\pm$ se	0.4 $\pm$ 0.1	0.5 $\pm$ 0.1	< 0.45
	20 th %ile	-	-	-
	50 th %ile	0.3	0.6	-
	80 th %ile	-	-	-
CD3	Mean $\pm$ se	0.6 $\pm$ 0.2	0.6 $\pm$ 0.2	-
	20 th %ile	-	-	0.5
	50 th %ile	0.4	0.7	1.0
	80 th %ile	-	-	2.0
CD4	Mean $\pm$ se	0.3 $\pm$ 0.1	0.7 $\pm$ 0.2	< 0.45
	20 th %ile	-	-	-
	50 th %ile	< 0.2	0.6	-
	80 th %ile	-	-	-
CD5	Mean $\pm$ se	0.2 $\pm$ 0.1	0.4 $\pm$ 0.1	< 0.45
	20 th %ile	-	-	-
	50 th %ile	< 0.2	0.3	-
	80 th %ile	-	-	-

Table notes:

1. n = 3 to 7
2. WQOs sourced from EHP (2014b)
3. QE3 results collected from January 2015 to July 2015

The nutrient trends below were observed from monthly sample results collected across the eight monitoring sites during the baseline monitoring period:

- TP concentrations were higher in samples collected at inshore sites QE3 and P2B/WB50 (16 to 25µg/L), than in those collected at all offshore sites (CD1 to CD5) (9 to 15µg/L), with no significant variation evident across seasons. Spikes in TP concentrations were observed in samples from P2B/WB50 in August 2014 (43µg/L), September 2014 (56µg/L), and June 2015 (42µg/L). Spikes in TP concentrations were observed in samples from QE3 in January (28µg/L), February (31µg/L) and March 2015 (33µg/L).
- A similar pattern was evident for the bioavailable phosphorus form, orthophosphate, with significantly higher concentrations in samples from QE3 and P2B/WB50 (2 to 3µg/L), than in those from all offshore sites (< 2µg/L), and no significant seasonal variation. Intermediate concentrations of phosphorus forms were found in samples collected from site P5/MH30. Minor spikes in orthophosphate were observed in samples from P2B/WB50 in September (4µg/L) and November 2014 (4µg/L).
- Orthophosphate was undetected in samples from offshore sites on the majority of occasions, over both seasons, with the exception of March 2015 samples which were collected shortly after the rainfall event associated with Tropical Cyclone Marcia in February 2015. Elevated orthophosphate concentrations were detected in samples from all monitoring sites on this occasion. Stormwater runoff increases the level of organic matter (from detritus) into the system which decomposes releasing available nutrients. Additionally the flow of particulate bound phosphorous particles (potentially geologically derived) from freshwater into more saline environments, has the potential to result in an increase in the bioavailable forms of phosphorus (Fox et al. 1986).
- Similar to phosphorus, TN was significantly higher in samples from QE3 and P2B/WB50 (133 to 237µg/L) than in samples from the offshore sites (84 to 128µg/L), with intermediate concentrations evident in samples from P5/MH30 (157 to 180µg/L). However, TN was also significantly higher in samples collected during the wet season (108 to 237µg/L) than during the dry season (84 to 157µg/L). This may be a result of an increase in microalgal populations which contain nitrogen, which are present in the warmer months (as evidenced by higher chlorophyll a concentrations).
- Nitrogen forms: ammonia, nitrogen oxides (NO_x) and nitrite; did not exhibit significant seasonal or site variation
- Spikes in ammonia concentrations were seen in samples from P2B/WB50 (12µg/L), CD1 (8µg/L), CD4 (12µg/L) and CD5 (17µg/L) in October 2014. Ammonia concentrations in samples from P2B/WB50 and QE3 and CD4 were above the LOR on several sampling occasions. Concentrations in samples from CD5 were below the LOR except for two spikes recorded in July (11µg/L) and October 2014 (17µg/L).
- Chlorophyll a concentrations were significantly higher ($p < 0.05$) at QE3 and P2B/WB50 (means of 0.9 to 2.6) than at all remaining sites (0.2 to 0.9µg/L) and were significantly higher ($p < 0.05$) during the wet season (means of 0.3 to 2.6µg/L) than during the dry season (means of 0.2 to 1.2µg/L)
- Chlorophyll a concentrations at P5/MH30 during preliminary monitoring were also slightly elevated (1.8µg/L) compared to during the baseline monitoring period and parallel the concurrent elevation in TSS for this period
- Seasonal differences were also found when chlorophyll a concentrations were examined in both summer and winter in 2008 in two Port Curtis waterways: Calliope River and Graham's Creek (Melville et al. 2009)
- Spikes in NO_x were observed in samples from CD4 (25µg/L) and CD5 (58µg/L) in July 2014, CD2 in March 2015 (34µg/L), and QE3 in April 2015 (20µg/L).

4.8.12 Metals and metalloids

Mean seasonal monthly sample results for total metals/metalloids are outlined in Table 4.27 and Table 4.28. Mean seasonal monthly sample results for dissolved metals/metalloids are outlined in Table 4.29 and Table 4.30. Monthly sample results for each monitoring site are plotted in Appendix B Section 3.5.4.

Table 4.27 Seasonal total metal/metalloids concentrations at monitoring sites (June 2014 to June 2015)

Metal (µg/L)	Statistic	QE3		P2B/ WB50		P5/MH10		CD1		CD2		CD3		CD4		CD5		WQO % of species protection
		Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	
Aluminium	Mean	375	595	1,088	787	241	358	77	47	119	169	254	162	24	31	20	29	2.1 (99%)
	se	± 65	± 184	± 382	± 155	± 65	± 118	± 43	± 7	± 46	± 41	± 111	± 28	± 8	± 4	± 6	± 8	24 (95%)
	50 th %ile	375	530	800	805	190	295	54	41	79	168	120	145	24	30	13	26	
Arsenic	Mean	1.3	1.1	1.6	1.2	1.3	1.3	1.6	1.2	1.4	1.2	1.5	1.3	1.6	1.4	1.6	1.9	-
	se	± 0.3	± 0.1	± 0.2	± 0.1	± 0.1	± 0.1	± 0.1	± 0.1	± 0.1	± 0.1	± 0.1	± 0.1	± 0.1	± 0.1	± 0.1	± 0.5	
	50 th %ile	1.3	1.2	1.6	1.2	1.4	1.3	1.5	1.2	1.5	1.2	1.6	1.3	1.5	1.3	1.6	1.4	
Chromium	Mean	1	< 1	2	1	2	< 1	2	< 1	2	< 1	2	< 1	2	< 1	2	< 1	7.7 (99%) (III)
	se	± 0	-	± 0	± 0	± 0	-	± 0	-	± 0	-	± 0	-	± 0	-	± 0	-	0.14 (99%)(VI)
	50 th %ile	1	< 1	2	< 1	2	< 1	2	< 1	2	< 1	2	< 1	2	< 1	2	< 1	27.4 (95%) (III) 4.4 (95%) (VI)
Cobalt	Mean	0.3	0.4	0.4	0.3	< 0.1	0.2	< 0.1	< 0.1	< 0.1	< 0.1	0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.005 (99%)
	se	± 0.0	± 0.1	± 0.1	± 0.1	-	± 0.1	-	-	-	-	± 0.0	-	-	-	-	-	1 (95%)
	50 th %ile	0.3	0.4	0.3	0.4	< 0.1	0.2	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	
Copper	Mean	0.9	2.3	1.5	1.5	0.6	0.9	0.3	0.3	0.4	0.6	0.4	0.5	0.2	0.5	0.5	0.3	0.3 (99%)
	se	± 0.0	± 0.8	± 0.3	± 0.2	± 0.1	± 0.2	± 0.0	± 0.1	± 0.1	± 0.1	± 0.1	± 0.1	± 0.0	± 0.2	± 0.2	± 0.0	1.3 (95%)
	50 th %ile	0.9	1.7	1.5	1.5	0.6	1.0	0.3	0.3	0.4	0.6	0.4	0.5	0.3	0.3	0.3	0.3	
Iron	Mean	325	558	964	638	224	319	72	50	104	158	228	127	23	33	18	33	-
	se	± 45	± 178	± 337	± 138	± 61	± 103	± 35	± 14	± 36	± 43	± 100	± 21	± 6	± 6	± 5	± 9	
	50 th %ile	325	550	700	710	180	295	42	39	76	160	100	119	21	32	16	30	
Lead	Mean	0.1	0.2	0.3	0.2	0.1	0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.1	0.1	< 0.1	0.1	< 0.1	< 0.1	2.2 (99%)
	se	± 0.1	± 0.1	± 0.1	± 0.1	± 0.0	± 0.1	-	-	-	-	± 0.0	± 0.0	-	± 0.0	-	-	4.4 (95%)
	50 th %ile	0.1	0.2	0.2	0.2	< 0.1	0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.1	< 0.1	< 0.1	< 0.1	< 0.1	

Metal (µg/L)	Statistic	QE3		P2B/ WB50		P5/MH10		CD1		CD2		CD3		CD4		CD5		WQO % of species protection
		Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	
Manganese	Mean	13	20	21	19	6	11	2	2	2	4	5	5	1	2	1	2	-
	se	± 1	± 4	± 5	± 3	± 1	± 3	± 1	± 0	± 1	± 1	± 1	± 0	± 0	± 0	± 0	± 0	
	50 th %ile	13	19	20	19	6	12	1	2	2	4	3	5	1	2	1	2	
Molybdenum	Mean	9.8	9.7	11.4	10.5	9.7	10.3	10.8	10.7	11.3	10.9	13.1	11.1	12.4	11.1	12.2	11.1	-
	se	± 0	± 1	± 1	± 1	± 0	± 1	± 1	± 1	± 1	± 0	± 3	± 1	± 2	± 1	± 2	± 1	
	50 th %ile	9.8	9.9	11	10.5	10	11	11	10.5	10	11	11	11.5	11	11	11	11	
Nickel	Mean	1.0	1.2	1.0	0.9	0.4	0.6	0.3	0.3	0.3	0.5	0.3	0.6	< 0.2	0.3	< 0.2	0.3	7 (99%)
	se	± 0.1	± 0.1	± 0.2	± 0.1	± 0.0	± 0.1	± 0.1	± 0.0	± 0.0	± 0.1	± 0.1	± 0.2	-	± 0.0	-	± 0.0	70 (95%)
	50 th %ile	1.0	1.3	0.9	1.0	0.4	0.5	0.2	0.3	0.2	0.4	0.3	0.4	< 0.2	0.3	< 0.2	0.3	
Vanadium	Mean	2.7	3.9	3.5	3.9	2.1	2.73	1.7	1.9	1.7	2.1	1.9	2.3	1.7	2.0	1.7	2.0	50 (99%)
	se	± 0.2	± 0.4	± 0.6	± 0.5	± 0.2	± 0.4	± 0.2	± 0.2	± 0.2	± 0.1	± 0.2	± 0.2	± 0.2	± 0.1	± 0.2	± 0.1	100 (95%)
	50 th %ile	2.7	3.6	3.7	4.0	2.4	2.7	1.8	1.9	1.7	2.2	1.9	2.3	1.8	2.1	1.9	2.1	
Zinc	Mean	1.6	4.4	4.6	4.9	2.5	6.9	1.9	3.3	2.4	3.8	2.3	4.5	2.4	5.0	2.3	3.2	7 (99%)
	se	± 0.1	± 1.0	± 0.8	± 1.1	± 0.4	± 2.3	± 0.4	± 0.8	± 0.6	± 1.0	± 0.7	± 1.1	± 0.6	± 2.0	± 0.4	± 0.7	15 (95%)
	50 th %ile	1.6	4.4	4.6	4.8	2.2	5.1	1.7	3.4	2.1	3.7	2.0	4.3	1.7	3.1	2.2	3.0	

Table notes:

1. All sites n = 6 (wet) and 7 (dry) except QE3 n = 2 (dry) and 4 (wet)
2. For indicative biological or toxicological risks refer dissolved metals/metalloids results in Table 4.29
3. WQOs sourced from ANZECC (2000a) and EHP (2014b)
4. Results recorded <LOR were half LOR for statistical calculations. For full monthly results refer Appendix B Table 6.28 to Table 6.45
5. Monthly LORs for Chromium varied in dry season (refer Appendix B Table 6.13 for full monthly results)

Table 4.28 Total metals/metalloids results all sample concentrations below LOR

Metal (µg/L)	QE3		P2B/ WB50		P5/MH10		CD1		CD2		CD3		CD4		CD5		WQO % of species protection
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	
Cadmium	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.7 (99%) 5.5 (95%)
Gallium	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	-
Mercury	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.1 (99%) 0.4 (95%)
Selenium	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	-
Silver	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	0.8 (99%) 1.4 (95%)

Table notes:

WQOs sourced from ANZECC (2000a) and EHP (2014b)

Table 4.29 Seasonal dissolved metal concentrations at monitoring sites (June 2014 to June 2015)

Metal (µg/L)	Statistic	QE3		P2B/ WB50		P5/MH10		CD1		CD2		CD3		CD4		CD5		WQO % of species protection
		Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	
Aluminium	Mean	< 5	< 5	< 5	7	< 5	6	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	2.1 (99%)
	se	-	-	-	± 2		± 1	-	-	-	-	-	-	-	-	-	-	24 (95%)
	50 th %ile	< 5	< 5	5.3	7.3	< 5	7.3	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	
	80 th %ile	< 5	6.0	8.1	8	5	8	5.1	6.5	< 5	< 5	5.4	< 5	< 5	< 5	< 5	6.1	
	95 th %ile	< 5	6.0	9.4	11.8	8.5	8.5	6.7	10.6	6.1	6.1	7.3	11.9	5.4	6.6	5.1	7.2	
Arsenic	Mean	0.8	0.8	0.8	0.9	0.9	1.0	1.2	1.0	1.1	1.0	1.0	1.1	1.2	1.1	1.3	1.2	-
	se	± 0.1	± 0.1	± 0.1	± 0.1	± 0.1	± 0.1	± 0.1	± 0.0	± 0.1	± 0.0	± 0.1	± 0.1	± 0.1	± 0.1	± 0.1	± 0.1	
	50 th %ile	0.8	0.8	0.9	0.9	1.0	1.0	1.2	1.1	1.1	1.0	1.0	1.1	1.2	1.2	1.2	1.2	
	80 th %ile	0.9	0.9	0.9	1.0	1.0	1.1	1.4	1.1	1.2	1.1	1.2	1.1	1.3	1.2	1.4	1.3	
	95 th %ile	0.9	1.0	1.0	1.1	1.1	1.3	1.5	1.2	1.3	1.2	1.2	1.3	1.4	1.3	1.5	1.4	
Cobalt	Mean	0.12	0.16	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.005 (99%)
	se	±0.01	±0.02	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1 (95%)
	50 th %ile	0.12	0.15	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	
	80 th %ile	0.13	0.18	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	
	95 th %ile	0.13	0.20	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	
Copper	Mean	0.6	0.8	0.6	0.9	0.3	0.6	< 0.2	< 0.2	0.3	0.5	0.2	0.5	0.2	0.2	< 0.2	0.2	0.3 (99%)
	se	± 0.0	± 0.0	± 0.1	± 0.1	± 0.1	± 0.1	-	-	± 0.1	± 0.1	± 0.0	± 0.2	± 0.1	± 0.1	-	± 0.1	1.3 (95%)
	50 th %ile	0.6	0.8	0.6	0.9	0.4	0.7	< 0.2	< 0.2	0.2	0.4	0.2	0.4	< 0.2	0.2	0.2	0.2	
	80 th %ile	0.6	0.9	0.7	1.0	0.4	0.8	< 0.2	0.3	0.3	0.7	0.3	0.6	0.3	0.3	0.3	0.3	
	95 th %ile	0.6	0.9	0.9	1.1	0.5	0.9	< 0.2	0.3	0.7	0.7	0.4	1.1	0.4	0.5	0.4	0.5	

Metal (µg/L)	Statistic	QE3		P2B/ WB50		P5/MH10		CD1		CD2		CD3		CD4		CD5		WQO % of species protection
		Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	
Iron	Mean	< 5	5	9	7	< 5	8	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	-
	se	-	± 2	± 5	± 2	-	± 3	-	-	-	-	-	-	-	-	-	-	
	50 th %ile	< 5	5.3	< 5	5.6	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	
	80 th %ile	< 5	8.2	10.9	10	2.50	17.00	< 5	8.8	< 5	8.6	< 5	< 5	< 5	< 5	< 5	< 5	
	95 th %ile	< 5	8.3	29.1	12.3	8.4	18.5	9.1	9.7	7.7	9.5	7.6	8.1	7.1	9.6	6.5	7.7	
Manganese	Mean	5.6	10	2.4	4.7	2.2	3.5	< 0.6	0.9	< 0.6	< 0.6	0.7	1.2	< 0.6	0.8	< 0.6	0.7	-
	se	± 1.4	± 2	± 0.6	± 2.5	± 0.6	± 1.3	-	± 0.1	-	-	± 0.2	± 0.2	-	± 0.1	-	± 0.1	
	50 th %ile	5.6	9.1	2.5	2.6	1.4	2.3	< 0.6	0.9	< 0.6	< 0.6	0.3	1.2	< 0.6	0.8	< 0.6	0.7	
	80 th %ile	6.4	13.4	3.8	4.3	3.0	3.4	0.5	1.1	0.3	0.7	1.1	1.6	0.3	1.0	0.6	1.0	
	95 th %ile	6.8	14.4	4.6	13.8	4.4	8.4	0.6	1.3	0.3	0.9	1.4	1.7	0.5	1.2	0.7	1.1	
Molybdenum	Mean	9.9	9.6	10.5	10.2	10	10.3	9.9	10.3	10.2	10.6	10.5	10.6	10.2	10.5	10.6	10.6	-
	se	± 0	± 1	± 1	± 1	± 0	± 1	± 0	± 0	± 0	± 1	± 0	± 1	± 0	± 0	± 0	± 0	
	50 th %ile	9.9	9.6	11	10.5	9.9	10.3	9.8	10.4	10	10.5	10	11	10	10	11	10	
	80 th %ile	9.9	11.4	11.8	12	11	11	10.8	11	11	12	11	12	11	12	11	12	
	95 th %ile	9.9	11.9	12	12.8	11	12.5	11	11.8	11	12	11.7	12	11	12	11.7	12	
Nickel	Mean	0.7	0.8	0.4	0.5	0.3	0.4	< 0.2	0.3	0.2	0.3	0.2	0.3	< 0.2	0.3	< 0.2	0.3	-
	se	± 0.0	± 0.0	± 0.0	± 0.0	± 0.0	± 0.0	-	± 0.0	± 0.0	± 0.0	± 0.0	± 0.0	-	± 0.0	-	± 0.1	
	50 th %ile	0.7	0.8	0.4	0.5	0.3	0.4	< 0.2	0.3	0.2	0.3	0.2	0.3	< 0.2	0.3	< 0.2	0.3	
	80 th %ile	0.7	0.9	0.5	0.6	0.3	0.4	0.2	0.3	0.2	0.4	0.2	0.4	0.2	0.4	0.2	0.4	
	95 th %ile	0.7	0.9	0.5	0.7	0.4	0.4	0.2	0.3	0.3	0.4	0.3	0.5	0.2	0.4	0.2	0.5	
Selenium	Mean	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	-
	se	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
	50 th %ile	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	
	80 th %ile	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	
	95 th %ile	< 0.5	< 0.5	< 0.5	< 0.5	1.11	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	

Metal (µg/L)	Statistic	QE3		P2B/ WB50		P5/MH10		CD1		CD2		CD3		CD4		CD5		WQO % of species protection
		Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	
Vanadium	Mean	1.9	2.7	1.8	2.6	1.7	2.3	1.6	1.8	1.6	2.0	1.5	2.0	1.7	2.0	1.8	2.0	50 (99%)
	se	± 0.0	± 0.2	± 0.2	± 0.3	± 0.2	± 0.3	± 0.2	± 0.2	± 0.2	± 0.1	± 0.2	± 0.2	± 0.2	± 0.1	± 0.2	± 0.1	100 (95%)
	50 th %ile	1.9	2.6	1.8	2.8	1.6	2.4	1.8	1.8	1.6	2.1	1.4	2.1	1.7	2.1	1.9	2.1	
	80 th %ile	1.9	3.0	2.1	3.2	2.0	2.8	2.0	1.9	1.9	2.1	1.7	2.4	1.9	2.2	2.0	2.3	
	95 th %ile	1.9	3.1	2.5	3.2	2.7	2.9	2.4	2.6	2.3	2.3	2.1	2.4	2.4	2.2	2.4	2.3	
Zinc	Mean	0.7	2.8	6.7	4.5	2.4	4.0	1.5	3.1	1.8	4.0	1.7	7.0	3.3	3.8	3.7	3.7	7 (99%)
	se	± 0.4	± 1.1	± 4.3	± 1.3	± 1.2	± 1.0	± 0.6	± 0.7	± 0.7	± 1.5	± 0.7	± 3.0	± 1.5	± 0.6	± 2.0	± 0.8	15 (95%)
	50 th %ile	0.7	2.1	2.3	3.6	1.4	3.9	1.0	2.9	1.5	3.1	1.1	3.8	1.2	3.7	1.5	4.2	
	80 th %ile	0.9	4.0	5.4	7.1	3.9	5.5	2.3	4.5	2.7	4.0	2.8	13.0	4.8	5.1	4.6	5.0	
	95 th %ile	1.1	5.4	24.1	8.1	6.6	7.2	3.8	5.3	4.3	9.3	4.7	17.5	9.2	5.7	12.1	5.6	

Table notes:

1. All sites n = 6 (wet) and 7 (dry) except QE3 n = 2 (dry) and 4 (wet)
2. Zones which are designated HEV or SD are proposed to meet the AWQG trigger value for 99% level of species protection for metals/metalloids and other toxicants, while MD zones are proposed to meet the AWQG trigger value for 95% level of species protection (ANZECC/ARMCANZ 2000a)
3. WQOs sourced from ANZECC (2000a) and EHP (2014b)

Table 4.30 Dissolved metals/metalloids results all below LOR

Metal	QE3		P2B/WB50		P5/MH10		CD1		CD2		CD3		CD4		CD5		WQO (level of protection: % species)
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	
Cadmium	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.7 (99%) 5.5 (95%)
Chromium	< 0.1	< 1 < 3 < 4	< 0.1	< 1 < 3 < 4	< 0.1	< 1 < 3 < 4	< 0.1	< 1 < 3 < 4	< 0.1	< 1 < 3 < 4	< 0.1	< 1 < 3 < 4	< 0.1	< 1 < 3 < 4	< 0.1	< 1 < 3 < 4	7.7 (99%) (III) 0.14 (99%) (VI) 27.4 (95%) (III) 4.4 (95%) (VI)
Gallium	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	-
Lead	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	2.2 (99%) 4.4 (95%)
Mercury	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.1 (99%) 0.4 (95%)
Silver	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	0.8 (99%) 1.4 (95%)

Table notes:

1. Zones which are designated HEV or SD are proposed to meet the AWQG trigger value for 99% level of species protection for metals/metalloids and other toxicants, while MD zones are proposed to meet the AWQG trigger value for 95% level of species protection (ANZECC/ARMCANZ 2000a)
2. WQOs source from ANZECC (2000a) and EHP (2014b)
3. Monthly LORs for Chromium varied in dry season (refer Appendix B Table 6.13 for full monthly results)

The below trends were observed from monthly sampling and analysis of metals/metalloids concentrations at each monitoring site:

- The following metals/metalloids were found to be below the LOR in samples from all sites on the majority of occasions:
 - Total and dissolved cadmium (LOR < 0.1µg/L)
 - Total and dissolved chromium (LOR < 1µg/L)
 - Total and dissolved gallium (LOR < 0.5µg/L)
 - Total and dissolved mercury (LOR < 0.1µg/L)
 - Total and dissolved selenium (LOR < 0.5µg/L)
 - Total and dissolved silver (LOR < 0.5µg/L)
- Metal concentrations measured at P5/MH10 during preliminary monitoring period were overall similar to those recorded during the baseline monitoring period (refer Table 6.3 in Appendix B).
- Statistically significant seasonal variation in metal concentrations was not evident for most metals/metalloids. However, total and dissolved copper, nickel and vanadium, and dissolved manganese were significantly higher in samples collected during the wet season.
- Overall there was a general trend for the majority of total and dissolved metals/metalloids in samples to be more elevated in sampling months after rain events. This has been a historical finding for Port Curtis with elevated total metals/metalloids in the post January 2011 and 2013 flood events (VE 2013a). Elevated metals/metalloids were also recorded in other catchment areas in Queensland following the January 2011 floods (DERM 2011; VE 2012a).
- A number of total metals/metalloids detected in samples were significantly correlated with TSS concentrations, indicating that in areas where TSS was higher (such as at the inshore sites of QE3 and P2B/WB50), metal concentrations were also higher. This included aluminium, copper, iron, lead, manganese and nickel. Similar relationships have been identified previously in Port Curtis with increased turbidity and TSS concentrations highly associated with increased total aluminium, iron, cobalt and manganese (VE 2012a), indicating metals/metalloids in the water column are predominately bound to particulates.
- For the detectable metals/metalloids, total concentrations were generally considerably higher than dissolved concentrations. This suggests that most metals/metalloids were predominantly bound to particulates, as supported by the linear regressions between TSS and total metal concentrations. Certain metals/metalloids are known to readily adsorb onto iron hydroxides and colloidal particles (Salomons et al. 1995).
- Significant spatial variation was also evident for a number of metals/metalloids. Concentrations of total aluminium, lead, iron and vanadium, and total and dissolved cobalt, copper, nickel, manganese were significantly higher in samples from P2B/WB50 and QE3 than in those samples from offshore sites. Decreasing metal concentrations from lower estuary and enclosed coastal waters to open coastal waters have been a consistent historical finding for Port Curtis (Storey et al. 2007; VE 2011a; VE 2013b).
- WQOs for metals/metalloids in Port Curtis have been set by EHP (2014b), with the majority of these originally established in the National Water Quality Management Strategy (ANZECC/ARMCANZ 2000a). EHP has designated zones in Port Curtis into different levels of ecosystem protection, including 'high ecological value' (HEV), 'slightly disturbed' (SD), 'moderately disturbed' (MD) and 'highly disturbed' (HD). Zones which are designated HEV or SD are proposed to meet the AWQG trigger value for 99% level of species protection for metals/metalloids and other toxicants, while MD zones are proposed to meet the AWQG trigger value for 95% level of species protection (ANZECC/ARMCANZ 2000a). Previously, the 95% AWQG trigger value has been applied to all inshore sites, whereas the 99% AWQG trigger value was considered more appropriate for reference or offshore sites.

- Of the current monitoring sites, QE3 (The Narrows area) has been classified as HEV/SD, and thus 99% AWQG trigger values for metals/metalloids are applicable. Zones in which sites P2B/WB50, P5/MH10, CD1 and CD3 are located are classified as MD, indicating that the 95% AWQG are applicable. Sites CD2, CD4 and CD5 are located in coastal waters outside Gladstone Harbour, which are classified as slightly to moderately disturbed (SMD), and thus the 95% AWQG trigger values are considered most appropriate for use.
- Due to the use of more stringent guidelines (e.g. use of 99% rather than 95% AWQG trigger value) at QE3, a number of water quality samples collected for the Project at this site were above the WQOs assigned to these waters, including concentrations of total aluminium in both the wet season and dry season, and total and dissolved cobalt and copper in both seasons.
- For the remaining sites where the 95% AWQG trigger value has been designated for use, total aluminium sample concentrations from all sites were above the WQO during both wet and dry seasons, with the exception of samples from CD4 and CD5 which exceeded during the wet season only. However, dissolved aluminium sample concentrations remained well below the WQO at each site.
- Additionally in samples from site P2B/WB50, concentrations of total copper in both the wet and dry season were above the WQO, with dissolved concentrations remaining below the WQO. Although AWQG exceedances of certain total metals/metalloids in Port Curtis have been recorded previously, the majority of dissolved and therefore potentially bioavailable metals/metalloids, have generally been below AWQG (VE 2012a; VE 2013b; VE 2013c) and are therefore not current contaminants of concern in terms of biological or toxicological risk for this Project.

4.8.13 Organics

Organic contaminants are those containing carbon and include herbicides, pesticides, oil and grease, which encompass petroleum hydrocarbons and polycyclic aromatic hydrocarbons (PAH). Potential sources of herbicides and pesticides are thought to be minimal in Port Curtis due to very few agricultural and farming sources within surrounding catchments. Nonetheless, increased industrial and anthropogenic activities indirectly associated with Port development may contribute to an increase in some organic compounds in the water column.

Mean seasonal monthly sample results for organic compounds are outlined in Table 4.31 and include Total Recoverable Hydrocarbon (TRH) and Benzene, Toluene, Ethyl Benzene, Xylenes (BTEX), while Table 4.32 contains PAHs. Due to the exhaustive list of pesticides analysed, results have been included in Appendix C.

Table 4.31 Total Recoverable Hydrocarbons and BTEX sample concentrations

Parameter (µg/L)		QE3	P2B/WB50	P5/MH10	CD1	CD2	CD3	CD4	CD5
TRH	TRH C6-C10	< 25	< 25	< 25	< 25	< 25	< 25	< 25	< 25
	TRH >C10-C16	< 50	< 50	< 50	< 50	< 50	< 50	< 50	< 50
	TRH >C16-C34	< 100	< 100	< 100	< 100	< 100	< 100	< 100	< 100
	TRH >C34-C40	< 100	< 100	< 100	< 100	< 100	< 100	< 100	< 100
BTEX	Benzene	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
	Toluene	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2
	Ethyl Benzene	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2
	m+p xylenes	< 4	< 4	< 4	< 4	< 4	< 4	< 4	< 4
	o-xylene	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2
	Total BTEX	< 11	< 11	< 11	< 11	< 11	< 11	< 11	< 11

Table notes:

1. N = 1
2. Monthly sampling for organics undertaken during July 2014, October 2014, January 2015 and April 2015

Table 4.32 Polycyclic Aromatic Hydrocarbon sample concentrations

Parameter (µg/L)	QE3	P2B/WB50	P5/MH10	CD1	CD2	CD3	CD4	CD5
Naphthalene	< 4	< 4	< 4	< 4	< 4	< 4	< 4	< 4
Acenaphthylene	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
Acenaphthene	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
Fluorene	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
Phenanthrene	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
Anthracene	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
Fluoranthene	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
Pyrene	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
Benz(a)anthracene	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
Chrysene	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
Benzo(b)&(k)fluoranthene	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
Benzo(a)pyrene	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2
Indeno(1,2,3-cd)pyrene	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
Dibenz(a,h)anthracene	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
Benzo(g,h,i)perylene	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
Coronene*	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
Benzo(e)pyrene*	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
Perylene*	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1

Table notes:

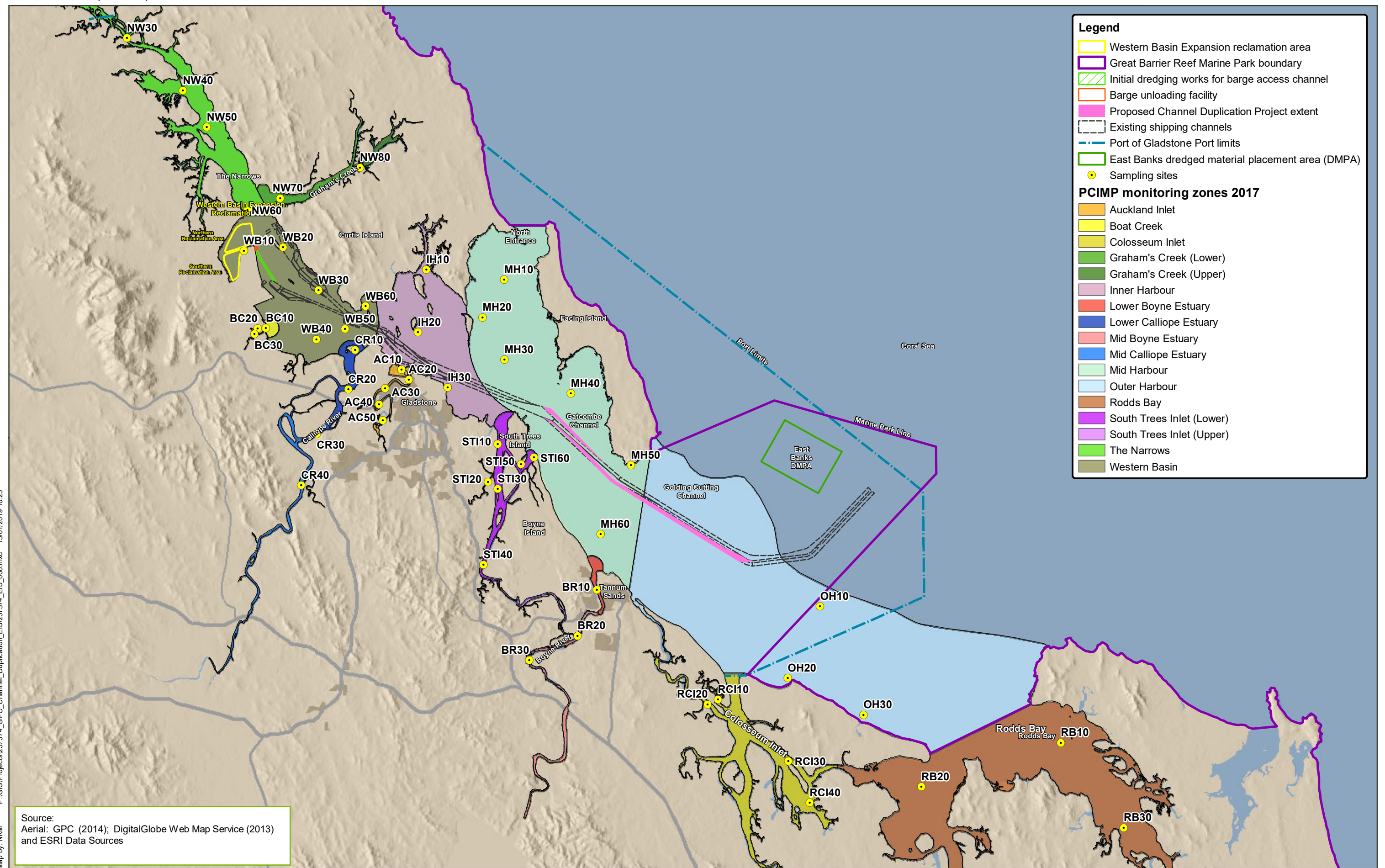
1. N = 1
2. Monthly sampling for organics undertaken during July 2014, October 2014, January 2015 and April 2015

4.9 Supplementary water quality monitoring

Water quality investigations that were being undertaken simultaneously during the Project EIS baseline period are outlined in Table 4.33.

Table 4.33 Supplementary water quality investigations

Investigation scope	Author	Year
Quarterly water quality monitoring at 54 sites across Port Curtis, including sites at The Narrows, Inner Harbour, Boat Creek, Inner Harbour/Calliope, Mid-Harbour, Auckland Creek, Inner Harbour/South Trees, Boyne/Tannum, Colosseum Inlet (estuarine reference sites), Rodds Bay (estuarine reference sites), and open coastal waters reference sites (refer Figure 4.7)	PCIMP	2014 to ongoing
Water quality monitoring for Long Term Monitoring and Management for Sea Disposal of Maintenance Dredge Material at sites within the Inner Harbour, Mid Harbour, Graham's Creek, East Banks DMPA, and at deep water seagrass meadows	GPC	2014 to ongoing
Gladstone Healthy Harbour Partnership - Health Report Card	GPC	2014 ongoing



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Map by NKM



0 2,550 5,100 Metres

Date: 15/01/2019 Version: 8 Job No: 237374
Coordinate system: GDA_1994_MGA_Zone_56

Gatcombe and Golding Cutting Channel Duplication Project

Figure 4.7: PCIMP water quality zones and sampling sites

4.9.1 PCIMP monitoring 2013 to 2017

The PCIMP is a partnership of Gladstone industries and organisations, which has been undertaking monitoring of the coastal and marine environments of Port Curtis and surrounds since 2005. The program was redesigned in 2012 into its current format of quarterly water quality monitoring, biannual oyster deployments and annual sediment quality surveys.

In 2017, quarterly water quality monitoring was undertaken across 15 sampling zones at 54 sites across Port Curtis, from The Narrows in the north to Rodds Bay in the south (refer Figure 4.7) between March and November 2017. Sites align with the water quality zones outlined in 'Curtis Island, Calliope River and Boyne River Basins Environmental Values and Water Quality Objectives', with varying zone and seasonal WQO applicable to the water quality data (EHP 2014). SQG are applicable to sediment metal concentrations (Simpson et al 2013).

The monitoring program included:

- Quarterly measurement of physical and chemical parameters and nutrient, fluoride, metal and metalloid concentrations in water samples (March, June, August and November 2017)
- Annual measurement of metal, metalloid and nutrient concentration and particle size distribution in sediment samples (June 2017)
- Biannual oyster sampler deployment (in March 2017 and August 2017) and collection after three months (in June 2017 and November 2017) to measure bioaccumulation of metals, metalloids and fluoride.

A summary of water quality results and seasonal variation for 2017 are provided below.

4.9.1.1 Physiochemical parameters

Seasonal variation in water physicochemistry was observed, with significantly higher temperatures, turbidity and TSS and significantly lower DO during the wet season surveys of March and November 2017 (VE 2018). Higher turbidity and TSS during the wet season was likely attributable to sampling during spring tides, freshwater flow from recent rainfall and increased wind conditions (VE 2018).

Across Port Curtis, spatial variation in physiochemical parameters was seen, with Boat Creek distinct from all other zones due to its significantly higher turbidity and TSS concentrations, which exceeded applicable guidelines throughout the year.

Typical estuarine characteristics of lower pH and DO, higher turbidity and TSS were exhibited in other inner Port Curtis areas, including The Narrows, Graham's Creek, Western Basin, Calliope River, Auckland Creek and South Trees Inlet.

4.9.1.2 Water nutrients and chlorophyll a

Significantly higher concentrations of all nutrients except orthophosphate were observed during the wet season and thus significantly higher chlorophyll a concentrations were also recorded. Increased inputs from the catchments during periods of higher precipitation are most likely to have caused higher nutrient concentrations in the wet season. Stormwater runoff can increase the amount of organic matter that enters the aquatic system and decomposes, releasing available nutrients.

The more open water areas of the Western Basin, Graham's Creek, Inner Harbour, Mid Harbour, Outer Harbour, Colosseum Inlet and Rodds Bay, contained lower nutrient concentrations than the creeks and rivers, although occasional WQO exceedances were recorded. The spatial pattern of more elevated nutrients inshore, with a decreasing gradient towards the oceanic environment has been previously recorded in numerous surveys within Port Curtis.

4.9.1.3 Water metal(loid)s

During the wet season surveys concentrations of seven total and dissolved metal(loid)s (i.e. aluminium, arsenic, copper, iron, molybdenum, vanadium and zinc), in addition to two total metal(loid)s (i.e. manganese and nickel) were significantly higher, most likely due to the increased catchment inputs.

A spatial pattern of more elevated concentrations inshore, with decreasing concentrations towards the oceanic zones, of total metal(loid)s was evident. Boat Creek contained significantly higher concentrations of nine (out of 17 analysed) total metal(loid)s than all other zones.

In addition to catchment inputs, elevated concentrations of total metal(loid)s within the inner Port Curtis zones, particularly Boat Creek, were likely to be attributable to the higher suspended solids in the water column.

4.9.1.4 Oysters

During the March to June 2017 deployment period, higher accumulation (or lower depuration) for 10 of the metal(loid)s was recorded (i.e. arsenic, cadmium, cobalt, copper, gallium, lead, mercury, molybdenum, nickel and silver), while higher accumulation was evident for two metal(loid)s during the August to November deployment (i.e. manganese and vanadium). Higher accumulation during the March to June deployment period may be due to the considerably higher rainfall (and resulting runoff) during this time in comparison with the August to November period.

4.9.1.5 Sediments

Sediment metal(loid)s and nutrients during the 2017 survey exhibited a spatial pattern of elevated inshore concentrations that decreased towards the oceanic zones. Concentrations of the majority of metal(loid)s and nutrients were significantly higher in Auckland Creek sediments than at all other zones.

The lowest proportions of fine sediment particles were recorded in the mid and outer Port Curtis zones (i.e. Mid Harbour, Outer Harbour, Rodds Bay and Colosseum Inlet) where the lowest sediment and water metal and nutrient concentrations were recorded, while intermediate fine sediment content, metal(loid)s and nutrients were evident at the inner Port Curtis zones.

For the metal(loid)s where SQG are available, no exceedances were recorded.

4.9.1.6 2017 Summary

Significant temporal variation was evident for all physicochemical parameters during 2017. The multivariate and univariate analyses indicated that water physicochemistry differed overall between the dry season (June and August) and the wet season (March and November), with temperature, turbidity, TSS and DO being the driving factors causing the variation between seasons (VE 2018).

Based on physiochemical properties, metal concentrations, nutrient concentrations and oyster accumulation rates, the 2017 results indicated Port Curtis monitoring zones could be grouped. Due to its significantly higher turbidity, TSS and elevated environmental parameters, Boat Creek was distinct from all other zones. Turbidity exceeded the relevant WQO during March and November, with TSS exceeding QWQG during all four surveys (VE 2018).

The next greatest water and oyster metal concentrations were seen in the inner Port Curtis zones of The Narrows, Graham's Creek, and Auckland Creek. Other inner Port Curtis zones (i.e. Western Basin, Inner Harbour, Calliope River and South Trees Inlet) were similar to each other with generally intermediate concentrations of sediment and water metal(loid)s and nutrients (VE 2018).

The lowest fine particle content and lowest water and sediment metal and nutrient concentrations were seen in the mid to outer Port Curtis zones of Mid Harbour, Outer Harbour and Rodds Bay. Sandy sediments are less likely to bind metal(loid)s and nutrients and be suspended into the water column, resulting in lower metal and nutrient concentrations overall (VE 2018).

4.9.1.7 Monitoring from late 2012 to 2017

Results from 2012 to 2017 indicate that the greatest variations in physiochemical, water metal and nutrient concentration data were associated with the monitoring undertaken in February 2013 (2012/2013 wet season) and March 2014 (2013/2014 wet season). A designated 1 in 2,000 year flood event occurred during the 2012/2013 wet season, with almost the annual average rainfall in Gladstone falling within a four day period after the passing of ex-Tropical Cyclone Oswald. Almost 350mm of rain was recorded during the March 2014 survey (2013/2014 wet season). Significantly lower conductivity and higher turbidity were recorded during these seasons, as well as significantly higher concentrations of several metal(loid)s and nutrients (VE 2018).

Boat Creek remained distinct from all other zones, following statistical grouping of the monitoring zones using data collected from 2012 to 2017, due to its consistently different physicochemical, water and sediment characteristics. Other zone groupings were similar to the 2017 results, however the Calliope and Boyne Rivers formed their own separate group. The significant rainfall events of 2013 and 2014 were highly influential in separating these two zones from the other monitoring zones.

The variation between wet and dry seasons over the past six years (2012 to 2017) of monitoring were similar to the parameters causing variation in 2017. Significantly higher temperatures, turbidity and TSS, and significantly lower DO were recorded during the wet season surveys in comparison with dry season surveys. The 2017 dry season was comparable to the four previous dry seasons. Within the wet season, the surveys conducted in 2017 remained similar to those conducted from late 2014 to 2016, with the 2012/2013 and 2013/2014 wet seasons remaining the most dissimilar

Any changes in physicochemical parameters, water and sediment quality and oyster accumulation rates that have occurred over the past five years (2013 to 2017) in the PCIMP monitoring zones could be considered minor in comparison with the variation introduced by the two significant rainfall event monitoring periods during the 2012/2013 and 2013/2014 wet seasons.

4.9.2 Gladstone Healthy Harbour Report Card

The GHHP is a collaboration of 26 representatives from industry, research, community, Indigenous and Government stakeholder groups. The GHHP has been established to annually report on the health of the Gladstone Harbour (GHHP 2017a; GHHP 2017b).

The Gladstone Harbour Report Card 2017 presents results of monitoring conducted between 1 July 2016 and 30 June 2017 for four components; environmental, social, cultural and economic. The Gladstone Harbour Report Card 2017 reports on the environmental health of 13 zones in and around Gladstone Harbour and the overall environmental, social, cultural and economic health of Gladstone Harbour (GHHP 2017a).

Monitoring data were reviewed and key indicators pertaining to the four aforementioned components were scored on a scale from 0.00 to 1.00 and graded according to the following:

- Score of 0.85 to 1.00: Very good (**A**)
- Score of 0.65 to 0.84: Good (**B**)
- Score of 0.50 to 0.64: Satisfactory (**C**)
- Score of 0.25 to 0.49: Poor (**D**)
- Score of 0.00 to 0.24: Very poor (**E**).

The Gladstone Harbour Report Card 2017 presented the following scores for the four components:

- Environmental: 0.60, Satisfactory (C)
- Social: 0.66, Good (B)
- Cultural: 0.62, Satisfactory (C)
- Economic: 0.74 Good (B).

Compared to the 2016 report card, the social, cultural and economic grades have remained constant and the component scores the same or very similar to the 2016 score (refer Table 4.34.) Direct comparison with the 2016 results for environment are not possible due to the addition of an indicator for mud crabs and a new sub-indicator for coral 'coral cover change' in the environmental component. Overall scores for each of the four components from the pilot study in 2014 to the 2017 Report Card are presented in Table 4.34.

Table 4.34 Overall scores for each of the four components of Gladstone Harbour health from 2014 to 2017

Component	2017	2016	2015	2014 (pilot)*
Environmental	0.60 (C)	0.50 (C)	0.59 (C)	0.58 (C)
Social	0.66 (B)	0.66 (B)	0.64 (C)	0.62 (C)
Cultural	0.62 (C)	0.62 (C)	0.65 (B)	Not measured
Economic	0.74 (B)	0.75 (B)	0.77 (B)	0.82 (B)

Table note:

* Pilot study indicative results only

The summary below of the key findings of the Gladstone Harbour Report Card 2017 focuses on the environmental health of Gladstone Harbour.

Monitoring conducted to assess the environmental health of Gladstone Harbour collected data pertaining to three key indicator groups including water and sediment quality, habitats (including coral and seagrass health), and fish and crabs. The scores attributed to each key indicator group include:

- Water and sediment quality: 0.87, Very good (A)
 - Water quality received a score of 0.78 (Good [B])
 - Sediment quality received a score of 0.95 (Very good [A])
- Habitats: 0.33, Poor (D)
 - Seagrass health received a score of 0.39 (Poor [D])
 - Coral health received a score of 0.28 (Poor [D])
- Fish and crabs: 0.63, Satisfactory (C)
 - Fish recruitment received a score of 0.71 (Good [B])
 - Mud crabs received a score of 0.55 (Satisfactory [C]).

4.9.2.1 Water quality

Using a data-sharing agreement, PCIMP provided GHHP with water quality data for calculating scores and grades for the 2015 to 2017 report cards. Data are based on samples collected from 50 sites across the 13 harbour zones. Eleven water quality parameters were assessed for the 2017 Gladstone Harbour Report Card. Details on methodology used to obtain water quality samples are detailed in the technical report (GHHP 2017a).

Scores for the water quality indicator have remained high since the first Gladstone Harbour Report Card in 2015, receiving a good score (B) in all years (refer Table 4.36). The overall water quality score improved from 0.72 in 2016 to 0.78 in 2017.

In 2017, water quality was relatively uniform across the harbour and all zones received good or very good scores (0.71 to 0.90) except Boat Creek (0.59) which received a satisfactory score (refer Table 4.35). The two zones with the highest scores were Graham Creek (0.88) and Outer Harbour (0.90). Improvements were observed for both turbidity and nutrients in most zones. In 2016, five zones had poor or very poor scores for nutrients compared to only two zones in 2017. As in 2015 and 2016, scores for dissolved metals were very good in all zones.

Table 4.35 Overall water quality indicator scores for Gladstone Harbour zones (2015 to 2017)

Water quality	Physio-chemical score	Nutrients score	Dissolved metals score	Zone score for 2017	Zone score for 2016	Zone score for 2015
1. The Narrows	0.76	0.44	0.93	0.71	0.68	0.82
2. Graham's Creek	0.99	0.69	0.94	0.88	0.75	0.86
3. Western Basin	0.74	0.64	0.93	0.77	0.70	0.82
4. Boat Creek	0.58	0.32	0.89	0.59	0.58	0.70
5. Inner Harbour	0.76	0.69	0.95	0.79	0.78	0.88
6. Calliope Estuary	0.68	0.70	0.94	0.77	0.71	0.86
7. Auckland Inlet	0.83	0.60	0.94	0.79	0.71	0.77
8. Mid Harbour	0.85	0.59	0.95	0.79	0.77	0.80
9. South Trees Inlet	0.91	0.68	0.95	0.84	0.79	0.85
10. Boyne Estuary	1.00	0.53	0.95	0.83	0.71	0.70
11. Outer Harbour	1.00	0.74	0.95	0.90	0.72	0.84
12. Colosseum Inlet	1.00	0.55	0.95	0.83	0.73	0.78
13. Rodds Bay	0.80	0.50	0.95	0.75	0.73	0.80

Source: GHHP (2017a)

4.9.2.2 Sediment quality

Similar to 2016 and 2015, sediment quality was scored as very good (A) across all Gladstone Harbour reporting zones, with low concentrations of metals (i.e. arsenic, cadmium, copper, lead, nickel, mercury and zinc) (refer Table 4.36). Sediment mercury levels were assessed for the first time in 2017. PAHs will not be reported as a sediment quality indicator as this measure was not monitored in 2017 owing to the low concentrations recorded in 2015.

4.9.2.3 Habitats

The overall score for habitats in 2017 was poor (0.33, D). The Gladstone Harbour Report Card 2017 found that both seagrass health and coral health were in poor condition. The overall seagrass score in 2017 of 0.39 (D) was similar to that recorded in 2016 of 0.35 (D), indicating a poor overall condition of seagrass (refer Table 4.36). Multiple years of high rainfall and cyclone activity in the Gladstone region may have reduced the resilience and capacity for recovery of seagrass communities in Gladstone as it has in other locations in Queensland (GHHP 2017b). There were limited signs of seagrass recovery across the harbour between 2016 and 2017. The overall poor condition of the seagrass meadows for four consecutive years indicates that meadows in Gladstone Harbour remain in a stable but vulnerable state (GHHP 2017a).

The coral score improved from very poor (0.15, E) to poor in 2017 (0.28, D) (refer Table 4.36). This is largely attributable to the addition of the coral cover change indicator as scores for coral cover, juvenile density and macroalgal cover have remained broadly similar to those recorded in previous years, although there has been a slight decline in juvenile density and a slight increase in coral cover (GHHP 2017a).

Poor results for seagrass and coral health may be attributed to flooding events which occurred in 2011 and 2013. Flooding in 2011 and 2013 reduced salinity and increased turbidity and nutrient loads within Gladstone Harbour resulting in adverse impacts to seagrass and coral health. These findings were consistent with inshore seagrass and coral habitats monitored elsewhere in Queensland where flooding events occurred. The Technical Report: *Gladstone Harbour Report Card 2015* (GHHP 2015a) could not conclude the extent to which flooding events or other factors contributed to the poor habitat condition recorded in Gladstone Harbour.

4.9.2.4 Connectivity

From 2016, the connectivity indicator group has been reported separately and not part of the environmental component as in previous years. Connectivity was considered to be a system driver rather than a measure of environmental health and will continue to be reported in the 'Drivers and Pressures' section of the report (GHHP 2017a).

4.9.2.5 Fish and crabs

In 2016, the fish and crab indicator was added for the first time, although only fish recruitment (bream) was measured in 2016 (refer Table 4.36). For the first time, the 2017 Gladstone Harbour Report Card provides grades and scores for mud crab health and abundance indicators. Fish recruitment (bream species) is included for the second time and indicators for fish health are being developed and will be included in future report cards.

The overall score for fish recruitment in 2017 was 0.71 (B) compared to 0.40 (D) in 2016, although this may be partly because of natural cycles. Hence this result is regarded as provisional at this stage as it may incorporate natural variability. Confidence in this indicator will improve as the dataset (number of years sampled) grows.

Table 4.36 Comparison of environmental indicator scores 2015 to 2017

Environmental results	2017 score/grade	2016 score/grade	2015 score/grade
Overall environmental	0.60 (C)	0.50 (C)	0.59 (C)
Water and sediment	0.87 (A)	0.84 (B)	0.90 (A)
- Water	0.78 (B)	0.72 (B)	0.81 (B)
- Sediment	0.95 (A)	0.96 (A)	0.98 (A)
Habitats	0.33 (D)	0.25 (D)	0.30 (D)
- Seagrass	0.39 (D)	0.35 (D)	0.43 (D)
- Coral	0.28 (D)	0.15 (E)	0.18 (E)
Fish and crabs*	0.63 (C)	0.40 (D)	Not measured
- Fish	0.71 (B)	0.40 (D)	Not measured
- Crabs	0.55 (C)	Not measured	Not measured
Connectivity**	N/A	N/A	0.61 (C)
Flushing rate	N/A	N/A	0.77 (B)
Contaminant connectivity	N/A	N/A	0.78 (B)
Ecological connectivity	N/A	N/A	0.29 (D)

Table notes:

* Fish and crabs were introduced as an environmental indicator in 2016, crabs were not measured until 2017

** From 2016 connectivity was removed from the environmental component (connectivity is now reported under 'drivers and pressures')

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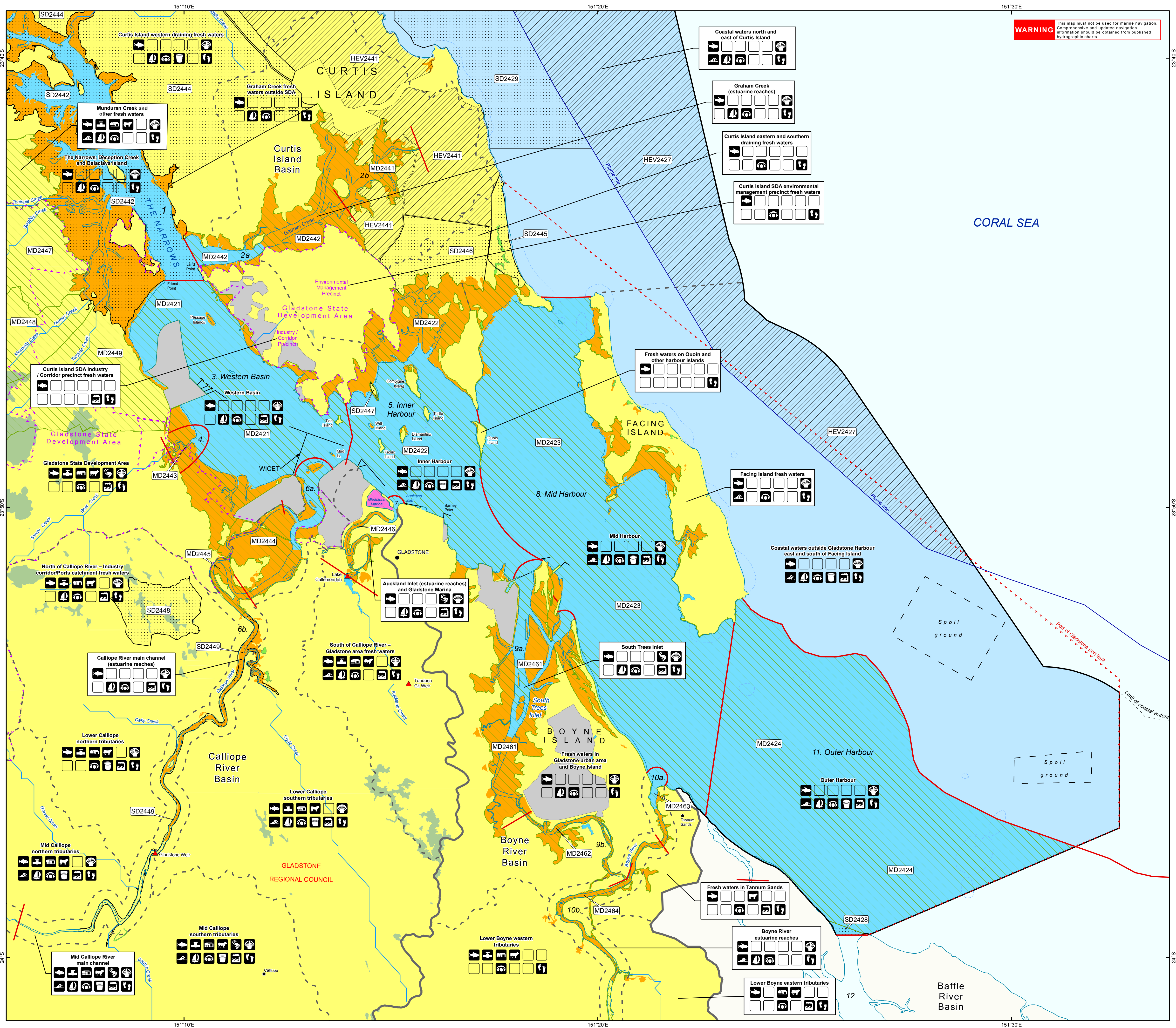
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A

EPP (Water) Schedule 1:
Curtis Island, Calliope River
and Boyne River Basins
Environmental Values and
Water Quality Objectives (extract)



WQ1312 Gladstone Harbour and The Narrows

Part of basins 131, 132 and 133

Environmental Protection (Water) Policy 2009 Central Queensland Map Series

This plan forms part of the Curtis Island, Calliope River and Boyne River Basins
Environmental Values and Water Quality Objectives scheduling document,
prepared pursuant to the *Environmental Protection (Water) Policy 2009*.



Publication date: November 2014

Legend

- Town
- Dam / weir
- Coastline
- River / creek
- Port of Gladstone port limits
- Plume line
- Gladstone Harbour sub-zone boundary
- Environmental value (subcatchment) boundary
- Basin boundary
- Boundary of waters covered by the scheduling document

Aquatic Ecosystem Environmental Values to identify Management Intent

- High ecological value (HEV) waters
- Slightly disturbed (SD) waters
- Moderately disturbed (MD) waters (sub-zone)

Water Types

- Fresh waters**
 - Lowland fresh waters
 - Upland fresh waters
 - Lakes / reservoirs
 - Wetlands (palustrine)
- Marine / estuarine waters**
 - Open coastal waters
 - Enclosed coastal waters / lower estuary
 - Middle estuary
 - Marnas / boat harbours / constructed estuaries
- Excluded waters**
 - Water type exclusion

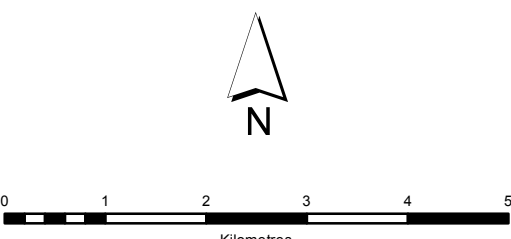
Key to Environmental Values

Aquatic Ecosystems	Irrigation	Farm Supply	Stock Water	Aquaculture	Human Consumer
Primary Recreation	Secondary Recreation	Drinking Water	Industrial Use	Cultural Use	Spiritual Values

Notes:
1. Waters in the scheduled area that are not shown as high ecological value or slightly disturbed waters have an aquatic ecosystem environmental value of moderately disturbed.
2. Wetlands shown on this map are sourced from the Queensland Wetland Data Version 3.0 developed by the Queensland Wetlands Program. Refer to the WetlandInfo website (www.ehp.qld.gov.au) for the most current information on Queensland wetlands.

Disclaimer:
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Includes data © Commonwealth of Australia (Geoscience Australia, GBRMPA) 2014.

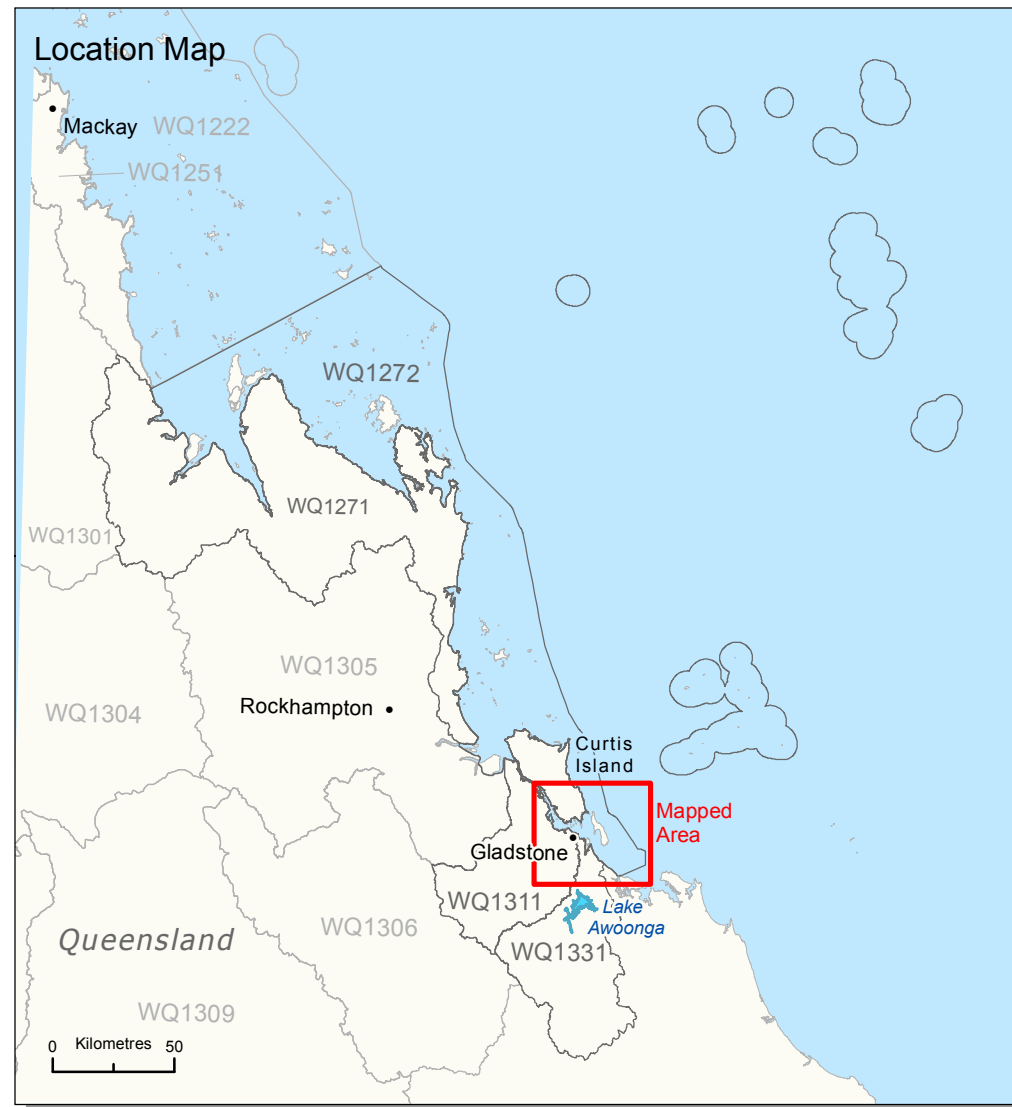
© State of Queensland, 2014



Scale: 1:75,000 @ A1

Projection: Mercator

Horizontal Datum: Geocentric Datum of Australia 1994 (GDA94)



ENVIRONMENTAL VALUES FOR

- **GLADSTONE HARBOUR, ADJACENT COASTAL WATERS**
- **MAINLAND ESTUARIES**
- **THE NARROWS**

Table 1A Environmental values for Gladstone Harbour and adjacent coastal waters, mainland estuaries, the Narrows and Fitzroy Delta

GLADSTONE HARBOUR, ADJACENT COASTAL WATERS, MAINLAND ESTUARIES THE NARROWS FITZROY DELTA	Environmental values ¹⁻⁷											
	Aquatic ecosystems	Irrigation	Farm supply/use	Stock water	Aquaculture	Human consumer	Primary recreation ⁵	Secondary recreation ⁵	Visual recreation	Drinking water	Industrial use	Cultural and spiritual values
Water												
GLADSTONE HARBOUR (listed west to east)⁷ AND ADJACENT COASTAL WATERS												
Western Basin	✓					✓		✓ ⁵	✓		✓	✓
Inner Harbour (including waters adjacent to Spinnaker Park beach, Barney Point)	✓					✓	✓ ⁵	✓ ⁵	✓	✓ ⁶	✓	✓
Mid Harbour	✓					✓	✓ ⁵	✓ ⁵	✓	✓ ⁶	✓	✓
Outer Harbour	✓					✓	✓ ⁵	✓ ⁵	✓	✓ ⁶	✓	✓
Coastal waters outside Gladstone Harbour east and south of Facing Island (to southern limits of Port)	✓					✓	✓ ⁵	✓ ⁵	✓	✓ ⁶	✓	✓
Coastal waters east of Curtis Island	✓					✓	✓ ⁵	✓ ⁵	✓			✓
Coastal waters around Heron Island Group (Capricorn Group)	✓					✓	✓ ⁵	✓ ⁵	✓	✓ ⁶		✓

GLADSTONE HARBOUR, ADJACENT COASTAL WATERS, MAINLAND ESTUARIES THE NARROWS FITZROY DELTA	Environmental values ¹⁻⁷											
	Aquatic ecosystems	Irrigation	Farm supply/use	Stock water	Aquaculture	Human consumer	Primary recreation ⁵	Secondary recreation ⁵	Visual recreation	Drinking water	Industrial use	Cultural and spiritual values
Water												
MAINLAND ESTUARIES ENTERING GLADSTONE HARBOUR (listed north to south)⁷												
Calliope River estuary, Boat Creek	✓					✓		✓ ⁵	✓		✓	✓
Auckland Inlet and Gladstone Marina	✓				✓	✓		✓ ⁵	✓		✓	✓
South Trees Inlet	✓				✓	✓		✓ ⁵	✓		✓	✓
Boyne River estuary	✓					✓	✓ ⁵	✓ ⁵	✓			✓
NARROWS and FITZROY DELTA LOWER ESTUARY⁷												
The Narrows (north of Graham Creek), Deception Creek, East Balaclava Island, Connor Creek and Kamiesh Passage (estuarine reaches)	✓					✓		✓ ⁵	✓			✓
Lower Fitzroy River (estuarine waters)	✓					✓		✓ ⁵	✓		✓	✓
GLADSTONE HARBOUR - ISLAND FRESH WATERS⁷												
Facing Island fresh waters	✓					✓	✓		✓			✓
Island fresh waters (Quoin and other harbour islands, excluding Curtis and Facing islands)	✓											✓

Notes:

1. Refer to the accompanying plans WQ1311, WQ1312, WQ1331, and WQ1273 for locations of EVs. For fresh water and estuarine rows, the EVs shown relate to waters within each subcatchment (for example 'Boyne River estuarine reaches') as shown on the plans.
2. ✓ means the EV is selected for protection. Blank indicates that the EV is not chosen for protection.
3. Refer to the dictionary for further explanation of EVs.
4. Refer to section 3 for WQOs applying to the EVs in this table.
5. The selection of recreational EVs for waters does not mean that these waters are free of dangerous aquatic organisms, for example venomous organisms (e.g. marine stingers including box jellyfish, irukandji jellyfish), crocodiles, and sharks. Direct contact with dangerous aquatic organisms should be avoided. Refer to EHP CrocWatch, council, www.health.qld.gov.au, www.beachsafe.org.au, www.marinestingers.com.au and other information sources for further details on swimming safety and information on specific waters.
6. Waters in which desalination for drinking water may apply.
7. For more specific information on activity restrictions in waterways including Gladstone Port refer to Gladstone Ports Corporation (GPC) website ('security'), and Maritime Services Queensland ('restricted areas'). Within Gladstone Port, landside and waterside restricted zones limit activities when activated. Further details on landuse planning for strategic port lands are provided in the GPC's landuse plan (available from the GPC website).

WATER QUALITY OBJECTIVES TO PROTECT ENVIRONMENTAL VALUES

3 Water quality objectives to protect environmental values

This section provides WQOs to support and protect different EVs identified for waters in Table 1. WQOs are long-term goals for water quality management. They are numerical concentration levels or narrative statements of indicators established for receiving waters to support and protect the designated EVs for those waters. Water quality objectives are not individual point source emission objectives, but the receiving water quality objectives.

This section is in two main parts.

Aquatic ecosystem WQOs

Following stakeholder consultation and analysis of water quality data, WQOs have been derived for both baseflow and event WQOs in Gladstone Harbour and other waterways where data was available. Section 3.1 (tables 2 and 14) outlines WQOs to protect the aquatic ecosystem EV. Key WQOs tables in this section are:

- table 2A: Gladstone Harbour, the Narrows, adjacent coastal waters and estuaries – baseflow WQOs
- table 2B: Gladstone Harbour and the Narrows: time/flow thresholds for applying baseflow WQOs
- table 2C: Gladstone Harbour, the Narrows and adjacent estuaries – toxicants WQOs
- table 2D: Gladstone Harbour and Boat Creek: event WQOs
- table 2E: Boyne River Basin: baseflow WQOs
- table 2F: Calliope River Basin: baseflow WQOs
- table 2G: Curtis Island, Facing Island and coastal waters WQOs
- table 14: surface water and groundwater WQOs (ionic indicators).

The aquatic ecosystem EV is a default applying to all Queensland waters, and therefore the WQOs for aquatic ecosystems form the minimum WQOs for all waters. Where no human use EVs are identified, the WQOs identified for aquatic ecosystem protection remain applicable.

Human use EVs

Section 3.2 (tables 3 to 12) provides WQOs for EVs other than aquatic ecosystem ('human use EVs') such as recreational water use, irrigating crops, and aquaculture.

Sources used in deriving WQOs are provided in and after the tables.

Where reference to table 1 indicates more than one EV applies to a given water (for example aquatic ecosystem and recreational use), the most stringent WQO for each water quality indicator applies, which will then protect all identified EVs. Refer to the following example on selection of most stringent WQOs. Note that this is an example only and should not be directly adopted for use.

Example

For lowland freshwater streams with aquatic ecosystem and drinking water EVs, the respective turbidity WQOs are:

- aquatic ecosystem lowland freshwater stream: less than 10 nephelometric turbidity units (NTU)
- drinking water: less than 25 NTU.

In this case the aquatic ecosystem WQO for turbidity (less than 10 NTU) is the more stringent, and its adoption therefore supports both the aquatic ecosystem and drinking water EVs.

3.1 Water quality objectives to protect aquatic ecosystems

This section provides physico-chemical, biological (section 3.1.1) and riparian (section 3.1.2) WQOs to support the aquatic ecosystem EV. Sources used in deriving locally relevant WQOs are provided in and after the tables in each of these sections. Section 3.1.3 provides information about the State Planning Policy (SPP) (state interest – water quality).

3.1.1 Physico–chemical and biological water quality objectives

Each table includes the following information:

- water area or water type (column 1) (for boundaries of specified areas, refer to the accompanying plans)
- the corresponding management intent (level of protection) for the identified waters (column 2)
- the corresponding physico-chemical and biological WQOs to achieve the management intent (level of protection) for the identified waters (column 3).

Waters for which all physico-chemical WQOs (e.g. nutrients, toxicants) have been set corresponding to HEV management intent are identified in columns 1 and 2 of table 2. Each of these waters is given a specific label in the table (e.g. 'HEV1234') which links to the accompanying plans. Slightly disturbed (SD) waters are similarly identified.

The management intent (level of protection) for most waters other than HEV or SD is to achieve a 'moderately disturbed' (MD) condition, for which corresponding WQOs have been derived. Where local WQOs are derived for MD areas these are also identified with specific labels (e.g. 'MD1234'). For some indicators and water types, WQOs correspond with a 'slightly to moderately disturbed' (SMD) level of protection, based on management intent categories specified in source technical guidelines, in particular the Australian water quality guidelines (ANZECC, 2000). For ease of interpretation, this document and accompanying mapping include these within the MD level of protection. For some MD waters a higher level of protection may be provided for toxicants (e.g. pesticides).

WQOs for metals and other toxicants, where not stated in this document, are referred to the ANZECC guidelines. In the case of aluminium, reference is made to a recent peer reviewed study of toxicity of aluminium in marine waters by Golding et al. (2014). This study used ANZECC protocols to derive a marine guideline value of 24 µg/L of aluminium (that applies to the measured concentration in seawater that passes through a 0.45 µm filter) to protect 95% of species (with a 99% species protection value of 2.1 µg/L). This supersedes the existing low reliability guideline of 0.5 µg/L which was derived using conservative safety margins from limited data.

Source: Golding, L.A., Angel, B.M., Batley, G.E., Apte, S.C., Krassoi, R. and Doyle, C.J. 2014. Derivation of a water quality guideline for aluminium in marine waters. *Environmental Toxicology and Chemistry* (Accepted) (DOI: 10.1002/etc.2771).

Application

The QWQG (section 5, Appendix D) address procedures for the application of guidelines for aquatic ecosystem protection, and compliance assessment protocols. For the comparison of test site monitoring data against WQOs, the median water quality value (e.g. concentration) of a number (preferably five or more) of independent samples at a particular monitoring ('test') site should be compared against the water quality objective of the same indicator, water type and level of aquatic ecosystem protection, as listed in table 2 below.

For WQOs based on GBRMPA data, where single value WQOs are given for specified indicators (e.g. Secchi depth, particulate N), these should be compared to annual mean (rather than median) values. Relevant seasonal adjustments can be referenced in GBRMPA (2010) Water quality guidelines for the Great Barrier Reef Marine Park 2010. Also refer to notes after the tables.

AQUATIC ECOSYSTEM EV

WATER QUALITY OBJECTIVES FOR GLADSTONE HARBOUR, AND ADJACENT WATERS

Table 2A: Gladstone Harbour, the Narrows, adjacent coastal waters and estuaries – baseflow WQOs

Table 2B: Gladstone Harbour and the Narrows: time/flow thresholds for use of baseflow WQOs

Table 2C: Gladstone Harbour, the Narrows and adjacent estuaries – toxicants WQOs

Table 2D: Gladstone Harbour and Boat Creek: event WQOs

Table 2A Gladstone Harbour, the Narrows, adjacent coastal waters and estuaries: Water quality objectives to protect aquatic ecosystem environmental value under baseflow conditions (peak discharge < 100 m³/sec)

Water area/type Refer plans WQ1311, 1312, 1331, 1272 (s1–s5: source for WQOs, listed after table)	Management intent /level of protection	GLADSTONE HARBOUR, THE NARROWS, COASTAL WATERS, ESTUARIES: Baseflow water quality objectives (WQOs) ^{1–7}										
		Note: WQOs for indicators are shown as 20 th , 50 th and 80 th percentiles (e.g. 3–4–5), lower and upper limits (20 th /80 th %iles, e.g. pH: 7.2–8.2), or as a single values (median or 80 th percentile) (e.g. <15). HEV: high ecological value; SD: slightly disturbed; MD: moderately disturbed										
		Amm N (µg/L)	Oxid N (µg/L)	Total N (µg/L)	FRP (µg/L)	Total P (µg/L)	Chl-a (µg/L)	DO (% sat)	Turb (NTU)		pH	
									Dry (May–Oct)	Wet (Nov–Apr)	<40mS/cm	>40mS/cm
GLADSTONE HARBOUR, THE NARROWS, ADJACENT COASTAL WATERS												
MD2421 Western Basin (s1)	MD	3–3–8	1–4–16	145–170–210	1–3–7	14–18–29	0.5–1.0–2.0	91–96–100	4–8–17	7–13–29	7.2–8.2	7.4–8.3
MD2422 Inner Harbour (s1)	MD	3–3–10	2–5–12	130–160–220	1–3–6	15–21–33	0.5–1.0–2.0	93–96–98	4–8–17	7–13–29	7.2–8.2	7.4–8.3
MD2423 Mid Harbour (s1)	MD	3–3–12	1–3–9	110–135–200	1–2–3	9–14–23	0.5–1.0–2.0	94–97–101	2–4–7	4–9–16	7.2–8.2	7.4–8.3
MD2424 Outer Harbour (EC waters) (s1)	MD	3–4–5	1–3–6	115–130–170	1–1–3	9–13–21	0.5–1.0–2.0	94–97–100	1–3–6	2–7–13	8.0–8.1–8.2	
SD2428 Colosseum Inlet (s1)	HEV	3–3–15	1–3–5	105–130–180	1–1–3	8–10–15	0.5–0.8–1.4	86–91–97	1–3–4	3–7–14	7.2–8.2	7.4–8.3
SD2441, 2442 The Narrows, Deception Creek, East Balaclava Is (s1)	HEV	3–3–10	2–3–9	140–170–220	3–3–7	15–20–29	0.5–1.0–2.0	87–92–95	4–7–12	8–15–30	7.2–8.2	7.4–8.3
Rodds Bay – the following water quality guidelines have been derived for Rodds Bay and are provided to assist in the derivation of the Gladstone Healthy Harbour report card. EVs and WQOs for Rodds Bay will be included in the Baffle Basin EVs and WQOs document.												
Rodds Bay (s4, s3, s2)	all	3–3–4	1–1–3	140–160–200	1–1–3	11–13–21	0.5–1.0–2.2	93–96–98	3–4–7	2–5–12	7.2–8.2	7.4–8.3

Table 2A continued

Water area/type Refer plans WQ1311, 1272 (s1–s5: source for WQOs, listed after table)	Management intent /level of protection	COASTAL AND MARINE WATERS OUTSIDE GLADSTONE HARBOUR: Water quality objectives (WQOs) ^{1–7}															
		Note: WQOs for indicators are shown as 20 th , 50 th and 80 th percentiles (e.g. 3–4–5), lower and upper limits (20 th /80 th %iles, e.g. pH: 7.2–8.2), or as a single values (median or 80 th percentile) (e.g. <15). HEV: high ecological value; SD: slightly disturbed; MD: moderately disturbed															
		Amm N (µg/L)	Oxid N (µg/L)	Partic N (µg/L)	Total Diss N (µg/L)	Total N (µg/L)	FRP (µg/L)	Partic P (µg/L)	Total Diss P (µg/L)	Total P (µg/L)	Chl-a (µg/L)	Silicate (µg/L)	DO (% sat)	Turb (NTU)	Secchi (m)	SS (mg/L)	pH
Open coastal waters adjacent to Gladstone Harbour (east of Facing Island) (landward of GBR plume line) (s4, s1, s3, s2)	SMD	<3	<1	≤20 (ann. mean)	<70	<100	<1	≤2.8 (ann. mean)	<6	<8	≤0.45 (ann. mean)	>60	95–105	Dry:<1 (May-Oct) Wet:<2 (Nov-Apr)	≥10 (ann. mean)	≤2 (ann. mean)	8.1–8.4
Open coastal designated spoil grounds (s1, s2, s3)	MD	<3	<1	≤20 (ann. mean)	-	<100	<1	≤2.8 (ann. mean)	-	<8	≤0.45 (ann. mean)	-	95–105	Dry:<1 (May-Oct) Wet:<2 (Nov-Apr)	≥10 (ann. mean)	≤2 (ann. mean)	8.1–8.4
Other coastal/marine waters	Refer to Table 2G																
Coastal and marine waters (s3)	all	Temperature: increases of no more than 1°C above long-term (20 year) average maximum. (GBRMPA, 2010)															
All waters: toxicants, metals	all	Refer to Table 2C															
All waters: biological	all	<u>Seagrass:</u> Minimum light requirement is a photosynthetic active radiation (PAR) two week moving average of greater than 6 mol m ⁻² day ⁻¹ . This is minimum requirement only and is generally below the current average conditions of the harbour. It does not include potential impacts on benthic microalgae and phytoplankton at this light level. Objective based on Chartrand et al. (2012) <i>Development of a Light-Based Seagrass Management Approach for the Gladstone Western Basin Dredging Program</i> . <u>Mangroves:</u> No loss of mangrove area. EHP/ Queensland Herbarium conducts biennial mapping of mangrove cover and this could be used as an assessment tool. Mapping is available from EHP.															

Table 2A continued

Water area/type	Management intent /level of protection	GLADSTONE HARBOUR, THE NARROWS, ADJACENT ESTUARIES: Baseflow water quality objectives (WQOs) ^{1–7}											
		Note: WQOs for indicators are shown as 20 th , 50 th and 80 th percentiles (e.g. 3–4–5), lower and upper limits (20 th /80 th percentiles, e.g. pH: 7.2-8.2), or as a single values (median or 80 th percentile) (e.g. <15).											
		HEV: high ecological value; SD: slightly disturbed; MD: moderately disturbed											
		Amm N (µg/L)	Oxid N (µg/L)	Total N (µg/L)	FRP (µg/L)	Total P (µg/L)	Chl-a (µg/L)	DO (% sat)	Turb (NTU)		pH		
Refer plans WQ1311, 1312, 1331, 1272													
(s1–s5: source for WQOs, listed after table)													
</													

Water area/type Refer plans WQ1311, 1312, 1331, 1272 (s1–s5: source for WQOs, listed after table)	Management intent /level of protection	GLADSTONE HARBOUR, THE NARROWS, ADJACENT ESTUARIES: Baseflow water quality objectives (WQOs) ^{1– 7}											
		Note: WQOs for indicators are shown as 20 th , 50 th and 80 th percentiles (e.g. 3–4–5), lower and upper limits (20 th /80 th percentiles, e.g. pH: 7.2-8.2), or as a single values (median or 80 th percentile) (e.g. <15).											
		HEV: high ecological value; SD: slightly disturbed; MD: moderately disturbed											
		Amm N (µg/L)	Oxid N (µg/L)	Total N (µg/L)	FRP (µg/L)	Total P (µg/L)	Chl-a (µg/L)	DO (% sat)	Turb (NTU)		pH		
Dry (May–Oct)	Wet (Nov–Apr)								<40mS/cm	>40mS/cm			
Toxicants, metals	all	Refer to Table 2C											
Calliope River Basin													
SD2449, MD2445 Calliope middle estuary (s1)	SD/MD	2–8–23	2–8–27	150–200–275	3–7–14	16–22–33	1.7–3.0–5.3	87–93–99	5–9–17	5–12–25	7.0–8.4		
MD2444 Calliope lower estuary (s1)	MD	3–6–10	3–3–10	140–175–210	2–4–6	17–22–25	1.0–1.7–2.7	91–95–100	5–11–21	6–11–24	7.2–8.2	7.4–8.3	
MD2443 Boat Creek estuary (s1)	MD	3–4–11	1–3–8	160–190–220	1–3–6	15–22–32	1.0–2.0–4.0	85–92–98	9–14–22	13–25–32	7.2–8.2	7.4–8.3	
MD2446 Auckland Inlet (s1)	MD	3–6–13	3–6–13	140–160–200	2–3–5	12–16–23	1.1–1.9–2.9	93–98–100	3–6–13	5–8–12	7.2–8.2	7.4–8.3	
Toxicants, metals	all	Refer to Table 2C											

Water area/type Refer plans WQ1311, 1312, 1331, 1272 (s1–s5: source for WQOs, listed after table)	Management intent /level of protection	GLADSTONE HARBOUR, THE NARROWS, ADJACENT ESTUARIES: Baseflow water quality objectives (WQOs) ^{1– 7}											
		Note: WQOs for indicators are shown as 20 th , 50 th and 80 th percentiles (e.g. 3–4–5), lower and upper limits (20 th /80 th percentiles, e.g. pH: 7.2-8.2), or as a single values (median or 80 th percentile) (e.g. <15).											
		HEV: high ecological value; SD: slightly disturbed; MD: moderately disturbed											
		Amm N (µg/L)	Oxid N (µg/L)	Total N (µg/L)	FRP (µg/L)	Total P (µg/L)	Chl-a (µg/L)	DO (% sat)	Turb (NTU)		pH		
Curtis Island Basin													
MD2441, 2442 Graham Creek estuary (Curtis Island) (s1)	MD	3–3–8	1–3–7	140–170–220	2–4–7	15–20–29	0.5–1.0–2.3	83–88–94	3–8–14	10–13–28	7.2–8.2	7.4–8.3	
Toxicants, metals	all	Refer to Table 2C											
OTHER CURTIS ISLAND ESTUARINE WATERS – refer to Table 2G													
Fitzroy lower estuary													
Fitzroy delta middle estuarine waters (s2)	MD	<10	<10	<300	<8	<25	<4.0	85–100	id	id	7.0–8.4		
Fitzroy delta LE/EC waters (s1, s2)	MD	<8	<3	<200	<6	<20	<2.0	90–100	Dry ATMD 0 – 9km: <114 Other EC: <101 (near bottom turbidity)		8.0–8.4		
Toxicants, metals	all	Refer to Table 2C											

Sources:

S1: Local datasets (e.g. DSITIA, key stakeholder); S2: QWQG guidelines and /or data; S3: GBRMPA (2010) WQG; S4: GBRMPA analysis of Reef Rescue Marine Monitoring Program and/or Long Term Monitoring Program datasets; S5: ANZECC (2000) AWQG

Notes 1–7: Refer notes after Table 2G.

Table 2B Gladstone Harbour and the Narrows: time thresholds for use of baseflow WQOs (relative to flows – also see Table 2D: Event flow WQOs)

Water area/type Refer plans WQ1311, 1312, 1331, 1272	Discharge threshold (m ³ /s) (Castlehope gauging station, Calliope River)	TIME THRESHOLDS for WQO indicators ¹⁻⁴ (aquatic ecosystem EV)			
		Nutrients (N, P)	Chl-a	DO (% sat)	Turb (NTU)
MD2421 Western Basin	100–500	No withholding period	No withholding period	No withholding period	No withholding period
	500–1000	3 weeks	3 weeks	3 days	3 days
	>1000	3 weeks	3 weeks	7 days	7 days
MD2422 Inner Harbour	100–500	No withholding period	No withholding period	No withholding period	No withholding period
	500–1000	3 weeks	3 weeks	3 days	3 days
	>1000	3 weeks	3 weeks	7 days	7 days
MD2423 Mid Harbour	100–500	No withholding period	No withholding period	No withholding period	No withholding period
	500–1000	3 weeks	3 weeks	No withholding period	No withholding period
	>1000	3 weeks	3 weeks	7 days	7 days
SD2442 The Narrows	100–500	2 weeks	2 weeks	3 days	3 days
	500–1000	3 weeks	3 weeks	3 days	3 days
	>1000	3 weeks	3 weeks	7 days	7 days

Notes:

1. Interpretation: The table shows the time periods after which baseflow WQOs are to be applied to waters, relative to different sized peak flow events at the Castlehope gauging station. For example, when peak discharge at the Castlehope gauging station is in the range of 100-500 m³/sec, baseflow turbidity and DO WQOs for the Narrows are not applicable until three days after the flows have returned to <100 m³/sec. During the withholding period, event flow WQOs are applicable. After the withholding period has concluded, baseflow WQOs apply.
2. Castlehope gauging station (132001A) is located at lat -23.984983/long 151.097564. Details are available from the DNRM website.
3. Within the event and withholding periods refer to Table 2D below.
4. No withholding period means the baseflow WQOs can be applied at any stage.

Table 2C Gladstone Harbour, the Narrows and adjacent estuaries: Water quality objectives for toxicants

Metal / toxicant	Water quality objective for marine waters, slightly-moderately disturbed systems (95% species protection unless specified) (µg/L)	Interim sediment quality guideline (ISQG) – low (mg/kg dry weight)
Aluminium	24 (MD waters – 95%) 2.1 (HEV/SD waters – 99%) Source: Golding et al, 2014	id
Arsenic (AsIII)	id ¹	20
Arsenic (AsV)	id	
Cadmium	0.7 (99%)	1.5
Chromium (CrIII)	27.4	80
Chromium (CrVI)	4.4	
Copper (Cu)	1.3	65
Cyanide	4	id
Gallium	id	id
Lead (Pb)	4.4	50
Molybdenum	id	id
Nickel (Ni)	7 (99%)	21
Zinc (Zn)	15	200
Other toxicants	- Toxicants in water: refer to AWQG volume 1 section 3.4—‘water quality guidelines for toxicants’ (including tables 3.4.1, 3.4.2, and Figure 3.4.1), and AWQG volume 2 (section 8, including s 8.3.4.4 on application in estuarine waters). AWQG values for the MD level of protection typically correspond to protection of 95% species (in a small number of cases where bioaccumulation may occur, the AWQG recommends 99% species protection level). - Toxicants in sediments: refer to AWQG volume 1 section 3.5—‘sediment quality guidelines’ (including Table 3.5.1, Figure 3.5.1), and AWQG volume 2 (section 8) - Pesticides: As per GBRMPA and AWQG water quality guidelines, to protect marine species at the HEV level of protection (except where noted). Pesticides/biocides specified in GBR water quality guidelines include: Ametryn: <0.5 µg/L; Atrazine: <0.6 µg/L; Diuron: <0.9 µg/L; Hexazinone: <1.2 µg/L; Simazine: <0.2 µg/L; Tebuthiuron: <0.02 µg/L; 2,4-D: <0.8 µg/L; Tributyltin: <0.006 µg/L (95% species protection) Sewage: Release of sewage from vessels to be controlled in accordance with requirements of the Transport Operations (Marine Pollution) Act 1995 and Regulations. (Refer to Maritime Services Queensland website for further information.) Anti-fouling: Comply with <i>Anti-fouling and in-water cleaning guidelines</i> (June 2013)	

Notes:

1. id: insufficient data. Values to be updated when available.

Sources:

ANZECC & ARMCANZ (2000) Australian and New Zealand Guidelines for Fresh and Marine Water Quality (AWQG).

Golding, LA, Angel, BM, Batley, GE, Apte, SC, Krassoi, R and Doyle, CJ (2014) Derivation of a water quality guideline for aluminium in marine waters, *Environ Toxicol Chem.*, Accepted Article • DOI: 10.1002/etc.2771, accepted 3 October 2014

Great Barrier Reef Marine Park Authority (2010) Water quality guidelines for the Great Barrier Reef Marine Park 2010, Great Barrier Reef Marine Park Authority, Townsville, available on the Great Barrier Reef Marine Park Authority's website.

Table 2D Gladstone Harbour and Boat Creek: Event flow water quality objectives to protect aquatic ecosystem environmental value

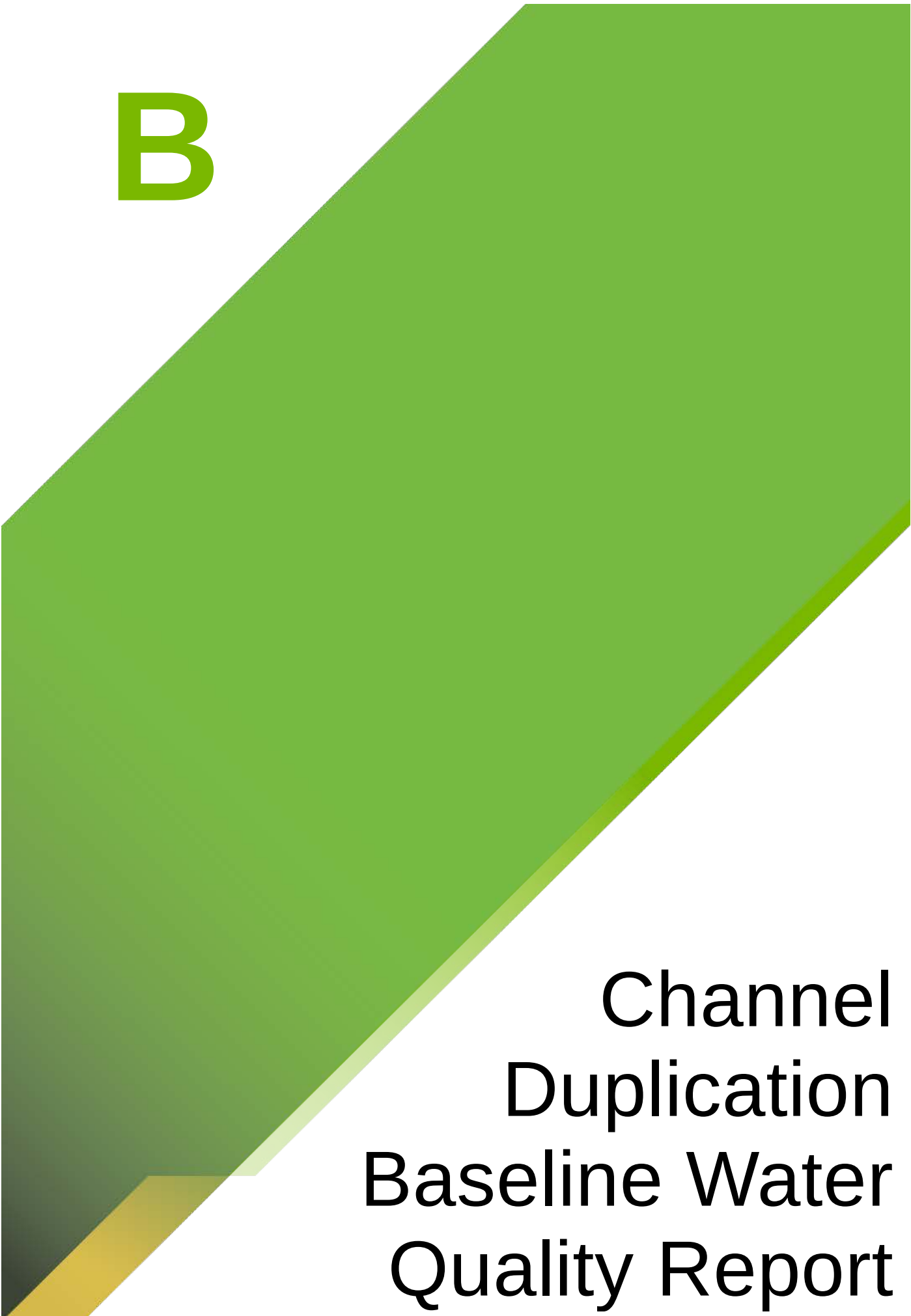
Water area/type Refer plans WQ1311, 1312, 1331, 1272 (s1–s5: source for WQOs, listed after table)	Management intent /level of protection	Discharge threshold (m³/s) (Castlehope gauging station, Calliope River)	GLADSTONE HARBOUR: Event flow ^{1, 2} water quality objectives (WQOs)								
			Note: WQOs for indicators are shown as 20 th , 50 th and 80 th percentiles (e.g. 3–4–5), lower and upper limits (20 th /80 th percentiles, e.g. pH: 7.2-8.2), or as a single values (median or 80 th percentile) (e.g. <15). HEV: high ecological value; SD: slightly disturbed; MD: moderately disturbed								
			Amm N (µg/L)	Oxid N (µg/L)	Total N (µg/L)	FRP (µg/L)	Total P (µg/L)	DO (% sat)	Turb (NTU)	SS (mg/L)	pH
FRESH WATERS											
Boat Creek (s1)	MD	Above local baseflow	12–50–95	7–65–390	50–600–1540	5–10–30	id	85–90–95	5–28–48	8–59–85	-
GLADSTONE HARBOUR, THE NARROWS											
MD2421 Western Basin (s1)	MD	100–500	-	-	-	-	-	80–110	Apply baseflow WQO	-	-
		500–1000						65–115	300		
		>1000						50–170	1000		
MD2422 Inner Harbour (s1)	MD	100–500	-	-	-	-	-	80–110	Apply baseflow WQO	-	-
		500–1000						70–115	110		
		>1000						60–140	650		
MD2423 Mid Harbour (s1)	MD	100–500	-	-	-	-	-	90–135	Apply baseflow WQO	-	-
		500–1000						85–130	Apply baseflow WQO		
		>1000						80–160	150		
SD2442 The Narrows (s1)	HEV	100–500	-	-	-	-	-	80–140	120	-	-
		500–1000						50–135	130		
		>1000						70–160	850		

Notes:

1. Interpretation: The table shows the values applying during event flow and withholding period, relative to peak flow events at the Castlehope gauging station. Withholding periods are specified in Table 2B. For baseflow WQOs refer to separate tables in this document.

2. Castlehope gauging station (132001A) is located at lat -23.984983/long 151.097564. Details are available from the DNRM website.

Sources: S1: Local datasets (e.g. DSITIA, key stakeholder); S2: QWQG guidelines and /or data; S3: GBRMPA (2010) WQG; S4: GBRMPA analysis of Reef Rescue Marine Monitoring Program and/or Long Term Monitoring Program datasets; S5: ANZECC (2000) AWQG



B

Channel
Duplication
Baseline Water
Quality Report



Port of Gladstone Gatcombe and
Golding Cutting Channel
Duplication Project

Environmental Impact Statement

Baseline Data Collection

Water Quality Monitoring

June 2014 to June 2015

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Acronyms

AA	Advanced Analytical
AWQG	Australian Water Quality Guidelines
BOD	Biological Oxygen Demand
BOM	Bureau of Meteorology
BPAR	Benthic Photosynthetically Active Radiation
BTEX	Benzene, Toluene, Ethylene and Xylene
COD	Chemical Oxygen Demand
DMPA	Dredged Material Placement Area
DO	Dissolved Oxygen
DoE	Department of the Environment
DSITIA	(former) Department of Science, Information Technology, Innovation and the Arts, Queensland
EHP	Department of Environment and Heritage Protection
EIS	Environmental Impact Statement
EPP (Water)	<i>Environmental Protection (Water) Policy 2009</i>
EV	Environmental Value
EWMA	Exponentially Weight Moving Average
GPC	Gladstone Ports Corporation
GBRMPA	Great Barrier Reef Marine Park Authority
HEV	High Environmental Value
HSEQ	Health, Safety, Environment and Quality
LOR	Limits of Reporting
LSD	Least Significant Difference
MD	Moderately Disturbed
MS	Management System
ND	Not determined
NO _x	Oxidised nitrogen (includes nitrate and nitrite)
NTU	Nephelometric Turbidity Units
OCP	Organochlorine pesticides
OPP	Organophosphate pesticides
PAH	Polycyclic Aromatic Hydrocarbons
PAR	Photosynthetically Active Radiation
QA/QC	Quality Assurance/Quality Control
QWQG	Queensland Water Quality Guidelines
SD	Slightly Disturbed
SE	Standard error
SMD	Slightly to Moderately Disturbed
SMART	Self-Monitoring Algorithm in Real Time
TC	Tropical Cyclone
TDP	Total Daily PAR
TKN	Total Kjeldahl Nitrogen
ToR	Terms of Reference
TSS	Total Suspended Solids

VE	Vision Environment
WBDDP	Western Basin Dredging and Disposal Project
WQG	Water Quality Guidelines
WQO	Water Quality Objective

Executive Summary

Water quality monitoring was conducted by Vision Environment for Gladstone Ports Corporation, over a 13 month period, to support the process of the Environmental Impact Statement for the Port of Gladstone Gatcombe and Golding Cutting Channel Duplication Project (the “Project”). Eight water quality sites were established for the water quality monitoring program, which involved the monitoring of physicochemistry, benthic light (Benthic Photosynthetically Active Radiation), sedimentation rates, and water metal, nutrient and organic concentrations. An interpretation of the driving factors that may influence the Port Curtis marine environment, in addition to a comparison of results with appropriate water quality guidelines and historical results, was undertaken. Based on the *Environmental Protection (Water) Policy 2009* Environmental Values and Water Quality Objectives for Port Curtis (Department of Environment and Heritage Protection 2014), water quality monitoring sites were included in the following water areas/zones: Open Coastal Waters (CD2, CD4 and CD5), Outer Harbour (CD1), Mid Harbour (CD3 and P5/MH10), Western Basin (P2B/WB50) and The Narrows (QE3).

For the purposes of this report the water areas mentioned above have been grouped into offshore (CD1, CD2, CD3, CD4 and CD5) and inshore (P5/MH10, P2B/WB50 and QE3) sites.

Turbidity is commonly used as a compliance trigger in dredging projects therefore there was a particular focus on this parameter during the baseline water quality monitoring program. Surface and benthic turbidity, measured in nephelometric turbidity units, were measured continuously by dual telemetered sondes at 15 minute intervals at offshore sites, while surface turbidity only was measured at the inshore sites, due to the well mixed water column at this locale. Turbidity followed patterns previously established in historical monitoring programs (Vision Environment 2013d, Vision Environment 2013f). This was confirmed by mean seasonal turbidity values being within the 20th and 80th percentile Water Quality Objectives, established for Port Curtis (Department of Environment and Heritage Protection 2014).

Inshore sites (QE3, P2B/WB50 and P5/MH10) exhibited elevated turbidity in comparison with offshore sites (CD1 to CD5), due to their protected coastal and lower estuarine location, and higher turbidity during the wet season. At offshore sites, benthic turbidity was higher and more variable than surface turbidity, due to the proximity of the benthic loggers to resuspending sediments. However, significant linear regressions were evident between benthic and surface turbidity, which trended similarly. Thus, based on these relationships, dredging compliance water quality triggers could potentially be based on either surface (less variable) or benthic measurements, removing the necessity of monitoring multiple water column depths.

Turbidity at offshore sites CD4 and CD5 was wind driven, which was particularly evident upon landfall of Tropical Cyclone Marcia, whereas inshore sites (P5/MH10, P2B/WB50, and QE3) and those offshore sites closer to land masses (CD1 and CD3) tended to be more influenced by lunar and tidal cycles, and significant rain events. The deeper offshore sites (CD4 and CD5) demonstrated lower benthic turbidity. The comprehensive turbidity dataset collected over the 13 month period has provided a clear indication of background turbidity through a range of environmental variables experienced over wet and dry seasons in Port Curtis, on which percentiles for dredging compliance water quality trigger values could confidently be established.

Continuous measurements were also collected for other physicochemical parameters concurrently with turbidity, such as temperature, pH, conductivity, and dissolved oxygen,

utilising the same multiparameter dual loggers at offshore and inshore sites. A geographical gradient of lower pH and dissolved oxygen from inshore to offshore was evident and is a consistently recorded pattern for Port Curtis (Vision Environment 2010, Vision Environment 2012a, Vision Environment 2013d, Vision Environment 2013f). Only marginal differences between the benthic and surface parameters were evident at offshore sites, suggesting that similar to the inshore sites, the water column is also well mixed. This was supported by the results of monthly depth profiling data. The exception was during significant rain events at sites closer to inshore, with some benthic parameters, namely conductivity, differing from surface parameters.

Significant rain events, particularly at inshore sites, generated a pattern of longer term decreased conductivity and short-lived declines in pH and dissolved oxygen, which fluctuated with tidal cycles. This pattern was also evident at CD3, located at the mouth of the Boyne River, which also exhibited stratification of the water column in regards to conductivity. This post rain event pattern has been recorded previously (Vision Environment 2013b) with freshwater flows introducing organic matter into the system, which in turn creates an increase in biological oxygen demand and chemical oxygen demand, resulting in lower pH and available oxygen. Similar to turbidity, other physicochemical parameters were within acceptable water quality objective ranges for Port Curtis (Department of Environment and Heritage Protection 2014).

To complement turbidity measurements, sedimentation was measured by benthic acoustic altimeters at all monitoring sites. Two forms of information were provided, including instantaneous bed level change (the volatility in the change in bed level), and cumulative bed level change (net erosion or deposition) per deployment period. Similar to turbidity, instantaneous bed level change at furthest offshore sites (CD4 and CD5) was wind driven, whereas at closer inshore sites lunar and tidal cycles, in addition to rain events, were more influential. There was often a minimum threshold in turbidity required to generate a noticeable increase in bed level flux, with deeper offshore sites demonstrating more stable bed levels.

Periods of erosion and deposition were generally equal at most inshore sites, leading to little net change over time. Site CD2 at Gatcombe Head was the most volatile site, with persistent erosion up to three times higher than other sites. In contrast, site CD3 at the mouth of the Boyne River consistently experienced deposition, particularly after significant rain events. Wind direction appeared highly influential on the outcome of bed level change during Tropical Cyclone Marcia. Prior to the landfall of Tropical Cyclone Marcia, erosion was recorded at a number of sites whereas after landfall and a rapid change to wind prevailing from the opposite direction, rapid deposition occurred at two sites. The modelling of cumulative sediment change in response to wind direction in sediment transport models may assist to discern predictable sediment transport patterns, during dredging operations.

Light is required for seagrass and corals to photosynthesise. Measuring turbidity is commonly used as a proxy for measuring light reaching benthic primary producers, such as seagrass. However, for the Western Basin Dredging and Disposal Project, a dual turbidity and light based management approach was developed (Gladstone Ports Corporation, 2012) to manage the impacts of changes to the light climate resulting from dredging on intertidal seagrass meadows. As the Project area of interest incorporates subtidal seagrass meadows, in addition to fringing coral reefs, light was considered an important parameter to measure to establish the offshore subtidal light environment. Subsequently, light or Benthic Photosynthetically Active Radiation was measured utilising dual telemetered instruments at offshore sites,

concurrently with physicochemistry and sedimentation. As Benthic Photosynthetically Active Radiation is affected by the amount of natural sunlight, ambient light was also measured at a land base, to assist in interpretation of results.

The main variables found to influence Benthic Photosynthetically Active Radiation are: ambient light, turbidity, light attenuation and water depth. Ambient light was highest during the wet season (November to April) when daylight hours were longer, however Benthic Photosynthetically Active Radiation was higher at all offshore sites during the dry season (May to October). This is due to the influence of other variables, such as water clarity. Deeper sites generally had lower Benthic Photosynthetically Active Radiation due to reduced light reaching the benthos. Higher turbidity also resulted in a decrease in Benthic Photosynthetically Active Radiation. At CD3, a relatively shallow site (~ 7m), water column total suspended solids were elevated and thus Benthic Photosynthetically Active Radiation was lower, due to light being highly attenuated before reaching the benthos. Mean total daily Benthic Photosynthetically Active Radiation recorded at offshore sites was low with means ranging up to 2.3 moles per square metre per day.

Monthly depth profiling of light and physicochemical parameters, in addition to analyses of water grab samples for a variety of parameters, was undertaken to supplement the in situ monitoring program. Total suspended solids, another measure of water clarity, was measured in samples from three depths at offshore sites and at the subsurface at inshore sites. Total suspended solids were significantly correlated with turbidity, with higher concentrations found in samples from inshore sites. Again similar to turbidity, total suspended solids concentrations were generally higher at the benthos. Concentrations in samples from offshore sites CD3 and CD2 were above water quality objectives (Department of Environment and Heritage Protection 2014) at all depths. Concentrations in samples from

Compliance triggers are commonly applied to total suspended solids measurements for dredging projects, with a total suspended solids/turbidity relationship often being well established. However, due to the delay from sampling to provision of results (because of the required laboratory analysis for total suspended solids), turbidity provides an instantaneous and more useful measure, for real-time dredging management.

Nutrients (nitrogen and phosphorus) are essential for plant growth. However, excessive concentrations can stimulate algal growth, resulting in blooms and consequentially a decrease in water clarity. Nutrients and chlorophyll a (a photosynthetic pigment used as a measure of algal biomass), were higher in samples from inshore sites than from offshore sites. Chlorophyll a was higher in samples during the wet season, indicating an increase in microalgal biomass in response to warmer temperatures and light. Although there was no significant seasonal variation in nutrient concentrations, chlorophyll a increased with increased nutrient concentrations and was also correlated with total suspended solids, suggesting a decrease in water clarity with increasing microalgae. Findings were similar to those found previously for Port Curtis (Vision Environment 2010, Vision Environment 2012a, Vision Environment 2013f).

Although most nutrients in samples were within recommended water quality objective ranges (DSITIA 2014), some concentrations in samples from inshore sites were above the water quality objectives, particularly during the wet season. Total phosphorus in Port Curtis is thought to be naturally derived from geological deposits, whereas total nitrogen has been found to be mostly organic, being derived from mangrove detritus and benthic primary producers, such as seagrass and algae.

Both total and dissolved metals are important to measure during any water quality program, but are particularly important to consider during dredging and dredged material placement works, due to disturbance of the benthic sediments, which can result in the addition of total metals to the water column. Dissolved metals are considered to be the potential bioavailable fraction, however potential changes in water chemistry (e.g. decrease in pH) can result in changes in metal bioavailability and thus an increase in dissolved metals, due to a smaller proportion of total metals being bound to particulate matter, such as sediments.

Although significant seasonal variation was not evident for most metals, the majority of metals in samples were found in higher concentrations after rain events. This has been reported previously in Port Curtis, with elevated total metals exhibited after the January 2011 and 2013 flood events (Vision Environment 2013b). A number of metal concentrations were significantly correlated with total suspended solids, with higher metal concentrations recorded in samples from inshore sites compared to offshore sites. Overall, concentrations of total metals were higher than dissolved metals, indicating metals were predominantly bound to particulates.

Water quality objectives for metals for Port Curtis have been set by the Department of Environment and Heritage Protection (2014), with the majority of these originally established in the National Water Quality Management Strategy and Australian Water Quality Guidelines (ANZECC/ARMCANZ 2000). Previously, the Australian Water Quality Guidelines 95% protection level was applied to all inshore sites, whereas the Australian Water Quality Guidelines 99% protection level was considered more appropriate for reference or offshore sites. Due to the establishment of new water 'areas' or 'zones' under the *Environment Protection (Water) Policy 2009*, and the use of more stringent guidelines in certain zones, a number of monitoring parameters at QE3 were above the water quality objectives for The Narrows zone. Concentrations of total aluminium and copper were also recorded above water quality objectives in samples from other inshore sites P2B/WB50 and P5/MH10. However, dissolved concentrations remained well below the water quality objectives at each site. Although exceedances of the Australian Water Quality Guidelines for several total metals in Port Curtis have been recorded previously (Vision Environment 2010, Vision Environment 2012a, Vision Environment 2013f), the majority of dissolved (and therefore potentially bioavailable metals), have generally been below Australian Water Quality Guidelines and therefore are not considered current contaminants of concern for this Project.

Organic contaminants are those containing carbon and include herbicides, pesticides and hydrocarbons. Organic compounds were measured quarterly under this program and were not detected at any site, on any occasion. Historically, low levels (mostly below laboratory detection limits) of organic compounds have been measured in Port Curtis sediments (Melville et al. 2007), and therefore are not considered current contaminants of concern for this Project.

The baseline water quality monitoring program has provided a comprehensive overview of the marine environment within the Project area of interest. Notably, it has also provided a comprehensive understanding of water clarity, sedimentation, the benthic light environment, and nutrient and contaminant concentrations, since the completion of the Western Basin Dredging and Disposal Project. Interestingly, results were found to be similar to those historically recorded during previous monitoring programs. This suggests that the key drivers for the measured environmental variables remains as previously identified. Variables such as season, wind speed, tidal cycles and extreme weather events are the main forces influencing environmental conditions and water quality in Port Curtis.

1 INTRODUCTION

Water quality monitoring undertaken by Vision Environment (VE) for Gladstone Ports Corporation Limited (GPC) commenced on 1 June 2014, to provide interpreted water quality baseline data to support the process of the Environmental Impact Statement (EIS) for Port of Gladstone Gatcombe and Golding Cutting Channel Duplication Project (the 'Project').

The dredging component of the Project involves duplicating the Gatcombe and Golding Cutting bypass channels to provide a duplicate channel parallel to the main shipping channel promoting an improved two-way passage. The location of the existing bypass channels is shown in Figure 2.1. The proposed duplicate channel will be approximately 14km long and dredging is proposed to be undertaken to an ultimate depth of 16.1m lowest astronomical tide (LAT), with a channel width (toe to toe) of 200m. The channel footprint is approximately 382ha, however, due to the existing bathymetry in the Port of Gladstone, the total area requiring dredging (i.e. above -16.1m LAT) is less, being 247.8ha. This equates to approximately 12.6Mm³ of seabed material (including dredging tolerance), requiring removal during the capital dredging program.

A Dredged Material Placement Options Investigation and subsequent option assessment analysis have been undertaken as part of the EIS. This investigation and analysis process identified a number of preferred Dredge Material Placement Areas (DMPAs) to be investigated as part of the EIS process. At the commencement of this monitoring program, four DMPAs options were being considered.

The baseline water quality monitoring program was proposed to address the Queensland Government's EIS Terms of Reference (ToR) and Commonwealth Department of the Environment (DoE) 'Guidelines for an EIS' requirements, to describe the existing water quality environment of the potential Project direct and indirect impact areas (the potential Project impact area). The potential Project impact area has been defined as the area to be dredged, DMPAs, new navigational aid locations and adjoining areas, within the potential zones of impact (Aurecon 2014).

The comprehensive water quality component of the programme involved the monitoring of:

- Physicochemistry including turbidity, temperature, pH, conductivity and dissolved oxygen (DO)
- Benthic Photosynthetically Active Radiation (BPAR)
- Total Suspended Solids (TSS)
- Sedimentation rates
- Nutrients including chlorophyll a
- Metals (total and dissolved)
- Organic contaminants.

This report presents data collected from 1 June to 4 July 2015. A summary of climatic conditions (wet season: 1 November to 30 April and dry season: 1 May to 31 October as defined by the Department of Environment and Heritage Protection (EHP) (2014) and the Department of Science, Information Technology, Innovation and the Arts (DSITIA) (2014)) during this period is provided, including an interpretation of the driving factors that may influence the Port Curtis marine environment, in addition to a comparison of results with appropriate water quality guidelines for reference purposes. An additional eight months of preliminary monitoring data from site P5/MH10 (October 2013 to May 2014) prior to the commencement of the Project baseline monitoring program, can also be found in the Appendix 6.1.

2 METHODOLOGY

2.1 Site selection

The location of baseline water quality monitoring sites was guided by the results of preliminary hydrodynamic modelling (Aurecon 2014). Sites were located within the zone of dredging and dredged material placement influence, while others were located outside of the area of predicted direct impact (i.e. area to be dredged and DMPAs). All sites were in the vicinity of known sensitive receptors (i.e. seagrass and/or coral reef).

Five offshore sites (CD1, CD2, CD3, CD4 and CD5) and two inshore sites (P2B/WB50 and P5/MH10) were established in June 2014 for the Project baseline water quality monitoring program. However, water quality data was collected from site P5/MH10 from the end of the Western Basin Dredging and Disposal Project (WBDDP) in October 2013 up to the commencement of the current Project baseline data collection period (refer Appendix 6.1). An additional inshore site in The Narrows (QE3) was established for monitoring in January 2015 to assist in providing additional water quality information in the vicinity of The Narrows and Western Basin areas (refer Table 2.1, Figure 2.1). The monitoring sites are located in two different but connected water type sub regions (open coastal waters and enclosed coastal waters/lower estuary) as defined under Schedule 1 of the *Environmental Protection (Water) Policy 2009* (EPP (Water)) on Plan WQ1312 (EHP 2014).

Table 2.1 Locations and depth of water quality monitoring sites

Site	Coordinates (WGS84)	Location description	Average depth (m)
QE3	S23 42.965, E151 08.574	Adjacent to Worthington Island in The Narrows	5.2
P2B/WB50	S23 47.029, E151 18.388	Outside the mouth of the Calliope River	4.8
P5/MH10	S23 48.289, E151 12.547	Adjacent to Pelican Banks seagrass meadows	4.5
CD1	S23 57.469, E151 30.115	Adjacent to Seal Rocks	8.5
CD2	S23 52.017, E151 24.380	Off East Point off Facing Island	6.3
CD3	S23 54.989, E151 21.569	Located outside the mouth of the Boyne River	7.0
CD4	S23 46.269, E151 22.639	Off the eastern side of Facing Island, adjacent to Pearl Ledge	16.8
CD5	S23 50.187, E151 27.153	Off the eastern side of Facing Island, 3km northwest of East Banks DMPA	17.8

Table 2.2 summarises the field instrumentation utilised at each of the monitoring sites. The offshore monitoring area (includes monitoring sites CD1 to CD5) is a deep water (generally > 10m) oceanic environment with turbidity being highly driven by wind speeds and wave heights, causing resuspension of material from the benthos. The use of surface water quality loggers only may not have been sufficient to detect all resuspension events and thus benthic water quality loggers were concurrently utilised. The concurrent measurement of BPAR was required to determine the light environment at subtidal seagrass and coral habitats in the vicinity of these sites.

The inshore monitoring area (including monitoring sites QE3, P2B/WB50 and P5/MH10) is a shallow environment (average ~ 5m depth at monitoring sites), highly tidally influenced and with a large tidal run (~ 0.4m/s). Historical depth profiling confirms the water column is well mixed at these sites with sub-surface measurements being similar to those above benthos, including little to no stratification after rain events (Vision Environment 2013b). Therefore only surface water quality loggers were required at inshore sites. As BPAR was already being monitored at intertidal seagrass meadows in the vicinity of these sites under the marine ecology component of the Project (Davies et al. 2015), BPAR measurements were not required at these inshore monitoring sites.

2.2 Telemetered water quality loggers

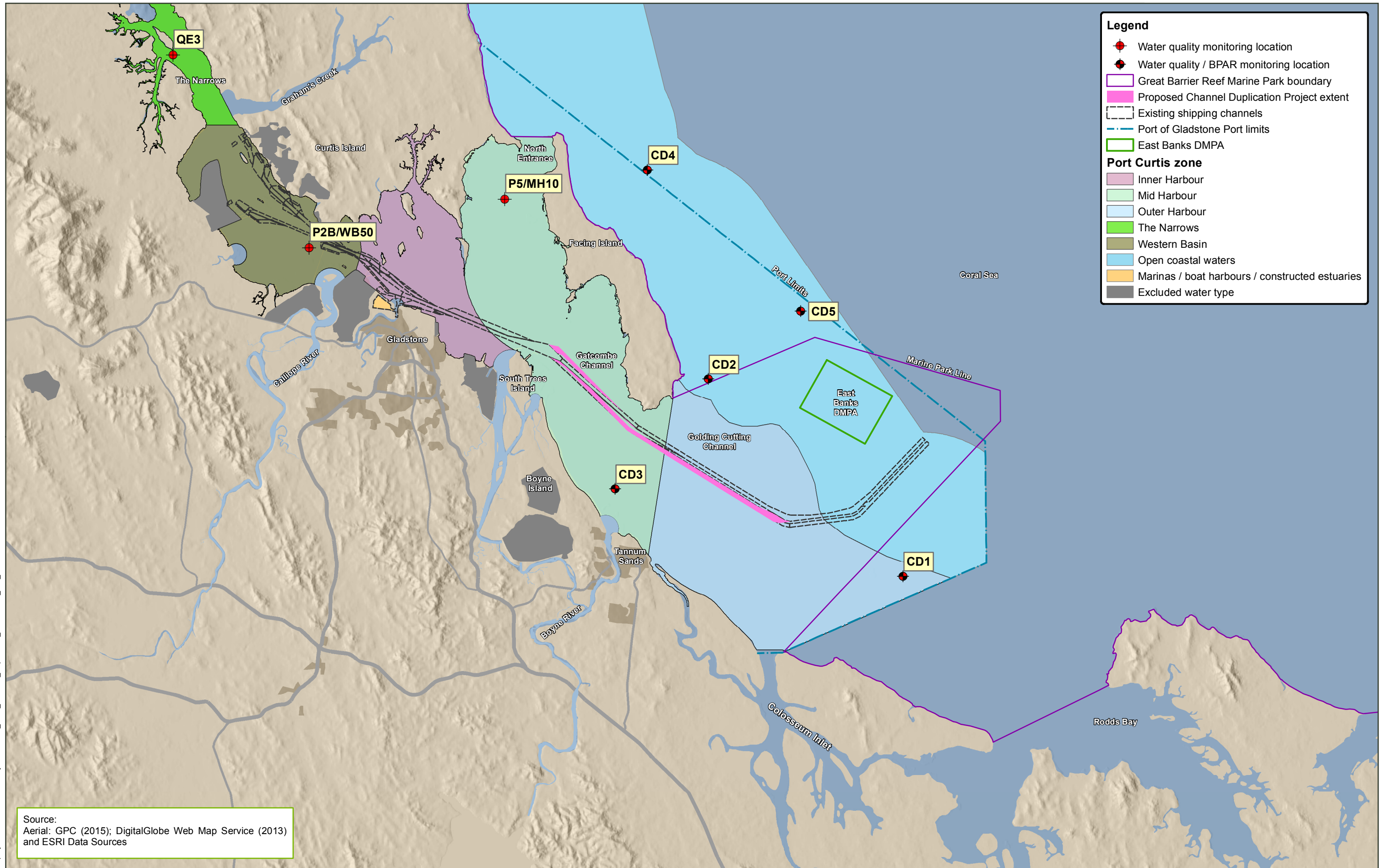
2.2.1 Field instrumentation

For surface water quality logging, two Aqualab DS5X sondes, each encased in a copper sheathed cage, were placed into secured, antifouled PVC tubes, which were inserted into the base of a modified Special Marker buoy at each site (refer Photograph 2.1). The loggers were programed to record temperature (°C), conductivity (mS/cm), pH, turbidity (Nephelometric Turbidity Units (NTU)) and DO (% saturation) at approximately 0.75 m below the surface.

Telemetered loggers were attached to solar powered telemetry units installed within the modified special marker buoy. Parameters were logged every 15 minutes and data transferred via telemetry to the VE cloud database every 30 minutes. The self-cleaning unit was set to wipe the probes prior to each data log. All loggers were scheduled to be exchanged fortnightly or as required based on examination of real time data.



Photograph 2.1 Dual telemetered data logger surface station offshore



P:\GIS\Projects\237374_GPC_Channel_Duplication_EIS\237374_EIS_083.mxd 10/03/2016 12:00
Map by RB



0 2,250 4,500 Metres

Date: 09/02/2016 Version: 1 Job No: 237374
Coordinate system: GDA_1994_MGA_Zone_56

Gatcombe and Golding Cutting Channel Duplication Project

Figure 2.1: Location of Project baseline water quality monitoring sites

Table 2.2 Field instrumentation at water quality sites

Site	Surface water quality loggers	Benthic water quality loggers	BPAR	Sedimentation
QE3	✓			✓
P2B/WB50	✓			✓
P5/MH10	✓			✓
CD1	✓	✓	✓	✓
CD2	✓	✓	✓	✓
CD3	✓	✓	✓	✓
CD4	✓	✓	✓	✓
CD5	✓	✓	✓	✓

Table note: Surface and benthic water quality loggers include measurement of turbidity, temperature, pH, conductivity and DO.

For the benthic loggers, two loggers were secured into a benthic frame, recording parameters approximately 1m above the benthos (refer Photograph 2.2) and transmitting data to the surface telemetry unit via an umbilical. Unfortunately, the umbilical system did not prove to be as robust as required during major storm events, with frequent breakdown of the benthic transmission. In order to gain more reliable data, autonomous benthic loggers were utilised beginning in January 2015 until the end of monitoring in July 2015. Dual loggers were placed in the benthic frame and were programed to log every 15 minutes, with data recorded within the sonde. Sondes were exchanged each fortnight and the recorded data downloaded.

**Photograph 2.2 Dual data logger/dual BPAR telemetered benthic station**

Each logger was calibrated and tested prior to deployment as per the VE Health, Safety, Environment and Quality (HSEQ) Management System (MS) protocols (Vision Environment 2013a). Calibration methodology included two-point calibrations for turbidity (1 and 20 NTU), conductivity (0 and 56.9mS/cm), pH (7 and 10), in addition to a one-point calibration for DO (100% saturation at ambient atmospheric pressure). Post-calibration testing involved a logtest of turbidity in a 10 NTU solution logging at 5 minute intervals for a one to two hour period. Turbidity values at 10 NTU $\pm$ 1 NTU during the logtest were considered acceptable.

2.2.2 Data management

Management of water quality logger data was undertaken as per VE HSEQ MS protocols, developed and peer reviewed during the three year WBDDP, and Narrows Crossing project (Vision Environment 2013f). All physicochemical data was uploaded to the VE cloud database either automatically for real time data or manually for autonomous data. A Self-Monitoring Algorithm in Real Time (SMART) was developed by VE as an initial automatic data deconfounding process in order to filter out erroneous raw real time data from multiple instruments, to provide a more accurate and instantly usable real time data set. Following automated deconfounding, SMART data was manually validated and reissued by VE personnel for final reporting after having undergone VE Quality Assurance/Quality Control (QA/QC) review. In most cases, the SMART data did not need altering. However, there were some instances where data was removed from the utilised dataset incorrectly, in which case it was inserted back into the dataset.

Erroneous data was identified using the following procedures as per VE HSEQ MS protocols:

- Turbidity
 - Continually increasing turbidity values (suggesting fouling)
 - Large drop or increase in turbidity on subsequent logger exchange
 - Continuous zeros recorded indicating probe malfunction. Note that continuous zero readings were often recorded at offshore sites, as the low turbidity at these sites was often at the lower limit of instrument capability. At offshore sites, continuous zeros were not considered erroneous, but data was compared to other loggers, other sites and weather conditions to confirm this reading
 - Intermittent, erratic values, either markedly higher or lower than the majority of values recorded at that time and inconsistent with previous trends.
- pH
 - pH values outside the typical lower estuarine and marine conditions (7.3 to 8.4), unless both loggers were showing pH outside this range, indicating a valid result
 - Where a logger had a conductivity result of zero (e.g. logger having been removed from the water during logger exchange), SMART automatically moved the pH data from the dataset.
- Conductivity
 - Conductivity values outside the typical lower estuarine and marine conditions (50 to 58mS/cm), unless both loggers were showing conductivity outside this range, indicating a valid result (e.g. during a rain event) it was not moved by SMART
 - If the difference between two of the loggers was 5mS/cm or greater, the value closest to 55mS/cm was kept, and the alternate values moved by SMART and identified as erroneous. However, this was manually checked and confirmed by VE personnel. Note that the 5mS/cm difference was based on $\pm 5\%$ difference between readings, which was slightly higher than the Hydrolab DS5X sensor accuracy, which is reported at 1%.
- Dissolved oxygen
 - Oxygen values outside the typical lower estuarine and marine conditions (70 to 120%), unless both loggers were showing DO outside this range, indicating a valid result
 - If the difference between two of the loggers was 5% or greater, the value closest to 100% saturation was kept, and the alternate values were moved by SMART and identified as erroneous. However, this was manually checked and confirmed by VE personnel. Note that the 5% difference was slightly higher than the Hydrolab DS5X

sensor accuracy, which is reported at 1% at concentrations < 8mg/L (or 100% saturation at 25°C).

- Where a logger has a conductivity result of zero (e.g. logger has been removed from the water during logger exchange), SMART automatically moved the DO data from the dataset.
- Temperature
 - Where a logger has a conductivity result of zero (e.g. logger has been removed from the water during logger exchange), SMART automatically moved the temperature data from the dataset.

Monthly and seasonal (wet season: 1 November to 30 April; dry season: 1 May to 31 October as per EHP (2014) and DSITIA (2014)) statistics were calculated for each site, including means, standard errors, ranges and percentiles. When plotting results a smoothing technique was applied. The 6 hourly Exponentially Weighted Moving Average (EWMA) was a weighted average of (i) the mean of the edited turbidity data for the previous 6-hour period and (ii) the previous EWMA. The weights applied to these two components are 0.6 and 0.4, respectively. This approach, utilised as part of the WBDDP water quality monitoring program (Vision Environment 2013f), removes outliers while maintaining true data trends, but also incorporates an element of background history to the calculations.

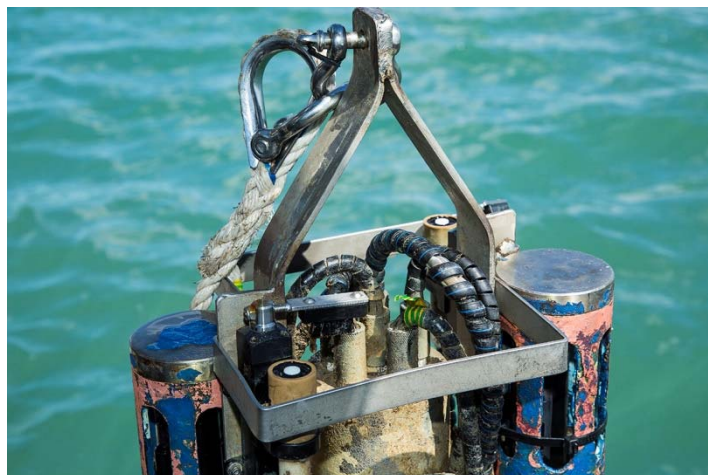
One and two-way analyses of variance ($p < 0.05$, 95% confidence intervals) were used to determine statistical differences in water quality parameters among sites, depth (surface and benthos), and seasons (wet season and dry season). Data were tested for homogeneity of variance and normality. Significance levels were increased ($p < 0.01$, 99% confidence intervals) where data did not meet that criterion (O'Neill 2000, Underwood 1997). In order to determine where significant differences among the four locations were, Fisher's Least Significant Difference (LSD) Post hoc tests were used to elucidate any differences among sites. Linear regressions were performed between surface and benthic turbidity to determine whether they varied similarly.

2.3 Telemetered BPAR

2.3.1 Field instrumentation

Telemetered BPAR units were located at the five offshore sites (CD1 to CD5). BPAR was recorded using dual LI-COR LI192SA Underwater Quantum Sensors (light loggers), which were attached to the benthic frame running concurrently with the dual benthic data loggers (refer Photographs 2.2 and 2.3). BPAR was logged every 15 minutes (averaged from 1 minute readings) with data transferred to the cloud database every 30 minutes. Wiper units were also attached to the frames and set to clean the light sensors every 15 minutes. Data were transferred to the surface telemetry unit via an umbilical.

Similar to the water quality loggers, autonomous light loggers (Odyssey submersible photosynthetically irradiance recording system with self-cleaning wipers) were utilised beginning in January 2015 until the end of monitoring in July 2015, due to umbilical transmission failure. The Odyssey loggers were placed in the benthic frame alongside the water quality loggers and programed to record at 15 minute intervals, with data recorded within the logger. Loggers were exchanged each fortnight and the recorded data downloaded at the VE base.



Photograph 2.3 Offshore dual data logger/dual BPAR telemetered benthic station

In order to record daily ambient changes in total available PAR, a telemetered light logger also operated at VE base in Gladstone. The inclusion of the VE base data allowed for variation in daily ambient PAR (e.g. due to cloud cover) to be accounted for, thus aiding in the interpretation of BPAR levels within Port Curtis waterways and acting as a 'control' PAR site. The VE base loggers recorded decreased levels of sunlight during overcast days, which assisted in the interpretation of some fluctuations in BPAR within Port Curtis. While small scale daily weather patterns such as scattered cloud were not consistent throughout Port Curtis, substantial overall daily changes were recorded and significant reductions in ambient PAR could be accounted for.

2.3.2 Data management

Management of BPAR logger data was undertaken as per VE HSEQ MS protocols. All BPAR data was uploaded to the VE cloud database either automatically for real-time data, or manually for autonomous data. BPAR values from each logger during the non-daylight period (according to sunrise and sunset times reported by Geoscience Australia (2015)) were zeroed. Erroneous data was removed from the dataset. Subsequent calculations were based on the mean BPAR recorded from both loggers. The mean logger readings at 15 minute intervals were summed to calculate total daily BPAR in moles per square metre per day ($\text{mol/m}^2/\text{day}$). Once the data was deconfounded, monthly and seasonal statistics were calculated for each site, including means and standard errors (se), and medians.

Erroneous data was identified by the two loggers differing by more than 20%. When this occurred, data from both loggers was flagged and examined. If the difference between the loggers persisted for a number of hours, or values were inconsistent with other BPAR sites, the data was considered erroneous. The 20% value was assigned assuming that a variance of $\pm 10\%$ is acceptable between loggers. Additionally, when the daily totals for each site were inconsistent with neighbouring sites and with previous trends, data was further investigated.

Similar to the continuous loggers, one and two-way analyses of variance were used to determine statistical differences in BPAR among sites and seasons. Data were tested for homogeneity of variance and normality, and significance levels increased where data did not meet that criterion (O'Neill 2000, Underwood 1997). Fisher's LSD Post hoc tests were also used. Linear regressions were performed between BPAR and turbidity to determine whether they varied similarly.

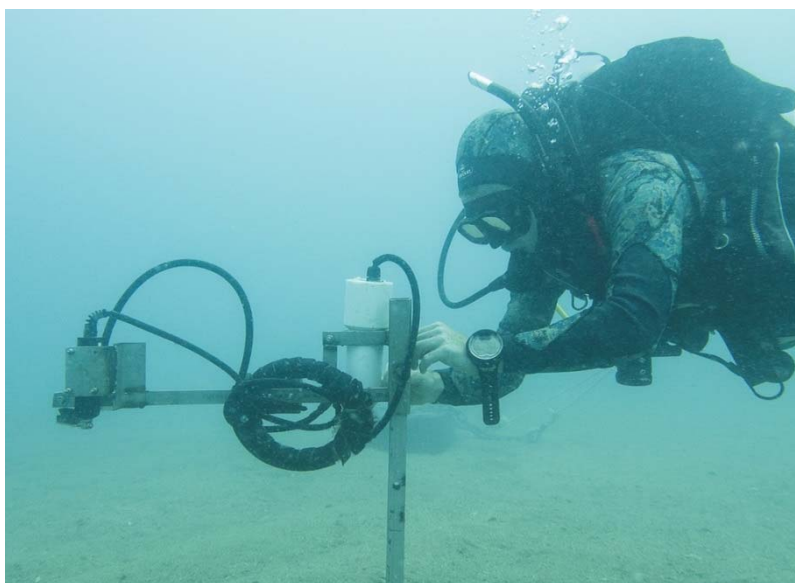
2.4 Altimeters

2.4.1 Field instrumentation

Continuous bed level measurements (sedimentation rates) were obtained using acoustic altimeters. The ALTUS altimeter is an autonomous instrument that obtains very high precision bed level measurements (millimetre scale) every 15 minutes, using a high frequency acoustic sensor and an inbuilt data logging device.

Altimeters were positioned between 300 and 700mm above the seabed at each site. Wipers were also installed to eliminate transducer interference caused by fouling. Distance to seabed data was recorded on four separate channels, each with unique detection threshold settings (11%, 23%, 39% and 70%). Threshold 1 (11%) was considered most useful in measurement of a non-homogenous medium such as found in Port Curtis (mix of silt, sand and gravel sediment fractions). Additional channels measured depth using an inbuilt pressure sensor to aid in data interpretation, and max echo to aid in data validation.

For the first three deployment periods in June to July 2014, altimeters were mounted on a frame system. However, it was found that gradual sinking of the frame into the soft sediments over the deployment period was occurring, providing some erroneous data and suggesting falsely elevated deposition rates. This problem was successfully corrected by altering the mounting system to a fixed stake on the seabed, designed to minimise turbulence (refer Photograph 2.4). Site QE3 was deployed in early January 2015 for the last half of the monitoring program. Due to diver safety restrictions at QE3, a modified drop down deployment frame was used at this site. Altimeters were downloaded and exchanged on a monthly basis, or when diving conditions permitted.



Photograph 2.4 Altimeter on fixed stake deployed by diver

2.4.2 Data management

Management of altimeter data was undertaken as per VE HSEQ MS protocols. Altitude data was produced every 15 minutes from threshold outputs. When insufficient echo was received back from the seafloor to produce a valid altitude reading, negative readings were logged. These readings were removed prior to further examination of the data.

Altitude data was used to analyse surficial sediment deposition and erosion. Instantaneous bed level change (change from the reading 15 minutes prior) was calculated, in addition to cumulative bed level change (calculated every 24 hours) per deployment period. Erroneous data was removed from the dataset using the following identifiers:

- Instantaneous sediment change > 50mm in 15 minutes;
- Rapid cumulative change beyond an acceptable level expected to be triggered by environmental factors, and
- Problems with the deployed unit observed upon altimeter retrieval and download (e.g. stake bent, fallen over, rope entanglement). The date upon which this occurred could usually be identified in the dataset using the points above.

When interference with marine organisms occurred, the period of erroneous data removal was often small, with data returning to expected levels within a short period. Longer term interferences, such as deployment unit problems, generally resulted in the data being removed for the remaining deployment period.

2.5 Discrete water sampling

Water sampling, including discrete physicochemical measurements and collection of samples for analysis, was carried out monthly at each monitoring site (refer Table 2.3). Sampling methodologies were as per VE HSEQ MS protocols, which were derived from worldwide authorities, including:

- Australian and New Zealand Standards for water quality sampling ((AS/NZS 1998a, AS/NZS 1998b, AS/NZS 1998c, AS/NZS 1998d)
- American Public Health Association Standard Methods for the Examination of Water and Wastewater (APHA 2005)
- Australian and New Zealand Water Quality Guidelines (ANZECC 1992, ANZECC 1998, ANZECC/ARMCANZ 2000)
- Queensland Water Quality Guidelines (DERM 2009)
- EHP Monitoring and Sampling Manual (DERM 2010)

Table 2.3 Summary of discrete water sampling at water quality monitoring sites

Site	Depth profiling	Sub-surface metals & nutrients	Sub-surface organics	Sub-surface TSS	Mid-column & benthic TSS
QE3	Monthly	Monthly	Quarterly	Monthly	-
P2B/ WB50	Monthly	Monthly	Quarterly	Monthly	-
P5/MH10	Monthly	Monthly	Quarterly	Monthly	-
CD1	Monthly	Monthly	Quarterly	Monthly	Monthly
CD2	Monthly	Monthly	Quarterly	Monthly	Monthly
CD3	Monthly	Monthly	Quarterly	Monthly	Monthly
CD4	Monthly	Monthly	Quarterly	Monthly	Monthly
CD5	Monthly	Monthly	Quarterly	Monthly	Monthly

2.5.1 Light attenuation

Down-welling PAR measured in micromoles per square metre per second ($\mu\text{mol}/\text{m}^2/\text{s}$) was measured through the water column at 0.5m depth intervals using a LI-COR LI192SA Underwater Quantum Sensor in a lowering frame and a LI-189 Quantum Radiometer Photometer until light was $< 10\mu\text{mol}/\text{s}/\text{m}^2$ (refer Photograph 2.5). The vertical light attenuation coefficient (K_d) was calculated in order to compare light attenuation through the water column at different sites and on different sampling occasions.

2.5.2 Depth profiling

Physicochemical parameters (i.e. temperature, conductivity, pH, DO and turbidity) were measured (concurrently with the light measurements) to the benthos, using a YSI 6820 multi-parameter water meter (refer Photograph 2.5). Triplicate sub-surface readings (0.5m depth) were recorded at each site.



Photograph 2.5 **Measurement of physicochemical parameters**

2.5.3 Water sample collection

Samples were collected using pre-acid washed Nalgene bottles (triple rinsed in Milli-Q and site water) in a Perspex pole sampler (refer Photograph 2.6). Samples for all analysis parameters were collected at the sub-surface (0.5m depth). At the five offshore sites, TSS samples were also collected at mid-column and above benthos, using a Van Dorn sampler (refer Photograph 2.7).

For samples which did not require filtration (TSS, total metals, total nutrients, chlorophyll a and organics), water samples were decanted directly into the laboratory provided sample bottles. Samples which required filtration (dissolved metals and nutrients) were filtered, in situ, through a $0.45\mu\text{m}$ sterile surfactant free cellulose acetate membrane syringe filter (Minisart 16555K)

into the laboratory provided sample bottle, with the syringe, filters and bottles also pre-rinsed in site water as appropriate (refer Photograph 2.8).



Photograph 2.6 **Collection of water samples for analysis using Perspex Pole sampler**



Photograph 2.7 **Collection of water samples for analysis using the Van Dorn sampler**

Samples were placed on ice for transport to the analysing laboratory, with filtered nutrient samples frozen overnight in order to prolong sample holding times. For chlorophyll a samples, the short holding time (48 hours) of the water sample means that pre-processing needed to occur at the VE laboratory. Chlorophyll a samples were filtered within 24 hours of collection, through 0.45µm glass fiber filters, using a manifold and vacuum pump, with the volume of water passed through the filter recorded in accordance with APHA method 12000H (APHA 2005). Filter papers were folded, and stored in airtight plastic bags and stored frozen thus extending their holding period to 28 days.



Photograph 2.8 Filtering of water samples

Duplicate water samples for all parameters were collected at 10% of sites as per established protocols, with a field and laboratory blank collected per sampling day. Analytical laboratory quality control measures included laboratory duplicates, laboratory blanks, analysis of certified reference material and matrix spikes. Both monthly and seasonal data were tabulated for each parameter for each site.

2.5.4 Data management

Similar to the continuous loggers and BPAR, one and two-way analyses of variance were used to determine statistical differences in water quality parameters among sites and seasons. Data were tested for homogeneity of variance and normality, and significance levels increased where data did not meet that criterion (O'Neill 2000, Underwood 1997). Fisher's LSD Post hoc tests were also used. Linear regressions were performed between individual water parameters and turbidity to determine whether parameters varied similarly.

2.6 Water quality guidelines and objectives

Historically, water quality monitoring data from Port Curtis has been compared to Queensland Water Quality Guidelines (QWQG) and Australian Water Quality Guidelines (AWQG) (ANZECC/ARMCANZ 2000, DERM 2009). While the AWQG include aquatic ecosystem water quality guideline values (numbers) for broad water regions and water types, it recommends that wherever possible, local guidelines should be developed. DSITIA and EHP have therefore assigned environmental values (EVs) and developed local water quality objectives (WQOs) for the Capricorn-Curtis Coast Region using available water quality data (DSITIA 2014, EHP 2014).

Schedule 1 of the EPP (Water) lists the EVs and WQOs for Queensland waters, including those for Curtis Island, Calliope River and Boyne River Basins (Basins 131, 132 and 133, including all waters of Gladstone Harbour, The Narrows, Curtis Island, Calliope River and Boyne River Basins, and adjacent coastal waters) (EHP 2014). Plan WQ1312 of Schedule 1 of the EPP (Water) also outlines water types and areas/zones along with EVs and the current management intent of these waters.

WQOs are numerical concentration levels or narrative statements of indicators established for receiving waters to support and protect the designated EVs for those waters (DSITIA 2014). WQOs are long term goals for water quality management and are used to help set

development conditions, influence local government planning schemes and underpin report card grades for ecosystem health monitoring programs like the Gladstone Healthy Harbour Partnership and other similar programs (DSITIA 2014).

For the purposes of this EIS technical report water quality results, which represent ambient baseline conditions across eight sites in Port Curtis from June 2014 to July 2015, have been compared against WQOs for reference purposes only, as this EIS baseline data has the potential to be utilised in refining the Gladstone Harbour WQOs. Where there is no local WQO provided, results have been compared against QWQG and AWQG as a default (DSITIA 2014). Baseline water quality data collected for the Project has the potential to be used in the development of Project specific water quality triggers, to be implemented during dredging and dredged material placement works, taking into account the assigned EHP WQOs.

Table 2.4 outlines the Project water quality monitoring sites and their respective water zone for Gladstone Harbour and The Narrows as per the EPP (Water) Schedule 1 (DSITIA 2014 and EHP 2014).

Table 2.4 Project water quality monitoring sites, corresponding water area/type and management intent

Site	Water area	Management intent/level of protection
QE3	The Narrows (SD2442)	Slightly disturbed
P2B/WB50	Western Basin (MD2421)	Moderately disturbed
P5/MH10	Mid Harbour (MD2423)	Moderately disturbed
CD1	Outer Harbour (MD2424)	Moderately disturbed
CD2	Coastal waters outside Gladstone Harbour east and south of Facing Island	Slightly to moderately disturbed
CD3	Mid Harbour (MD2423)	Moderately disturbed
CD4	Coastal waters outside Gladstone Harbour east and south of Facing Island	Slightly to moderately disturbed
CD5	Coastal waters outside Gladstone Harbour east and south of Facing Island	Slightly to moderately disturbed

Table note: Source EHP (2014)

EHP (2014) states that the median water quality value should be compared against the WQO, when multiple WQOs are provided (e.g. 20th, 50th and 80th percentile values). However, when only a single WQO value is provided, such as for most parameters in the coastal waters zone, these should be compared to the mean value. Given a mix of areas/zones have been monitored in this project, for ease of comparison both the mean and median values for results have been used to compare against WQOs at all sites.

WQOs have been derived for both baseflow and event flow in Gladstone Harbour and The Narrows. The WQOs that baseline results have been compared to in this report apply to baseflow conditions only. Schedule 1 of the EPP (Water) outlines the WQOs which apply during event flows, relative to peak discharges at the Castlehope gauging station (132001A). Time periods after which baseflow WQOs are to be applied to waters, following an event, are also outlined in Schedule 1 (EHP 2014).

3 RESULTS AND DISCUSSION

3.1 Climatic conditions

During the 13 month baseline monitoring period of 1 June 2014 to 4 July 2015, approximately 849mm of rainfall was recorded in Gladstone (refer Table 3.1, Figure 3.1), slightly below the average annual rainfall (1957 to 2015) of 893mm (BOM 2015). Overall > 100mm of rainfall was recorded per month during the wet season months of December 2014 (155mm), January 2015 (249mm) and February 2015 (128mm), while < 50mm per month was recorded from June to November 2014, and March, May and June 2015.

Table 3.1 Monthly rainfall recorded at Gladstone during baseline monitoring period compared to long-term averages.

Month	Rainfall (mm)	
	Baseline period (2014 to 2015)	Long-term average (1957 to 2015)
June	9.8	37.5
July	2.0	33.5
August	36.0	32.0
September	49.2	26.9
October	14.2	58.1
November	30.0	71.6
December	155.2	130.3
January	248.8	153.5
February	127.8	144.6
March	36.2	94.0
April	57.4	49.0
May	33.0	57.4
June	49.6	37.5

Table note: Source (BOM 2015)

Inshore winds generally ranged between 0 and 40km/hr, with the highest winds of the monitoring period experienced on 20 February, with gusts of up to 89km/hr recorded (BOM 2015). At this time, severe Tropical Cyclone (TC) Marcia made landfall as a category five system near Shoalwater Bay to the north of Gladstone, bringing almost 100mm of rainfall over a three day period to the Gladstone area. Wave heights were also considerably higher than typical at this time (2.1 Hsig), compared to 0.4 to 0.9 Hsig (20th to 80th percentile range) recorded throughout the monitoring period (refer Figure 3.1).

Overall, ambient air temperature ranged from 12.9°C in July 2014 (mean minimum temperature) to 32.3°C in February 2015 (mean maximum temperature), a slightly wider range than historical averages of 13.4°C to 31.3°C (BOM 2015). Spring tides associated with the new and full moon periods generally occurred bimonthly, alternating with neap tide periods. The highest tidal range of the monitoring period occurred on 19 February 2015 (4.44m), just prior to the landfall of TC Marcia.

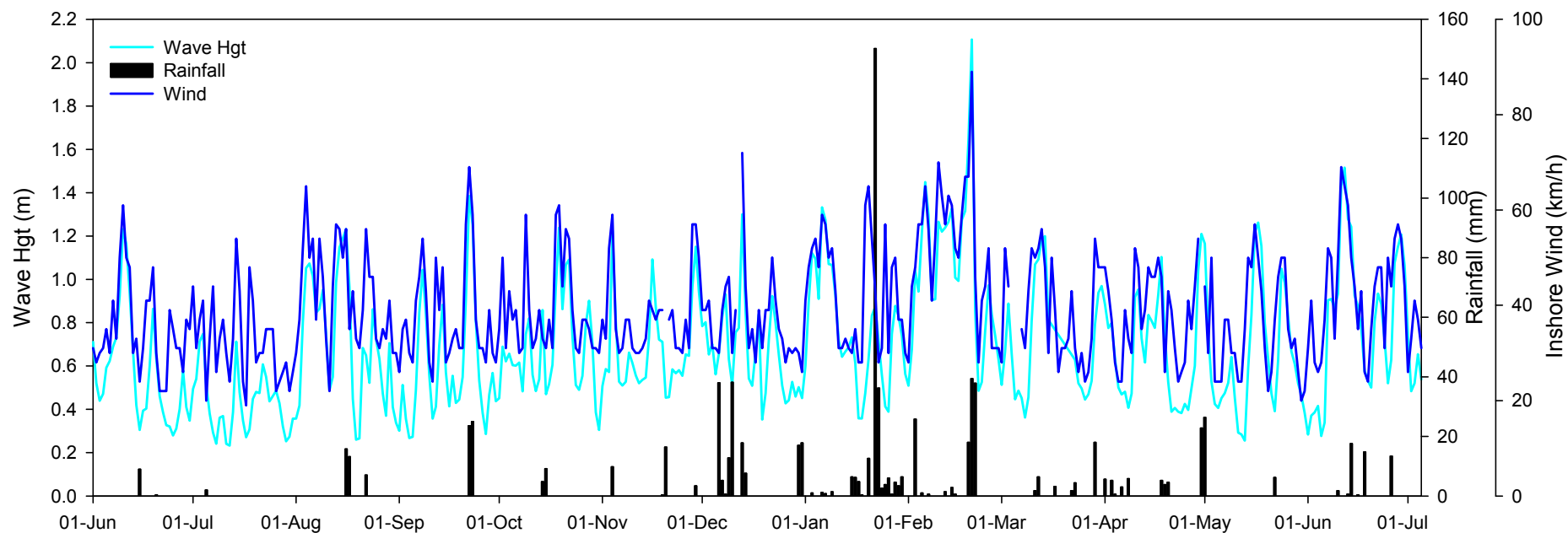


Figure 3.1 Rainfall, wave height and inshore wind at Port Curtis during the 2014/2015 monitoring period 1 June 2014 to 4 July 2015

Figure note: Source (BOM 2015)

3.2 Physicochemistry

Water physicochemistry was measured by continuous loggers located at eight sites, with dual surface loggers at all eight sites and dual benthic loggers at the five offshore sites (CD1 to CD5). Mean seasonal turbidity, temperature, pH, conductivity and DO results are reported in Tables 3.3 to 3.7, while benthic and surface values at the sites from continuous loggers are exhibited in Figures 3.2 to 3.26. Mean monthly values are tabulated in the Appendix 6.2 (refer Tables 6.5 to 6.9), as is depth-profiling data (refer Table 6.10).

Validated continuous data was utilised for further statistical analyses in order to calculate actual useable data retention. Mean validated (thus useable as opposed to raw collected) data retention across the 13 month period ranged between 83 (benthic/self-logging) and 98% (telemetered) per site (refer Table 3.2). Monthly validated data retention ranged up to 100% (refer Table 6.4 in Appendix 6.2), indicating a very high data retention rate. Raw data capture (prior to deconfounding erroneous values and validation) was greater than 95% across the sites. Episodes of data loss were generally rectified within a 72 hour period.

Table 3.2 Validated (useable) data retention rate at water quality monitoring sites

Site	Validated (useable) data retention rate (%)	
	Surface	Benthic
QE3	95	-
P2B/WB50	97	-
P5/MH10	96	-
CD1	96	92
CD2	98	83
CD3	93	94
CD4	94	84
CD5	89	88

Table note: Values are mean retention rate across the thirteen month monitoring period

3.2.1 Turbidity

Turbidity is a measurement of water clarity and is caused by suspended and colloidal matter, such as sediments and other organic and inorganic matter. Turbidity is an expression of the optical property of light to be scattered and absorbed rather than transmitted through the water sample (APHA 2005), with a greater amount of matter within the water column leading to a higher amount of light scattering, and thus higher turbidity. Measured in NTU, turbidity is an important parameter to measure during dredging and dredged material placement works because suspended sediments in the water column have the potential to increase. As such dredging licence conditions often focus on turbidity trigger values.

Of particular interest are the continuous surface and benthic turbidity measurements at each site (refer Table 3.3). Surface turbidity can be compared across all eight sites, while benthic turbidity can be compared across the five offshore sites (CD1 to CD5). Turbidity at sites was also compared across seasons: wet season (1 November to 30 April) and dry season (1 May to 31 October) as per EHP (2014) and DSITIA (2014), and to applicable WQOs (DSITIA 2014, EHP 2014).

Table 3.3 Mean seasonal turbidity at water quality logger sites

Site	Statistic	Dry Season			Wet Season		
		Surface	Benthic	WQO	Surface	Benthic	WQO
QE3	Mean $\pm$ se	7.0 $\pm$ 0.0	-		8.3 $\pm$ 0.1	-	
	Range	<1 – 77	-		<1 – 520	-	
	20 th	3.8	-	4	1.1	-	8
	50 th (Median)	7.3	-	7	3.8	-	15
	80 th	9.4	-	12	9.9	-	30
P2B/WB50	Mean $\pm$ se	9.0 $\pm$ 0.1	-		7.2 $\pm$ 0.1	-	
	Range	<1 – 138	-		<1 – 101	-	
	20 th	4.0	-	4	2.1	-	7
	50 th (Median)	6.7	-	8	5.3	-	13
	80 th	13	-	17	11	-	29
P5/MH10	Mean $\pm$ se	4.3 $\pm$ 0.0	-		4.7 $\pm$ 0.0	-	
	Range	<1 – 44	-		<1 – 98	-	
	20 th	1.8	-	2	1.1	-	4
	50 th (Median)	3.3	-	4	3.3	-	9
	80 th	5.9	-	7	6.6	-	16
CD1	Mean $\pm$ se	1.5 $\pm$ 0.0	3.3 $\pm$ 0.0		1.9 $\pm$ 0.0	5.2 $\pm$ 0.2	
	Range	<1 – 29	<1 – 142		<1 – 37	<1 – 130	
	20 th	<1	<1	1	<1	<1	2
	50 th (Median)	<1	1.9	3	1.4	2.2	7
	80 th	2.3	4.7	6	3.1	6.4	13
CD2	Mean $\pm$ se	2.4 $\pm$ 0.0	4.5 $\pm$ 0.0	<1	2.0 $\pm$ 0.0	7.2 $\pm$ 0.1	<2
	Range	<1 – 25	<1 – 104		<1 – 201	<1 – 250	
	20 th	<1	1.6		<1	1.9	
	50 th (Median)	1.9	3.3		1.3	4.9	
	80 th	3.7	6.7		3.3	9.8	
CD3	Mean $\pm$ se	4.1 $\pm$ 0.0	5.7 $\pm$ 0.0		3.1 $\pm$ 0.1	6.8 $\pm$ 0.1	
	Range	<1 – 42	<1 – 110		<1 – 40	<1 – 313	
	20 th	1.1	1.0	2	<1	<1	4
	50 th (Median)	3.2	3.9	4	2.5	3.7	9
	80 th	6.9	8.9	7	4.9	11	16
CD4	Mean $\pm$ se	1.0 $\pm$ 0.0	4.0 $\pm$ 0.0	<1	1.5 $\pm$ 0.0	2.5 $\pm$ 0.0	<2
	Range	<1 – 35	<1 – 173		<1 – 13	<1 – 44	
	20 th	<1	<1		<1	<1	
	50 th (Median)	<1	2.4		1.0	<1	
	80 th	1.7	6.0		2.6	4.9	
CD5	Mean $\pm$ se	<1	1.7 $\pm$ 0.0	<1	1.8 $\pm$ 0.0	3.0 $\pm$ 0.0	<2
	Range	<1 – 17	<1 – 98		<1 – 43	<1 – 127	
	20 th	<1	<1		<1	<1	
	50 th (Median)	<1	<1		<1	1.8	
	80 th	1.5	2.1		2.0	3.9	

Table notes:

1. N = 7,858 to 20,773
2. One WQO value only is denoted for CD2, CD4 and CD5 indicating the median or 80th percentile value
3. WQOs Source: EHP 2014

Surface turbidity was significantly higher ($p < 0.05$) at inshore sites (P2B/WB50, QE3 and P5/MH10) than at offshore sites (CD1 to CD5) during both wet and dry season monitoring. Of the three inshore sites, P2B/WB50 and QE3 recorded consistently higher turbidity values (7.0 to 9.0 NTU) than site P5/MH10 (4.3 to 4.7 NTU) during both wet and dry seasons. This is most likely due to their location in the inner estuarine Port Curtis, compared to P5/MH10 which has a more oceanic influence. Sites QE3 and P5/MH10 exhibited significantly higher ($p < 0.05$) turbidity during the wet season than during the dry season. However, this pattern was not evident at site P2B/WB50. The loss of data at this site during TC Marcia may have influenced this result.

3.2.1.1 Inshore turbidity

At the three inshore sites, turbidity increases were evident bimonthly during the spring tides associated with the full and new moon periods (refer Figures 3.2 to 3.4). Higher tidal ranges associated with spring tides at inshore sites permit a higher level of mixing and resuspension of particles within the water column. When tidal ranges are lower, such as during neap tides associated with the quarter moon phases, the turbidity levels tend to decrease accordingly.

The three inshore sites are located in different water areas within Port Curtis and as such have varying WQOs; QE3 located in The Narrows (SD2442), P2B/WB50 in the Western Basin (MD2421) and P5/MH10 in the Mid Harbour (MD2423) (refer Table 2.3) (EHP 2014). QE3 20th, 50th and 80th percentile values were equal to or below their corresponding WQO values, with mean turbidity values also equal to or lower than the 50th percentile WQO. Both P2B/WB50 and P5/MH10 exhibited mean dry season turbidity values which were slightly higher than the 50th percentile WQO, while mean wet season turbidity values at both sites were between the 20th and 50th percentile WQO. At these two sites, 20th, 50th and 80th percentile values were equal to or below their corresponding WQO values. This indicates turbidity during the 13 month monitoring period was within a similar range as the historical studies used to calculate the WQOs for Port Curtis (DSITIA 2014). Similarly, preliminary P5/MH10 data from October 2013 to June 2014 indicated that turbidity during that period was similar to historical studies, with 20th, 50th and 80th percentile values lower than their corresponding WQO values (refer Table 6.1 in Appendix 6.1).

3.2.1.2 Offshore turbidity

Turbidity results from the offshore sites (refer Figures 3.5 to 3.14), indicated that benthic turbidity at each site was significantly higher ($p < 0.05$) than surface turbidity. High and variable benthic turbidity is most likely due to the proximity of the loggers to the benthic sediment. The offshore benthic sediments tend to be resuspended during strong winds and elevated wave heights. While significant ($p < 0.05$) linear regressions were found between surface and benthic turbidity at each site, the relationships were not strong ($r^2 = 0.14$ to 0.52). However, both surface and benthic loggers responded similarly to environmental stimuli. Turbidity at the majority of offshore sites also tended to be significantly higher ($p < 0.05$) during the wet season than during the dry season (refer Table 3.3).

When comparing turbidity results across the offshore sites, CD2 and CD3 surface and benthic exhibited the highest turbidity values ($p < 0.05$), during both the wet season (2.0 to 7.2 NTU) and dry season (2.4 to 5.7 NTU). Lowest turbidity values were evident at CD1, CD4 and CD5, particularly during the dry season (< 1 to 4.0 NTU). CD4 and CD5 being the deepest sites ($> 16\text{m}$) are less likely to be affected by wind driven resuspension. Although CD1 is the third shallowest offshore site ($< 9\text{m}$), it is also located the furthest from any anthropogenic and

estuarine influences. Higher turbidity at CD2 and CD3 compared to the remaining offshore sites is likely to be due to their location closer to land masses and Port Curtis (refer Figure 2.1), with these sites also showing some effects from tidal action (refer Figures 3.7 to 3.10). CD3, located at the mouth of the Boyne River, tended to display more elevated benthic turbidity during increased wind speed events post TC Marcia. It is likely that fine sediments washed down from the Boyne River were being easily resuspended during these events.

The offshore monitoring sites were also separated into three different water areas, with CD1 located in the Outer Harbour (MD2424), CD3 located in the Mid Harbour (MD2423), and sites CD2, CD4 and CD5 located in coastal waters outside Gladstone Harbour. Mean turbidity at CD1 during the wet season ranged between 20th and 50th percentile WQO, while mean dry season turbidity ranged between the 20th and 80th percentile WQOs.

Similarly, CD3 mean wet season turbidity ranged between the 20th and 50th percentile WQOs, and mean dry season turbidity ranged between the 50th and 80th percentile WQOs. For the remaining three sites (CD2, CD4 and CD5), only one WQO value is provided by EHP (2014) for each season: dry season: < 1 NTU and wet season < 2 NTU. Only mean turbidity at CD5 surface during the dry season and CD4 and CD5 surface during the wet season were below the appropriate WQOs, with all other values above the WQO value.

3.2.1.3 Influence of natural events

The advent of TC Marcia in Central Queensland in February 2015 resulted in short term elevated turbidity at the offshore sites and at P5/MH10. Turbidity at the Mid Harbour site of P5/MH10 is often found to be influenced by increased wind, in addition to tidal phases (Vision Environment 2013f). Generally these types of events are acute in nature resulting in a rapid but short-lived elevation in turbidity, particularly when wind rather than rainfall is the driving factor, as with TC Marcia. Benthic EWMA turbidity values at sites CD1, CD2, CD3 and CD5 were greater than 50 NTU on 20 and 21 February, however raw values were consistently over 200 NTU at CD1, one of the shallower and most exposed sites. Surface turbidity peaks were not as high or variable, with values ranging from approximately 20 NTU up to 100 NTU during the same period. A return to lower turbidity values (< 10 NTU) occurred by 24 February at all sites. The inshore sites also exhibited an increase in turbidity (EWMA > 30 NTU) with the advent of TC Marcia, although high rainfall (~ 100mm) and spring tides which occurred concurrently with this event are likely to have been a contributing factor.

Major rain events such as the 249mm which fell over a short period in January 2015 were more influential on turbidity at the inshore sites than high wind speeds. Short term peaks in turbidity were particularly evident at QE3 (EWMA approximately 68 NTU on this occasion) following rain events, as evidenced in mid-January and mid-February 2015. This is likely due to QE3 being exposed to flood peaks which traverse down The Narrows from the Fitzroy River and surrounding catchments. This is a historical pattern which has been observed previously, particularly when higher rainfall is experienced in the Fitzroy catchment (Vision Environment 2013b). P2B/WB50 has also historically displayed post flood peaks in turbidity due to the proximity of the site to the mouth of the Calliope River (refer Figure 2.1). During mid-January and mid-February 2015, both sites exhibited concurrent declines in other physicochemical parameters such as conductivity (20mS/cm at QE3) and DO (< 70% at QE3), which are also generally associated with large fresh water flows. These physicochemical parameters are discussed further in the sections below.

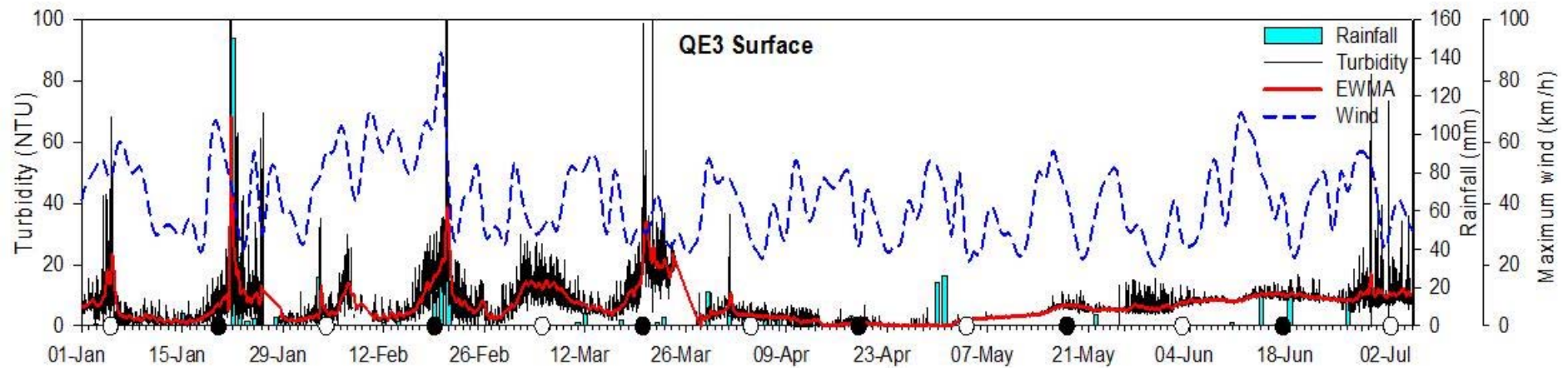


Figure 3.2 Surface turbidity, rainfall and inshore wind speed at site QE3.

Figure note: Open and closed circles indicate full and new moons, respectively

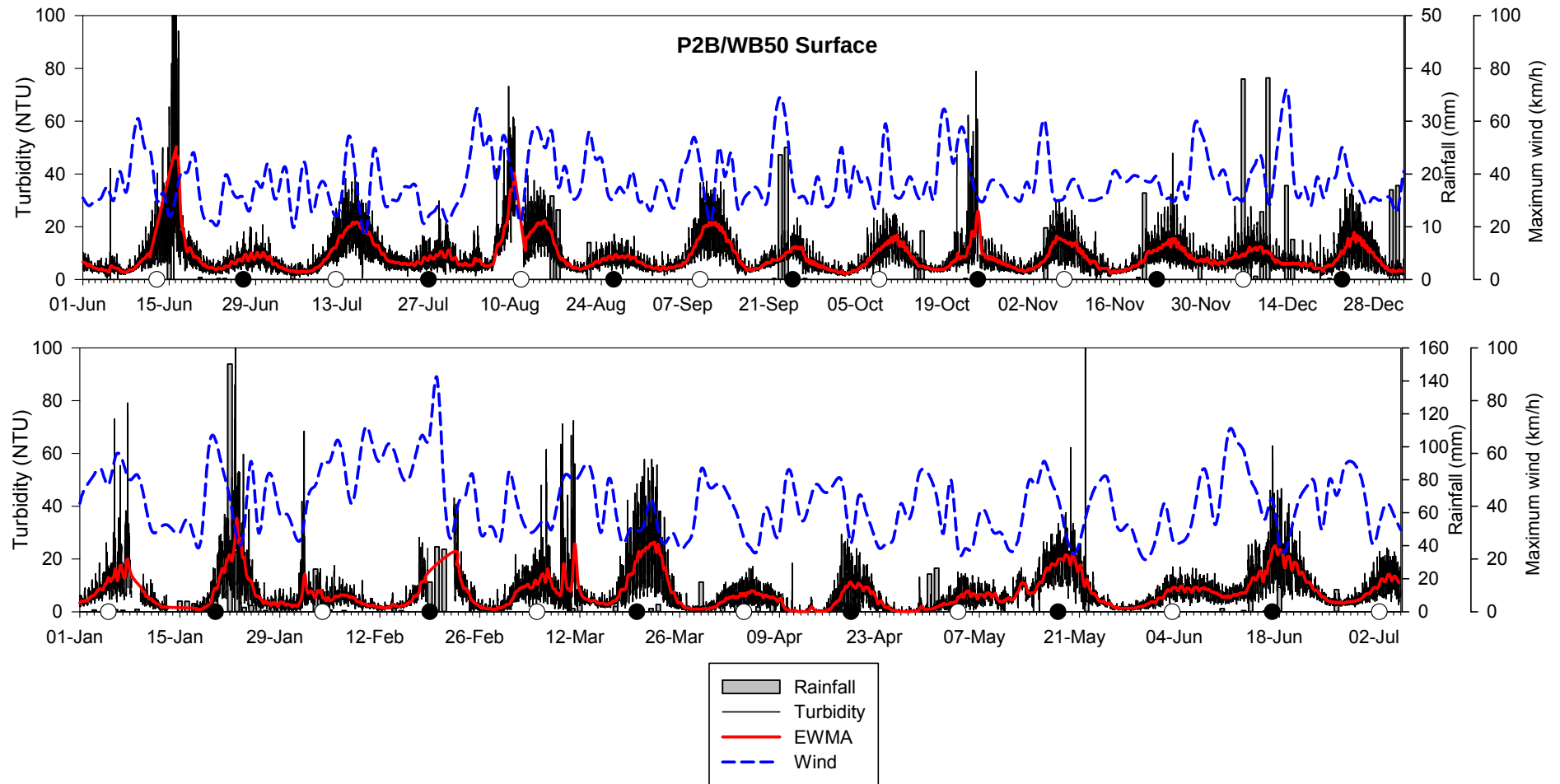


Figure 3.3 Surface turbidity, rainfall and inshore wind speed at site P2B/WB50.

Figure note: Open and closed circles indicate full and new moons, respectively.

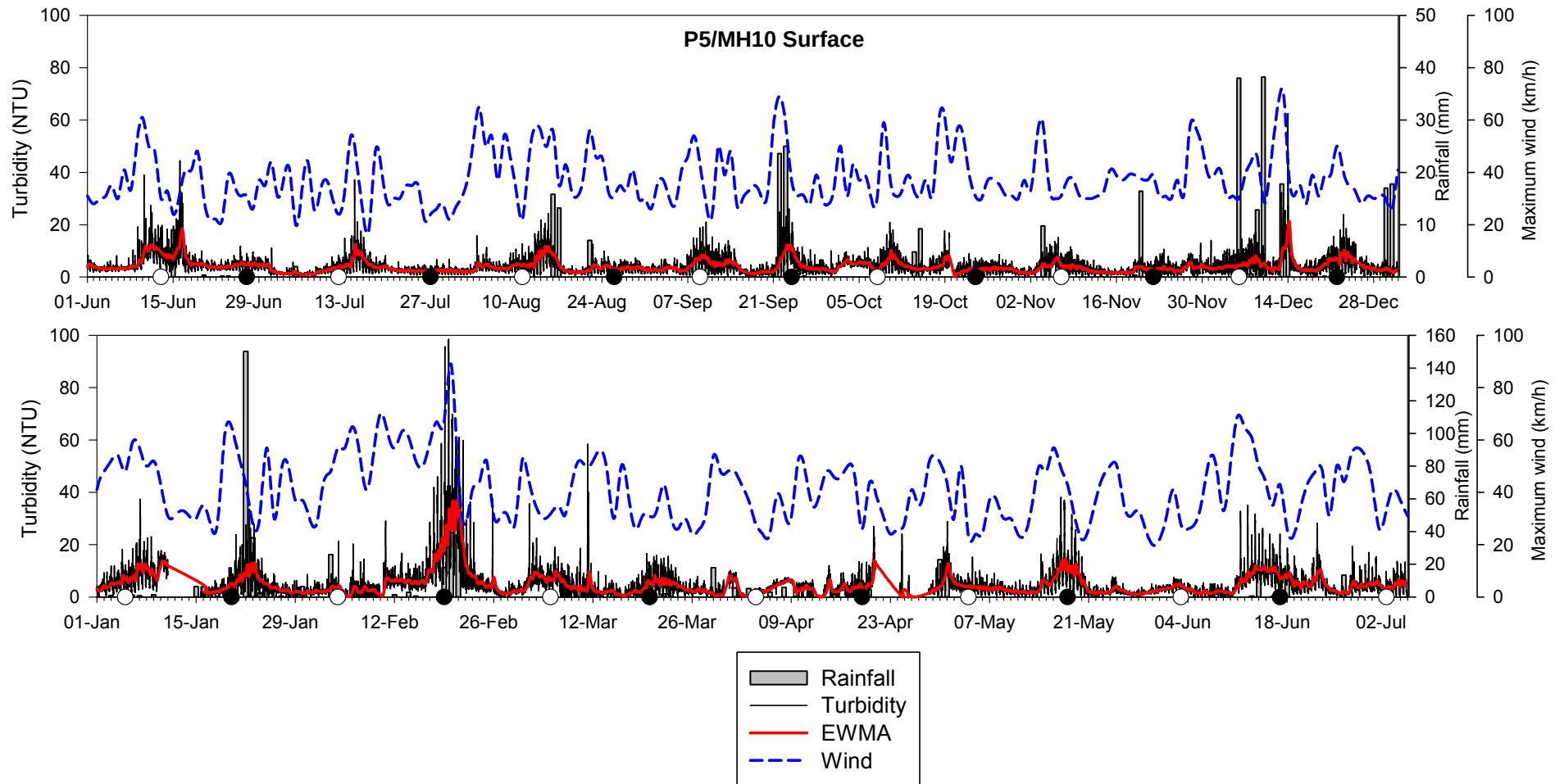


Figure 3.4 Surface turbidity, rainfall and inshore wind speed at site P5/MH10

Figure note: Open and closed circles indicate full and new moons, respectively.

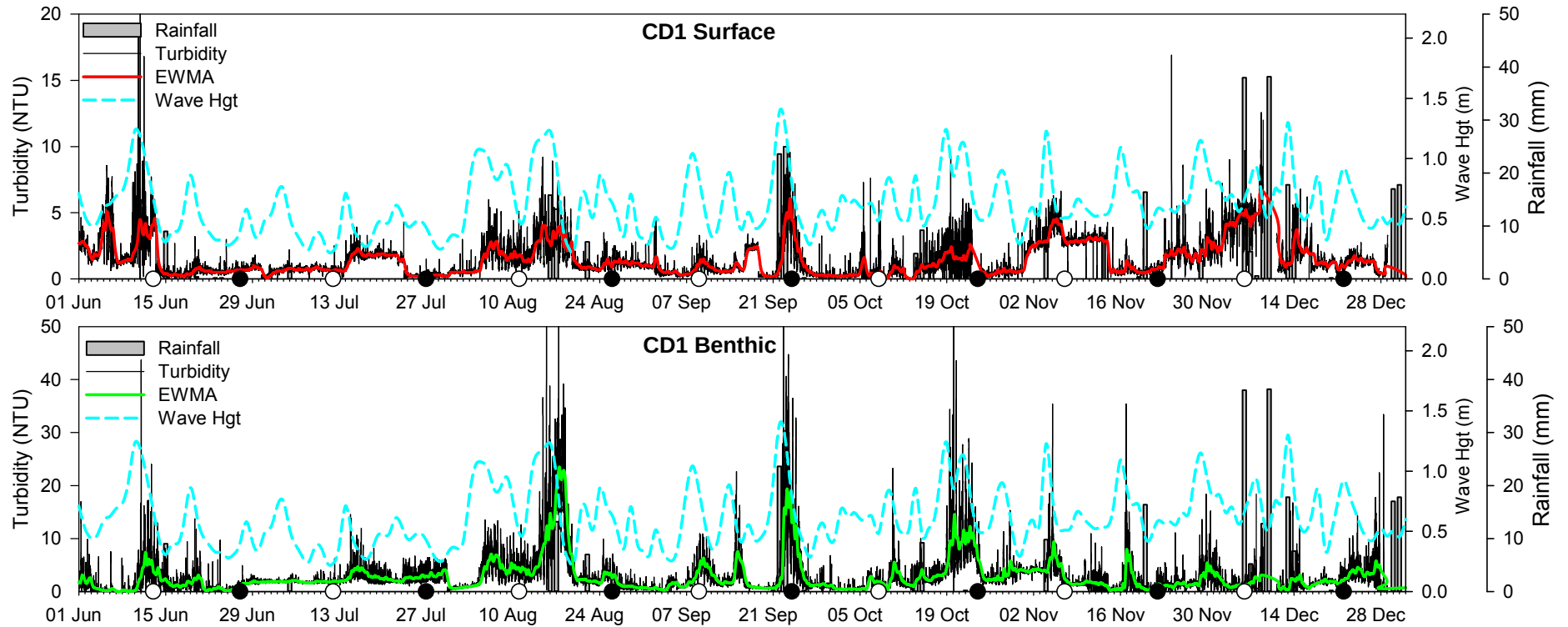


Figure 3.5 Surface and benthic turbidity, rainfall and offshore wave height at site CD1 from 1 June to 31 December 2014

Figure note: Open and closed circles indicate full and new moons, respectively.

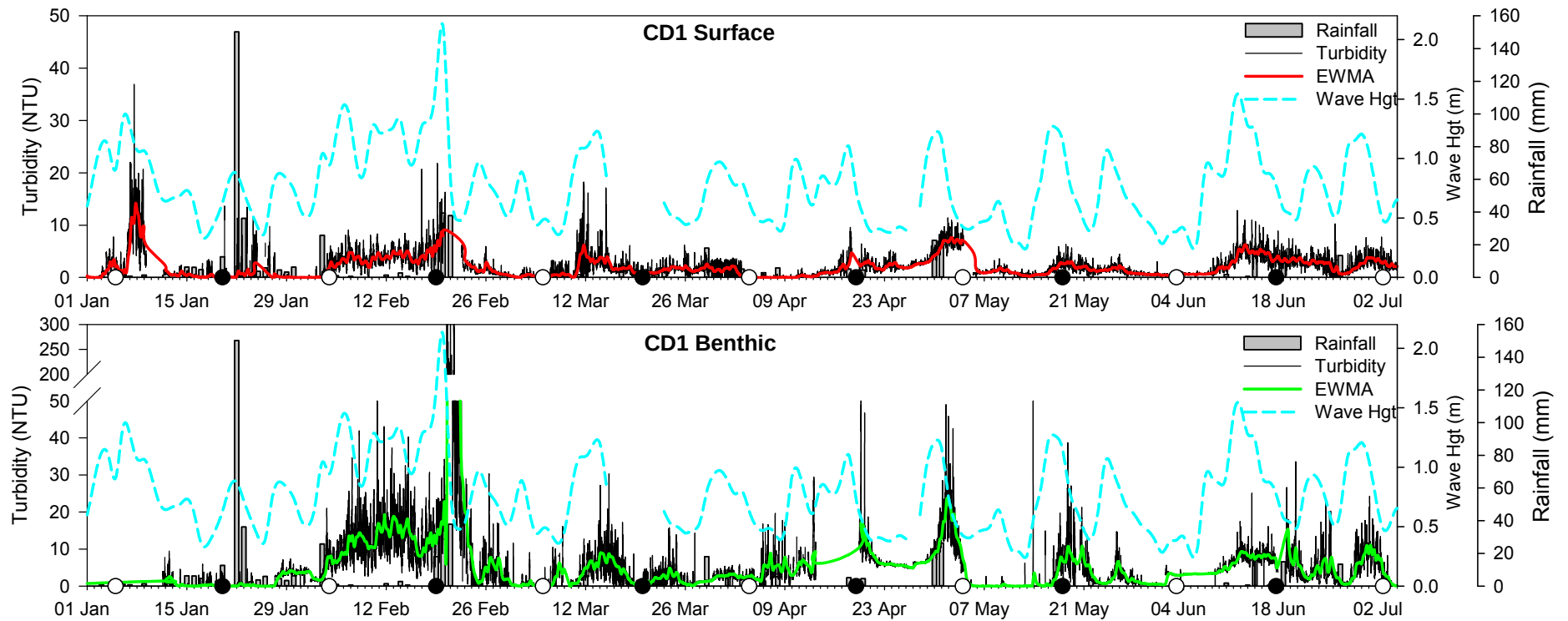


Figure 3.6 Surface and benthic turbidity, rainfall and offshore wave height at site CD1 from 1 January to 4 July 2015

Figure note: Open and closed circles indicate full and new moons, respectively.

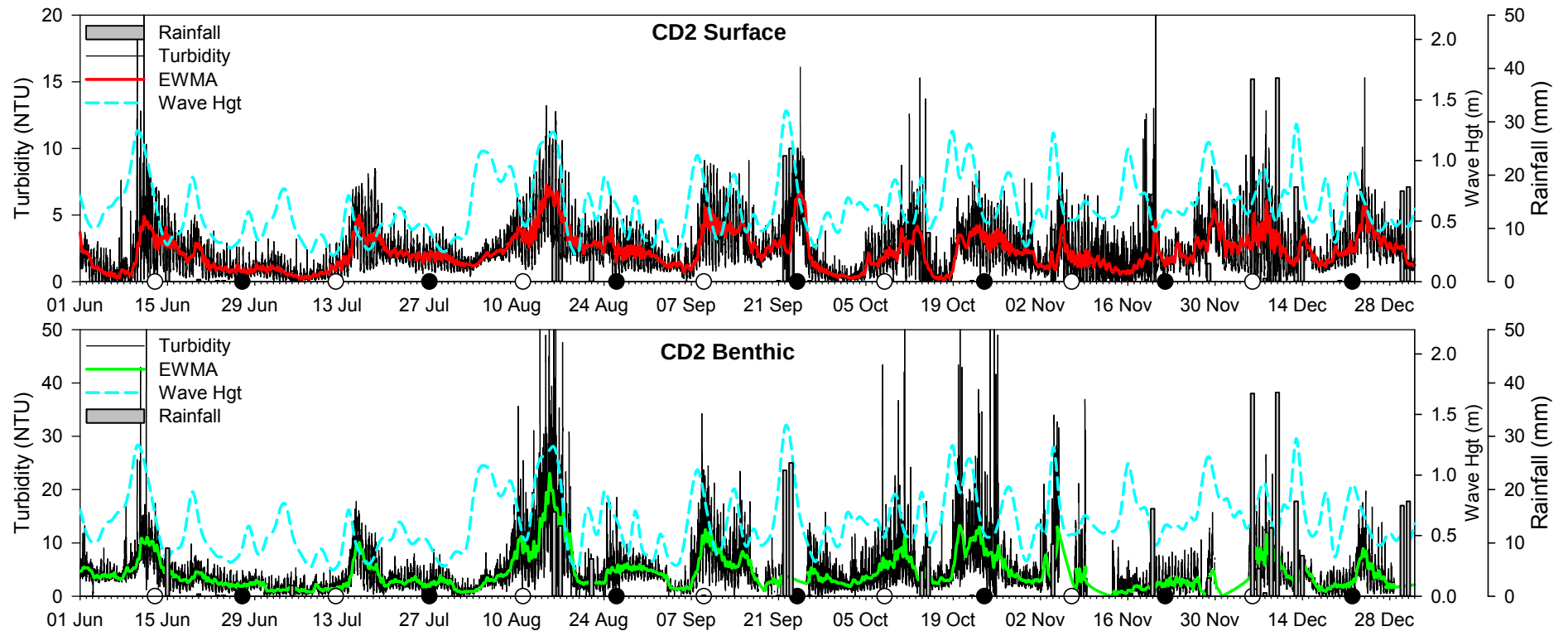


Figure 3.7 Surface and benthic turbidity, rainfall and offshore wave height at site CD2 from 1 June to 31 December 2014

Figure note: Open and closed circles indicate full and new moons, respectively.

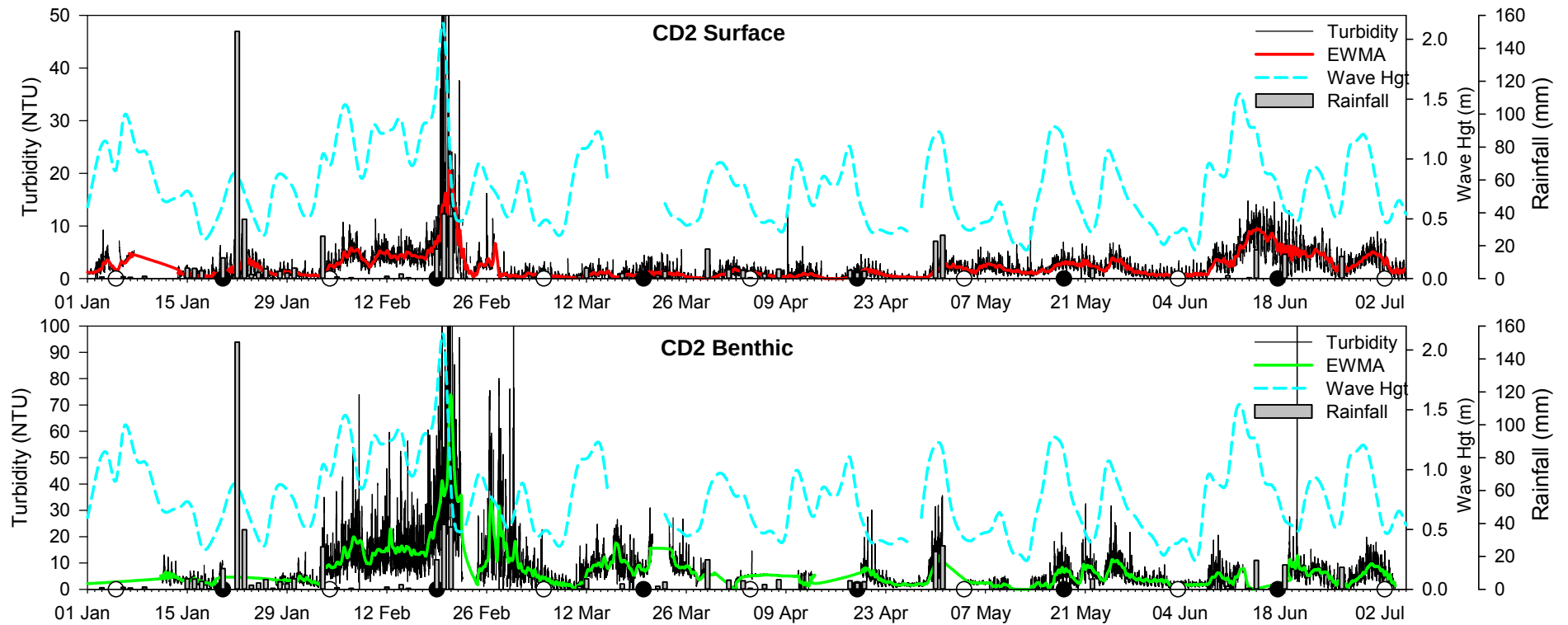


Figure 3.8 Surface and benthic turbidity, rainfall and offshore wave height at site CD2 from 1 January to 4 July 2015

Figure note: Open and closed circles indicate full and new moons, respectively.

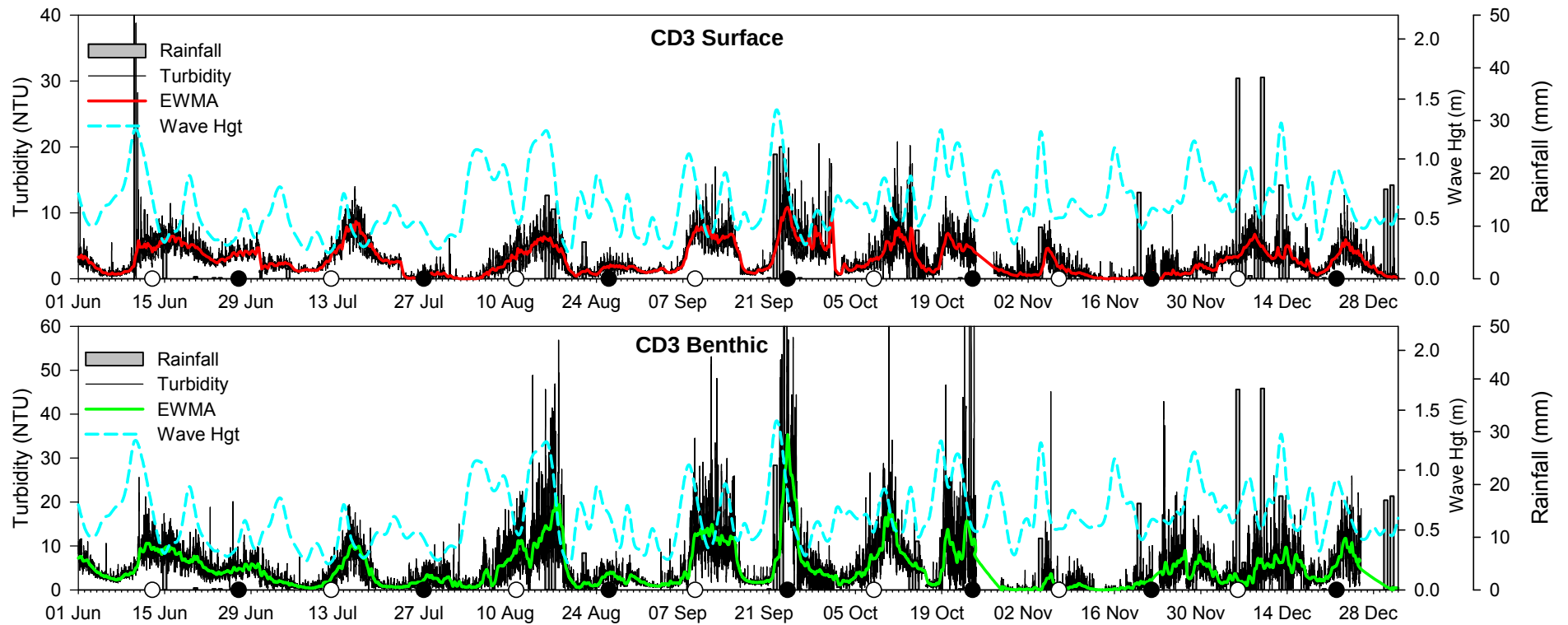


Figure 3.9 Surface and benthic turbidity, rainfall and offshore wave height at site CD3 from 1 June to 31 December 2014

Figure note: Open and closed circles indicate full and new moons, respectively.

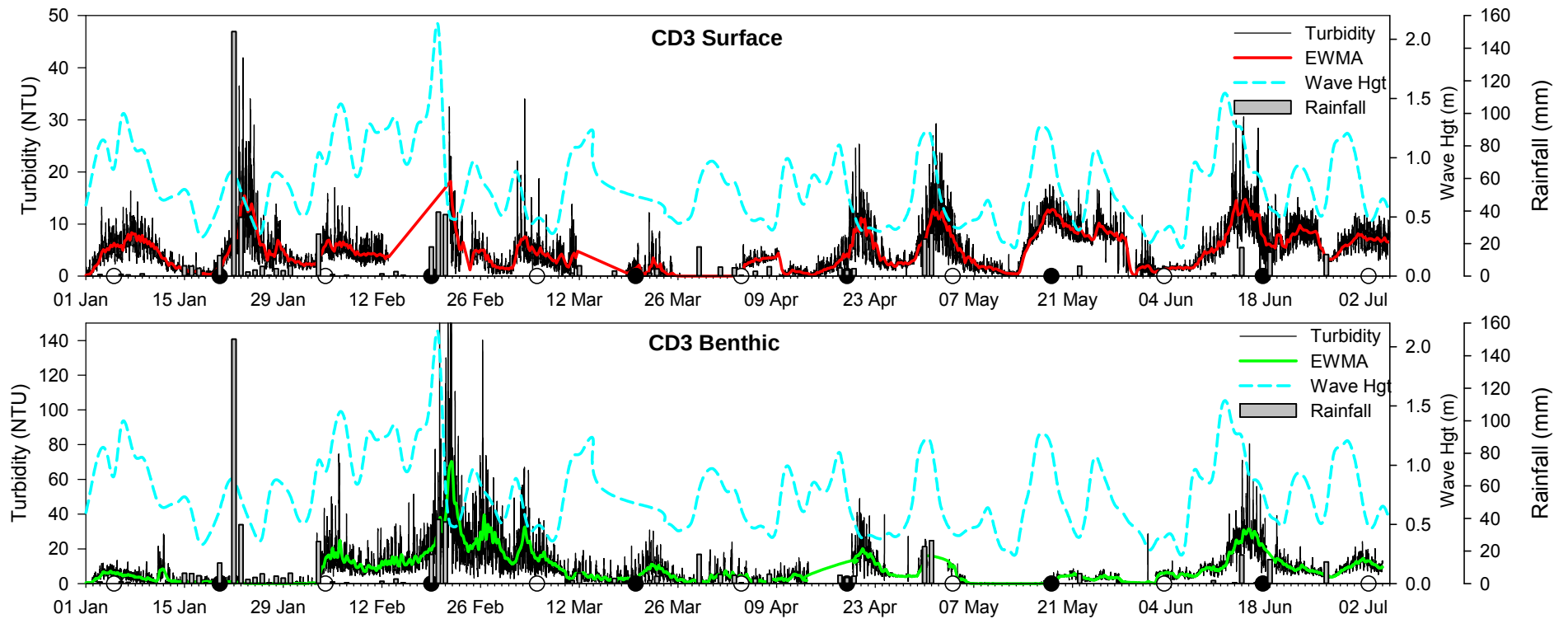


Figure 3.10 Surface and benthic turbidity, rainfall and offshore wave height at site CD3 from 1 January to 4 July 2015

Figure note: Open and closed circles indicate full and new moons, respectively.

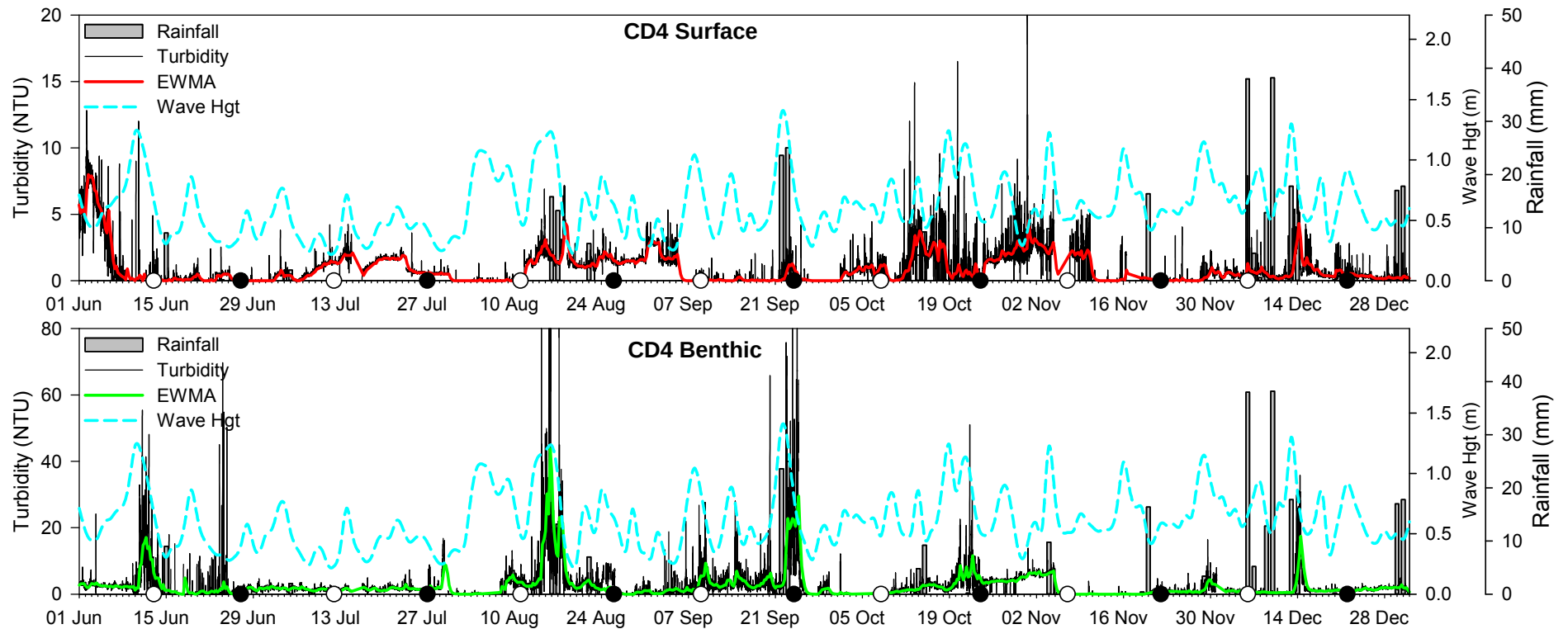


Figure 3.11 Surface and benthic turbidity, rainfall and offshore wave height at site CD4 from 1 June to 31 December 2014

Figure note: Open and closed circles indicate full and new moons, respectively.

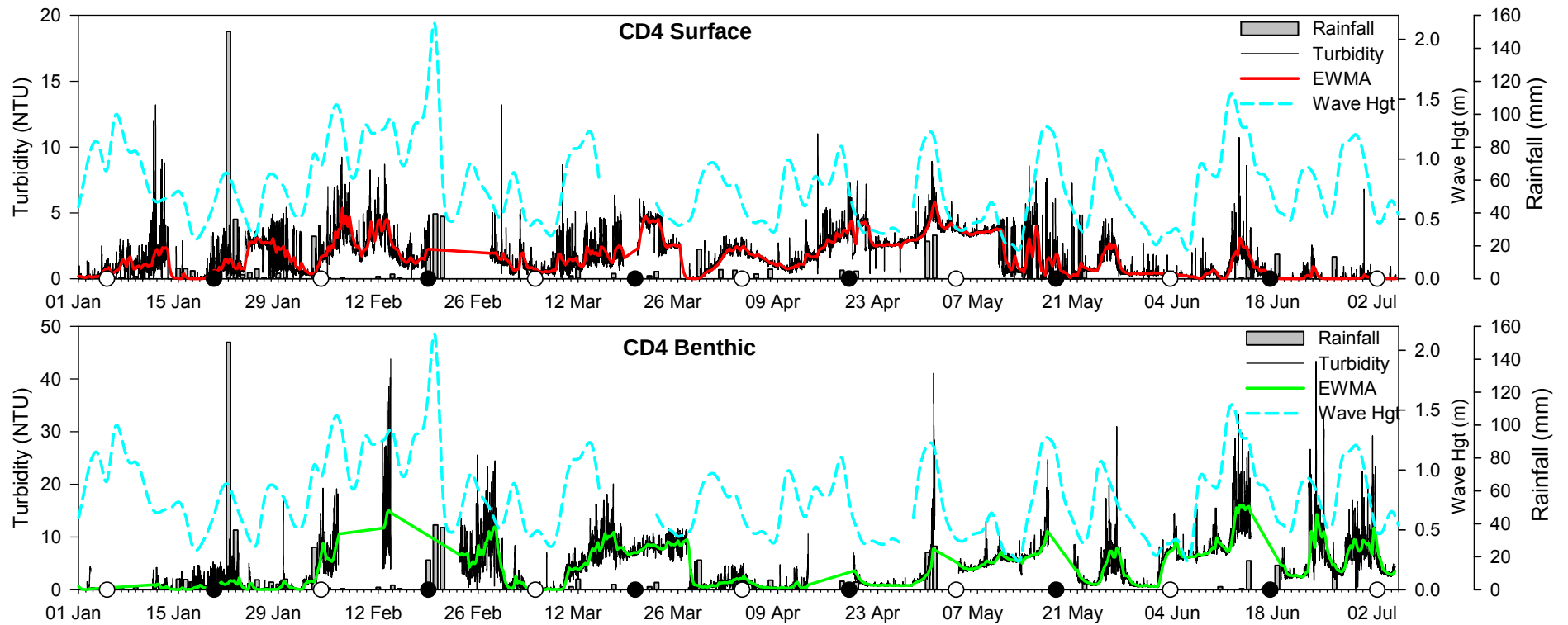


Figure 3.12 Surface and benthic turbidity, rainfall and offshore wave height at site CD4 from 1 January to 4 July 2015

Figure note: Open and closed circles indicate full and new moons, respectively.

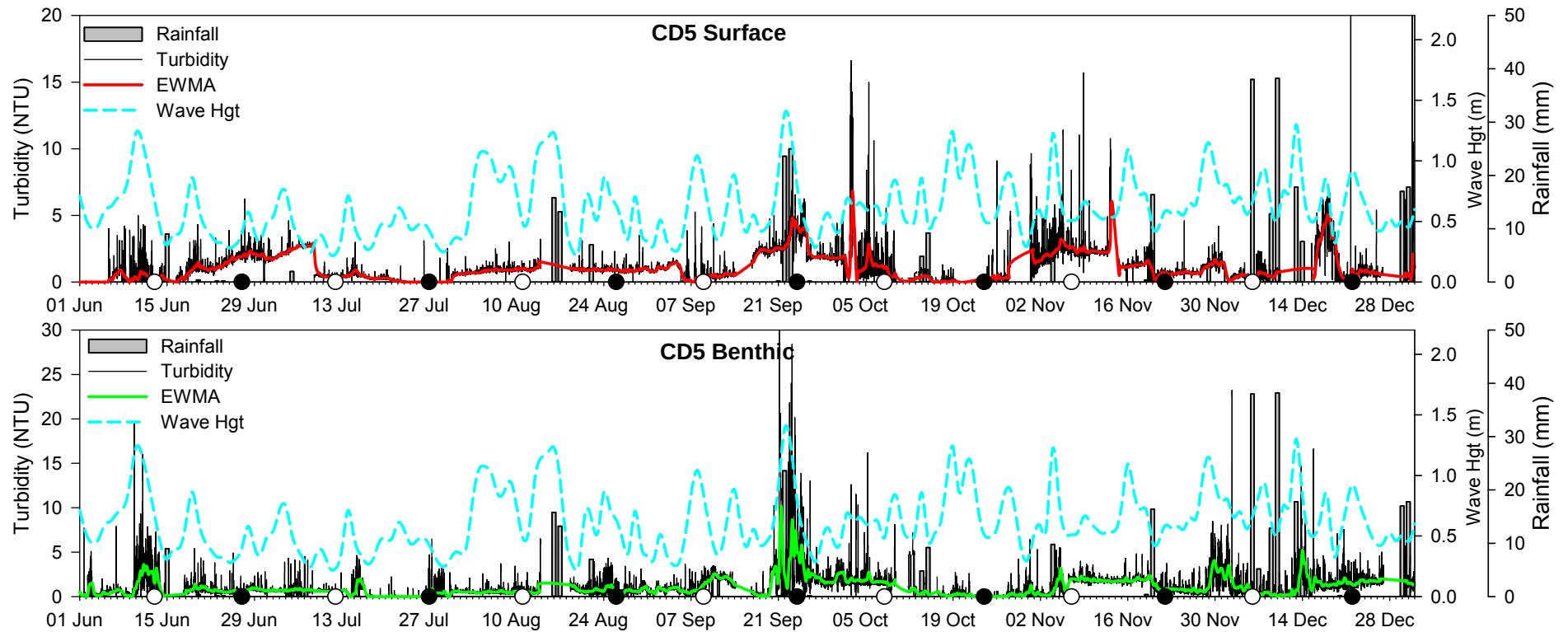


Figure 3.13 Surface and benthic turbidity, rainfall and offshore wave height at site CD5 from 1 June to 31 December 2014

Figure note: Open and closed circles indicate full and new moons, respectively.

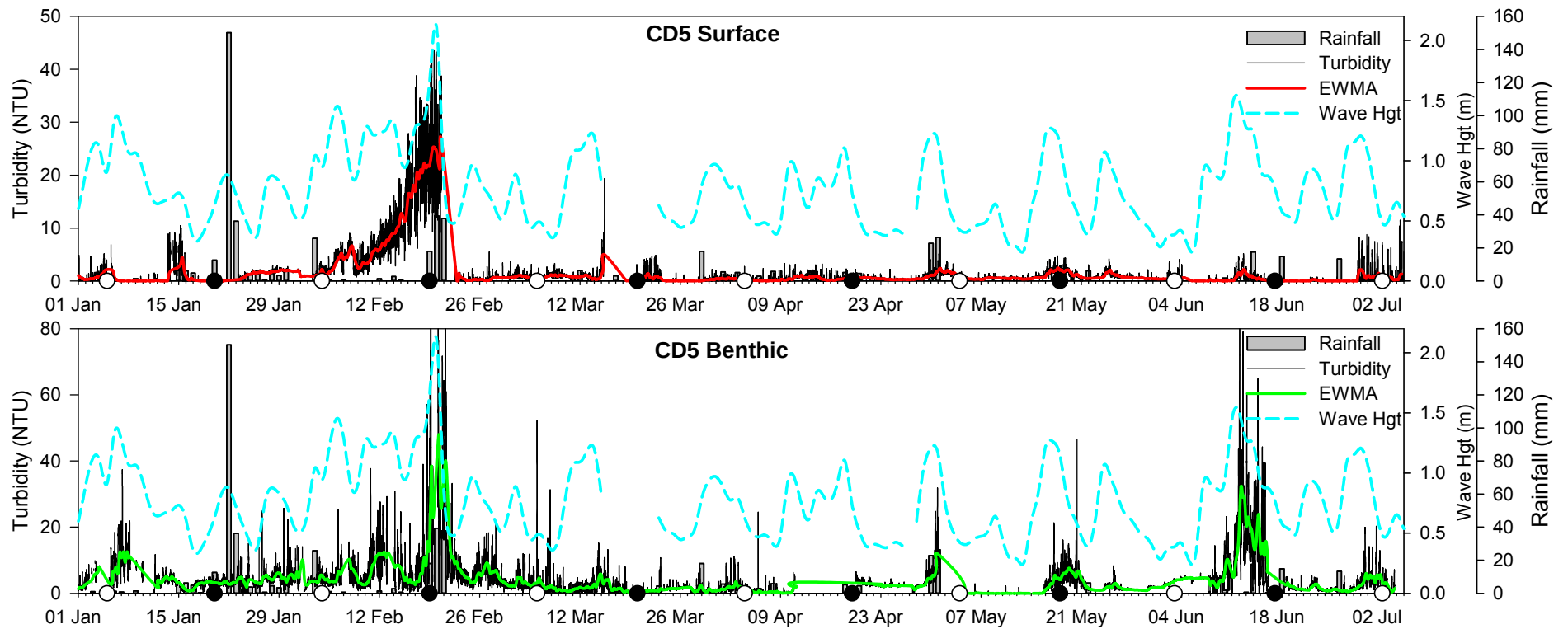


Figure 3.14 Surface and benthic turbidity, rainfall and offshore wave height at site CD5 from 1 January to 4 July 2015.

Figure note: Open and closed circles indicate full and new moons, respectively.

3.2.2 Temperature

During the monitoring period, water temperature at all sites exhibited a clear seasonal pattern, associated with ambient air temperatures. As expected, temperature at all sites was significantly higher ($p < 0.05$) during the wet season than during the dry season, paralleling ambient conditions (refer Table 3.4, Figures 3.15 to 3.17). Only minor differences were evident between mean site values within each season ($\leq 0.7^{\circ}\text{C}$), and mean benthic and surface temperatures at each site were also similar ($\leq 0.2^{\circ}\text{C}$ difference), indicating the absence of thermoclines at offshore sites. Of note were the small immediate decreases in temperature associated with rain events which were less evident at the deepest sites CD4 and CD5 further offshore.

Table 3.4 Seasonal temperature at water quality sites from 1 June 2014 to 4 July 2015

Site	Dry Season Temperature ($^{\circ}\text{C}$)		Wet Season Temperature ($^{\circ}\text{C}$)	
	Surface	Benthic	Surface	Benthic
QE3	20.8 ± 0.0 (20.6)	-	27.6 ± 0.0 (28.0)	-
P2B/WB50	21.2 ± 0.0 (20.8)	-	27.8 ± 0.0 (28.1)	-
P5/MH10	21.0 ± 0.0 (20.7)	-	27.4 ± 0.0 (27.6)	-
CD1	21.2 ± 0.0 (20.9)	21.1 ± 0.0 (20.8)	27.3 ± 0.0 (27.6)	27.2 ± 0.0 (27.4)
CD2	21.1 ± 0.0 (20.9)	21.1 ± 0.0 (20.8)	27.3 ± 0.0 (27.5)	27.4 ± 0.0 (27.7)
CD3	20.9 ± 0.0 (20.5)	20.9 ± 0.0 (20.5)	27.6 ± 0.0 (27.9)	27.6 ± 0.0 (27.8)
CD4	21.4 ± 0.0 (21.2)	21.2 ± 0.0 (21.0)	27.4 ± 0.0 (27.6)	27.2 ± 0.0 (27.4)
CD5	21.3 ± 0.0 (21.2)	21.2 ± 0.0 (21.1)	27.2 ± 0.0 (27.4)	27.1 ± 0.0 (27.4)

Table Note: Values are means $\pm$ se (median), N = 8,636 to 20,823

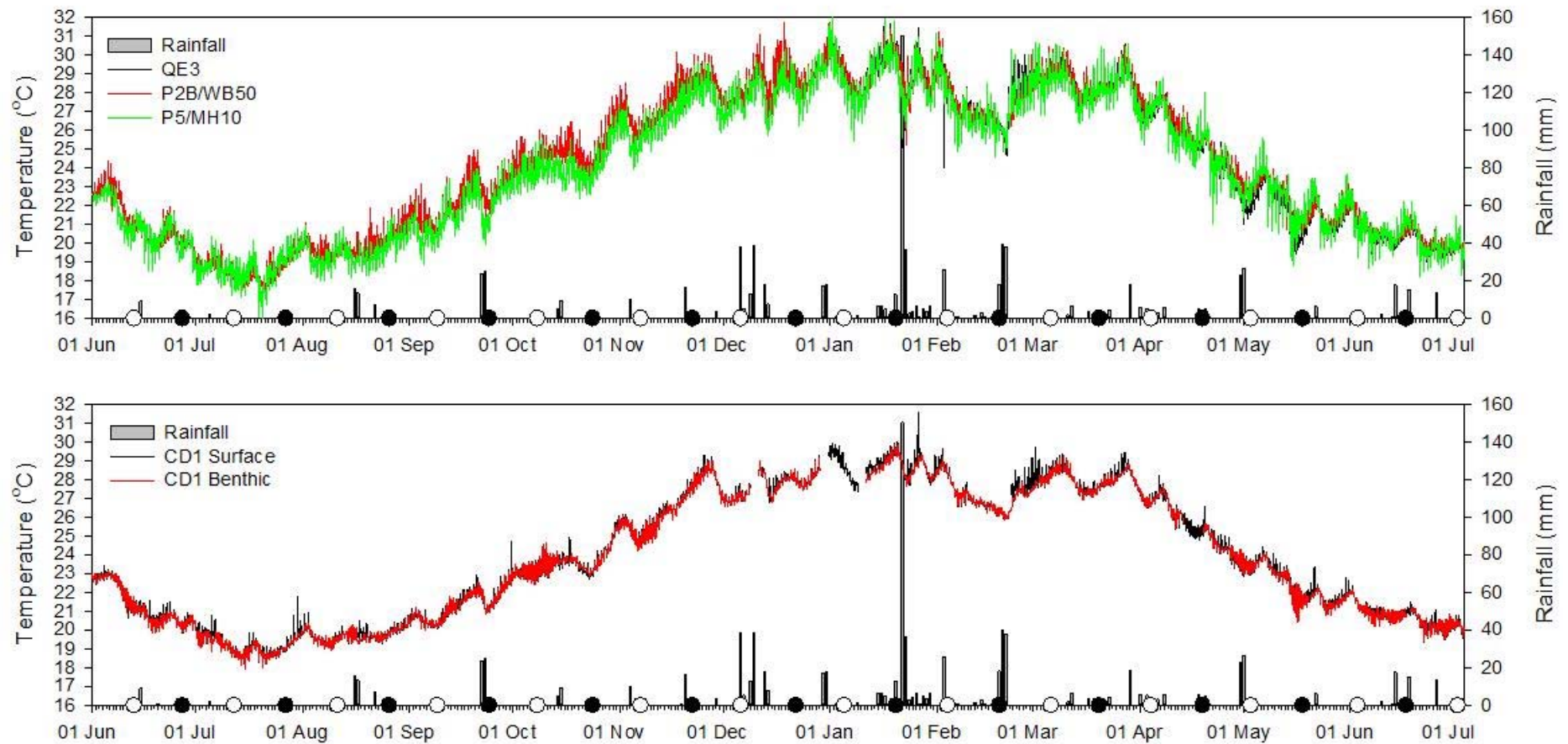


Figure 3.15 Surface temperature at QE3, P2B/WB50 and P5/MH10, and surface and benthic temperature at CD1 from 1 June 2014 to 4 July 2015 (QE3 January 2015 to July 2015)

Figure note: Open and closed circles indicate full and new moons, respectively.

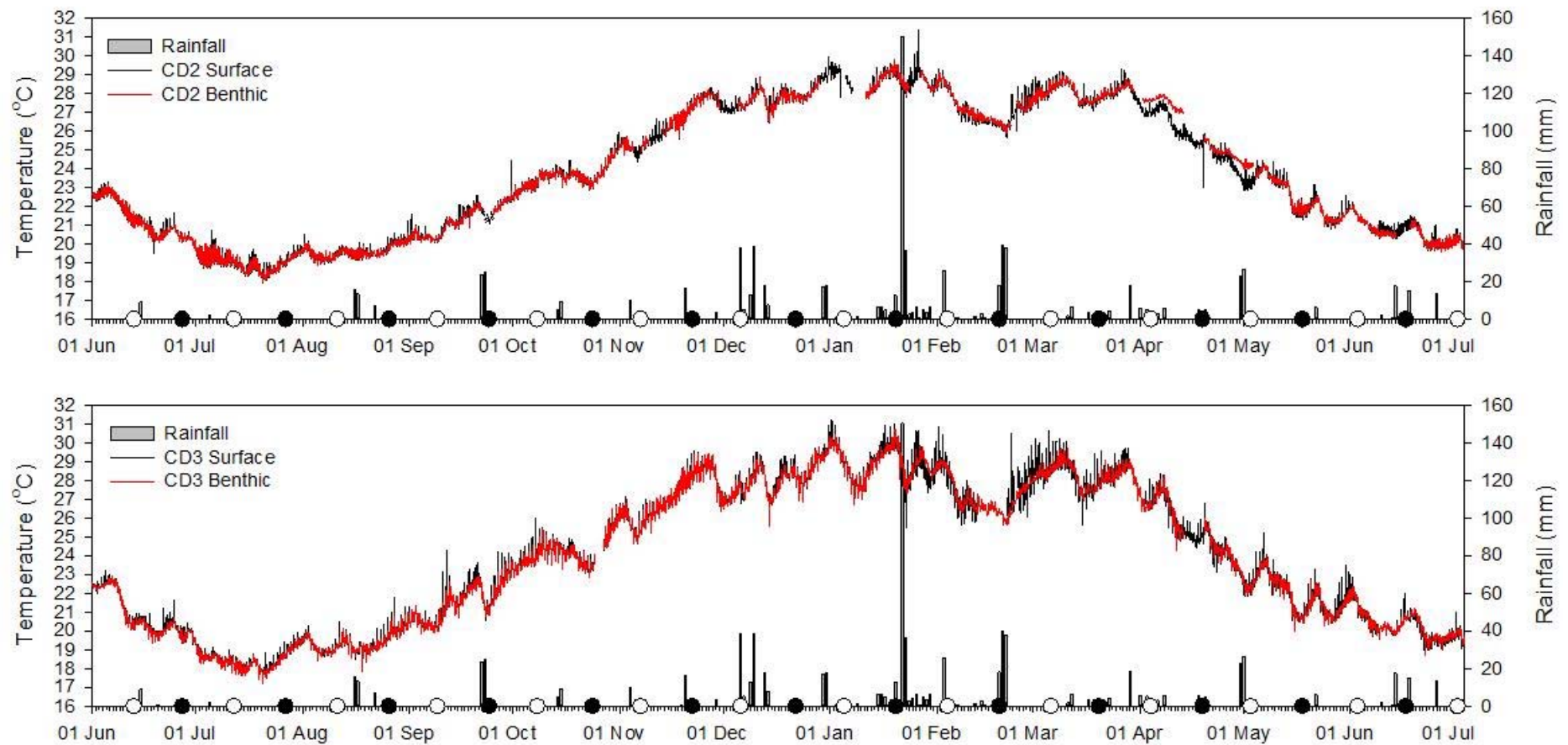


Figure 3.16 Surface and benthic temperature at CD2 and CD3 from 1 June 2014 to 4 July 2015

Figure note: Open and closed circles indicate full and new moons, respectively.

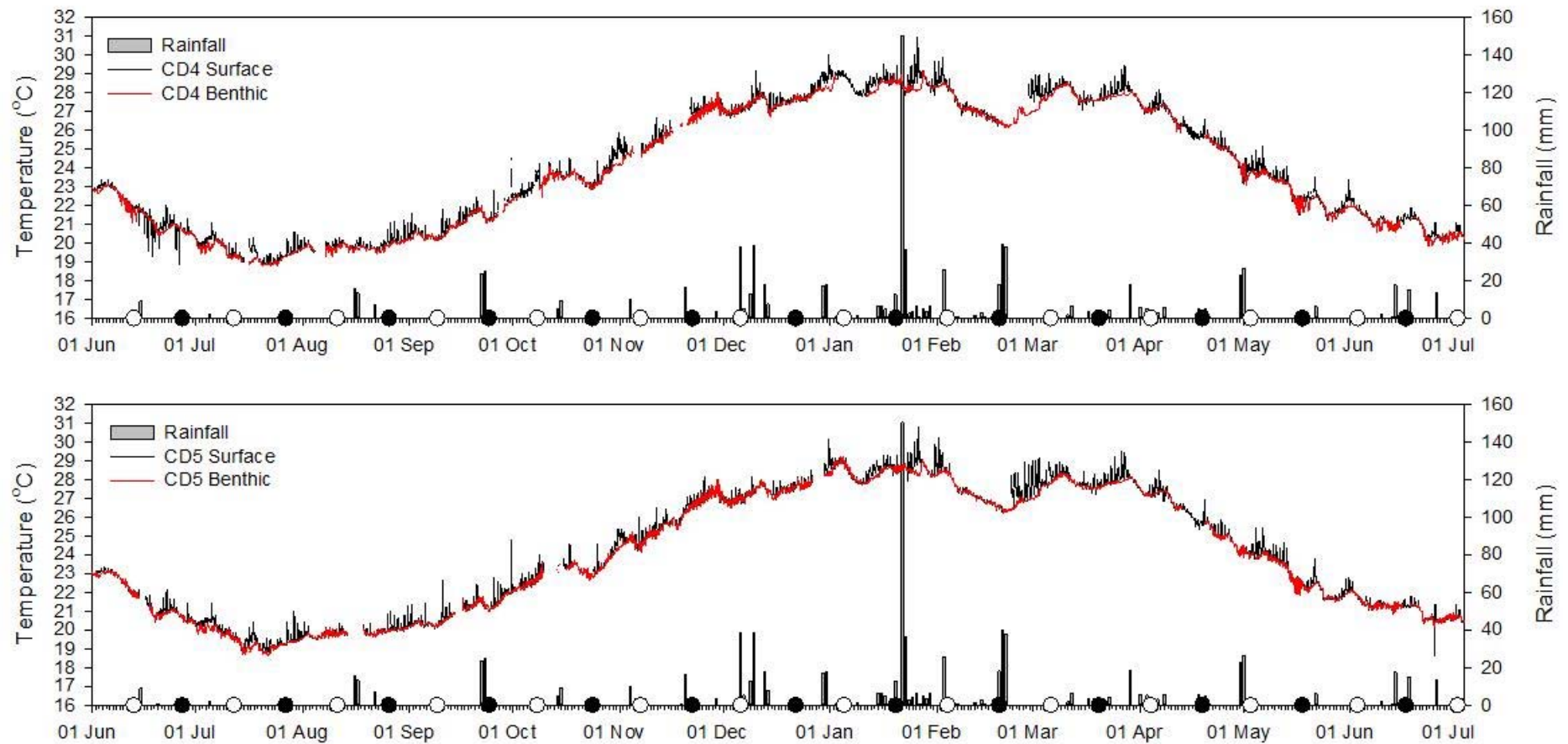


Figure 3.17 Surface and benthic temperature at CD4 and CD5 from 1 June 2014 to 4 July 2015

Figure note: Open and closed circles indicate full and new moons, respectively.

3.2.3 pH

The pH is a measure of the acidity or alkalinity of water, which has the potential to be impacted by a number of variables, including precipitation, coagulation and perturbation of benthic sediments among others (APHA 2005). A change in pH can have a direct toxic effect on aquatic biota and may also alter metal bioavailability to aquatic organisms. Exposure of benthic sediments, particularly those which are potential acid sulfate soils during dredging operations, have the potential to increase the amount of acidity in the water column, if not properly managed.

The pH at each site tended to remain reasonably consistent throughout the monitoring period (refer Table 3.5, Figures 3.18 to 3.20). While consistently lower pH was evident at inshore site QE3, typical of estuarine environments, only minor differences were evident between remaining sites (≤ 0.2 pH unit). Mean and median benthic and surface pH at each site were similar (≤ 0.1 pH unit difference) suggesting a well-mixed water column at offshore sites. Tidal fluctuations (~ 0.1 pH units) in pH were also evident at QE3, while P2B/WB50, P5/MH10 and CD3 demonstrated this pattern to a lesser extent and generally only after the significant rain events in mid-January and mid-February 2015.

Table 3.5 Seasonal pH at water quality sites from 1 June 2014 to 4 July 2015

Site	Dry Season pH		Wet Season pH		WQOs
	Surface	Benthic	Surface	Benthic	
QE3	8.0 $\pm$ 0.0 (8.0)	-	7.8 $\pm$ 0.0 (7.8)	-	7.4 – 8.3
P2B/WB50	8.0 $\pm$ 0.0 (8.0)	-	8.0 $\pm$ 0.0 (8.0)	-	7.4 – 8.3
P5/MH10	8.1 $\pm$ 0.0 (8.1)	-	8.1 $\pm$ 0.0 (8.1)	-	7.4 – 8.3
CD1	8.2 $\pm$ 0.0 (8.2)	8.1 $\pm$ 0.0 (8.1)	8.2 $\pm$ 0.0 (8.1)	8.2 $\pm$ 0.0 (8.2)	8.0 – 8.2
CD2	8.2 $\pm$ 0.0 (8.2)	8.2 $\pm$ 0.0 (8.2)	8.2 $\pm$ 0.0 (8.2)	8.2 $\pm$ 0.0 (8.2)	8.1 – 8.4
CD3	8.2 $\pm$ 0.0 (8.2)	8.2 $\pm$ 0.0 (8.2)	8.1 $\pm$ 0.0 (8.1)	8.1 $\pm$ 0.0 (8.1)	7.4 – 8.3
CD4	8.2 $\pm$ 0.0 (8.2)	8.2 $\pm$ 0.0 (8.2)	8.2 $\pm$ 0.0 (8.2)	8.2 $\pm$ 0.0 (8.2)	8.1 – 8.4
CD5	8.2 $\pm$ 0.0 (8.2)	8.2 $\pm$ 0.0 (8.3)	8.2 $\pm$ 0.0 (8.2)	8.1 $\pm$ 0.0 (8.1)	8.1 – 8.4

Table notes: Values are means $\pm$ se (median). N = 8,636 to 20,229. Upper and lower limits (20th to 80th percentiles) are listed for the WQOs.

Declines in pH occur when stormwater run-off introduces increased detritus and organic matter to the system resulting in an increase in biological oxygen demand (BOD) and a reducing environment. All mean and median seasonal pH values were within their appropriate WQO range (DSITIA 2014).

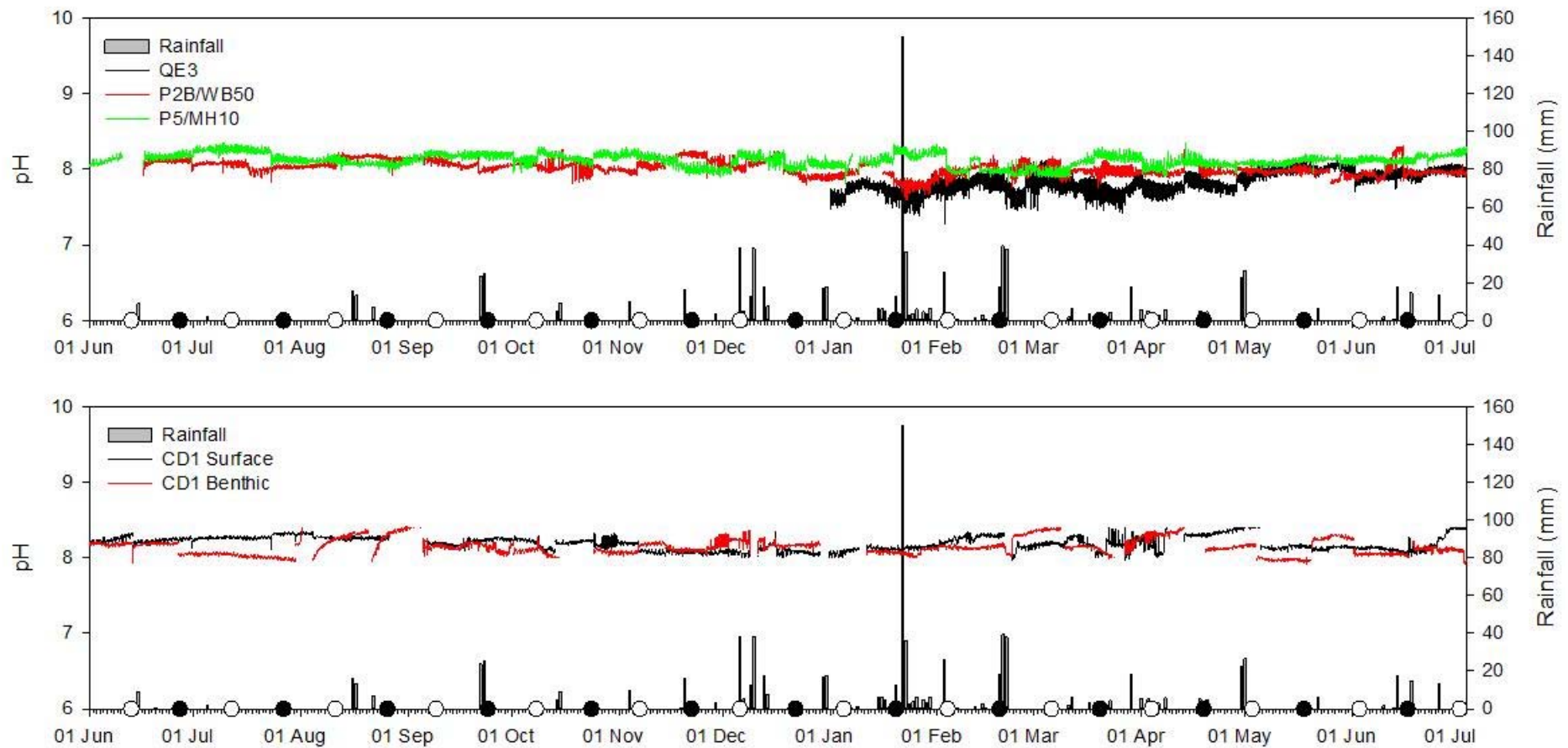


Figure 3.18 Surface pH at QE3, P2B/WB50 and P5/MH10, and surface and benthic pH at CD1 from 1 June 2014 to 4 July 2015 (QE3 January 2015 to July 2015)

Figure note: Open and closed circles indicate full and new moons, respectively.

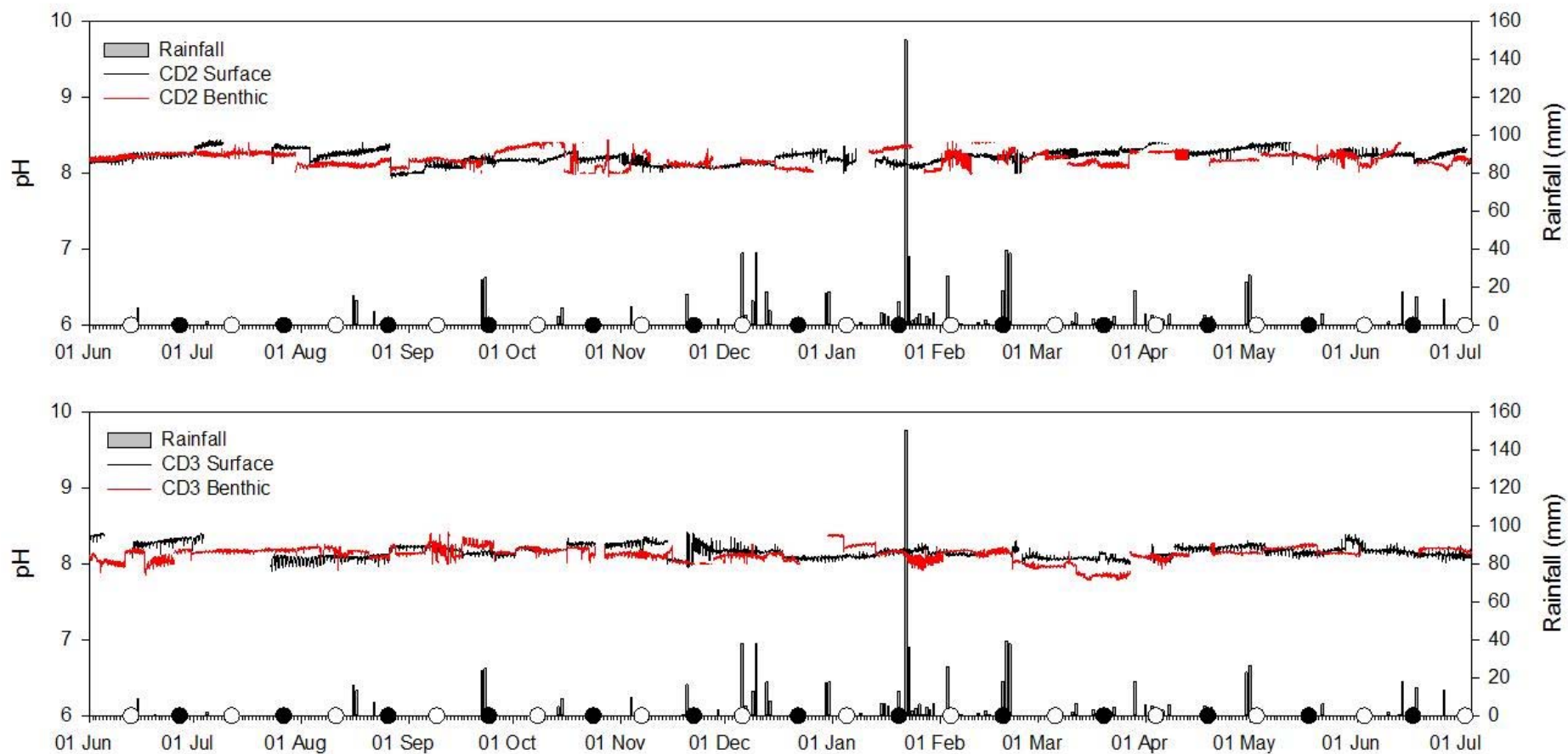


Figure 3.19 Surface and benthic pH at CD2 and CD3 from 1 June 2014 to 4 July 2015

Figure note: Open and closed circles indicate full and new moons, respectively.

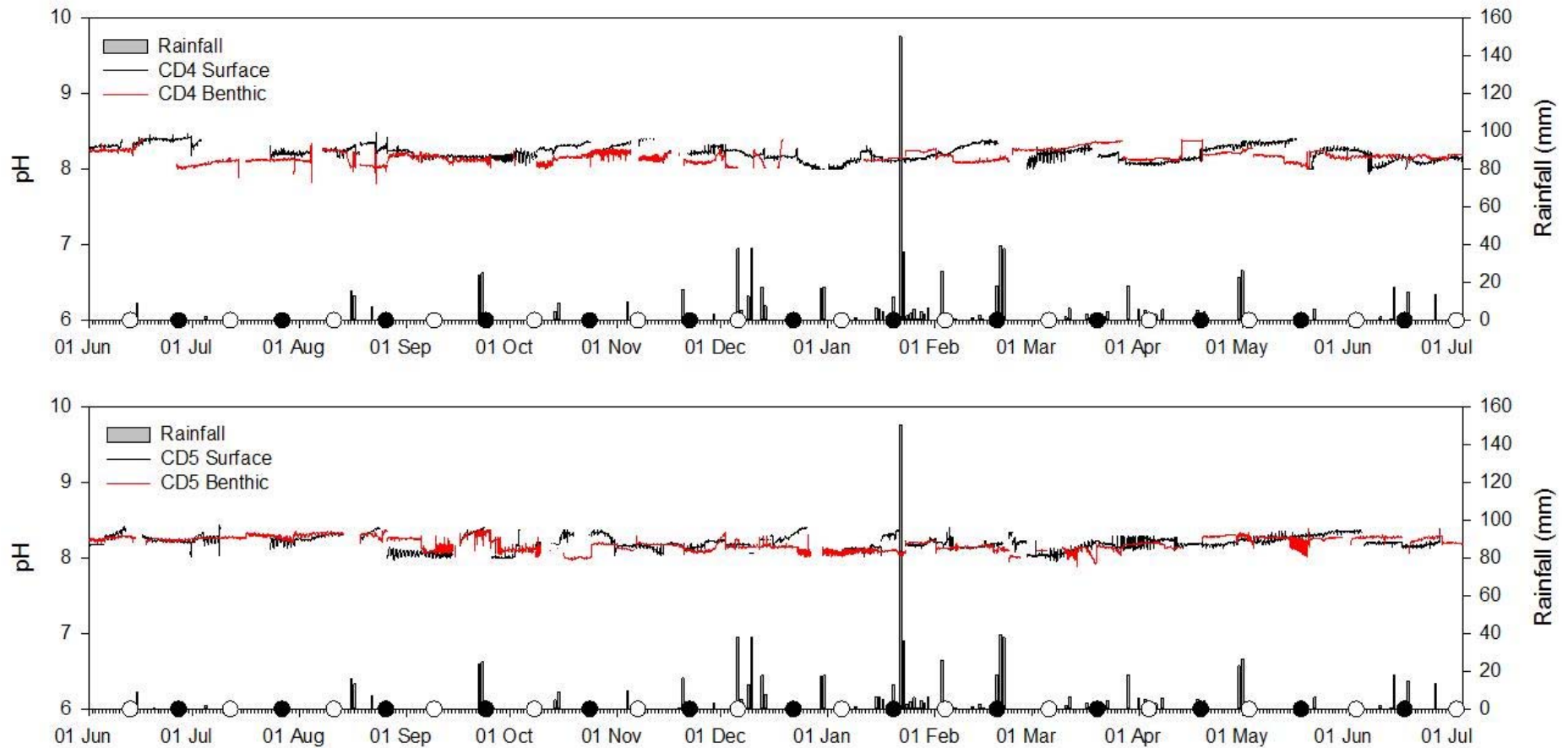


Figure 3.20 Surface and benthic pH at CD4 and CD5 from 1 June 2014 to 4 July 2015

Figure note: Open and closed circles indicate full and new moons, respectively.

3.2.4 Conductivity

Conductivity (mS/cm) is the ability of the water to conduct an electrical current, which is affected by the presence of inorganic dissolved solids, such as salts. In particular, conductivity (a stressor rather than toxicant) provides an indication of the degree of catchment rainfall entering the system.

Conductivity tended to remain stable (refer Table 3.6, Figures 3.21 to 3.23) except for during and after large rain events, which resulted in noticeable decreases, particularly at inshore sites and CD3, and to a lesser extent at site CD2. During mid-January and mid-February 2015, rain events (> 100mm) resulted in conductivity levels less than 20mS/cm at inshore sites QE3 and P2B, less than 40mS/cm at P5/MH10, and less than 10mS/cm at CD3 (surface). A similar pattern was observed at P5/MH10 during preliminary monitoring in March 2014, when over 300mm of rainfall in a three day period resulted in conductivity values as low as 30mS/cm at this site (refer Figure 6.3 in Appendix 6.1).

Table 3.6 Seasonal conductivity at water quality sites from 1 June 2014 to 4 July 2015

Site	Dry Season		Wet Season	
	Surface	Benthic	Surface	Benthic
QE3	51.4 ± 0.0 (51.0)	-	45.3 ± 0.0 (47.5)	-
P2B/WB50	53.2 ± 0.0 (53.0)	-	49.7 ± 0.0 (51.0)	-
P5/MH10	53.5 ± 0.0 (53.5)	-	52.4 ± 0.0 (52.5)	-
CD1	53.1 ± 0.0 (53.0)	53.9 ± 0.0 (54.0)	54.3 ± 0.0 (54.0)	54.1 ± 0.0 (54.2)
CD2	53.3 ± 0.0 (53.0)	53.4 ± 0.0 (53.5)	53.1 ± 0.0 (53.5)	54.1 ± 0.0 (53.9)
CD3	52.5 ± 0.0 (52.5)	53.9 ± 0.0 (53.5)	51.3 ± 0.0 (52.5)	52.9 ± 0.0 (53.5)
CD4	53.4 ± 0.0 (53.5)	52.8 ± 0.0 (53.0)	53.5 ± 0.0 (53.5)	54.1 ± 0.0 (54.5)
CD5	53.1 ± 0.0 (53.0)	53.1 ± 0.0 (53.5)	54.1 ± 0.0 (54.0)	54.5 ± 0.0 (54.7)

Table Notes: Values are means ± se (median). N = 8,635 to 20,831

Values during the Project were not as low as those recorded after the January 2013 flood event (820mm over a four day period), where values less than 5mS/cm (technically considered freshwater), were recorded at all inshore sites, which were being monitored as part of the WBDDP at the time. Conductivity of 0mS/cm was also recorded at site P2B/WB50 for short periods of time during the 2013 event (Vision Environment 2013d).

Recovery to almost typical dry season background conditions after the mid-January and mid-February 2015 rain events did not occur at these sites until April 2015. At CD3, surface conductivity during these times was considerably lower than benthic conductivity with pronounced tidal fluctuations, indicating vertical stratification of the water column and the presence of a surface layer of freshwater outflow from the Boyne River on outgoing tides. Apart from these occasions, only minor differences were evident between mean values calculated for surface and benthic loggers (≤ 1.6 mS/cm).

3.2.5 Dissolved oxygen

Dissolved oxygen (mg/L or % saturation) is the amount of gaseous oxygen that has dissolved in water. Measurements of DO can assist in the validation of the presence of algal blooms. While these parameters do not measure potential dredging related impacts, they can provide information on natural and anthropogenic effects which may be causing underlying stress to the ecosystem.

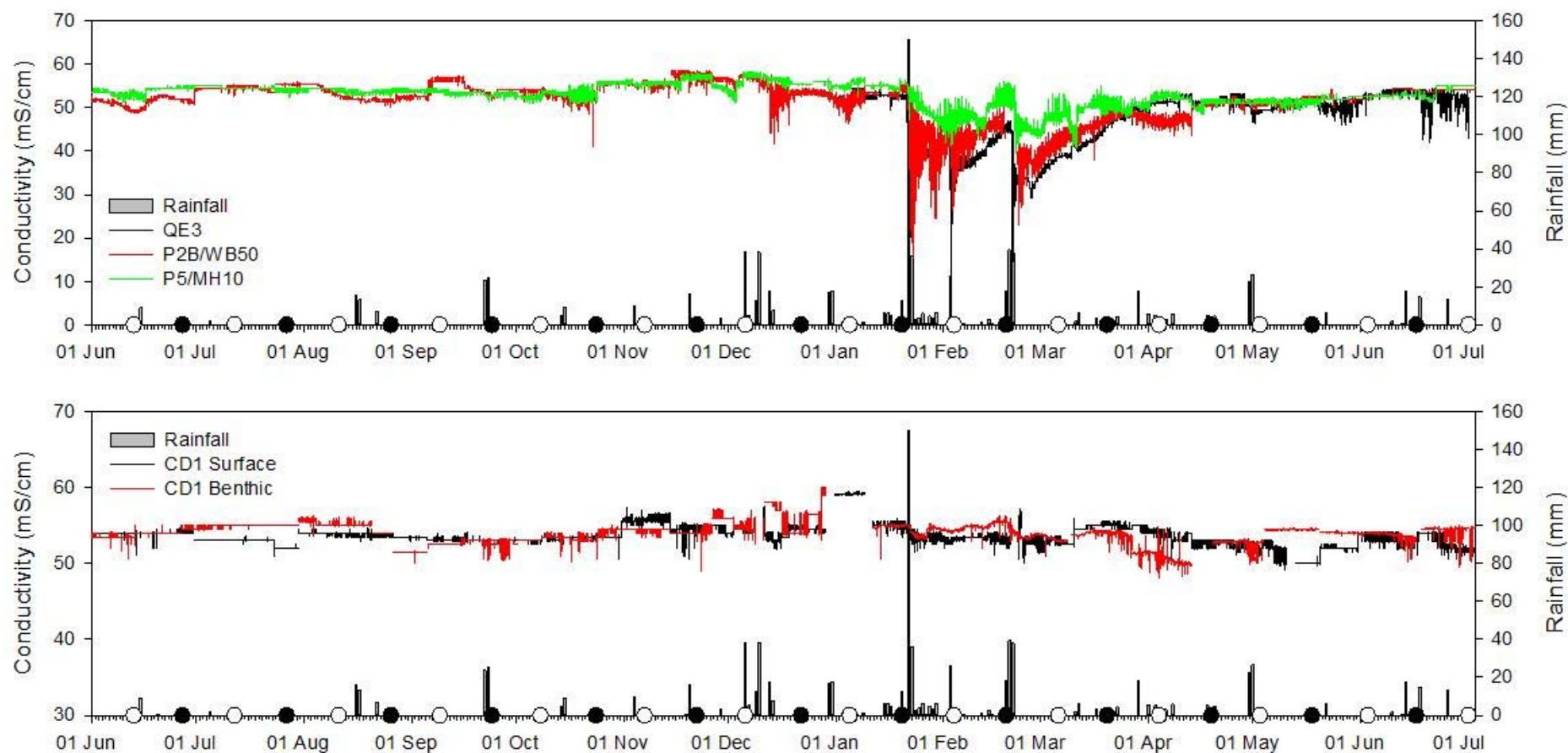


Figure 3.21 Surface conductivity at QE3, P2B/WB50 and P5/MH10, and surface and benthic conductivity at CD1 from 1 June 2014 to 4 July 2015 (QE3 January 2015 to July 2015)

Figure note: Open and closed circles indicate full and new moons, respectively.

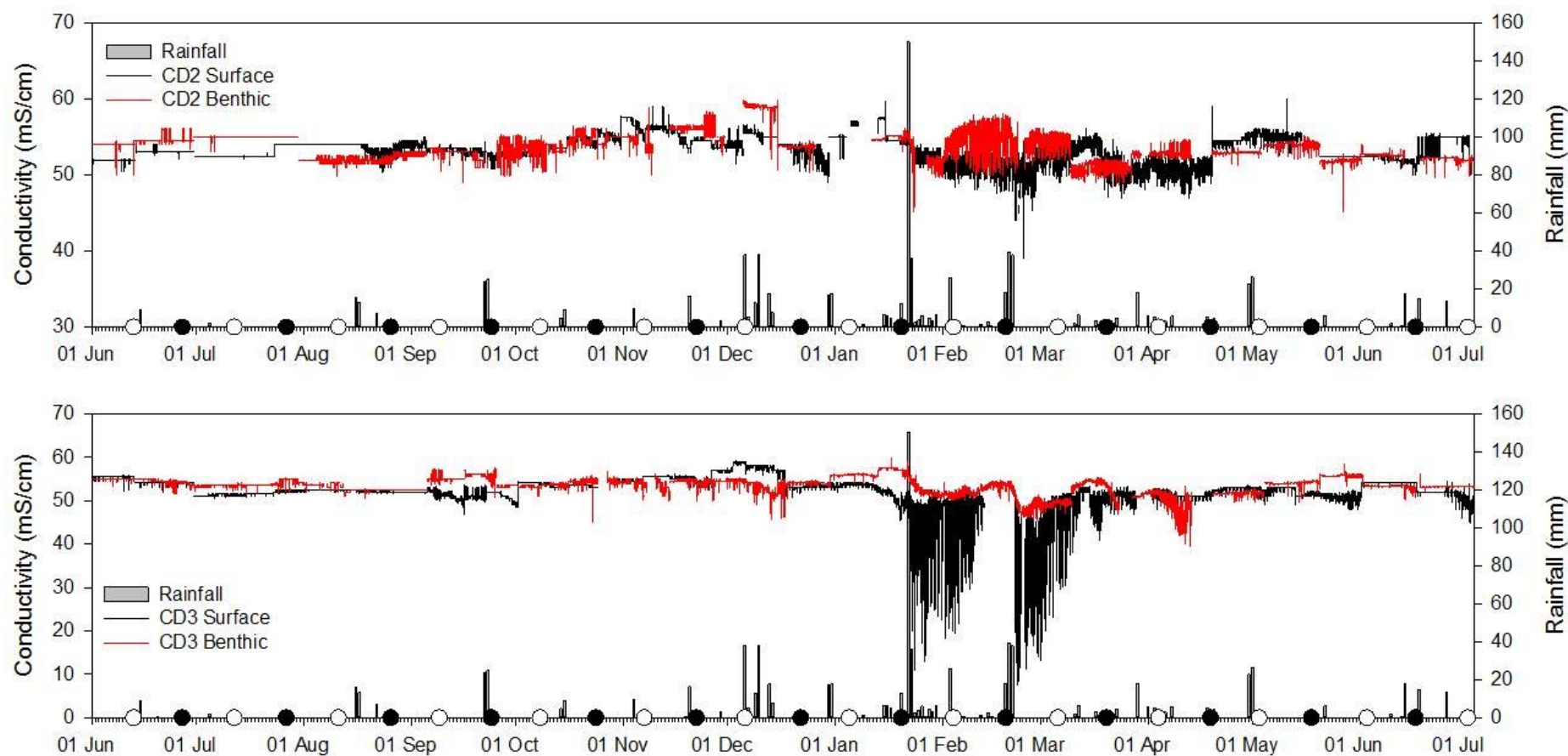


Figure 3.22 Surface and benthic conductivity at CD2 and CD3 from 1 June 2014 to 4 July 2015

Figure note: Open and closed circles indicate full and new moons, respectively.

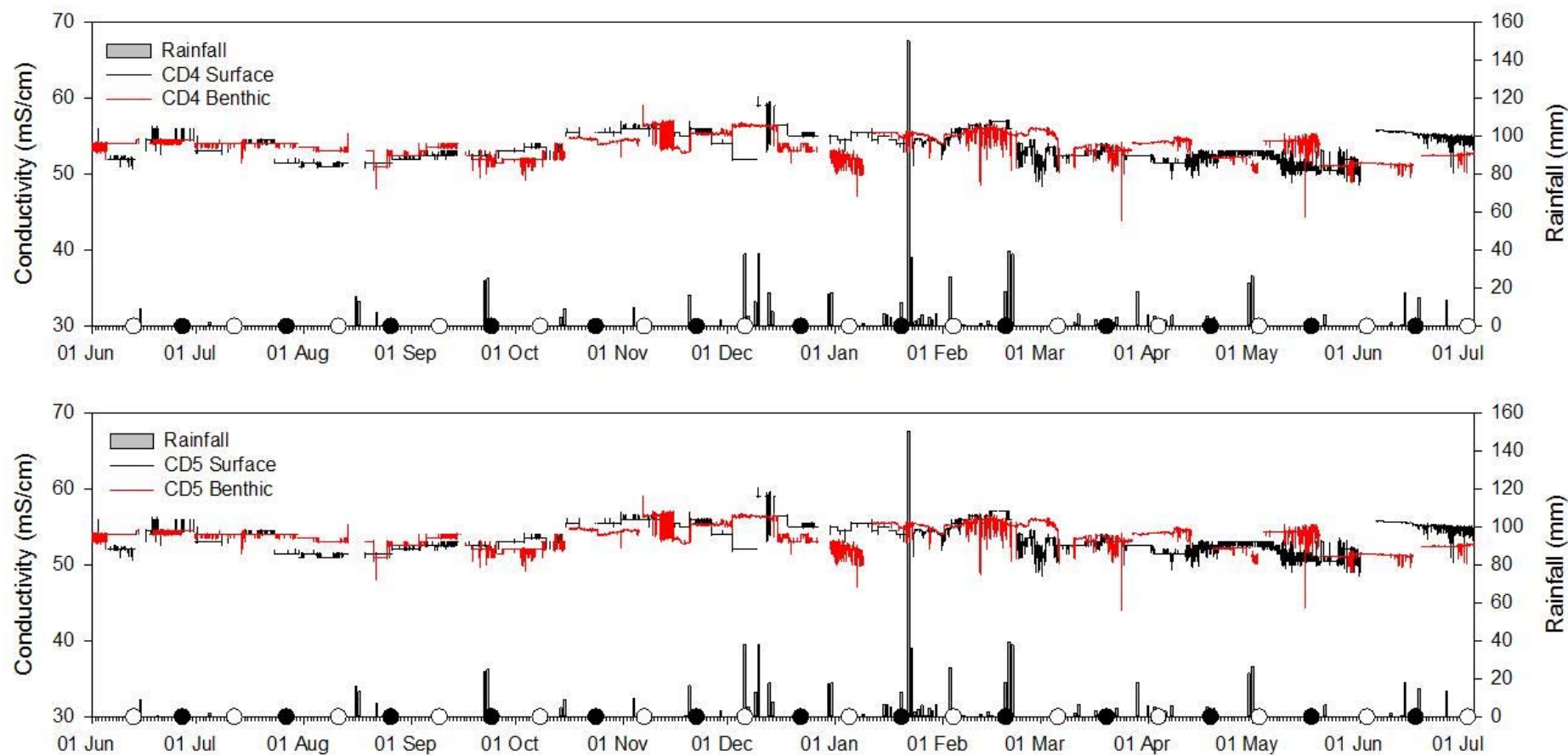


Figure 3.23 Surface and benthic conductivity at CD4 and CD5 from 1 June 2014 to 4 July 2015

Figure note: Open and closed circles indicate full and new moons, respectively.

The DO levels tended to display reasonably consistent patterns throughout the year, with little difference between mean dry and wet season values for each site (refer Figures 3.24 to 3.26, Table 3.7). Across the sites, mean QE3 and P2B/WB50 DO levels were lower than offshore sites by between 3 to 12%, a spatial pattern which has been recorded previously in Port Curtis (Vision Environment 2013f). Only minor differences were evident between mean values for surface and benthic loggers ($\leq 3\%$ saturation). All mean and median seasonal DO concentrations were within their appropriate 20th to 80th percentile WQO range (DSITIA 2014).

Table 3.7 Seasonal dissolved oxygen at water quality sites from 1 June 2014 to 4 July 2015

Site	Dry Season		Wet Season		WQO
	Surface	Benthic	Surface	Benthic	
QE3	93 $\pm$ 0 (93)	-	88 $\pm$ 0 (88)	-	87,92,95
P2B/WB50	97 $\pm$ 0 (97)	-	96 $\pm$ 0 (96)	-	91,96,100
P5/MH10	100 $\pm$ 0 (100)	-	100 $\pm$ 0 (99)	-	94,97,101
CD1	100 $\pm$ 0 (100)	100 $\pm$ 0 (100)	101 $\pm$ 0 (101)	99 $\pm$ 0 (99)	94,97,100
CD2	100 $\pm$ 0 (100)	100 $\pm$ 0 (100)	101 $\pm$ 0 (100)	101 $\pm$ 0 (101)	95 – 105
CD3	100 $\pm$ 0 (99)	100 $\pm$ 0 (99)	100 $\pm$ 0 (100)	99 $\pm$ 0 (99)	94,97,101
CD4	100 $\pm$ 0 (100)	100 $\pm$ 0 (99)	101 $\pm$ 0 (101)	100 $\pm$ 0 (100)	95 – 105
CD5	101 $\pm$ 0 (101)	100 $\pm$ 0 (99)	102 $\pm$ 0 (102)	99 $\pm$ 0 (100)	95 – 105

Table notes:

1. Values are means $\pm$ se (median). N = 8,636 to 20,832.
2. Note that three values are listed for the WQOs for QE3, P2B/WB50, P5/MH10, CD1 and CD3, denoting the 20th, 50th and 80th percentiles
3. Two values are denoted for CD2, CD4 and CD5 indicating the 20th to 80th percentile value range

Of additional note were the immediate decreases in DO associated with rain events. The introduction of detritus and organic matter through freshwater flows causes an increase in BOD and chemical oxygen demand (COD) during the breakdown of the organic matter, thus using up available oxygen in the water column. This was particularly evident at inshore sites QE3 and P2B/WB50 in mid-January and mid-February. Declines to < 70 and $< 80\%$ saturation, respectively, were recorded at the two sites. Declines were also evident at site CD3 but were more pronounced and persistent at CD3 benthic compared to CD3 surface, and were directly related to tidal flows. The difference is likely to be associated with the stratification or halocline of lower saline water at the surface on the outgoing tide. However, unlike conductivity, a return to pre-precipitation background levels was evident within a couple of weeks after each rain event at all sites.

Although diurnal patterns were evident at all sites, they were most pronounced at the inshore sites of QE3, P2B/WB50 and P5/MH10. Diurnal patterns in DO are likely to be due to plant (e.g. algae) photosynthesis and respiration and were particularly noticeable at site P5/MH10 (which is adjacent to large seagrass meadows at Pelican Banks) and QE3 in The Narrows (which is mangrove dominated).

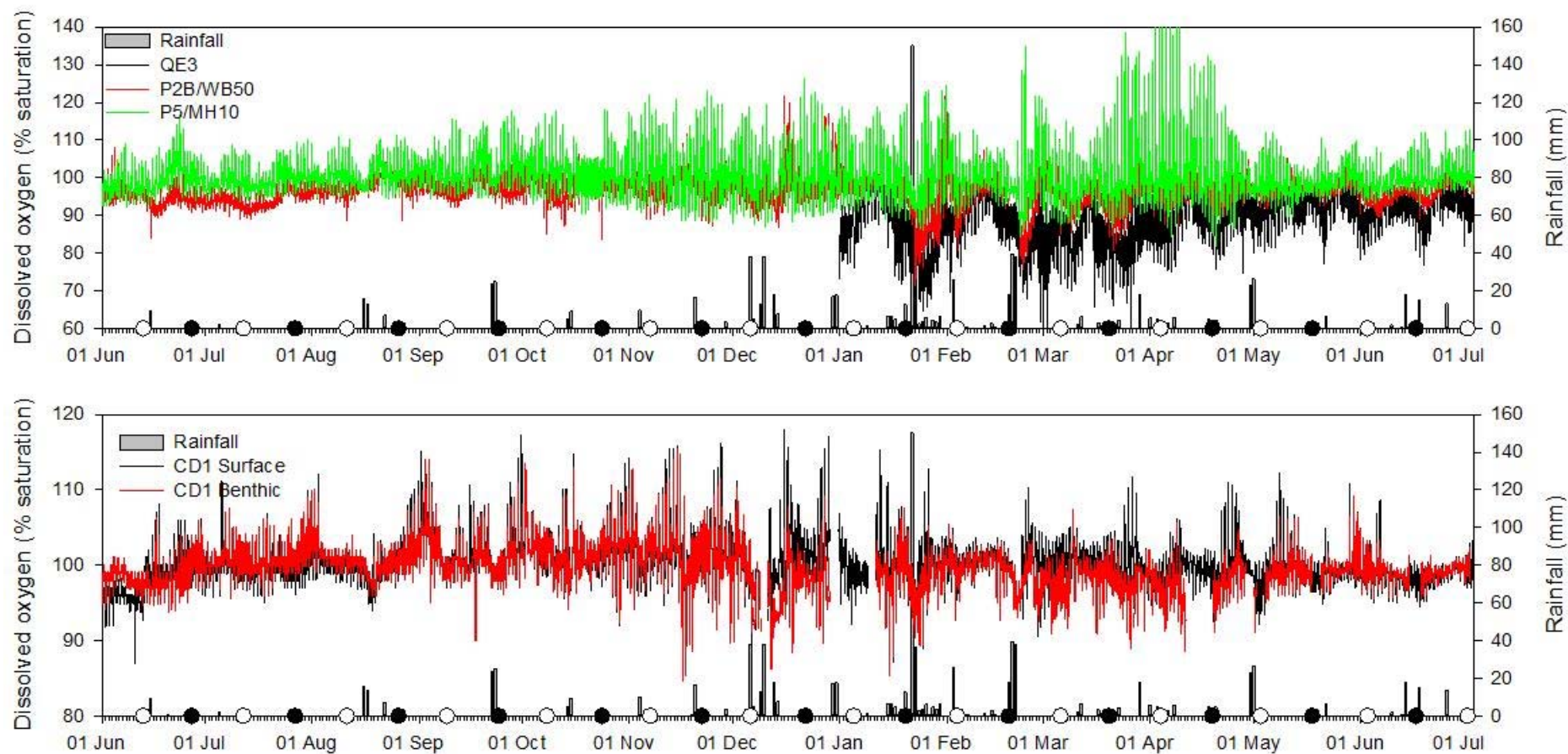


Figure 3.24 Surface dissolved oxygen at QE3, P2B/WB50 and P5/MH10, and surface and benthic dissolved oxygen at CD1

Figure note: Open and closed circles indicate full and new moons, respectively.

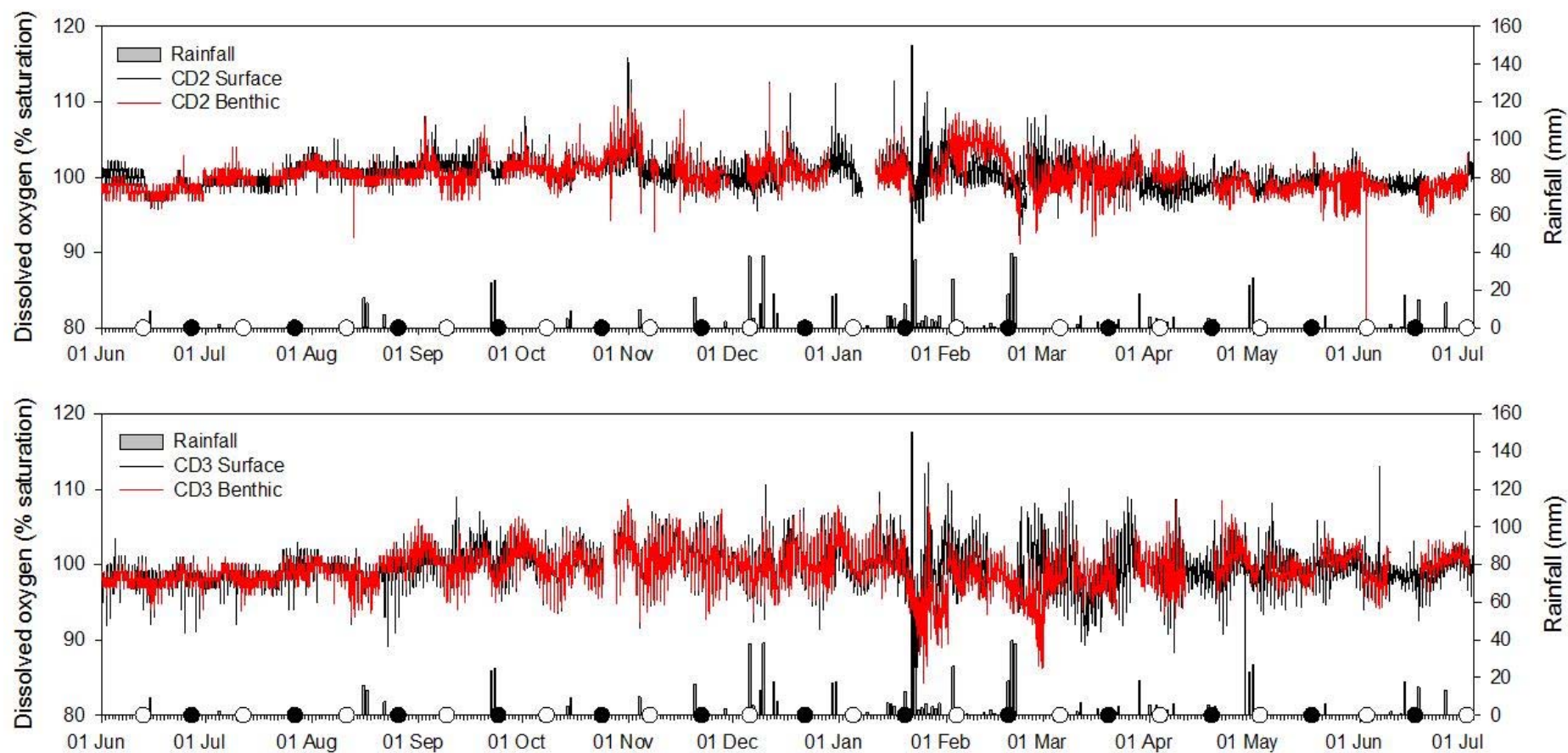


Figure 3.25 Surface and benthic dissolved oxygen at CD2 and CD3

Figure note: Open and closed circles indicate full and new moons, respectively.

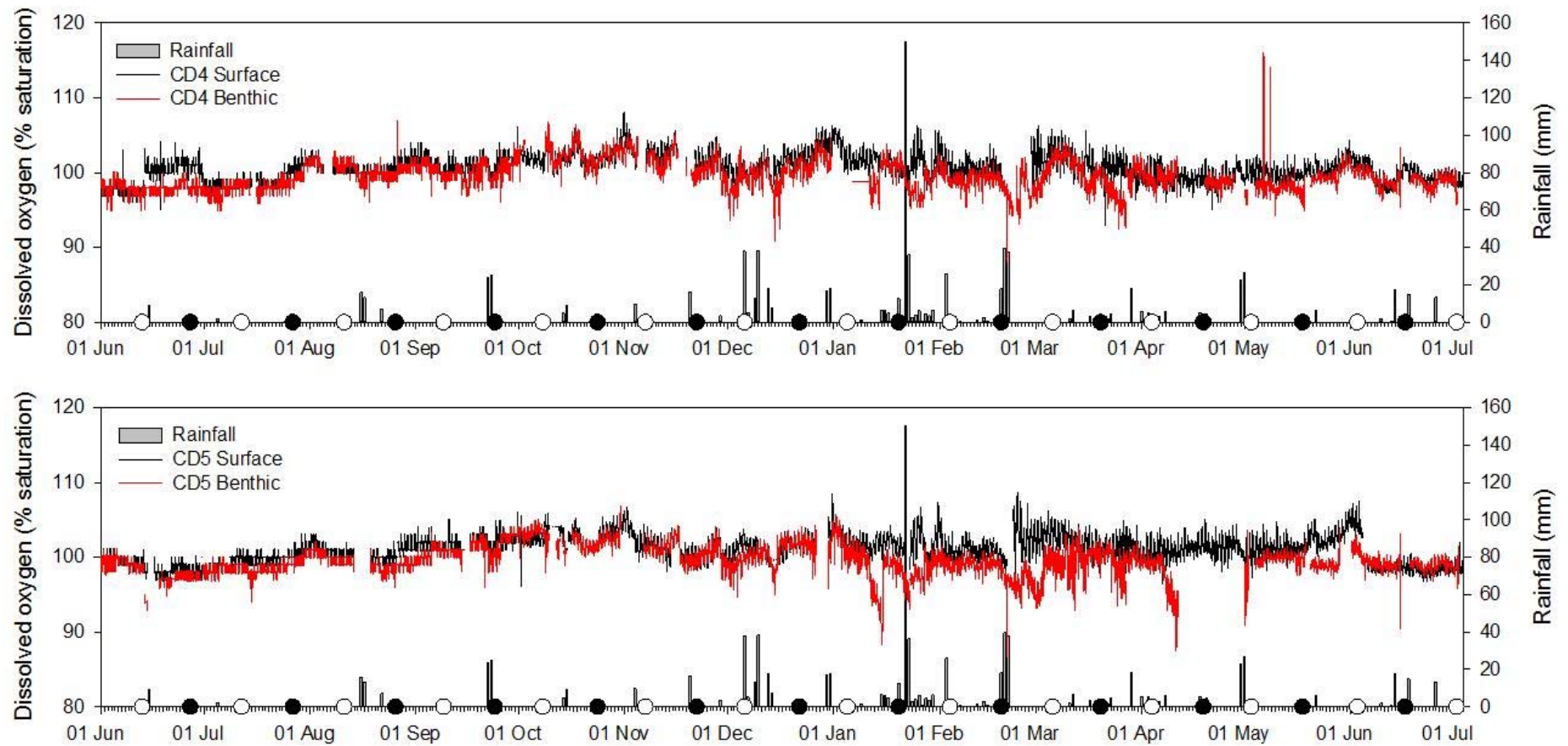


Figure 3.26 Surface and benthic dissolved oxygen at CD4 and CD5

Figure note: Open and closed circles indicate full and new moons, respectively.

Immediate declines after rain events were often followed by periods of more pronounced diurnal patterns with peaks of DO > 120% recorded at P5/MH10. These patterns suggest post rain event increases in photosynthetic activity generally associated with algal blooms. The break-down of stormwater introduced detritus generally results in an increase of nutrients, which can assist to stimulate algal blooms. Intermittent seasonal increases in DO were sometimes evident at offshore sites during the warmer months and often coincided with visual confirmation of algal blooms, during vessel water quality sampling.

One of the most visible effects of critically low DO concentrations is aquatic death (DERM 2009), which can include fish kills (ERISS 2001). The QWQG (DERM 2009) note that values as low as 40% may occur in estuaries for short periods following material inflow events after rainfall, but that values < 30% saturation are toxic to some fish species. The individual DO concentrations in the harbour as recorded by the continuous loggers were generally within the WQO ranges (DSITIA 2014) and therefore DO levels were sufficient to support aquatic life.

3.3 Sedimentation

The resuspension of sediments due to natural and anthropogenic influences, such as dredging related activities have the potential to not only cause a reduction of light and therefore decrease in primary productivity, but also smothering of benthic habitats, such as coral. The ecological significance of resuspension includes impact on cycling of nutrients and contaminants. Although traditional instruments such as sediment traps measure the downward flux of sediment particles over any given time, it is also important to measure the net flux or bed level change (i.e. whether there is overall deposition or erosion of sediments over a given time). The traditional sediment trap assumes all captured particles are permanently deposited, whereas in reality, the majority of particles are transient. Benthic habitats may be tolerant to short term temporary deposition periods, however long term deposition can cause smothering and habitat stress. Therefore it is more important to determine the actual bed level change over time.

Altimeters have the ability to measure the fine levels of the sea bed, by measuring altitude data from a known position over specified time intervals, using an acoustic eco-sounder, similar to a side scan sonar. An altimeter can measure both short and long term changes of bed elevation at locations, where deposition and erosion of fine sediments occur. Monitoring using altimeters is superior to monitoring with sediment traps as continuous data is gained, with the ability to incorporate and identify resuspension events, thus calculating actual rather than total deposition over time.

Sedimentation was measured at all eight monitoring sites using fixed deployment acoustic altimeters. Increases in wave energy as a result of increased wind speeds, or stronger currents as a result of higher tidal ranges has the potential to result in increased sediment resuspension. One of three outcomes may occur during such an event: deposition of sediment from another location, movement of sediment to another location, or resuspension with no net change. There are two forms of information provided by the altimeters:

- Instantaneous bed level change indicating the amount of sediment flux occurring at a set point in time
- Net cumulative change in bed level over a given period

Initial deployment periods in June and July 2014 resulted in deposition at most sites, but this may have been an artefact of sinking of the deployment frame, and therefore data during this time prior to fixed stake deployment should be treated with caution. Instantaneous bed level

change (measured every 15 minutes) and cumulative bed level change (calculated every 24 hours) during each deployment, has been plotted for the 13 month monitoring period (refer Figures 3.28 to 3.35). Cumulative bed level change per deployment period was calculated for each site and has been tabulated (refer Appendix 6.3 Tables 6.11 to 6.18). Note that net cumulative bed level change for the Project baseline monitoring period, cannot be accurately calculated due to data not being available for all deployment periods. Similarly, seasonal data can also not be accurately calculated.

As the instruments are continuous but not telemetered, faults could not be identified and rectified until retrieval of the self-loggers. Therefore some data gaps occurred at each site due to barnacle encrustation, movement of the unit during storm or rain events, in addition to external interference to the beam from marine organisms. Overall, across the 13 month period, validated data was captured on between 61 to 90% of monitoring days. This value is lower than telemetered validated data retention, which averaged > 92% across all sites (surface and benthic) and highlights the benefits of the use of dual telemetry in terms of more reliable data retention. An explanation of the plotted data can be found in Figure 3.27.

3.3.1 Instantaneous bed level change

Several external environmental factors had an effect on instantaneous bed level change (bed level flux) and the effects varied depending on the location of the site either inshore or offshore. For inshore sites, significant rain events (> 100mm in both January and February 2015) generally resulted in an increase in bed level flux. Unfortunately due to the extreme nature of the mid-February 2015 rain event during TC Marcia, data for the entire event was only captured at site QE3 (refer Figure 3.28), although partial data was captured at some other sites. At site QE3 increased turbidity (EWMA ~ 70 NTU and 40 NTU, for rain events in mid-January and mid-February 2015, respectively) generated more dynamic bed level flux. Instantaneous bed level change up to ~ 30mm either positively or negatively from the point of origin at deployment (base point) was recorded in January at QE3, and this was followed by a period of cumulative bed level deposition of up to ~ 30mm.

Although turbidity only reached approximately 10 NTU at P5/MH10 during the mid-January 2015 rain event, increased bed level fluctuation was also observed and this was followed by a period of cumulative bed level erosion of > 20mm for the remainder of the deployment period (refer Figure 3.30). At P2B/WB50 despite an increase in turbidity of up to 40 NTU in mid-January 2015, instantaneous measurements remained fairly static with only slight erosion over the deployment period, most likely due to increased freshwater flows (refer Figure 3.29).

For the inshore sites, spring tides coinciding with elevated turbidity also generated more dynamic bed level flux. Apart from the two rain events, one additional occasion of higher bed level flux was evident at QE3 in early February 2015, coinciding with a period of elevated turbidity associated with the higher spring tide. However consistent tidal patterns were particularly evident at P2B/WB50 over the 13 month deployment, with more volatile bed level changes coinciding with the higher turbidity recorded during the majority of spring tides.

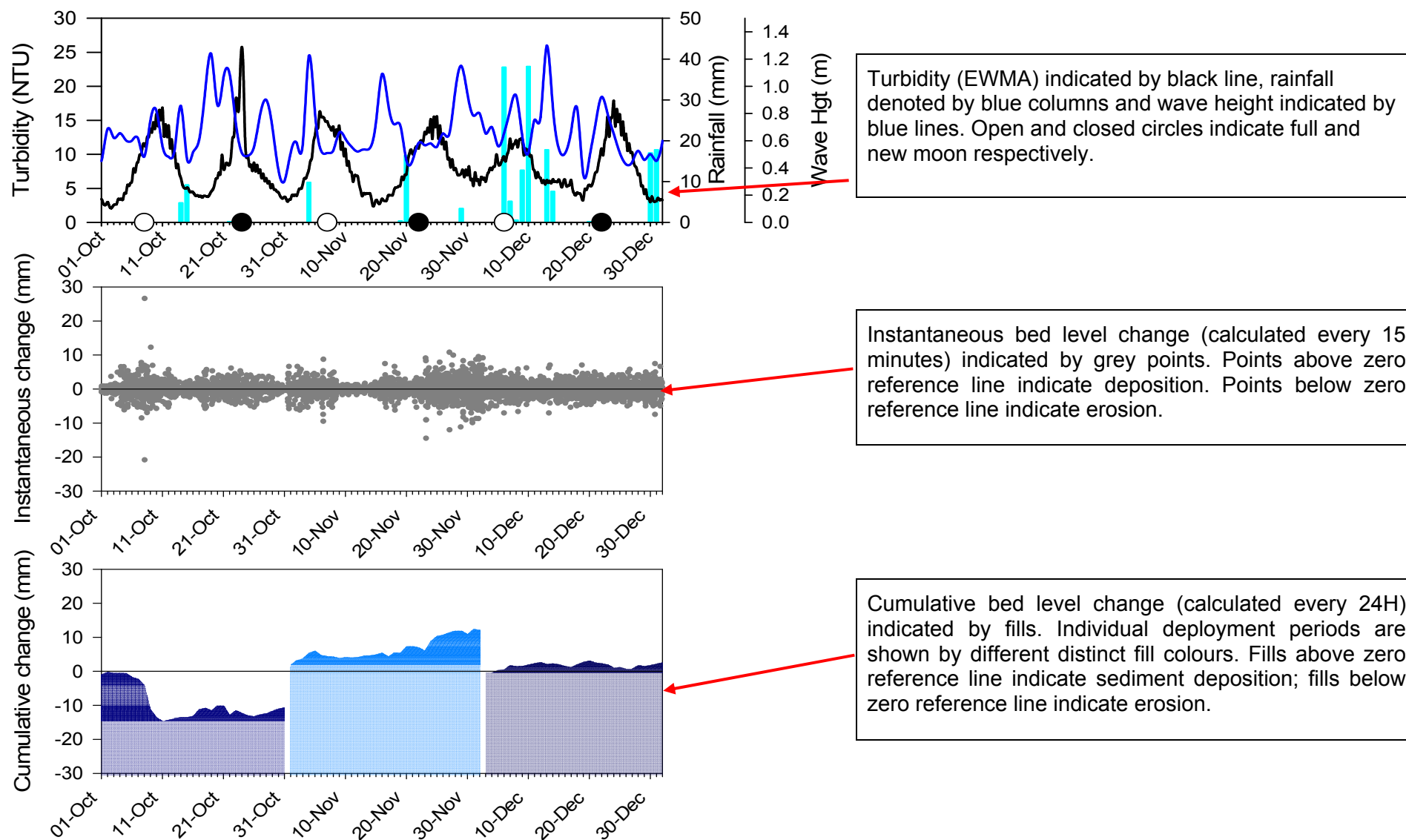


Figure 3.27 Example of turbidity, rainfall, instantaneous bed level change and cumulative bed level change plot.

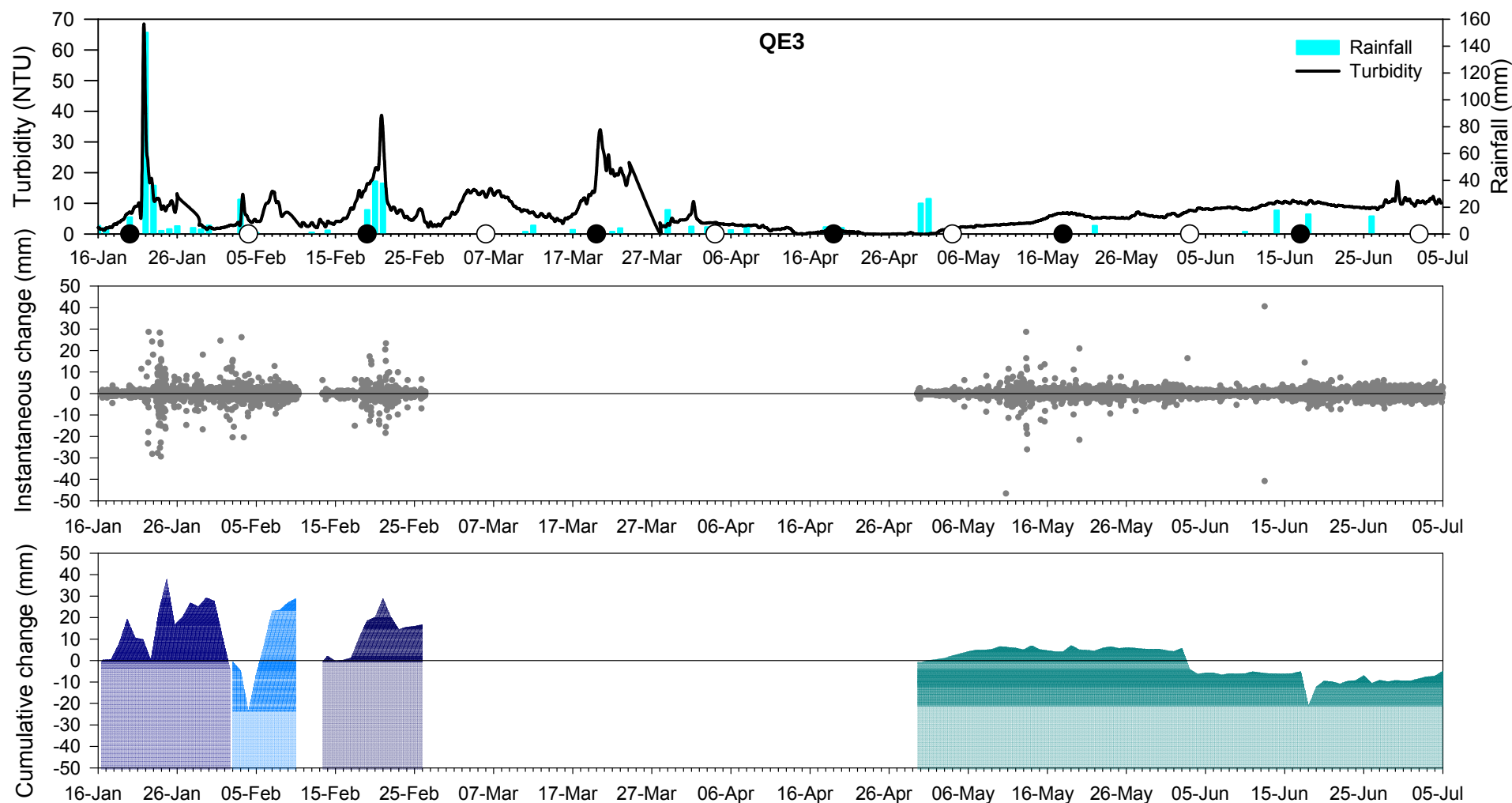


Figure 3.28 QE3 turbidity (EWMA) and rainfall in addition to instantaneous bed level change and cumulative bed level change from 1 January to 4 July 2015
Figure note: Positive sediment bed level change indicates sediment deposition while negative change indicates erosion (instantaneous sediment change (black dots) measured every 15 minutes). Fill indicates cumulative sediment change per deployment (calculated every 24 hours). Open and closed circles indicate full and new moons respectively.

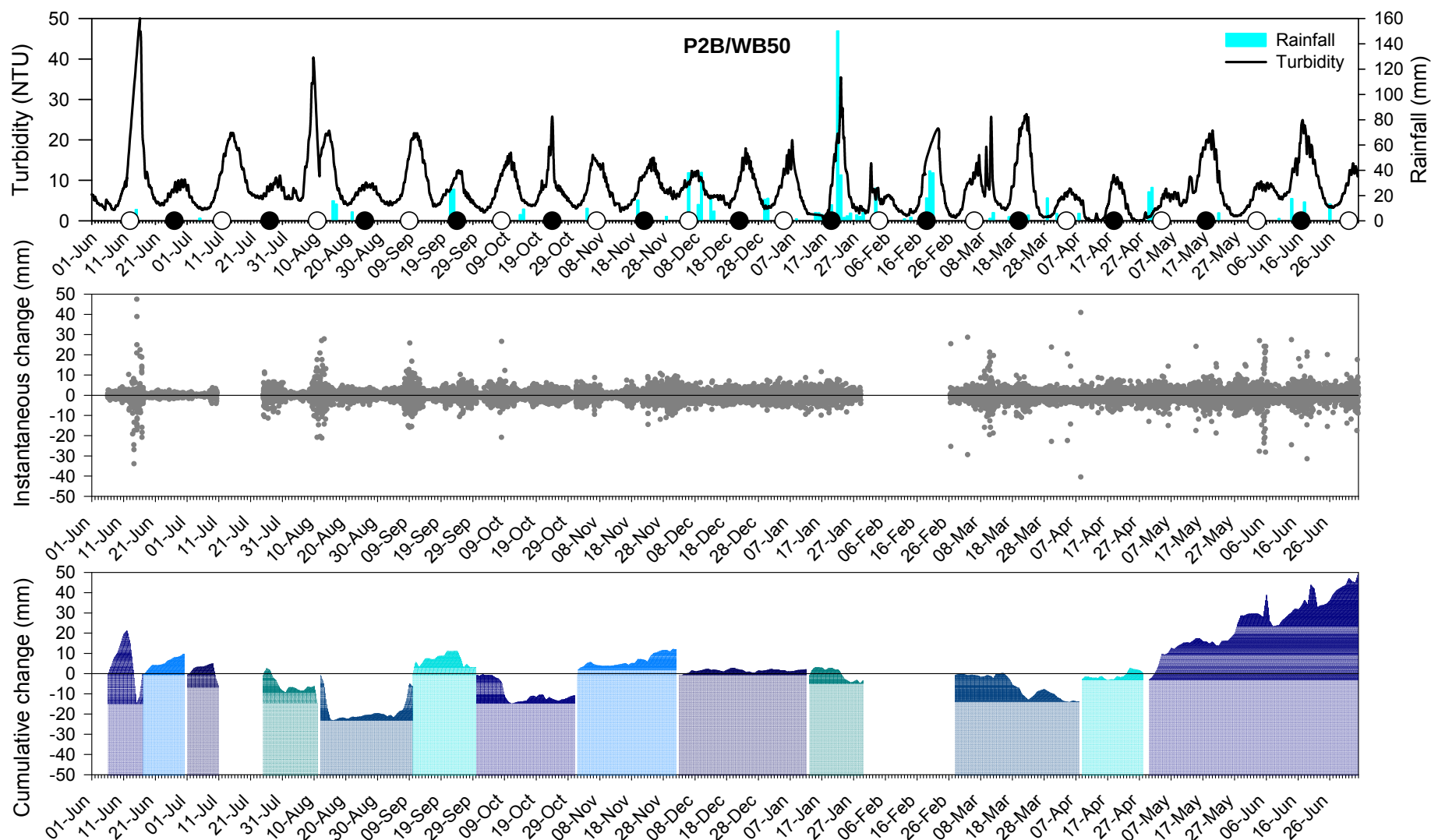


Figure 3.29 P2B/WB50 turbidity (EWMA) and rainfall, and instantaneous bed level change and cumulative bed level change from 1 June 2014 to 4 July 2015

Figure note: Positive sediment bed level change indicates sediment deposition while negative change indicates erosion (instantaneous sediment change (black dots) measured every 15 minutes). Fill indicates cumulative sediment change per deployment (calculated every 24 hours). Open and closed circles indicate full and new moons respectively.

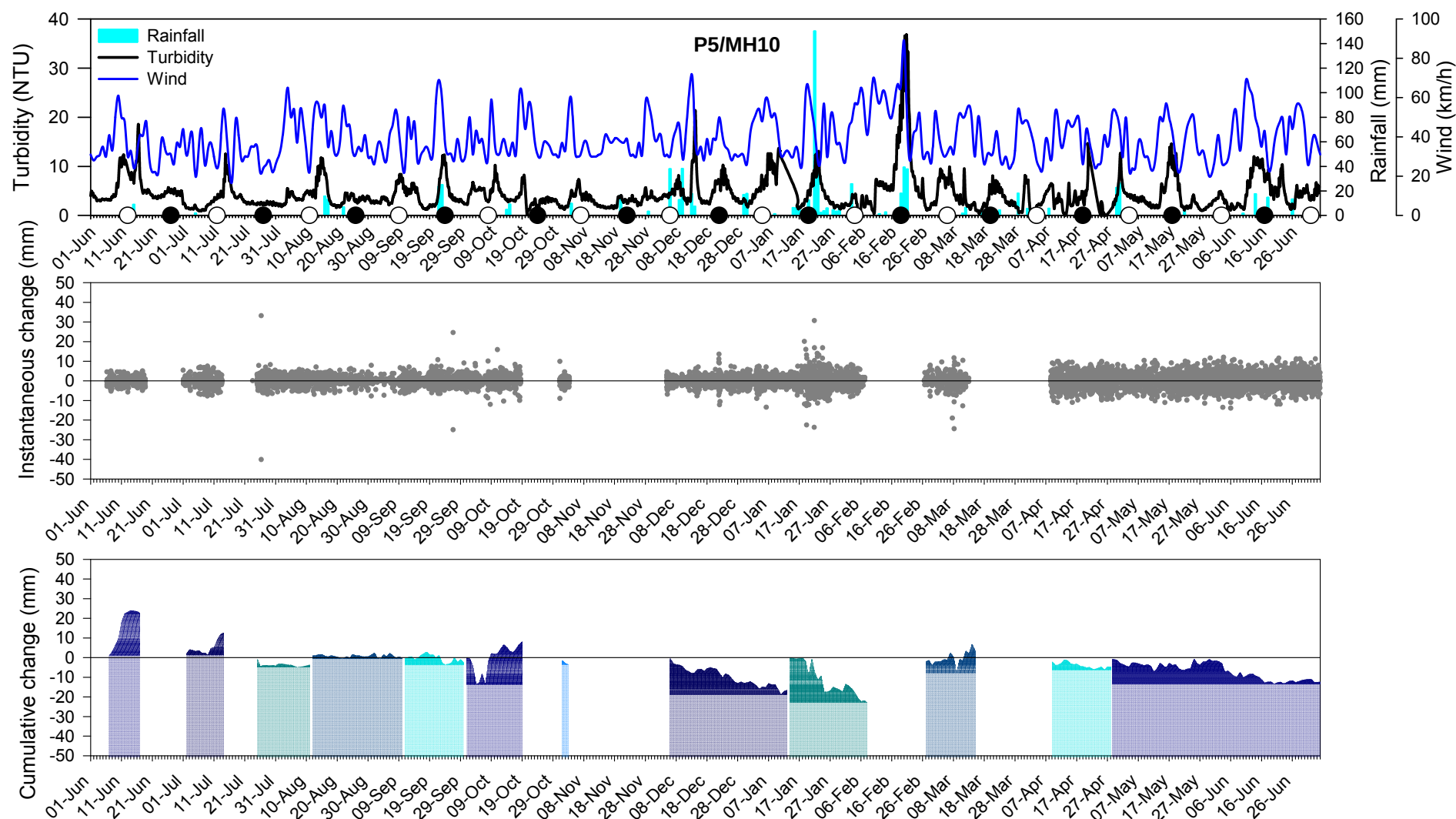


Figure 3.30 P5/MH10 turbidity (EWMA), wind speed and rainfall, and instantaneous bed level change and cumulative bed level change from 1 June 2014 to 4 July 2015

Figure note: Positive sediment bed level change indicates sediment deposition while negative change indicates erosion (instantaneous sediment change (black dots) measured every 15 minutes). Fill indicates cumulative sediment change per deployment (calculated every 24 hours). Open and closed circles indicate full and new moons respectively.

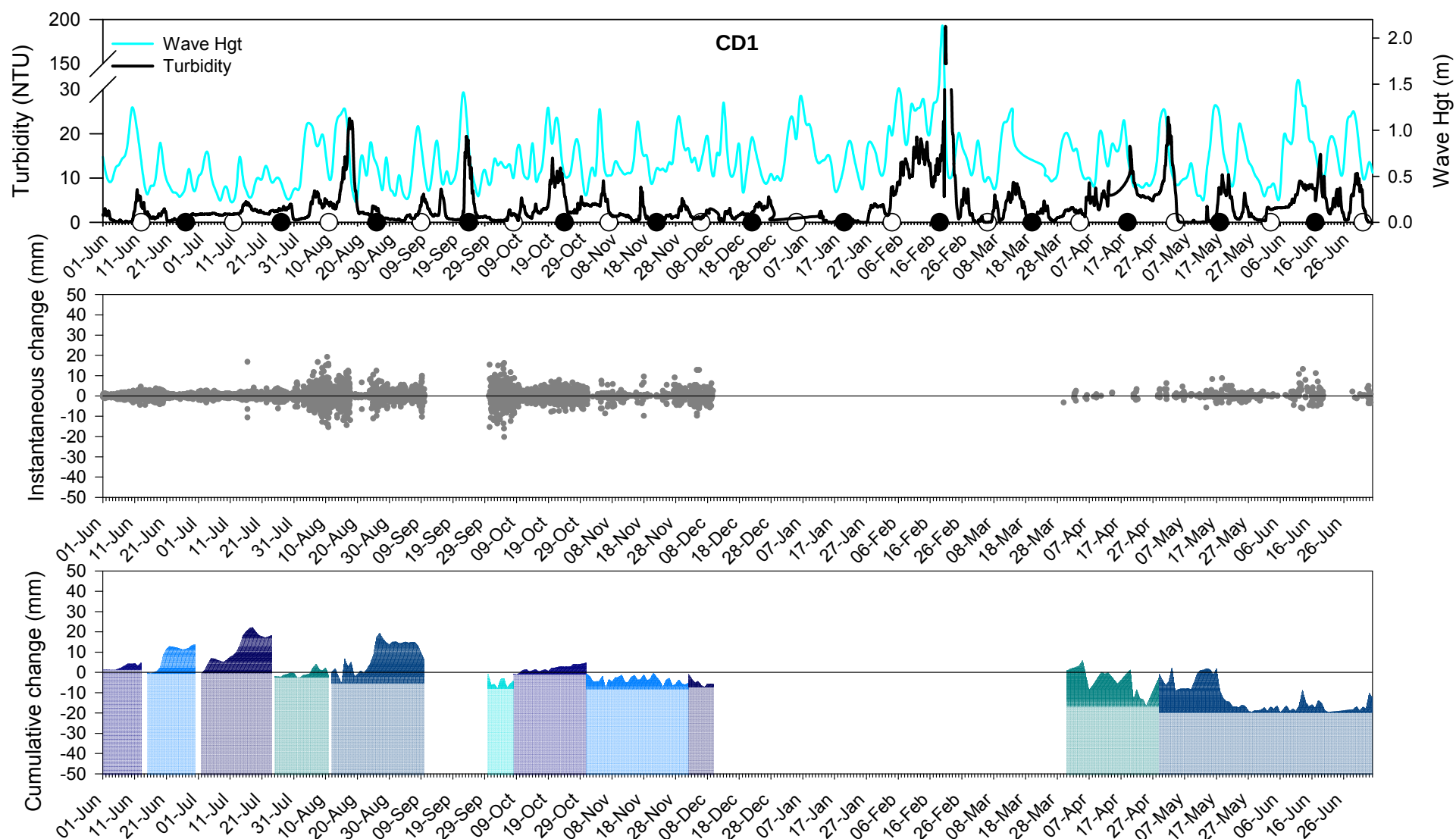
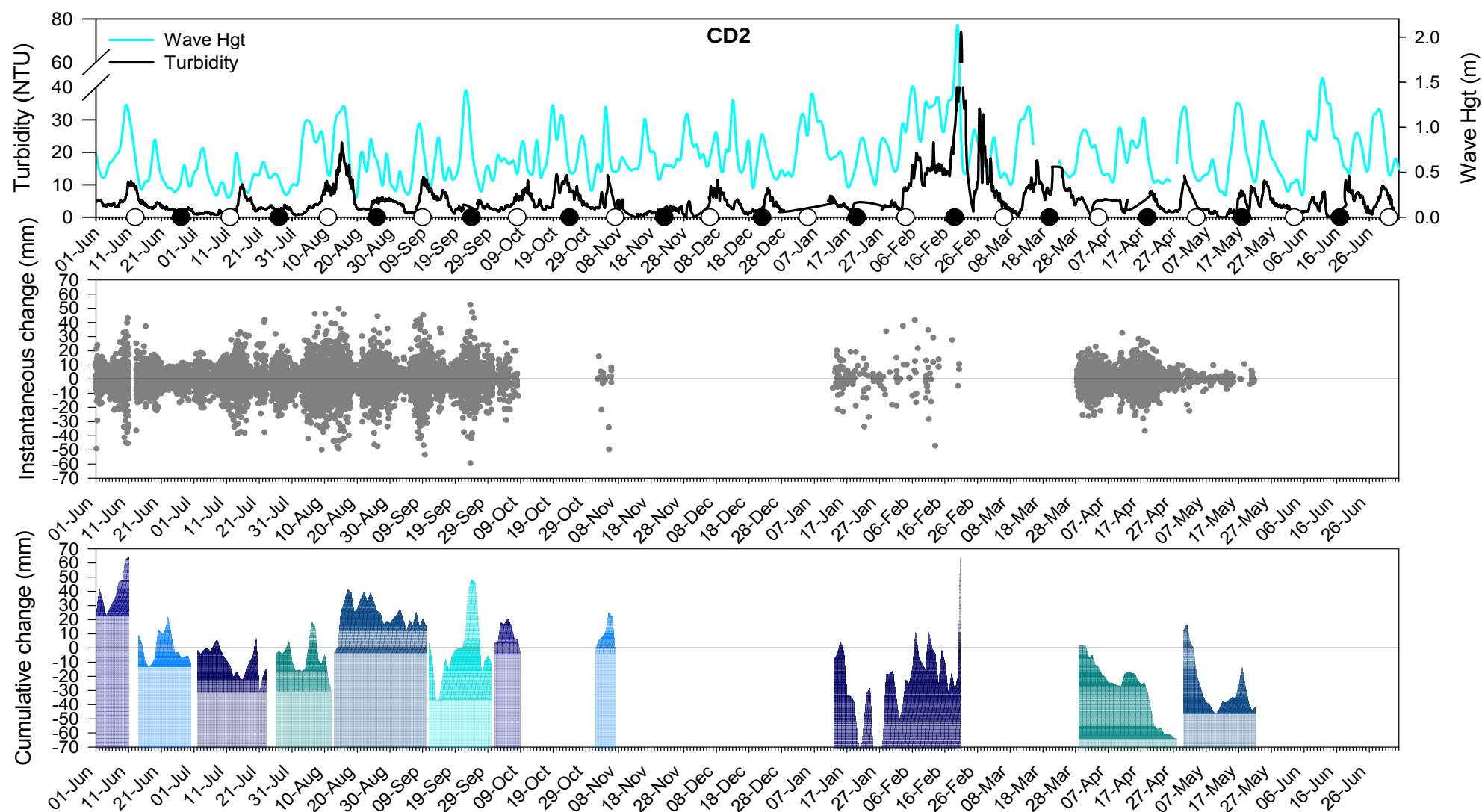


Figure 3.31 CD1 benthic turbidity (EWMA) and wave height, and instantaneous bed level and cumulative bed level change from 1 June 2014 to 4 July 2015

Figure note: Positive sediment bed level change indicates sediment deposition while negative change indicates erosion (instantaneous sediment change (black dots) measured every 15 minutes). Fill indicates cumulative sediment change per deployment (calculated every 24 hours). Open and closed circles indicate full and new moons respectively.



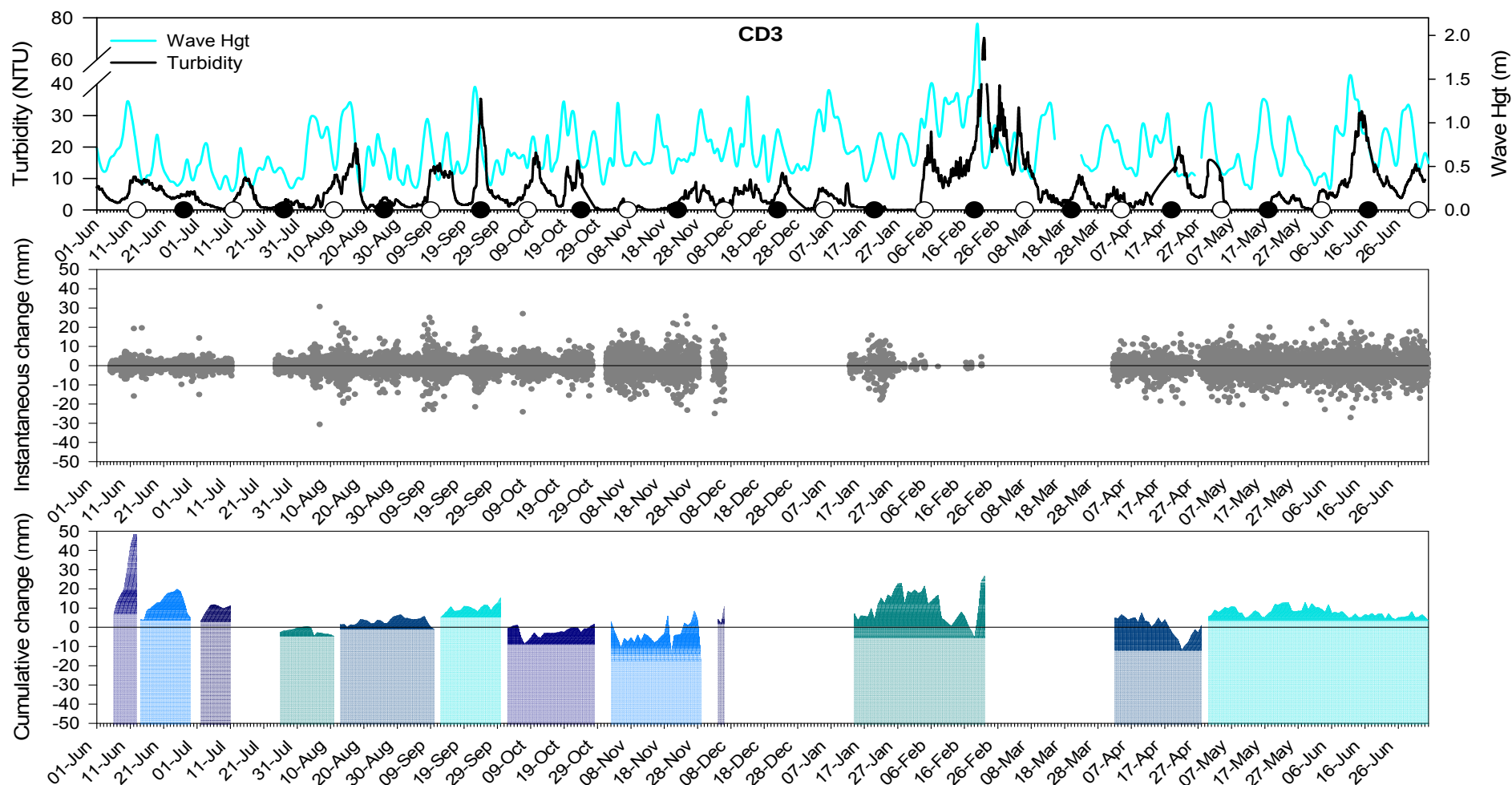
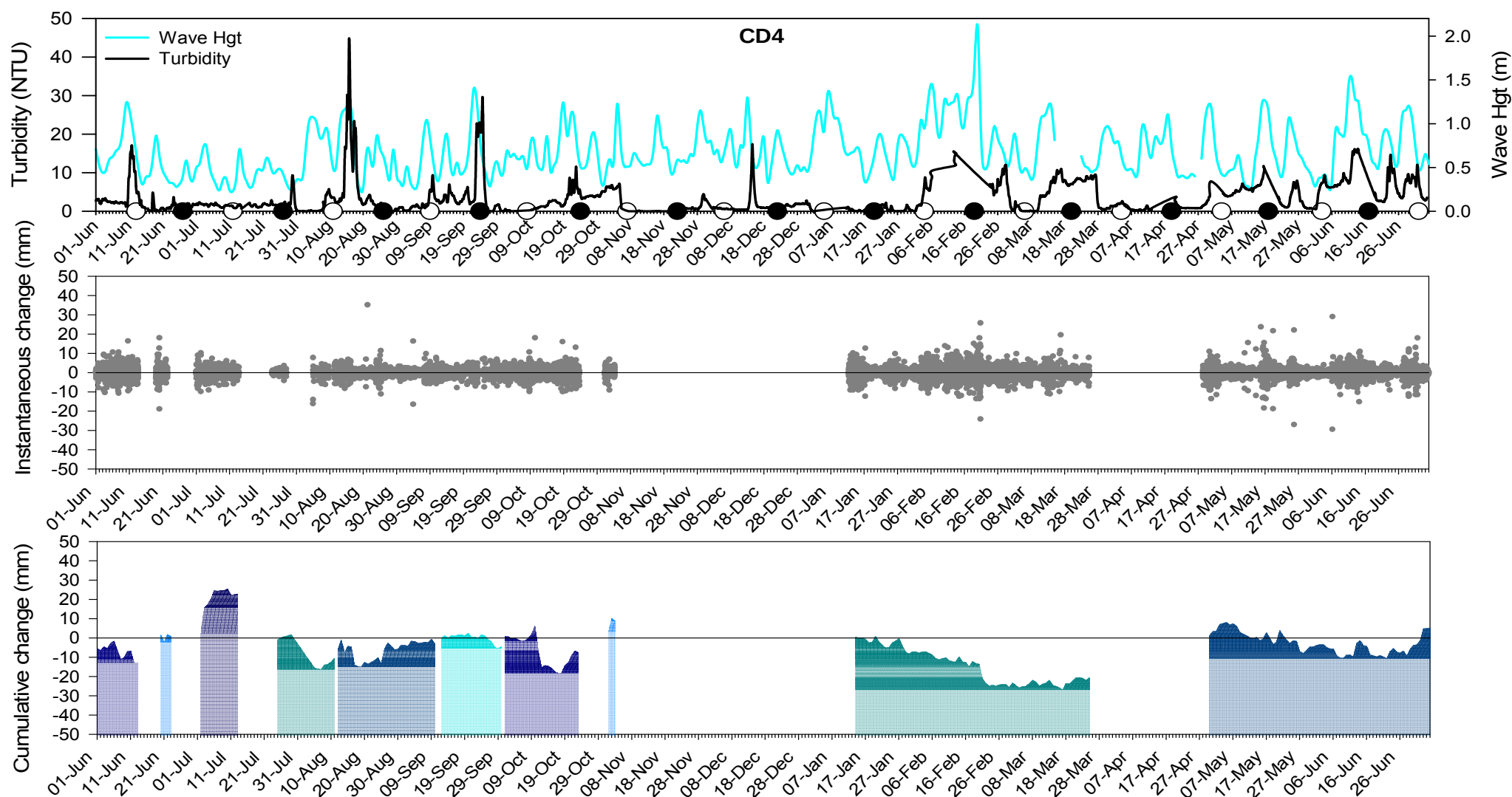


Figure 3.33 CD3 benthic turbidity (EWMA) and wave height, and instantaneous bed level change and cumulative bed level change from 1 June 2014 to 4 July 2015

Figure note: Positive sediment bed level change indicates sediment deposition while negative change indicates erosion (instantaneous sediment change (black dots) measured every 15 minutes). Fill indicates cumulative sediment change per deployment (calculated every 24 hours). Open and closed circles indicate full and new moons respectively.



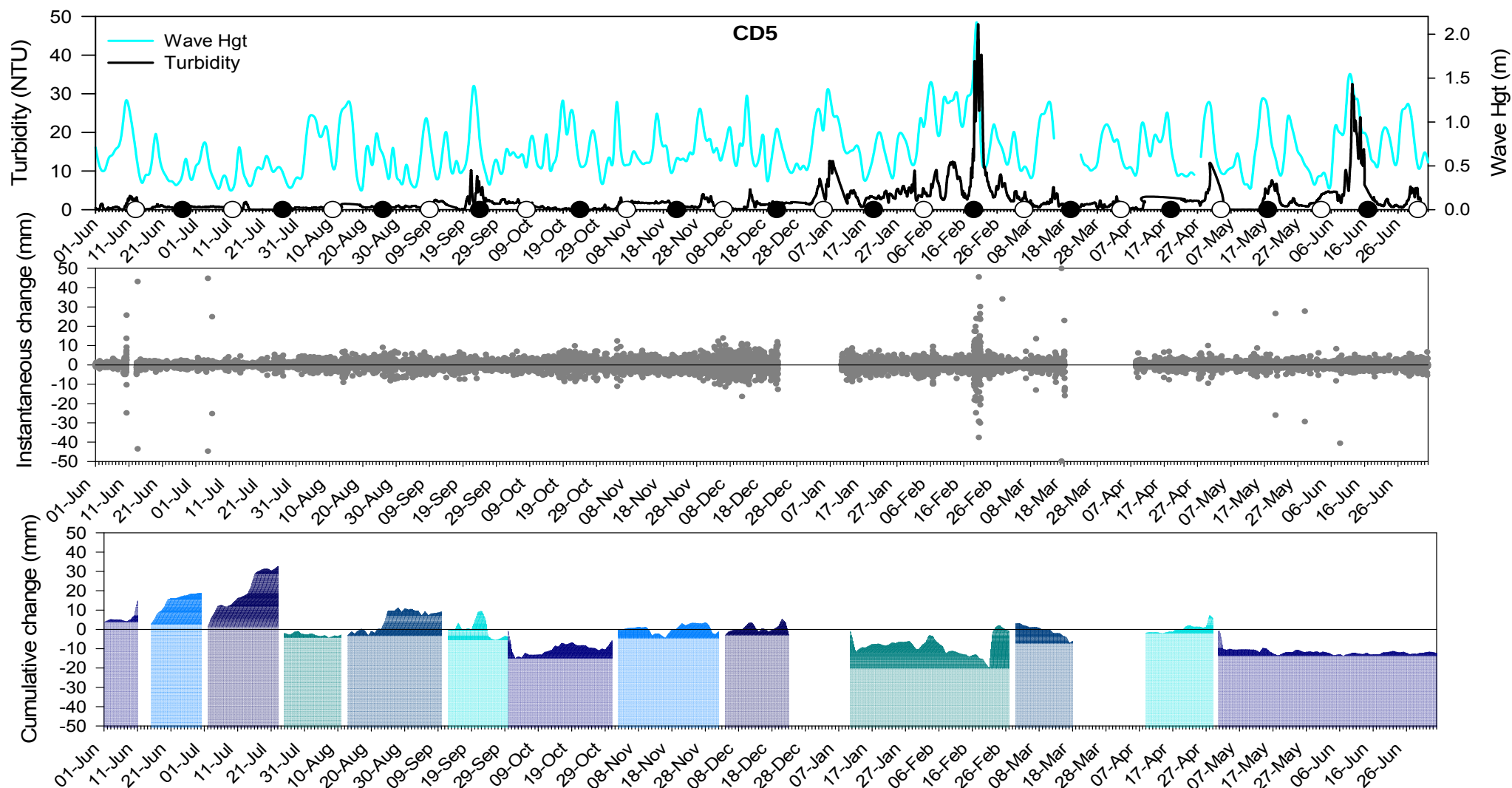


Figure 3.35 CD5 benthic turbidity (EWMA) and wave height, and instantaneous bed level and cumulative bed level change from 1 June 2014 to 4 July 2015

Figure note: Positive sediment bed level change indicates sediment deposition while negative change indicates erosion (instantaneous sediment change (black dots) measured every 15 minutes). Fill indicates cumulative sediment change per deployment (calculated every 24 hours). Open and closed circles indicate full and new moons respectively.

A threshold value of surface turbidity EWMA > 15 NTU at P2B/WB50 appeared to generate an altered bed level state. The spring tide of 11 August 2015 generated bed level change up to ~ 50mm from base point and resulted in cumulative erosion up to 20mm during the deployment period. In comparison to P2B/WB50, bed level flux at P5/MH10 was more stable suggesting sediment movement occurred less frequently, even during spring tides or high wind events. During the dry season deployment, turbidity at both QE3 and P5/MH10 remained reasonably stable, as did overall instantaneous bed level change which tended to mostly fluctuate around a fixed point.

In contrast to the furthest offshore sites CD1, CD4 and CD5, where wind speeds and wave heights were the driving factors for sediment resuspension, at sites CD2 and CD3, tidal influences appeared more influential (refer Figures 3.32 and 3.33). Instantaneous bed level change paralleled turbidity particularly at CD2, with a higher degree of bed level flux during each spring tide period. This tended to be the dominant overall pattern at this site overriding wind speed events, with volatile instantaneous bed level measurements regularly ranging up to ~ 50mm either positively or negatively from the base point at CD2. A similar pattern occurred at CD3, however bed level flux generally only deviated within 20mm of the fixed point.

At CD1, benthic turbidity remained relatively low during the majority of the 13 month monitoring period and as such, bed level flux also remained stable during these periods (refer Figure 3.31). However, similar to P2B/WB50, when turbidity (EWMA > 15 NTU) was recorded during periods of elevated wave height, variations in the bed level increased, including in August and October 2014 and to a lesser extent June 2015. Instantaneous bed level measurements ranged up to ~ 15mm either positively or negatively from the base point at CD1 during these occasions.

Over the 13 month monitoring period, sites CD4 and CD5 were less dynamic in terms of bed level flux compared to other offshore sites, most likely due to their deeper locations (refer Figures 3.34 and 3.35). Both sites captured data through the advent of TC Marcia and it was during this period that the highest instantaneous bed level change for CD5 was recorded. Elevated turbidity (EWMA > 45 NTU) generated bed level flux up to ~ 30mm either positively or negatively from the base point at CD5, on this occasion. At CD4, bed level flux was not as variable, with instantaneous bed level change up to ~ 20mm either positively or negatively from the base point.

3.3.2 Cumulative bed level change

Cumulative bed level change per deployment period has been tabulated (refer Tables 6.11 to 6.18 in Appendix 6.3) and plotted (refer Figures 3.28 to 3.36). At site QE3, all three deployment periods during the wet season exhibited a net accumulation of sediment (range between 12 and 30mm (refer Figure 3.36). In contrast, the one deployment period during the dry season (May to July 2015) exhibited slight, gradual erosion over the deployment period, with sediment levels ~ 4mm lower at the end of the 66 day deployment.

Of the 13 deployment periods at P2B/WB50, erosion and deposition occurred fairly evenly (refer Figure 3.36). No clear seasonal pattern was apparent, with periods of erosion interspersed with periods of deposition. The most evident cumulative deposition of ~ 50mm was recorded during May and June 2015, although no clear environmental trigger for this was apparent. A similar pattern was observed at P5/MH10 but with bed level deviating generally consistently from a fixed point. While no clear seasonal pattern was evident, highest erosion

rates at P5/MH10 for any one deployment (up to ~ 21mm) occurred from December to February, where wave heights and winds speeds were generally highest.

Following the period of initial potentially erroneous deposition, cumulative erosion occurred for the majority of deployment periods at CD1, CD2, CD4 and CD5 (refer Figure 3.36). This was most apparent at CD2 with up to ~ 63mm of cumulative erosion recorded in any one deployment period (March to April 2015). Maximum cumulative erosion only reached ~ 13mm, 20mm and 12mm at CD1, CD4 and CD5, respectively.

Compared to other sites, bed level at CD2 fluctuated greatly, demonstrating the overall result of the highly volatile bed level flux recorded at this site (refer Figure 3.36). Sediment erosion CD2 was generally up to three fold greater than that recorded at all other sites and was highest during the March/April 2015 deployment, post TC Marcia.

In contrast to all other sites, almost all deployment periods at CD3 resulted in deposition (refer Figure 3.36). Apart from the initial deployment periods, cumulative net deposition up to ~ 28mm was recorded for any one deployment period. Highest deposition occurred during the rain events of January and February 2015. This is an expected result considering this site's location at the mouth of the Boyne River and associated siltation issues.

Wind direction was also highly influential in determining the extent of instantaneous bed level change at the offshore sites and cumulative bed level change, whether accretion or erosion. Both CD4 and CD5 demonstrated a period of erosion for several days prior to landfall of TC Marcia, corresponding with increasing wind speeds in an east-south east direction (refer Figures 3.34 and 3.35). During the landfall of TC Marcia in mid-February 2015 and with wind direction rapidly changing to westerly, rapid erosion continued, with up to ~ 24mm recorded at CD4, which created a new stable baseline until the end of the deployment period in early April. In contrast, rapid deposition up to ~ 20mm was recorded at CD5 from 21 to 23 February, post TC Marcia. Data was only able to be captured for some of the period of the passing of TC Marcia at CD2 but prior erosion followed by a short period of deposition, was also recorded at this site before unit disruption. The differences may be related to CD2 and CD5 being located adjacent to the harbour entrance, East Banks DMPA and outer anchorage, whereas CD4 is located to the north in more open prevailing currents. On retrieval after TC Marcia, the CD2 altimeter buoy, mooring and stake with altimeter, were found approximately 2km from its deployed location, indicating the strong water movement through this area during this period.

Due to the altimeters measuring at a fixed point, with each new deployment after data retrieval, a new fixed base level was established. Due to missing data, net cumulative bed level change for the 13 month monitoring period nor seasonal statistics, could be accurately calculated. However cumulative bed level change for each particular deployment period, which assisted to identify trends, was able to be calculated (refer Tables 6.11 to 6.18 in Appendix 6.3). Thus longer term deployments were much more beneficial in capturing cumulative changes through lunar cycles and extreme meteorological events.

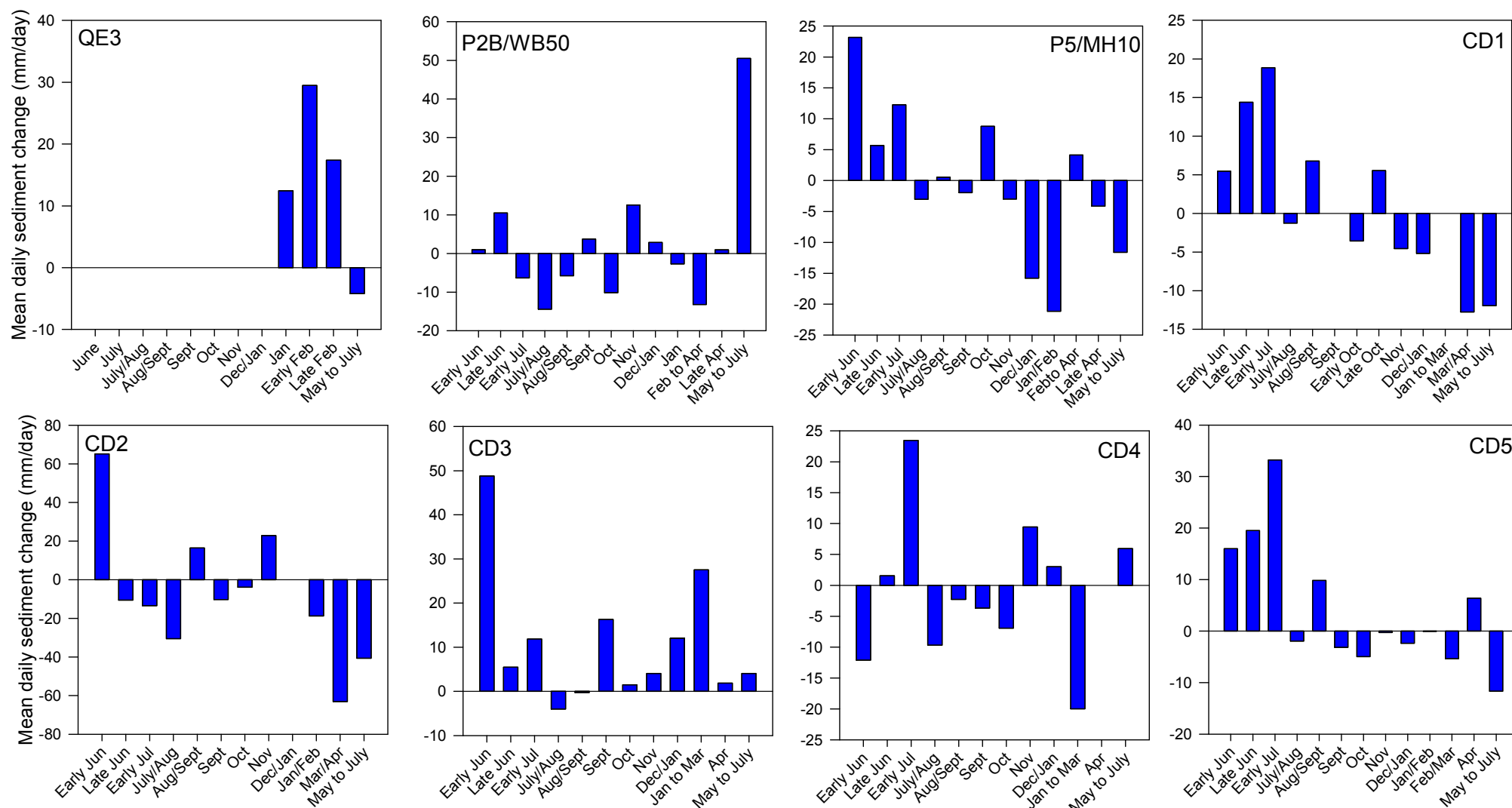


Figure 3.36 Net cumulative sediment change per deployment period at monitoring sites from 1 June 2014 to 4 July 2015

Figure note: Positive sediment bed level change indicates sediment deposition while negative change indicates erosion

Although increased instantaneous bed level change corresponded with increases in turbidity, there appeared to be a critical minimum threshold (e.g. EWMA > 10 NTU offshore and > 15 NTU inshore) of turbidity for this to occur in some cases. Bed level flux appeared to be driven by lunar phases and/or wave heights, but not all resuspension events resulted in cumulative bed level change. In some cases bed level fluctuated around a fixed mean, whereas in other cases there was measured deposition or erosion. Wind direction and its influence on bed level flux, which results in deposition or erosion, appeared to be a major factor in bed level change during the baseline data collection period, particularly at offshore sites.

The Great Barrier Reef Marine Park Authority (GBRMPA) have set a sedimentation trigger value at a maximum annual deposition of $3\text{mg}/\text{cm}^2/\text{day}$ and a daily maximum of $15\text{mg}/\text{cm}^2/\text{day}$ in the Water Quality Guidelines for the Great Barrier Reef (GBRMPA 2010). However, these are low confidence values based on limited field studies, which have examined the effects of sediments settling on a few coral species. The trigger value is expected to guard against excessive coral recruit mortality (GBRMPA 2010). However, values were derived using different instrumentation including traditional sediment traps (De'ath and Fabricius 2008) which measure downward flux only and cannot be compared to altimeter values (cumulative bed level change in mm, which includes resuspension).

3.4 Benthic Photosynthetically Active Radiation

Seagrass meadows (an important benthic primary producer) in Port Curtis are considered to have high economic and ecological value, having a role in providing food resources and habitat for vulnerable species of turtle and dugong (Hemminga and Duarte 2000, Hughes et al. 2009). Coastal fringing reef habitats have been identified in the near offshore environment of Port Curtis and the adjacent Great Barrier Reef Marine Park area (Ayling et al. 2012, Oceania Pty Ltd 2011). Due to their sensitivity to reduced light (i.e. decreased water clarity), seagrass and coral are considered sensitive indicators for measuring dredging related impacts (Erftemeijer and Lewis III 2006). BPAR or the light reaching the benthos is important to monitor, in order to determine whether sufficient light has reached the seagrass/coral to meet growth requirements and maintain health. Three major environmental factors can affect BPAR: the available ambient light, water depth and water clarity (as defined by TSS and NTU).

BPAR was measured by autonomous light loggers concurrently alongside the benthic physicochemical data loggers at the five offshore sites (CD1, CD2, CD3, CD4 and CD5). BPAR at inshore seagrass meadows was monitored under a separate investigation for the Project (Davies et al. 2015). In order to record daily changes in total available PAR, light loggers located at the VE Base (VB) also recorded ambient PAR (natural sunlight). The inclusion of the VB data allows for variation in daily ambient PAR (e.g. due to cloud cover and rain events) to be accounted for, thus aiding in the interpretation of BPAR levels at monitoring sites and acting as a 'control' PAR.

Mean seasonal ambient PAR and BPAR is reported as total daily PAR (TDP), in Table 3.8 and exhibited in Figures 3.37 to 3.41. Mean monthly values are tabulated in Appendix 6.4 (refer Table 6.19).

The Vision Base PAR exhibited significant higher ($p < 0.05$) PAR during the wet season ($51.1\text{mol}/\text{m}^2/\text{day}$) than during the dry season ($37.9\text{mol}/\text{m}^2/\text{day}$), most likely due to the increased daylight hours experienced during the wet season. Similar to ambient PAR, all five benthic sites also exhibited significant seasonal variation ($p < 0.05$). However, in contrast, dry season BPAR at these sites was found to be significantly higher than wet season BPAR,

despite lower ambient PAR, indicating ambient light was not the only driving factor influencing BPAR at these sites. This is supported by the lack of significant linear regressions between ambient PAR and BPAR at CD1, CD2 and CD5, indicating other variables were involved. At sites CD3 and CD4, only weak, yet significant linear regressions ($r^2 = 0.22$ to 0.33) were found between ambient PAR and BPAR.

Table 3.8 Seasonal total daily PAR at monitoring sites from 1 June 2014 to 4 July 2015

Site	Statistic	Dry season TDP mol/m ² /day	Wet season TDP mol/m ² /day
CD1	Mean $\pm$ se (median)	2.6 $\pm$ 0.2 (1.6)	1.4 $\pm$ 0.1 (0.7)
	Range	0.0 – 10.9	0.0 – 7.0
CD2	Mean $\pm$ se (median)	1.4 $\pm$ 0.1 (0.9)	0.9 $\pm$ 0.1 (0.4)
	Range	0.0 – 7.3	0.0 – 8.8
CD3	Mean $\pm$ se (median)	0.9 $\pm$ 0.1 (0.2)	0.6 $\pm$ 0.1 (0.2)
	Range	0.0 – 8.6	0.0 – 6.1
CD4	Mean $\pm$ se (median)	1.0 $\pm$ 0.1 (0.7)	0.7 $\pm$ 0.1 (0.7)
	Range	0.0 – 5.3	0.0 – 3.3
CD5	Mean $\pm$ se (median)	1.3 $\pm$ 0.1 (0.9)	0.5 $\pm$ 0.1 (0.3)
	Range	0.0 – 5.7	0.0 – 4.4
VB	Mean $\pm$ se (median)	37.9 $\pm$ 0.8 (36.0)	51.1 $\pm$ 0.9 (54.3)
	Range	9.1 – 59.5	6.4 – 67.5

Table note: N = 167 to 218

Across the benthic sites, CD1 and CD2 recorded significantly higher mean BPAR (0.9 to 2.6 mol/m²/day), than CD3, CD4 and CD5 (0.5 to 1.3 mol/m²/day). CD1 and CD2 were located at shallower depths (~ 6 to 9m) than CD4 and CD5 (~ 16 to 18m) and therefore light would not have been attenuated as much prior to reaching the benthic logger. CD3 was located at a similar depth to CD1 and CD2 (~ 7m) but experienced overall higher benthic turbidity (refer Table 3.3) during the dry season. In addition, TSS concentrations were found to be uniform through the water column for CD3 during the dry season, indicating elevated turbidity was not entirely restricted to the benthos as it may have been for other offshore sites, thus resulting in greater light attenuation. The location of CD3 adjacent to the Boyne River mouth would predispose this location to a lower light regime. Significant ($p < 0.05$) but weak linear regressions were evident between turbidity and BPAR at each site ($r^2 = 0.25$ to 0.38), with BPAR decreasing as turbidity increased.

Light requirement trigger values for intertidal seagrass species were utilised in the WBDDP as an ecological trigger on which management decisions could be made to inform the dredging operations (Vision Environment 2012b, Vision Environment 2012c, Vision Environment 2013c, Vision Environment 2013e). The BPAR data collected at the offshore locations has been utilised to inform the current and existing light environment and growing conditions for subtidal seagrass species (Davies et al. 2015). While light requirements for certain species of seagrass in Port Curtis are now well established (Chartrand et al. 2012), little information exists on applicable light requirements for local species of coral, another sensitive habitat within the Project area.

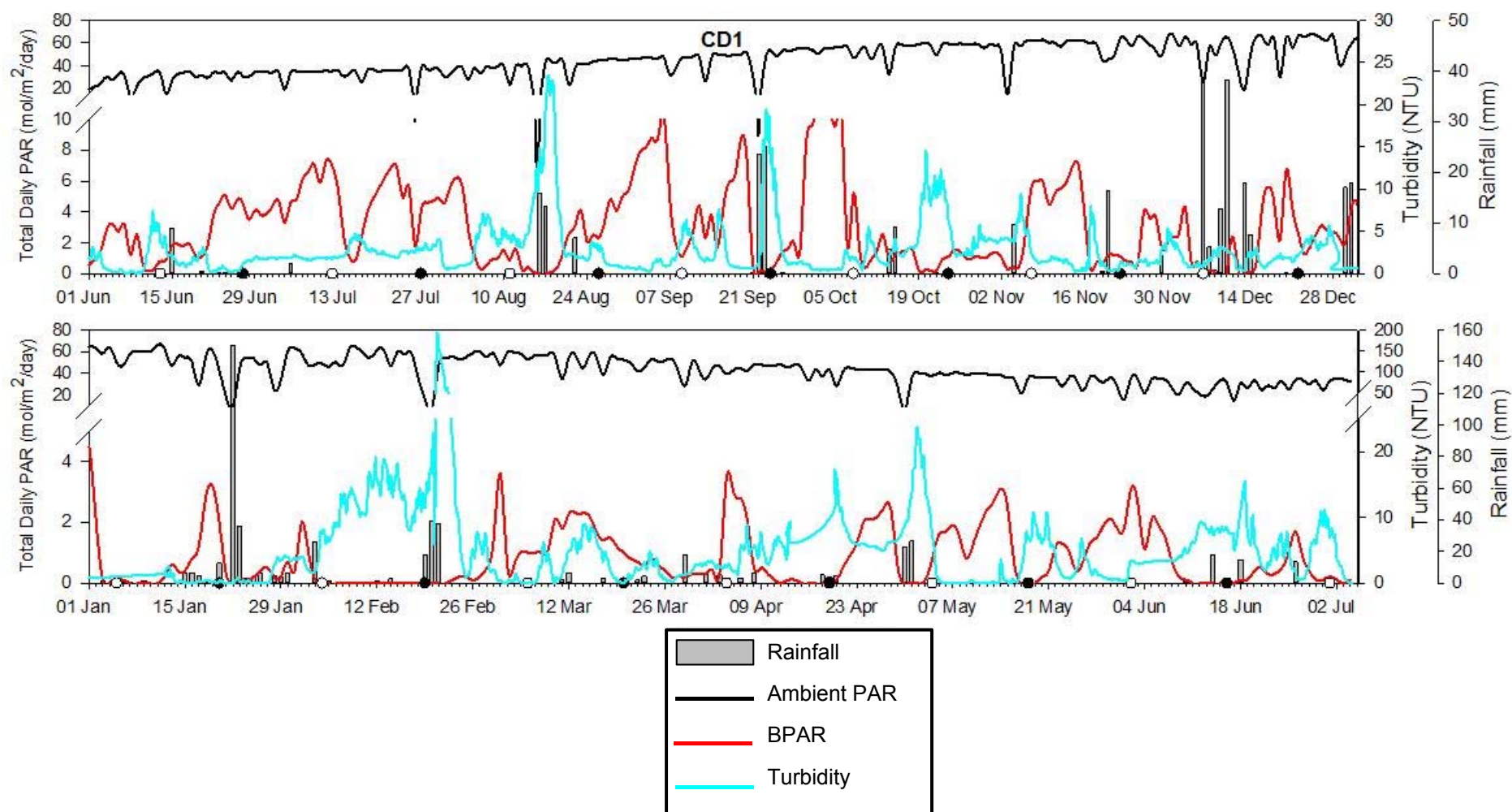


Figure 3.37 Ambient PAR and BPAR, benthic turbidity and rainfall at CD1

Figure note: Open and closed circles indicate full and new moons, respectively.

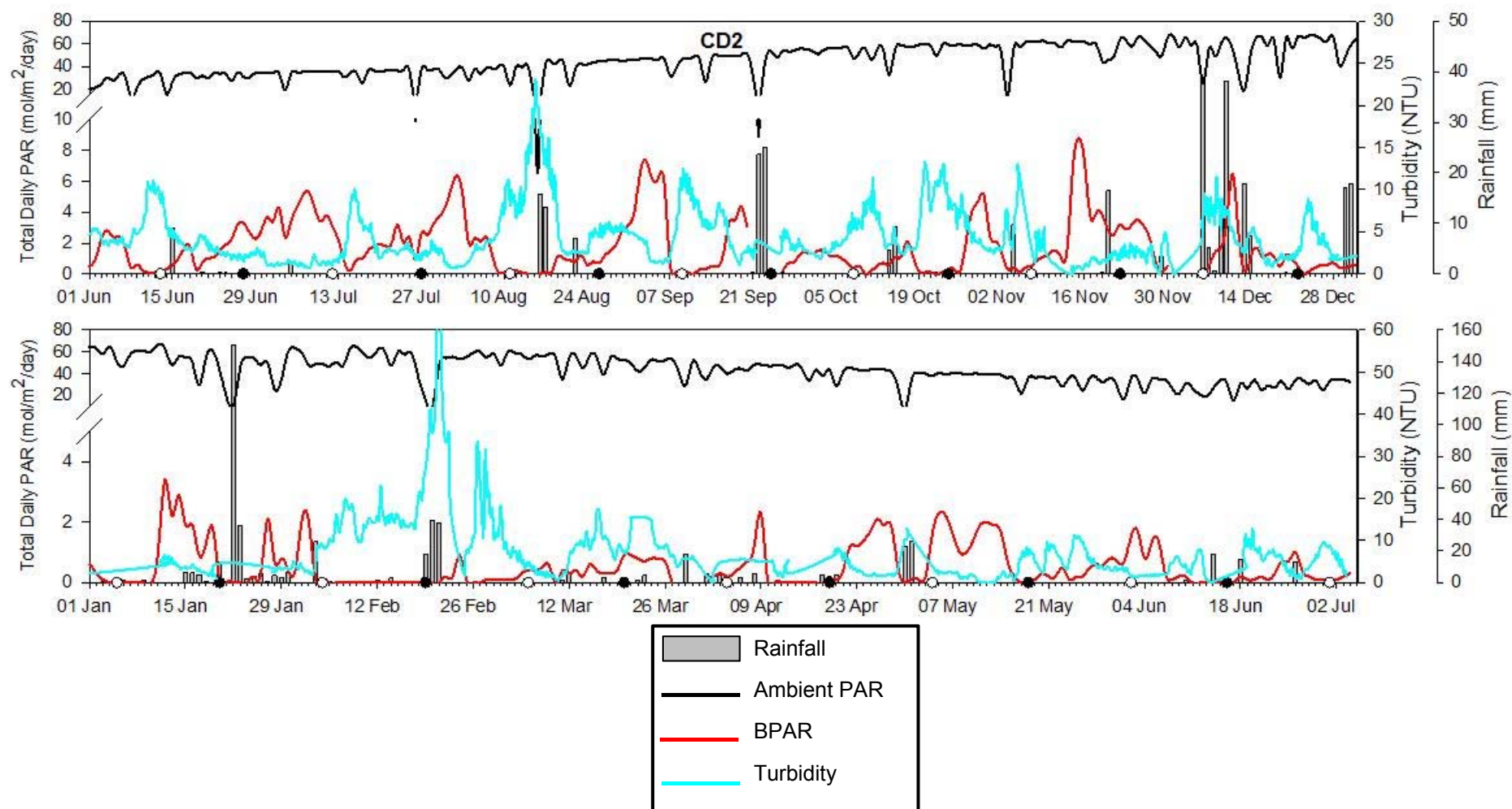


Figure 3.38 Ambient PAR and BPAR, benthic turbidity and rainfall at CD2

Figure note: Open and closed circles indicate full and new moons, respectively.

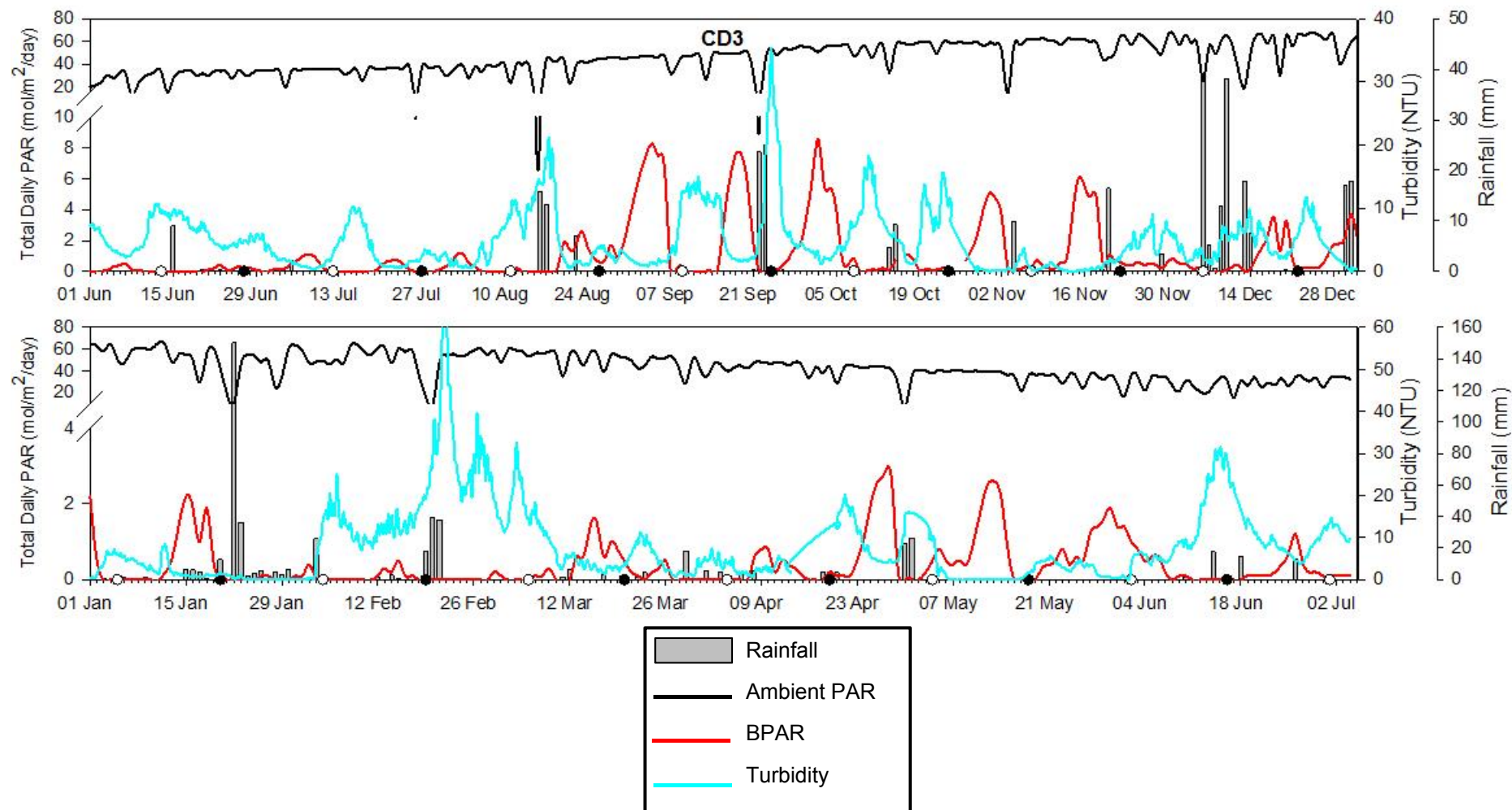


Figure 3.39 Ambient PAR and BPAR, benthic turbidity and rainfall at CD3

Figure note: Open and closed circles indicate full and new moons, respectively.

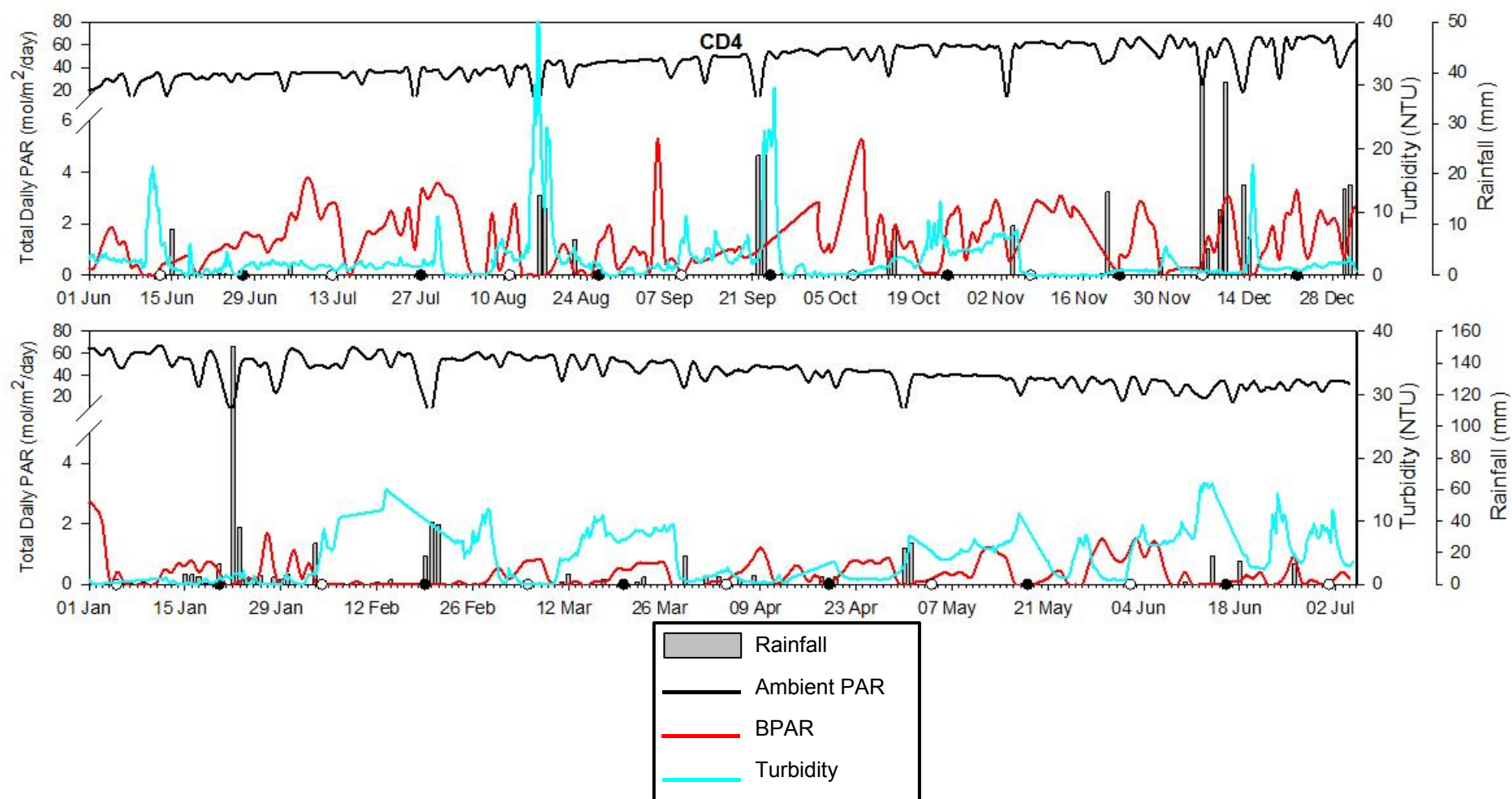


Figure 3.40 Ambient PAR and BPAR, benthic turbidity and rainfall at CD4
Figure note: Open and closed circles indicate full and new moons, respectively.

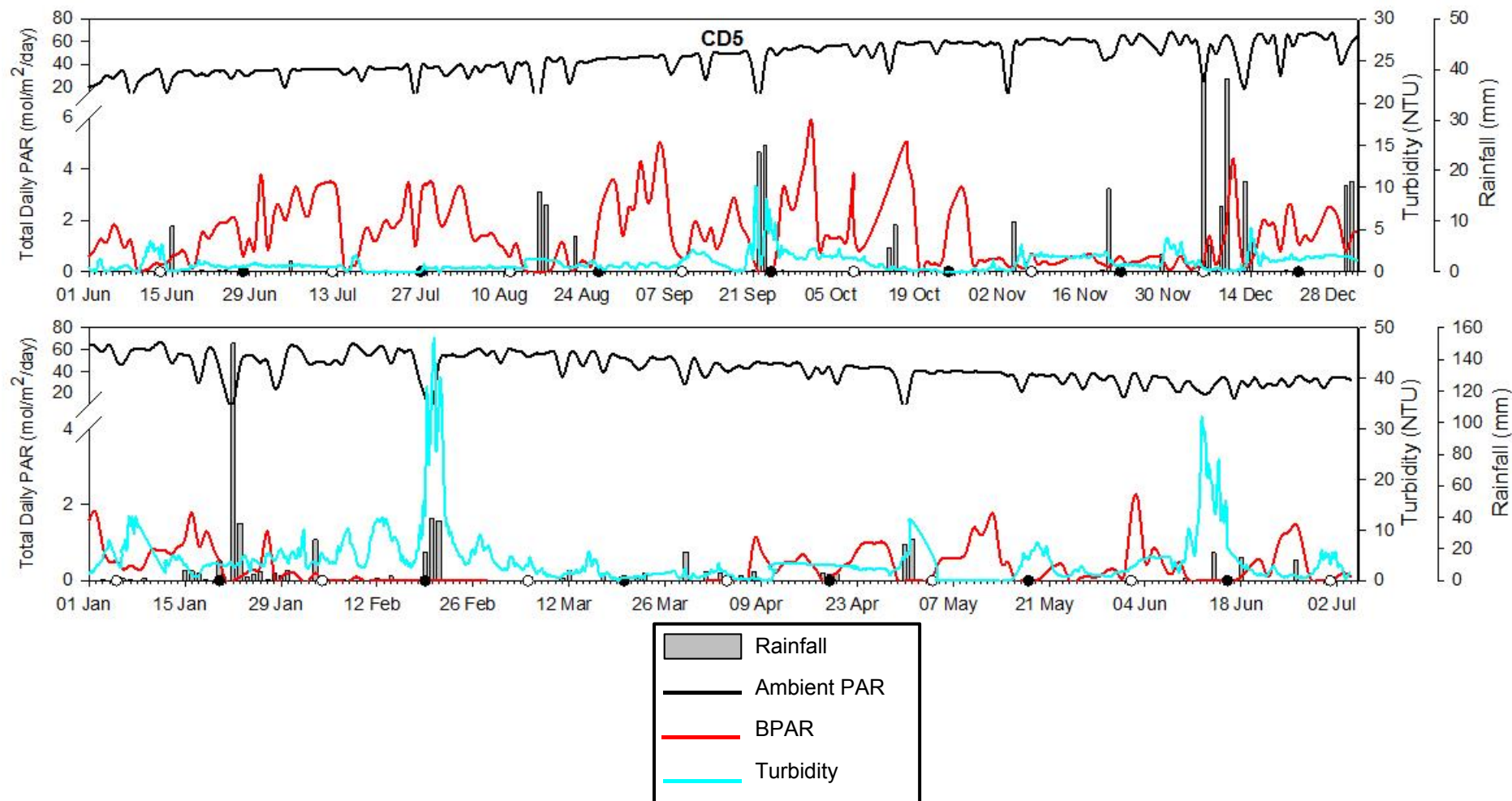


Figure 3.41 Ambient PAR and BPAR, benthic turbidity and rainfall at CD5

Figure note: Open and closed circles indicate full and new moons, respectively.

3.5 Water grab samples

Water sample collection was undertaken monthly at all eight monitoring sites. Duplicates were randomly collected at 10% of sites, in addition to a laboratory and field blank for each parameter for QA/QC purposes.

3.5.1 Total suspended solids

Total Suspended Solids (TSS) is another measurement of water clarity and refers to the amount of non-dissolved solids within the water column, both organic (e.g. algal blooms) and inorganic (APHA, 2005). As an additional measure of water clarity this is an important parameter to measure during dredge events. TSS is also used by hydrodynamic modellers to validate model predictions.

TSS sample concentrations were collected and analysed monthly at three depths in the water column at the five offshore sites: sub-surface, mid column and 1m above the benthos. At the three inshore sites, TSS samples were collected at the sub-surface only due to the well-mixed water column. Mean and median seasonal TSS results are reported in Table 3.9, while monthly mean values are plotted in Figures 3.42 and 3.43 and tabulated in the Appendix 6.5 (refer Table 6.20). Surface sample TSS results have been compared across all eight sites, while mid column and benthic TSS sample results have been compared across the five offshore sites.

Surface TSS was significantly higher ($p < 0.05$) in samples from site P2B/WB50 (means of 8.3 to 15.7mg/L) than at all offshore sites (means of < 2 to 7.6mg/L), with no significant seasonal variation found, which was a similar finding to that of surface logger turbidity results (refer Section 3.2.1). Samples from sites QE3 and P5/MH10 exhibited intermediate TSS concentrations (means of 4.9 to 8.5mg/L), which were similar to the majority of offshore surface TSS sample concentrations. However, mean TSS sample concentrations at P5/MH10 during preliminary monitoring in 2014 were somewhat more elevated (20mg/L) equalling the wet season WQO (refer Table 6.2 in Appendix 6.1).

Among the offshore sites, TSS sample concentrations at benthic layers (means of < 2 to 8.2mg/L) were significantly higher ($p < 0.05$) than concentrations collected at the surface and mid-level (means of < 2 to 3.2mg/L). Results paralleled those of logger recorded turbidity, with higher benthic compared to surface turbidity.

Inshore TSS sample concentrations were compared to QWQG (DERM 2009), with mean and median seasonal sample concentrations from all inshore sites lower than the WQO of 20mg/L. With the low WQO for the offshore sites, exceedances were recorded each time that TSS concentrations were above laboratory limits of reporting (LOR) (< 2 mg/L). WQO exceedances were evident in:

- Samples from all depths from CD3 over both seasons
- Samples from all depths from CD2 over both seasons except dry season surface
- All benthos samples from CD1, CD4 and CD5

However, it must be noted that WQOs for Port Curtis were likely to have been derived from surface TSS measurements and therefore may not be an appropriate comparison for mid-column or benthic TSS concentrations.

Table 3.9 Seasonal total suspended solids at varying depths at monitoring sites from June 2014 to June 2015

Site	Depth	Dry Season	Wet Season	WQO
QE3	Surface	7.0 ± 3.0 (7.0)	8.5 ± 2.7 (7.0)	20
P2B/WB50	Surface	15.7 ± 6.1 (9.0)	8.3 ± 2.2 (8.0)	20
P5/MH10	Surface	4.9 ± 2.3 (2.0)	6.0 ± 2.1 (5.0)	20
CD1	Surface	2.0 ± 1.0 (<2)	<2	1
	Mid	2.6 ± 0.6 (3.0)	<2	
	Benthos	2.9 ± 1.0 (2.0)	4.7 ± 1.3 (5.5)	
CD2	Surface	<2	2.5 ± 0.6 (2.0)	2
	Mid	3.1 ± 0.7 (3.0)	3.2 ± 1.4 (<2)	
	Benthos	3.4 ± 1.0 (3.0)	8.2 ± 3.6 (5.5)	
CD3	Surface	7.6 ± 4.2 (2.0)	3.7 ± 0.9 (3.5)	1
	Mid	8.0 ± 3.0 (5.0)	4.3 ± 1.0 (4.5)	
	Benthos	7.4 ± 3.2 (4.0)	14.2 ± 4.6 (9.5)	
CD4	Surface	<2	<2	2
	Mid	<2	<2	
	Benthos	<2	4.3 ± 1.4 (3.5)	
CD5	Surface	<2	<2	2
	Mid	<2	2.0 ± 0.7 (<2)	
	Benthos	2.4 ± 1.3 (<2)	3.2 ± 0.9 (3.0)	

Table note:

1. Values are means ± se (median), n = 3 to 7
2. Note that WQOs for sites CD2, CD4 and CD5 in coastal waters outside Gladstone have a WQO as specified by EHP (2014)
3. Specific zone WQO for the remaining sites have not been specified by EHP, therefore QWQG for Central Coast Queensland Region have been used (DERM 2009)
4. For inshore sites QE3, P2B/WB50 and P5/MH10, the guidelines are for Mid-Estuarine and Tidal Canals, Constructed Estuaries, Marinas and Boat Harbours (DERM 2009)
5. For sites CD1 and CD3, the Marine Open Coastal guidelines have been used (DERM 2009)

As expected, TSS sample concentrations paralleled the spatial patterns exhibited by turbidity measured by both continuous loggers (refer Table 3.3) and depth-profiling (refer Table 6.10 in Appendix 6.2). A significant ($p < 0.05$) linear regression was evident between TSS and depth-profiled turbidity measured concurrently ($r^2 = 0.87$, Figure 6.4 in Appendix 6.5). This indicates that as TSS concentrations increased, so did turbidity through the water column. As TSS was only sampled monthly, values were highly variable depending on the timing of sampling coinciding with spring or neap tides, and/or rain events, with sampling during spring tides resulting in higher TSS concentrations. Sampling on 2 February 2015 occurred approximately 10 days after > 200mm of rainfall was recorded for Gladstone (BOM 2015). However, these TSS results were no more elevated than other occasions, suggesting rapid recovery of water clarity to background conditions. The exception was CD3, where benthic and mid-column TSS concentrations were consistently elevated after the commencement of

the wet season in December 2014, while previously being within range of other monitoring sites' results prior to this. Wind driven resuspension of sediments deposited during rain events was likely the cause.

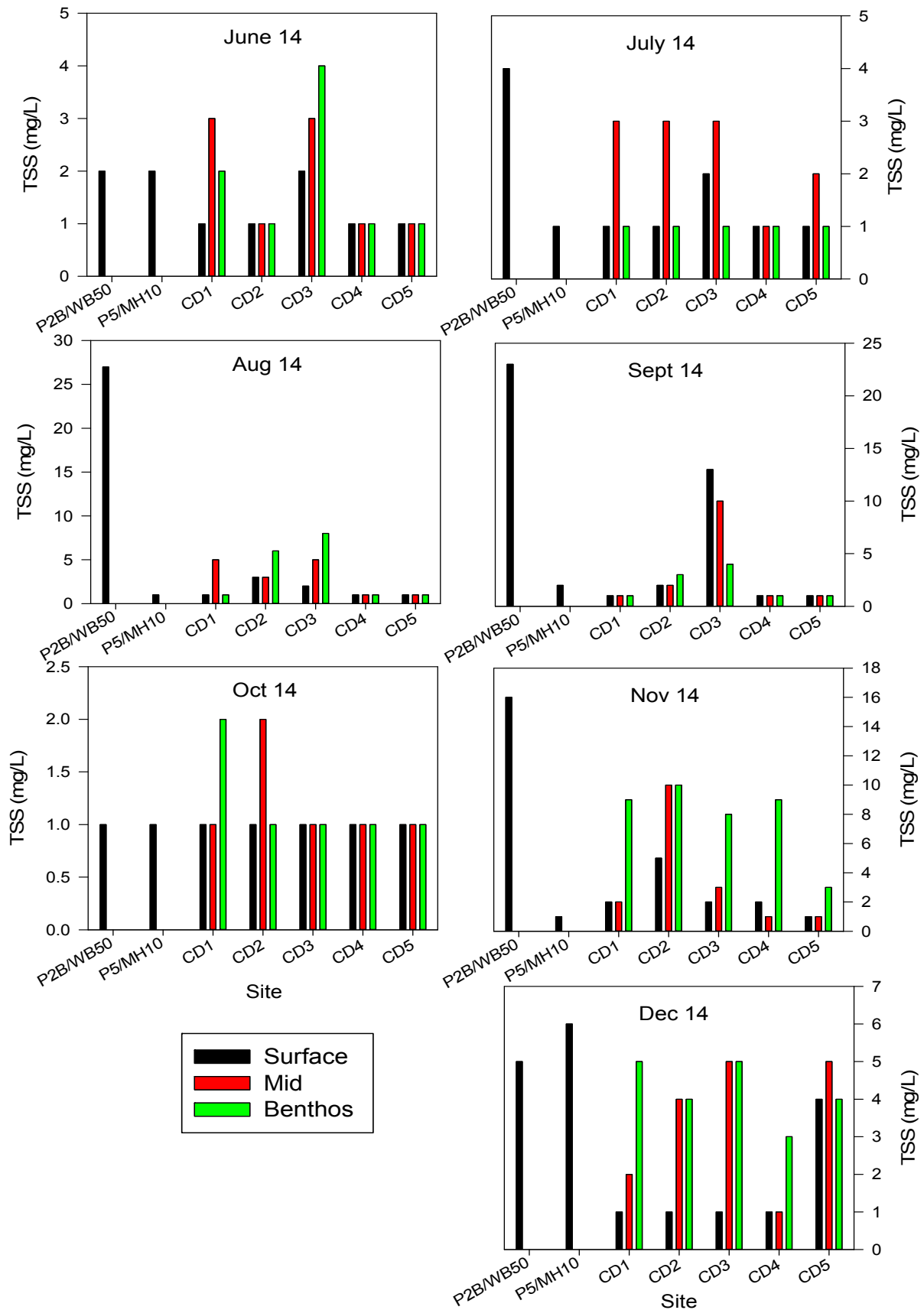


Figure 3.42 Total suspended solids at monitoring sites from June to December 2014

Figure note: N = 1

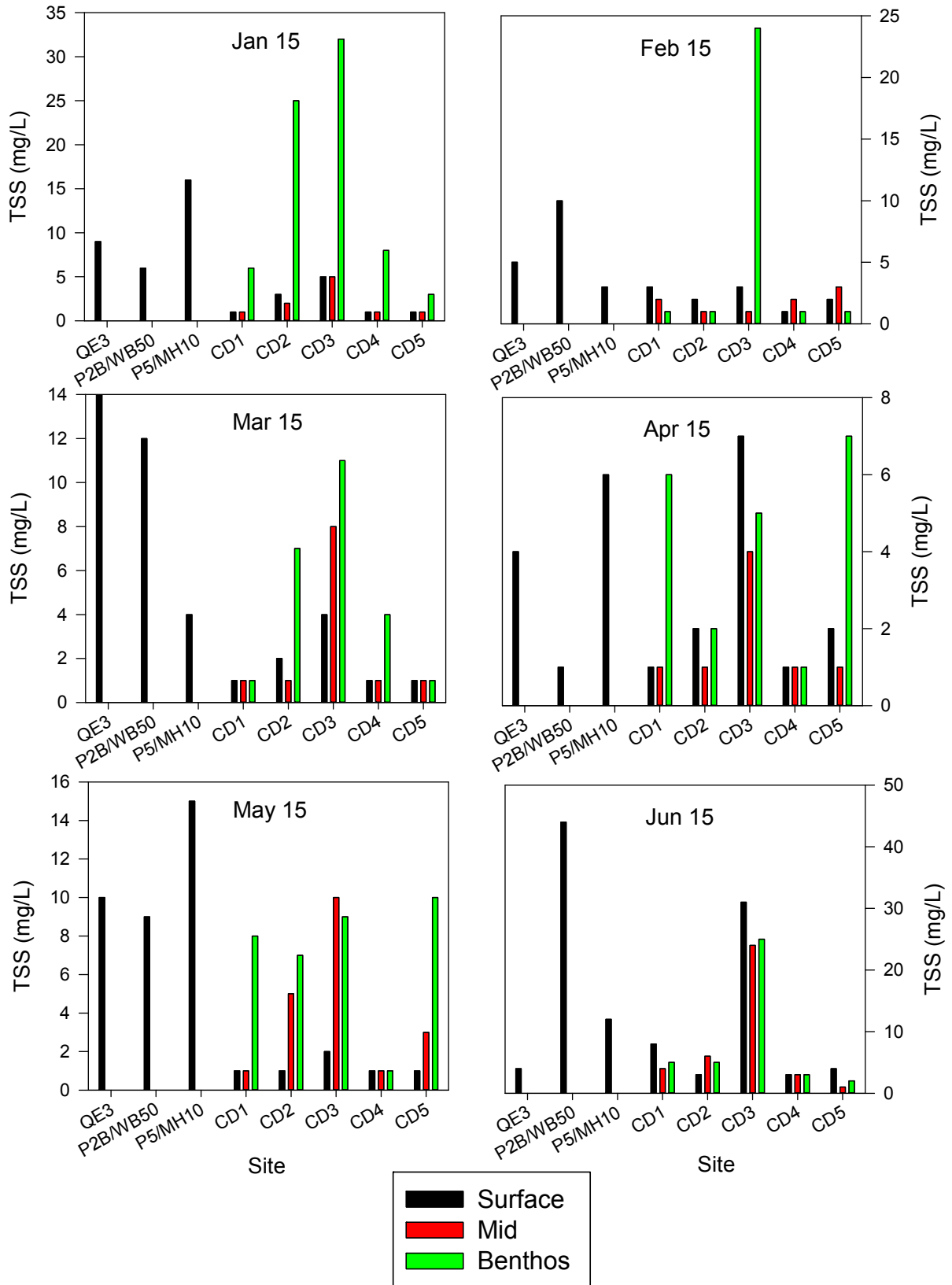


Figure 3.43 Total suspended solids at monitoring sites from January to June 2015

Figure note: N = 1.

3.5.2 Light attenuation

Down-welling light attenuation (or PAR) depth profiled through the water column is another measure of water clarity which has direct biological significance. This is an important water quality parameter to consider for proposed dredging and dredged material placement works, where light may temporarily decrease due to the higher amount of particles within the water column. The triplet relationship between NTU/TSS/BPAR may be utilised to predict the value of one parameter when the value of another has been observed.

Light attenuation was measured monthly during depth-profiling and collection of TSS samples. Monthly values (refer Table 6.10 in Appendix 6.2) paralleled the spatial patterns exhibited by turbidity and TSS.

3.5.3 Nutrients

Phosphorus and nitrogen are essential for the growth of organisms, including algae (APHA 2005). Nutrients are not necessarily considered to be directly toxic to aquatic organisms, but can directly affect the ecosystem and biota (ANZECC/ARMCANZ 2000). Eutrophication (excess nutrients) can stimulate the growth of macrophytes and algae (including toxic cyanobacteria – blue-green algae), which can result in an increase in chlorophyll *a*. Chlorophyll *a* is a green pigment found in plants, which is used in photosynthesis (USEPA 1997), and is measured as an indicator of algal biomass (APHA 2005).

Algal blooms can contribute to the TSS concentration in the water column and therefore a reduction in light environment. Such nuisance blooms have the potential to result in adverse impacts to the aquatic ecosystem through toxic effects (mortality and/or displacement of species), reduced light availability to benthic species, excessive fluctuations in pH, reduction in DO and changes in biodiversity (Valiela et al. 1997). Therefore nutrient enrichment is important to consider for proposed dredging and dredged material placement works. Subsurface samples for nutrient and chlorophyll *a* were collected monthly, concurrently with depth profiling. Mean seasonal nutrient results are reported in Tables 3.10 to 3.12, while monthly values are tabulated in the Appendix 6.5 (refer Tables 6.21 to 6.27) and plotted in Figures 3.44 to 3.46.

Total phosphorus concentrations were significantly higher ($p < 0.05$) in samples collected at inshore sites QE3 and P2B/WB50 (means of 17 to 30 µg/L), than in those collected at all offshore sites CD1 to CD5 (means of 9 to 15 µg/L), with no significant variation evident across seasons. A similar pattern was evident for the bioavailable phosphorus form, orthophosphate, with significantly higher ($p < 0.05$) concentrations in samples from QE3 and P2B/WB50 (means of 2 to 3 µg/L), than in those from all offshore sites (< 2 µg/L), and no significant seasonal variation. Intermediate concentrations of phosphorus forms were found in samples from site P5/MH10, similar to sample concentrations recorded during preliminary monitoring from October 2013 to June 2014 (refer Table 6.2 in Appendix 6.1).

Orthophosphate was undetected in samples from all offshore sites on the majority of occasions, over both seasons. The exception was the March 2015 sampling undertaken shortly after the rain event associated with TC Marcia in mid-February 2015, where elevated orthophosphate was detected in samples from all monitoring sites. Stormwater runoff increases the level of organic matter (from detritus) into the system which decomposes releasing available nutrients. Additionally, the flow of particulate bound phosphorous particles (potentially geologically derived) from freshwater into more saline environments, has the potential to result in an increase in the bioavailable forms of phosphorus (Fox et al. 1986).

This was particularly apparent at inshore sites QE3, P2B/WB50 and to a lesser extent P5/MH10 during sampling months where higher rainfall was recorded.

Similar to phosphorus, total nitrogen was significantly higher ($p < 0.05$) in samples from QE3 and P2B/WB50 (means of 130 to 213 $\mu\text{g/L}$) than in samples from offshore sites (means of 82 to 133 $\mu\text{g/L}$), with intermediate concentrations evident in samples from P5/MH10 (106 to 143 $\mu\text{g/L}$). Similar total nitrogen concentrations were recorded at P5/MH10 (107 $\mu\text{g/L}$) during preliminary monitoring from October 2013 to June 2014 (refer Table 6.2 in Appendix 6.1).

However, total nitrogen was also significantly higher ($p < 0.05$) in samples collected during the wet season (means of 108 to 213 $\mu\text{g/L}$) than during the dry season (means of 82 to 154 $\mu\text{g/L}$). This may be a result of an increase in microalgal populations which contain nitrogen, which are present in the warmer months (as evidenced by higher chlorophyll *a* concentrations). Nitrogen forms ammonia, nitrogen oxides (NO_x) and nitrite did not exhibit significant seasonal or site variation.

Anomalous spikes of total phosphorus, orthophosphate and to a lesser extent total nitrogen were recorded in samples at site P2B/WB50 in August, September and November 2014. The nutrient spikes corresponded with spikes in samples of total metals at this site including aluminium, cobalt, copper, iron, lead, manganese, nickel, vanadium and zinc. Although somewhat similar to concentrations for this site recorded in the post January wet season of 2015, the concentrations were atypical compared to other sites and months prior to January 2015. Fouling of equipment at site P2B/WB50 became problematic over the three month period and was thought to be related to the elevated nutrient and metal concentrations. However chlorophyll *a* concentrations at this site during this time remained within ranges of other sites. It is unknown what caused the anomalous elevations in nutrients and metals at this site.

Chlorophyll *a* concentrations were also significantly higher ($p < 0.05$) at QE3 and P2B/WB50 (means of 0.9 to 2.6) than at all remaining sites (0.2 to 0.9 $\mu\text{g/L}$) and were significantly higher ($p < 0.05$) during the wet season (means of 0.3 to 2.6 $\mu\text{g/L}$) than during the dry season (means of 0.2 to 1.2 $\mu\text{g/L}$). Concentrations at P5/MH10 during preliminary monitoring were also slightly elevated (1.8 $\mu\text{g/L}$) compared to during the baseline monitoring period and parallel the concurrent elevation in TSS for this period (refer Table 6.2 in Appendix 6.1). Seasonal differences were also found when chlorophyll *a* concentrations were examined in both summer and winter in 2008 in two Port Curtis waterways: Calliope River and Grahams Creek (Melville et al. 2009).

Chlorophyll *a* concentrations are generally stimulated by increasing temperature and light (Popovich and Marcovecchio 2008), with higher concentrations usually found in the summer months. As expected, significant ($p < 0.01$) linear regressions were found between chlorophyll *a* and total nitrogen ($r^2 = 0.74$) and chlorophyll *a* and total phosphorus ($r^2 = 0.55$), indicating that as total nutrient concentrations increased, chlorophyll *a* concentrations also increased. Similar relationships have been found in Port Curtis previously, with increased chlorophyll *a* also associated with increases in turbidity (Vision Environment 2009).

The eight monitoring sites are located in five different water quality guideline zones within Port Curtis (The Narrows, Western Basin, Mid Harbour, Outer Harbour, and Coastal waters outside Gladstone Harbour) (EHP 2014) and as such have varying WQOs (refer Tables 3.10 to 3.12). The majority of mean and median nutrient concentrations in samples from monitoring sites were within the 20th to 80th percentile range of their applicable WQO.

Table 3.10 Seasonal phosphorus concentrations at monitoring sites

Site	Total Phosphorus (µg/L)			Orthophosphate (µg/L)		
	Dry Season	Wet Season	WQO	Dry Season	Wet Season	WQO
QE3	17 ± 2 (17)	28 ± 5 (28)	15,20,29	2 ± 1 (2)	2 ± 1 (2)	3,3,7
P2B/WB50	30 ± 6 (24)	26 ± 3 (29)	14,18,29	3 ± 0 (3)	3 ± 0 (3)	1,3,7
P5/MH10	15 ± 1 (15)	18 ± 3 (17)	9,14,23	2 ± 0 (<2)	2 ± 1 (<2)	1,2,3
CD1	11 ± 0 (11)	11 ± 0 (11)	9,13,21	<2	<2	1,1,3
CD2	11 ± 1 (11)	15 ± 1 (14)	<8	<2	<2	<1
CD3	15 ± 2 (12)	14 ± 1 (14)	9,14,23	<2	<2	1,2,3
CD4	9 ± 1 (10)	11 ± 0 (11)	<8	<2	<2	<1
CD5	10 ± 0 (9)	10 ± 0 (10)	<8	<2	<2	<1

Table notes: Values are means ± se (median), n = 3 to 7. Note that three values are listed for the WQOs for QE3, P2B/WB50, P5/MH10, CD1 and CD3, denoting the 20th, 50th and 80th percentiles. One value only is denoted for CD2, CD4 and CD5 indicating the median or 80th percentile value.

Table 3.11 Seasonal total nitrogen and ammonia concentrations at monitoring sites

Site	Total Nitrogen (µg/L)			Ammonia (µg/L)		
	Dry Season	Wet Season	WQO	Dry Season	Wet Season	WQO
QE3	130 ± 40 (130)	213 ± 27 (220)	140,170,220	3 ± 1 (3)	5 ± 1 (7)	3,3,10
P2B/WB50	154 ± 13 (160)	183 ± 15 (175)	145,170,210	6 ± 2 (4)	4 ± 1 (4)	3,3,8
P5/MH10	106 ± 8 (100)	143 ± 10 (140)	110,135,200	3 ± 1 (3)	<3	3,3,12
CD1	87 ± 7 (80)	108 ± 4 (105)	115,130,170	<3	<3	3,4,5
CD2	89 ± 6 (90)	122 ± 5 (120)	<100	3 ± 1 (<3)	<3	<3
CD3	110 ± 5 (110)	133 ± 97 (135)	110,135,200	<3	<3	3,3,12
CD4	82 ± 11 (90)	120 ± 12 (110)	<100	4 ± 2 (<3)	3 ± 1 (<3)	<3
CD5	84 ± 5 (80)	115 ± 10 (110)	<100	5 ± 2 (<3)	<3	<3

Table notes: Values are means ± se (median), n = 3 to 7. Note that three values are listed for the WQOs for QE3, P2B/WB50, P5/MH10, CD1 and CD3, denoting the 20th, 50th and 80th percentiles. One value only is denoted for CD2, CD4 and CD5 indicating the median or 80th percentile value.

Table 3.12 Seasonal nitrate, nitrite and chlorophyll a concentrations at monitoring sites

Site	NOx (Nitrate + Nitrite) (µg/L)			Nitrite (µg/L)			Chlorophyll a (µg/L)		
	Dry Season	Wet Season	WQO	Dry Season	Wet Season	WQO	Dry Season	Wet Season	WQO
QE3	4 ± 3 (4)	8 ± 4 (5)	2,3,9	<2	<2	2,3,9	1.2 ± 0.2 (1.2)	2.6 ± 0.8 (2.7)	0.5,1.0,2.0
P2B/WB50	5 ± 1 (3)	5 ± 1 (4)	1,4,16	<2	<2	1,4,16	0.9 ± 0.3 (0.6)	2.4 ± 0.7 (1.4)	0.5,1.0,2.0
P5/MH10	2 ± 1 (<2)	2 ± 0 (2)	1,3,9	<2	<2	1,3,9	0.5 ± 0.1 (0.6)	0.9 ± 0.2 (0.9)	0.5,1.0,2.0
CD1	3 ± 1 (<2)	6 ± 2 (4)	1,3,6	<2	<2	1,3,6	0.4 ± 0.1 (0.3)	0.3 ± 0.1 (0.3)	0.5,1.0,2.0
CD2	3 ± 1 (<2)	8 ± 5 (3)	<1	<2	<2	<1	0.4 ± 0.1 (0.3)	0.5 ± 0.1 (0.6)	<0.45
CD3	2 ± 1 (2)	3 ± 1 (2)	1,3,9	<2	<2	1,3,9	0.6 ± 0.2 (0.4)	0.6 ± 0.2 (0.7)	0.5,1.0,2.0
CD4	8 ± 4 (3)	5 ± 2 (4)	<1	<2	<2	<1	0.3 ± 0.1 (<0.2)	0.7 ± 0.2 (0.6)	<0.45
CD5	11 ± 8 (2)	3 ± 2 (<2)	<1	3 ± 2 (<2)	<2	<1	0.2 ± 0.1 (<0.2)	0.4 ± 0.1 (0.3)	<0.45

Table notes: Values are means ± se (median), n = 3 to 7. Note that three values are listed for the WQOs for QE3, P2B/WB50, P5/MH10, CD1 and CD3, denoting the 20th, 50th and 80th percentiles. One value only is denoted for CD2, CD4 and CD5 indicating the median or 80th percentile value.

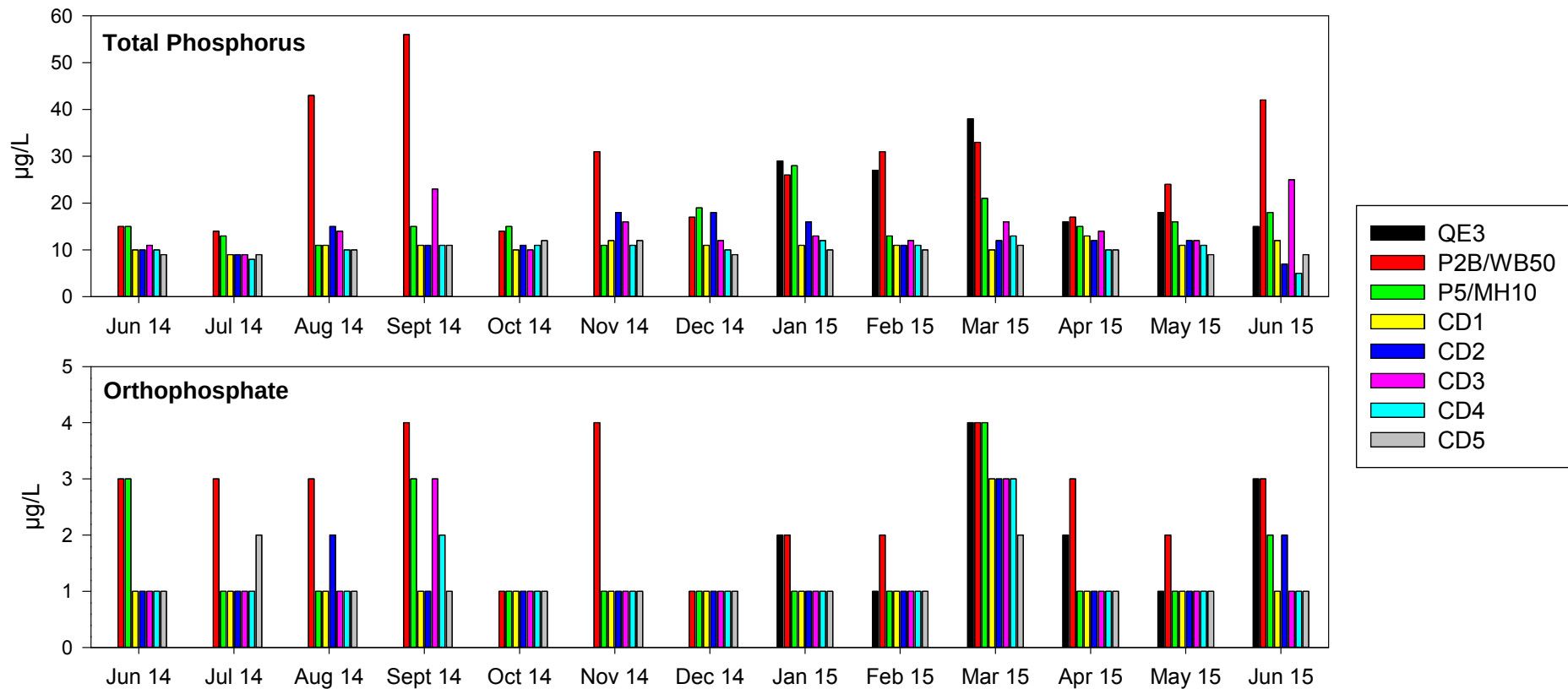


Figure 3.44 Total phosphorus and orthophosphate concentrations at monitoring sites

Figure note: Values which were < LOR, were plotted as half LOR.

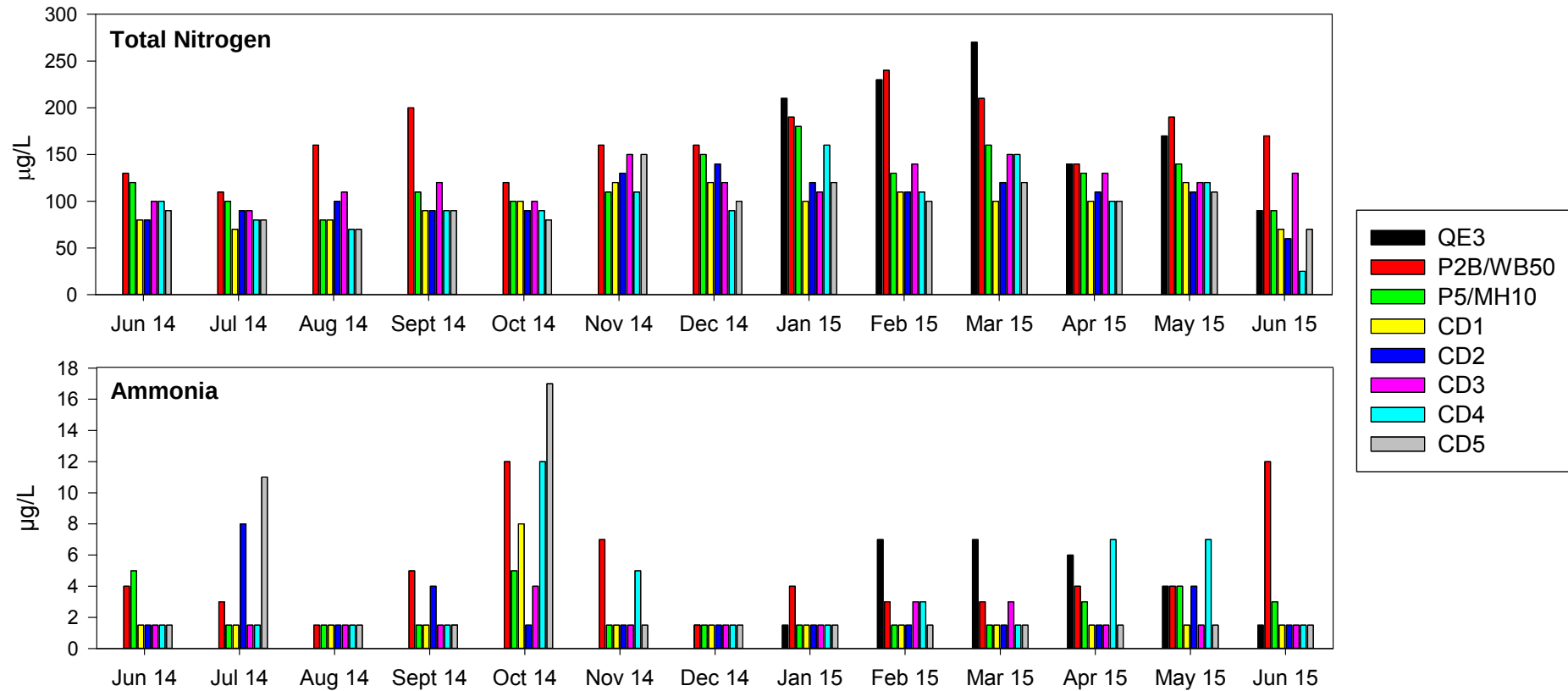


Figure 3.45 Total nitrogen and ammonia concentrations at monitoring sites

Figure note: Values which were < LOR, were plotted as half LOR.

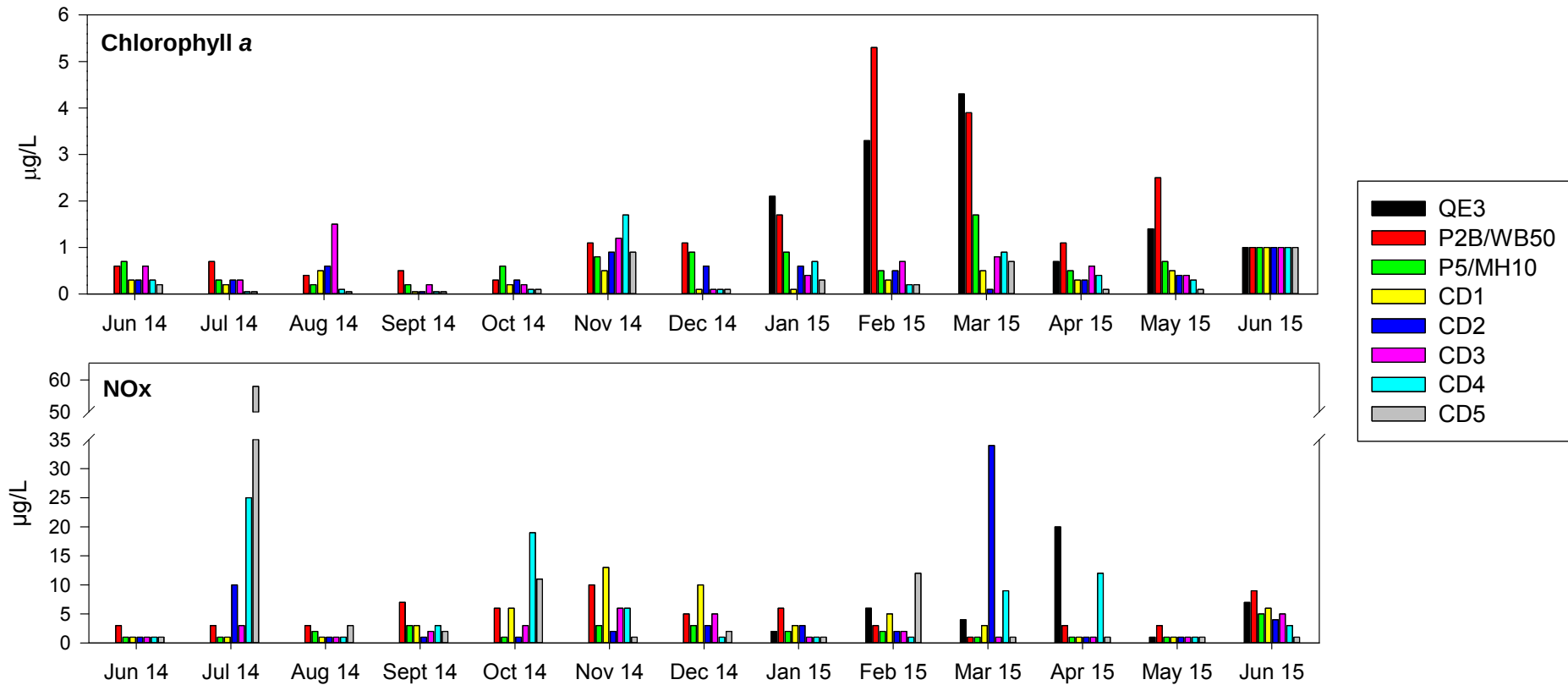


Figure 3.46 Chlorophyll a and NOx concentrations at monitoring sites

Figure note: Values which were < LOR, were plotted as half LOR.

However, mean wet season chlorophyll a concentrations at QE3 and P2B/WB50 were higher than the site specific 80th percentile WQO, with mean total phosphorus at P2B/WB50 also exceeding the 80th percentile WQO during the dry season. Additionally, for those sites located in the coastal waters outside Gladstone Harbour (CD2, CD4 and CD5), exceedances were recorded for the total phosphorus and nitrogen oxides WQO during both seasons, total nitrogen and chlorophyll a WQO during the wet season, and ammonia WQO during the dry season.

The predominant form of nitrogen historically recorded in Port Curtis is organic and therefore not readily bioavailable (Vision Environment 2010, Vision Environment 2013b). In marine and coastal environments, nitrogen has often been identified as the limiting nutrient, which is in contrast to inland lakes where phosphorus tends to be limited (Popovich and Marcovecchio 2008). However in moderately disturbed estuarine environments such as Port Curtis, nutrient limitation is rare with organic nitrogen being naturally derived from mangrove detritus and seagrass meadows, in combination with benthic algae.

Elevated phosphorus in Port Curtis estuarine waters has been previously attributed to natural geology with the common presence of phosphorus deposits confirmed (Donchak and Holmes 1991). While there is potential risk of algal blooms in certain areas of inner Port Curtis, due to some elevated concentrations of phosphorous, low levels of readily bioavailable nitrogen may ameliorate this risk.

3.5.4 Metals

Total metals are the concentration of metals (elements) determined in an unfiltered sample (including metals bound to sediments and colloidal particles), while dissolved metals are those which pass through a 0.45µm membrane filter. Some metals are essential to plant and animal growth but can become toxic at elevated concentrations (APHA 2005). Dissolved metals are considered to be the potential bioavailable fraction (ANZECC/ARMCANZ 2000). Both total and dissolved metals are important to measure during any water quality program, but particularly important to consider for proposed dredging and dredged material placement works, due to the disturbance and resuspension of potential contaminants in benthic sediments, which can result in the addition of total metals to the water column (Erftemeijer and Lewis III 2006). Potential changes in water chemistry (e.g. decrease in pH), have the potential to result in an increase in metal bioavailability by increasing the proportion of dissolved metals (those no longer bound to sediments and thus potentially more bioavailable).

Subsurface samples for total and dissolved metals concentrations were collected and analysed monthly. Mean seasonal metal results are reported in Table 3.13, while monthly values are tabulated in the Appendix 6.5 (refer Tables 6.28 to 6.45) and plotted in Figures 3.47 to 3.57.

A number of metals were found to be below LOR in samples from all sites on the majority of occasions. (refer Table 3.13). This included total and dissolved cadmium (< 0.1µg/L), chromium (< 1µg/L), gallium (< 0.5µg/L), mercury (< 0.1µg/L), selenium (< 0.5µg/L) and silver (< 0.5µg/L). Metal concentrations measured at P5/MH10 during preliminary monitoring were overall similar to those recorded during the baseline monitoring period (refer Table 6.3 in Appendix 6.1).

Table 3.13 Seasonal total and dissolved metal concentrations at monitoring sites from June 2014 to June 2015

Metal (µg/L)	Season	Form	QE3	P2B/WB50	P5/MH10	CD1	CD2	CD3	CD4	CD5	WQO
Aluminium	Dry	D	<5	<5	<5	<5	<5	<5	<5	<5	99% – 2.1
		T	375 ± 65 (375)	1088 ± 382 (800)	241 ± 65 (190)	77 ± 43 (54)	119 ± 46 (79)	254 ± 111 (120)	24 ± 8 (24)	20 ± 6 (13)	95% - 24
	Wet	D	<5	7 ± 2 (7)	6 ± 1 (7)	<5	<5	<5	<5	<5	
		T	595 ± 184 (530)	787 ± 155 (805)	358 ± 118 (295)	47 ± 7 (41)	169 ± 41 (168)	162 ± 28 (145)	31 ± 4 (30)	29 ± 8 (26)	
Arsenic	Dry	D	0.8 ± 0.1 (0.8)	0.8 ± 0.1 (0.9)	0.9 ± 0.1 (1.0)	1.2 ± 0.1 (1.2)	1.1 ± 0.1 (1.1)	1.0 ± 0.1 (1.0)	1.2 ± 0.1 (1.2)	1.3 ± 0.1 (1.3)	-
		T	1.3 ± 0.3 (0.3)	1.6 ± 0.2 (1.6)	1.3 ± 0.1 (1.4)	1.6 ± 0.1 (1.5)	1.4 ± 0.1 (1.5)	1.5 ± 0.1 (1.6)	1.6 ± 0.1 (1.5)	1.6 ± 0.1 (1.6)	
	Wet	D	0.8 ± 0.1 (0.8)	0.9 ± 0.1 (0.9)	1.0 ± 0.1 (1.0)	1.0 ± 0.0 (1.1)	1.0 ± 0.0 (1.0)	1.1 ± 0.1 (1.1)	1.1 ± 0.1 (1.2)	1.2 ± 0.1 (1.2)	
		T	1.1 ± 0.1 (1.2)	1.2 ± 0.1 (1.2)	1.3 ± 0.1 (1.3)	1.2 ± 0.1 (1.2)	1.2 ± 0.1 (1.2)	1.3 ± 0.1 (1.3)	1.4 ± 0.1 (1.3)	1.9 ± 0.5 (1.4)	
Cadmium	Dry	D	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	99% – 0.7
		T	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	95% - 5.5
	Wet	D	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	
		T	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	
Chromium	Dry	D	<1	<1	<1	<1	<1	<1	<1	<1	99% - 7.7 (III)
		T	<1	<1	<1	<1	<1	<1	<1	<1	99% - 0.14(VI)
	Wet	D	<1	<1	<1	<1	<1	<1	<1	<1	95% - 27.4(III)
		T	<1	<1	<1	<1	<1	<1	<1	<1	95% - 4.4 (VI)
Cobalt	Dry	D	0.1 ± 0.0 (0.1)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	99% - 0.005
		T	0.3 ± 0.0 (0.3)	0.4 ± 0.1 (0.3)	<0.1	<0.1	<0.1	0.1 ± 0.0 (<0.1)	<0.1	<0.1	95% - 1
	Wet	D	0.2 ± 0.0 (0.2)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	
		T	0.4 ± 0.1 (0.4)	0.3 ± 0.1 (0.4)	0.2 ± 0.1 (0.2)	<0.1	<0.1	<0.1	<0.1	<0.1	
Copper	Dry	D	0.6 ± 0.0 (0.6)	0.6 ± 0.1 (0.6)	0.3 ± 0.1 (0.4)	<0.2	0.3 ± 0.1 (0.2)	0.2 ± 0.0 (0.2)	0.2 ± 0.1(<0.2)	<0.2	99% - 0.3
		T	0.9 ± 0.0 (0.9)	1.5 ± 0.3 (1.5)	0.6 ± 0.1 (0.6)	0.3 ± 0.0 (0.3)	0.4 ± 0.1 (0.4)	0.4 ± 0.1 (0.4)	0.2 ± 0.0 (0.3)	0.5 ± 0.2 (0.3)	95% - 1.3
	Wet	D	0.8 ± 0.0 (0.8)	0.9 ± 0.1 (0.9)	0.6 ± 0.1 (0.7)	<0.2	0.5 ± 0.1 (0.4)	0.5 ± 0.2 (0.4)	0.2 ± 0.1 (0.2)	0.2 ± 0.1 (0.2)	
		T	2.3 ± 0.8 (1.7)	1.5 ± 0.2 (1.5)	0.9 ± 0.2 (1.0)	0.3 ± 0.1 (0.3)	0.6 ± 0.1 (0.6)	0.5 ± 0.1 (0.5)	0.5 ± 0.2 (0.3)	0.3 ± 0.0 (0.3)	

Metal (µg/L)	Season	Form	QE3	P2B/WB50	P5/MH10	CD1	CD2	CD3	CD4	CD5	WQO
Gallium	Dry	D	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	-
		T	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	
	Wet	D	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	
		T	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	
Iron	Dry	D	<5	9 ± 5 (<5)	<5	<5	<5	<5	<5	<5	-
		T	325 ± 45 (325)	964 ± 337 (700)	224 ± 61 (180)	72 ± 35 (42)	104 ± 36 (76)	228 ± 100 (100)	23 ± 6 (21)	18 ± 5 (16)	
	Wet	D	5 ± 2 (5)	7 ± 2 (6)	8 ± 3 (<5)	<5	<5	<5	<5	<5	
		T	558 ± 178 (550)	638 ± 138 (710)	319 ± 103 (295)	50 ± 14 (39)	158 ± 43 (160)	127 ± 21 (119)	33 ± 6 (32)	33 ± 9 (30)	
Lead	Dry	D	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	99% - 2.2 95% - 4.4
		T	0.1 ± 0.1 (0.1)	0.3 ± 0.1 (0.2)	0.1 ± 0.0 (<0.1)	<0.1	<0.1	0.1 ± 0.0	<0.1	<0.1	
	Wet	D	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	
		T	0.2 ± 0.1 (0.2)	0.2 ± 0.1 (0.2)	0.1 ± 0.1 (0.1)	<0.1	<0.1	0.1 ± 0.0 (0.1)	0.1 ± 0.0 (<0.1)	<0.1	
Manganese	Dry	D	5.6 ± 1.4 (5.6)	2.4 ± 0.6 (1.4)	2.2 ± 0.6 (1.4)	<0.6	<0.6	0.7 ± 0.2 (<0.6)	<0.6	<0.6	-
		T	13 ± 1 (13)	21 ± 5 (20)	6 ± 1 (6)	2 ± 1 (1)	2 ± 1 (2)	5 ± 1 (3)	1 ± 0 (1)	1 ± 0 (1)	
	Wet	D	10 ± 2 (9)	4.7 ± 2.5 (2.6)	3.5 ± 1.3 (2.3)	0.9 ± 0.1 (0.9)	<0.6	1.2 ± 0.2 (1.2)	0.8 ± 0.1 (0.8)	0.7 ± 0.1 (0.7)	
		T	20 ± 4 (19)	19 ± 3 (19)	11 ± 3 (12)	2 ± 0 (2)	4 ± 1 (4)	5 ± 0 (5)	2 ± 0 (2)	2 ± 0 (2)	
Mercury	Dry	D	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	99% - 0.1 95% - 0.4
		T	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	
	Wet	D	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	
		T	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	
Molybdenum	Dry	D	10 ± 0 (10)	11 ± 1 (11)	10 ± 0 (10)	10 ± 0 (10)	10 ± 0 (10)	11 ± 0 (10)	10 ± 0 (10)	11 ± 0 (11)	-
		T	10 ± 0 (10)	11 ± 1 (11)	10 ± 0 (10)	11 ± 1 (11)	11 ± 1 (10)	13 ± 3 (11)	12 ± 2 (11)	12 ± 2 (11)	
	Wet	D	10 ± 1 (10)	10 ± 1 (11)	10 ± 1 (10)	10 ± 0 (10)	11 ± 1 (10)	11 ± 1 (11)	11 ± 0 (10)	11 ± 0 (10)	
		T	10 ± 1 (10)	10 ± 1 (11)	10 ± 1 (11)	11 ± 1 (11)	11 ± 0 (11)	11 ± 1 (12)	11 ± 1 (11)	11 ± 1 (11)	

Metal (µg/L)	Season	Form	QE3	P2B/WB50	P5/MH10	CD1	CD2	CD3	CD4	CD5	WQO
Nickel	Dry	D	0.7 ± 0.0 (0.7)	0.4 ± 0.0 (0.4)	0.3 ± 0.0 (0.3)	<0.2	0.2 ± 0.0 (0.2)	0.2 ± 0.0 (0.2)	<0.2	<0.2	99% - 7
		T	1.0 ± 0.1 (1.0)	1.0 ± 0.2 (0.9)	0.4 ± 0.0 (0.4)	0.3 ± 0.1 (0.2)	0.3 ± 0.0 (0.2)	0.3 ± 0.1 (0.3)	<0.2	<0.2	95% - 70
	Wet	D	0.8 ± 0.0 (0.8)	0.5 ± 0.0 (0.5)	0.4 ± 0.0 (0.4)	0.3 ± 0.0 (0.3)	0.3 ± 0.0 (0.3)	0.3 ± 0.0 (0.3)	0.3 ± 0.0 (0.3)	0.3 ± 0.1 (0.3)	
		T	1.2 ± 0.1 (1.3)	0.9 ± 0.1 (1.0)	0.6 ± 0.1 (0.5)	0.3 ± 0.0 (0.3)	0.5 ± 0.1 (0.4)	0.6 ± 0.2 (0.4)	0.3 ± 0.0 (0.3)	0.3 ± 0.0 (0.3)	
Selenium	Dry	D	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	-
		T	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	
	Wet	D	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	
		T	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	
Silver	Dry	D	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	99% - 0.8
		T	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	95% -1.4
	Wet	D	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	
		T	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	
Vanadium	Dry	D	1.9 ± 0.0 (1.9)	1.8 ± 0.2 (1.8)	1.7 ± 0.2 (1.6)	1.6 ± 0.2 (1.8)	1.6 ± 0.2 (1.6)	1.5 ± 0.2 (1.4)	1.7 ± 0.2 (1.7)	1.8 ± 0.2 (1.9)	99% - 50
		T	2.7 ± 0.2 (2.7)	3.5 ± 0.6 (3.7)	2.1 ± 0.2 (2.4)	1.7 ± 0.2 (1.8)	1.7 ± 0.2 (1.7)	1.9 ± 0.2 (1.9)	1.7 ± 0.2 (1.8)	1.7 ± 0.2 (1.9)	95% - 100
	Wet	D	2.7 ± 0.2 (2.6)	2.6 ± 0.3 (2.4)	2.3 ± 0.3 (2.4)	1.8 ± 0.2 (1.8)	2.0 ± 0.1 (2.1)	2.0 ± 0.2 (2.1)	2.0 ± 0.1 (2.1)	2.0 ± 0.1 (2.1)	
		T	3.9 ± 0.4 (3.6)	3.9 ± 0.5 (4.0)	2.73 ± 0.4 (2.7)	1.9 ± 0.2 (1.9)	2.1 ± 0.1 (2.2)	2.3 ± 0.2 (2.3)	2.0 ± 0.1 (2.1)	2.0 ± 0.1 (2.1)	
Zinc	Dry	D	0.7 ± 0.4 (0.7)	6.7 ± 4.3 (2.3)	2.4 ± 1.2 (1.4)	1.5 ± 0.6 (1.0)	1.8 ± 0.7 (1.5)	1.7 ± 0.7 (1.1)	3.3 ± 1.5 (1.2)	3.7 ± 2.0 (1.5)	99% - 7
		T	1.6 ± 0.1 (1.6)	4.6 ± 0.8 (4.6)	2.5 ± 0.4 (2.2)	1.9 ± 0.4 (1.7)	2.4 ± 0.6 (2.1)	2.3 ± 0.7 (2.0)	2.4 ± 0.6 (1.7)	2.3 ± 0.4 (2.2)	95% - 15
	Wet	D	2.8 ± 1.1 (2.1)	4.5 ± 1.3 (3.6)	4.0 ± 1.0 (3.9)	3.1 ± 0.7 (2.9)	4.0 ± 1.5 (3.1)	7.0 ± 3.0 (3.8)	3.8 ± 0.6 (3.7)	3.7 ± 0.8 (4.2)	
		T	4.4 ± 1.0 (4.4)	4.9 ± 1.1 (4.8)	6.9 ± 2.3 (5.1)	3.3 ± 0.8 (3.4)	3.8 ± 1.0 (3.7)	4.5 ± 1.1 (4.3)	5.0 ± 2.0 (3.1)	3.2 ± 0.7 (3.0)	

Table notes:

1. Values are means ± se (median), n = 3 to 7.
2. Form: D = dissolved and T = total
3. WQOs are AWQG trigger values for two levels of species protection (99% or 95%)

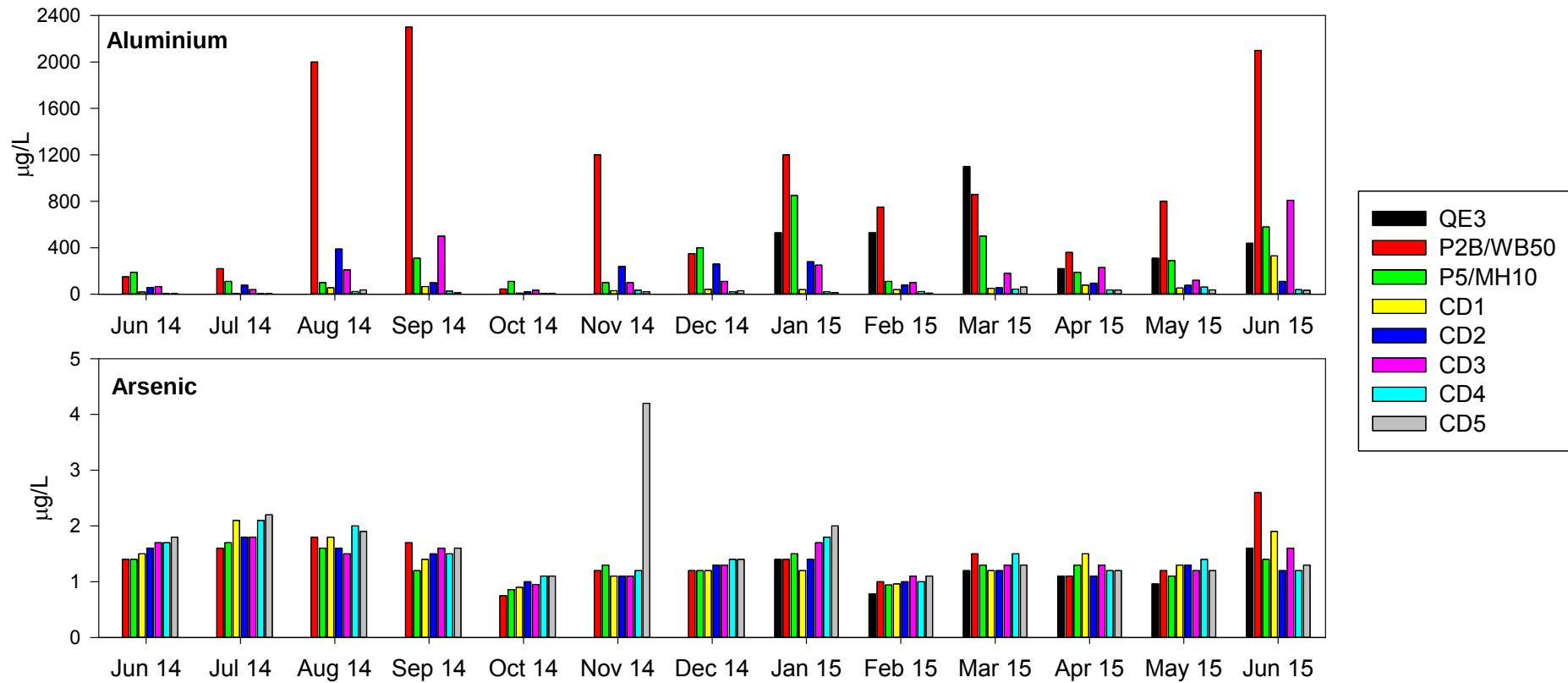


Figure 3.47 Total aluminium and arsenic concentrations at monitoring sites

Figure note: Values which were < LOR, were plotted as half LOR.

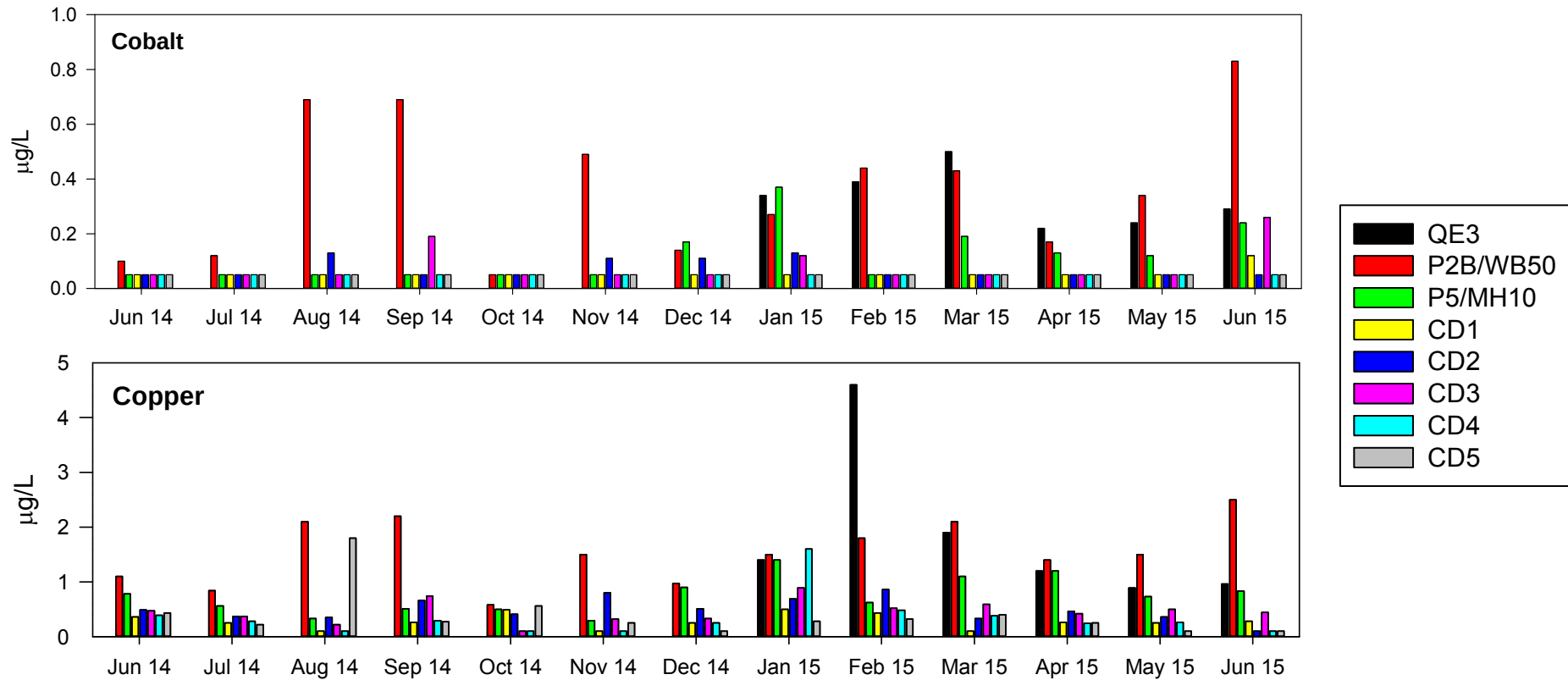


Figure 3.48 Total cobalt and copper concentrations at monitoring sites

Figure note: Values which were < LOR, were plotted as half LOR. Cadmium was not plotted as values were < LOR at all sites each month. Chromium was not plotted as most values were < LOR at all sites each month.

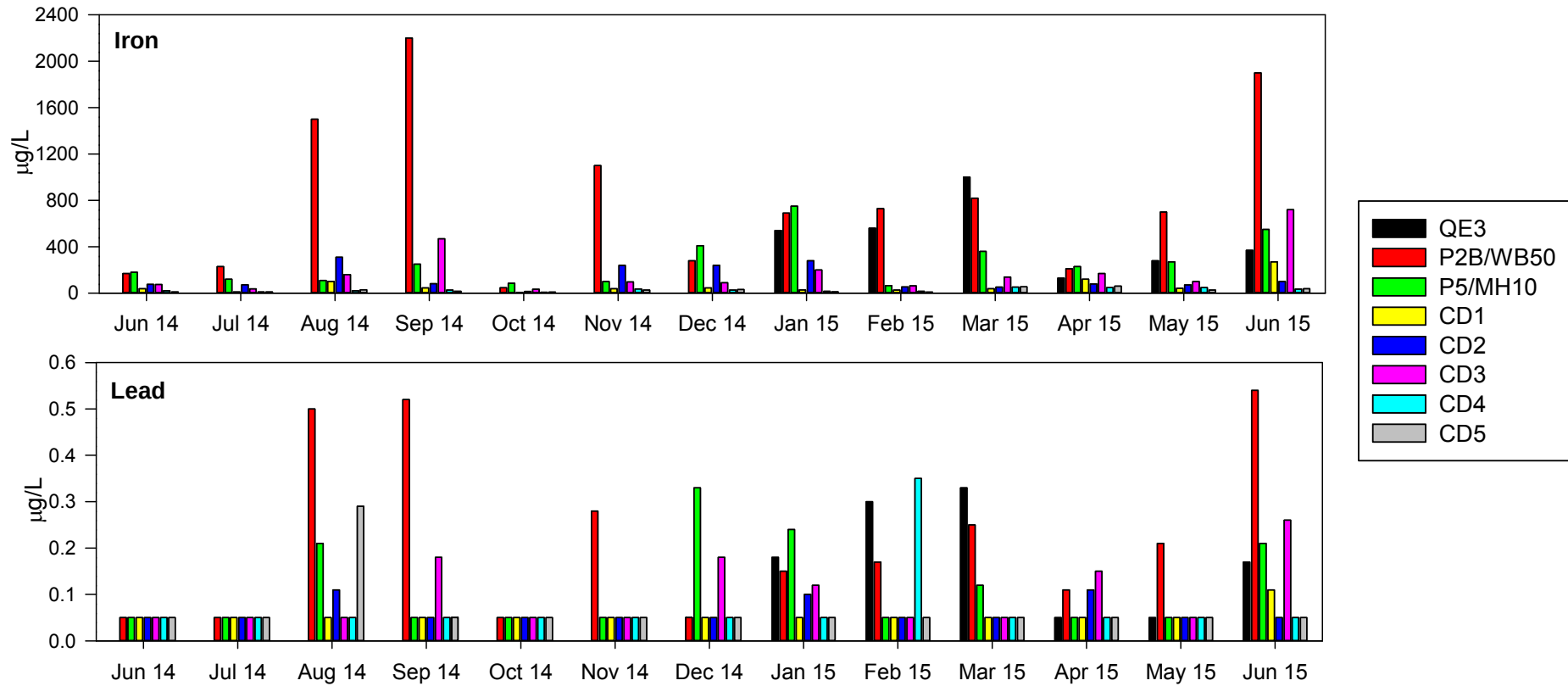


Figure 3.49 Total iron and lead concentrations at monitoring sites

Figure note: Values which were < LOR, were plotted as half LOR. Gallium was not plotted as values were < LOR at all sites most months.

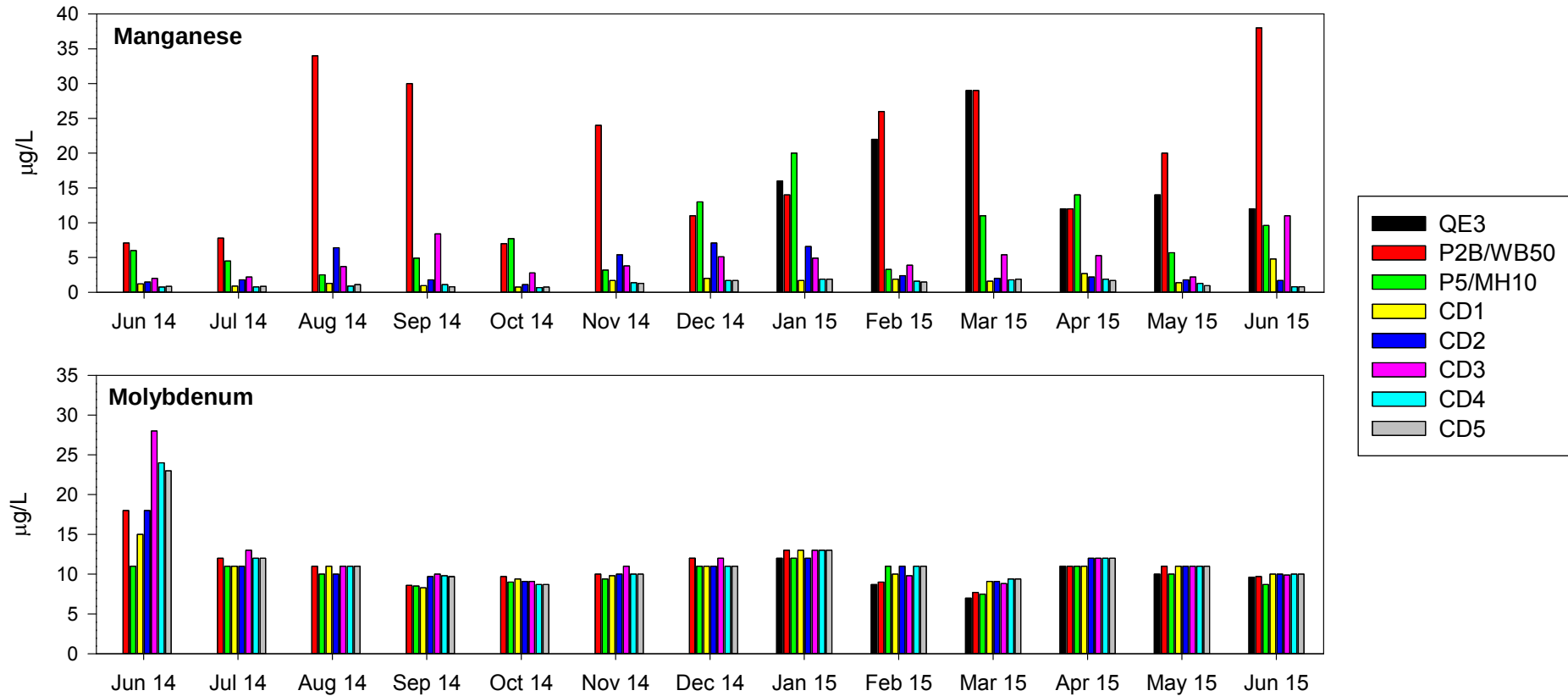


Figure 3.50 Total manganese and molybdenum concentrations at monitoring sites

Figure note: Values which were < LOR, were plotted as half LOR. Mercury was not plotted as values were < LOR at all sites each month.

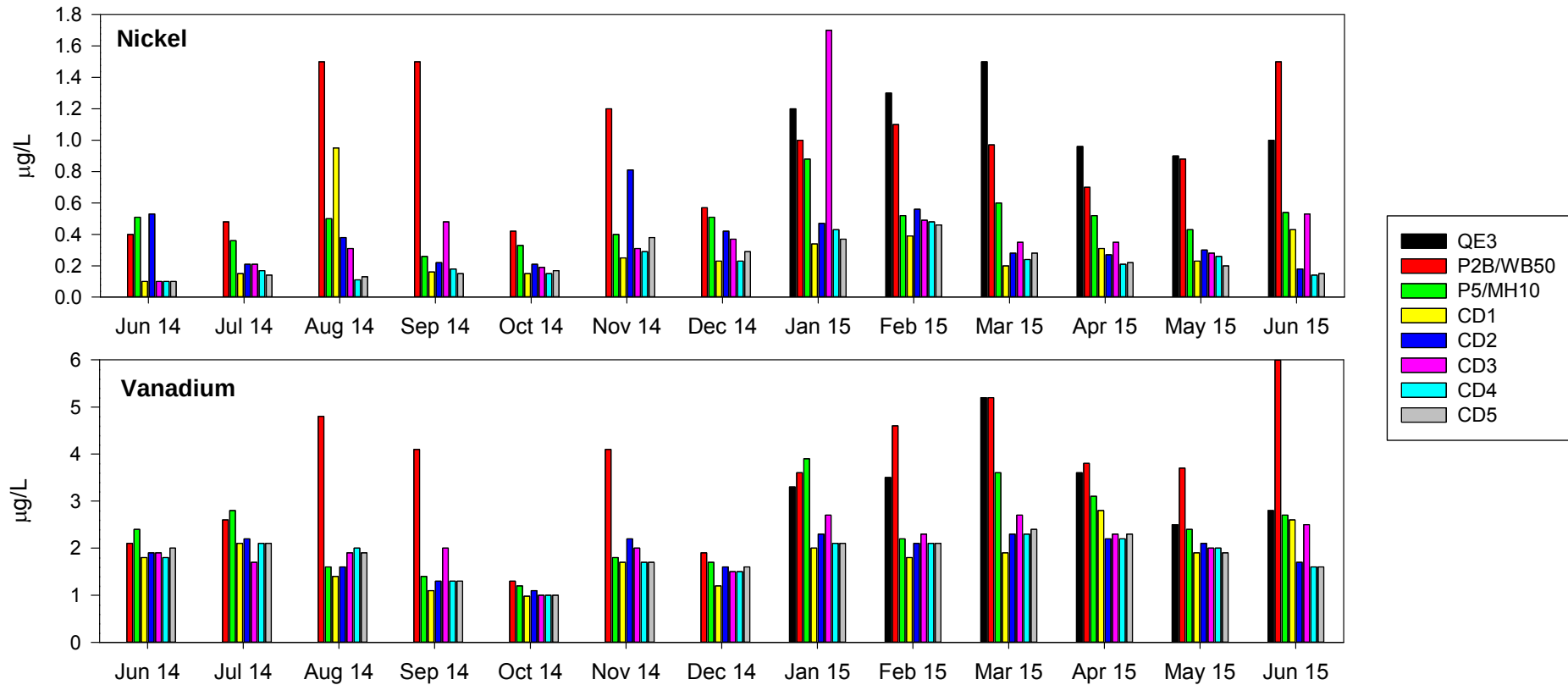


Figure 3.51 Total nickel and vanadium concentrations at monitoring sites

Figure note: Values which were < LOR, were plotted as half LOR. Selenium and silver were not plotted as values were < LOR at all sites each month.

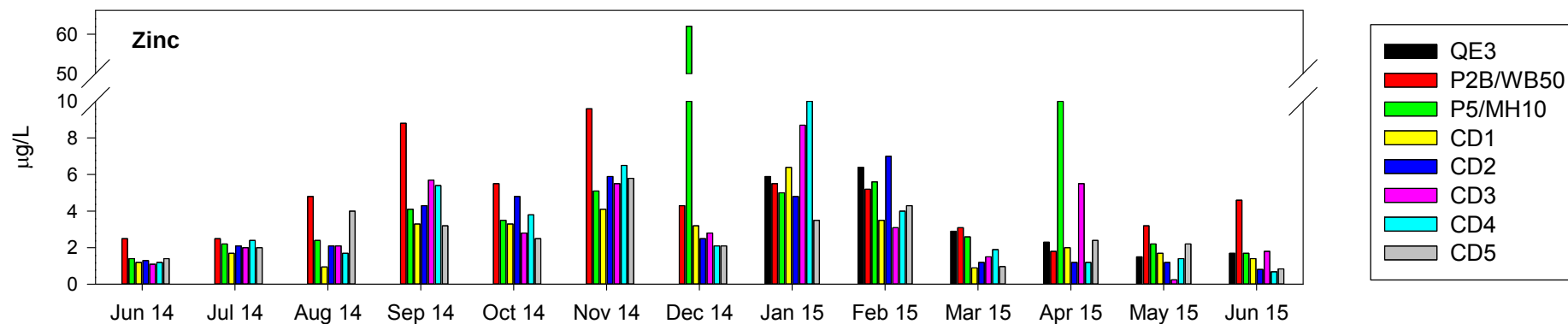


Figure 3.52 Total zinc concentrations at monitoring sites

Figure note: Values which were < LOR, were plotted as half LOR.

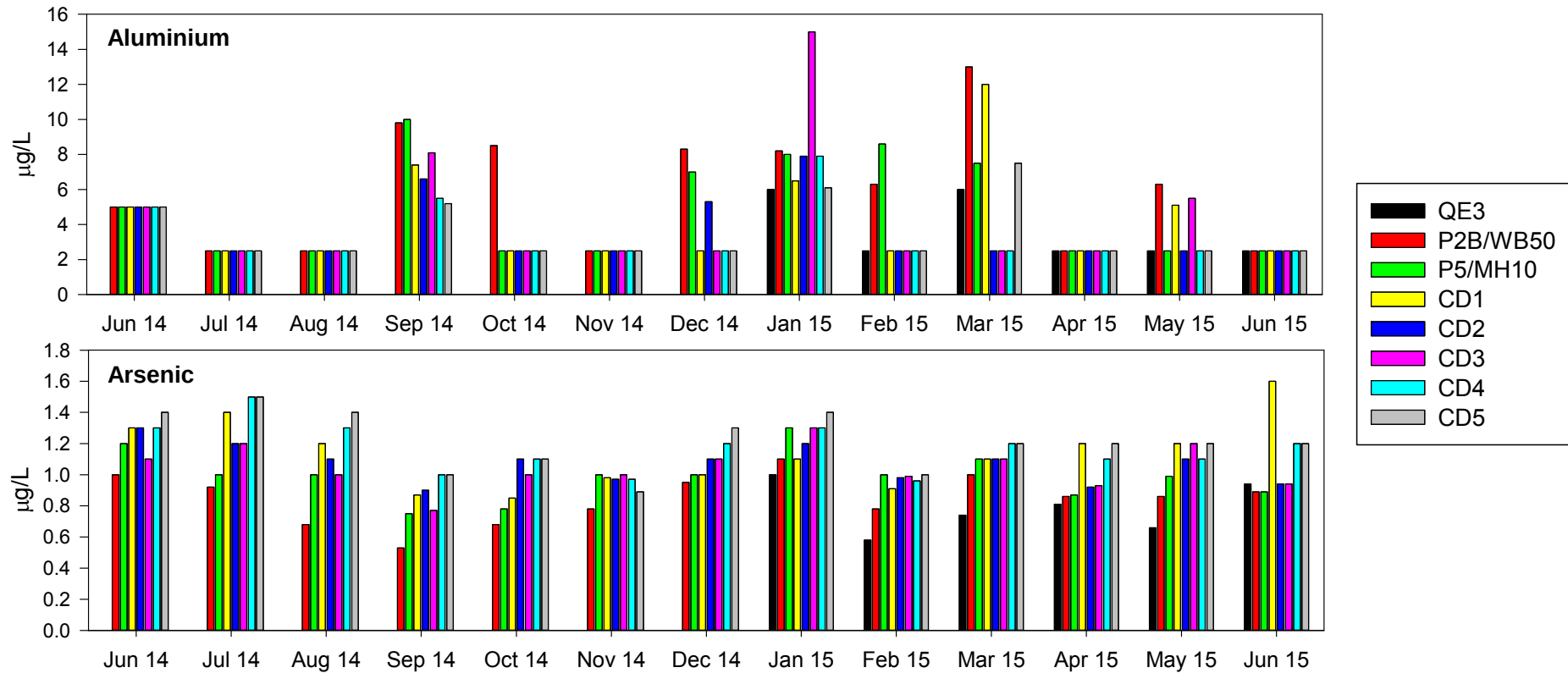


Figure 3.53 Dissolved aluminium and arsenic concentrations at monitoring sites

Figure note: Values which were < LOR, were plotted as half LOR.

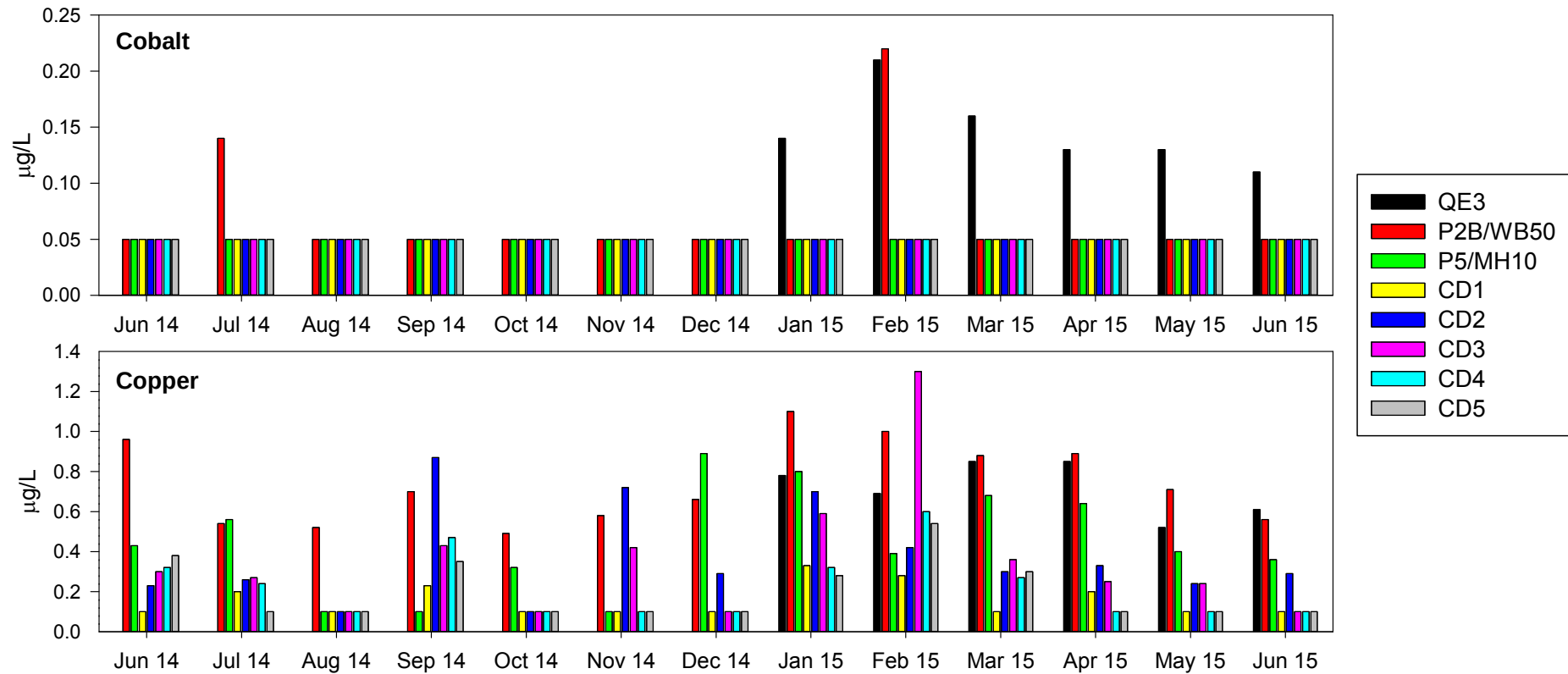


Figure 3.54 Dissolved cobalt and copper concentrations at monitoring sites

Figure note: Values which were < LOR, were plotted as half LOR. Cadmium and chromium were not plotted as values were generally at or < LOR at all sites each month.

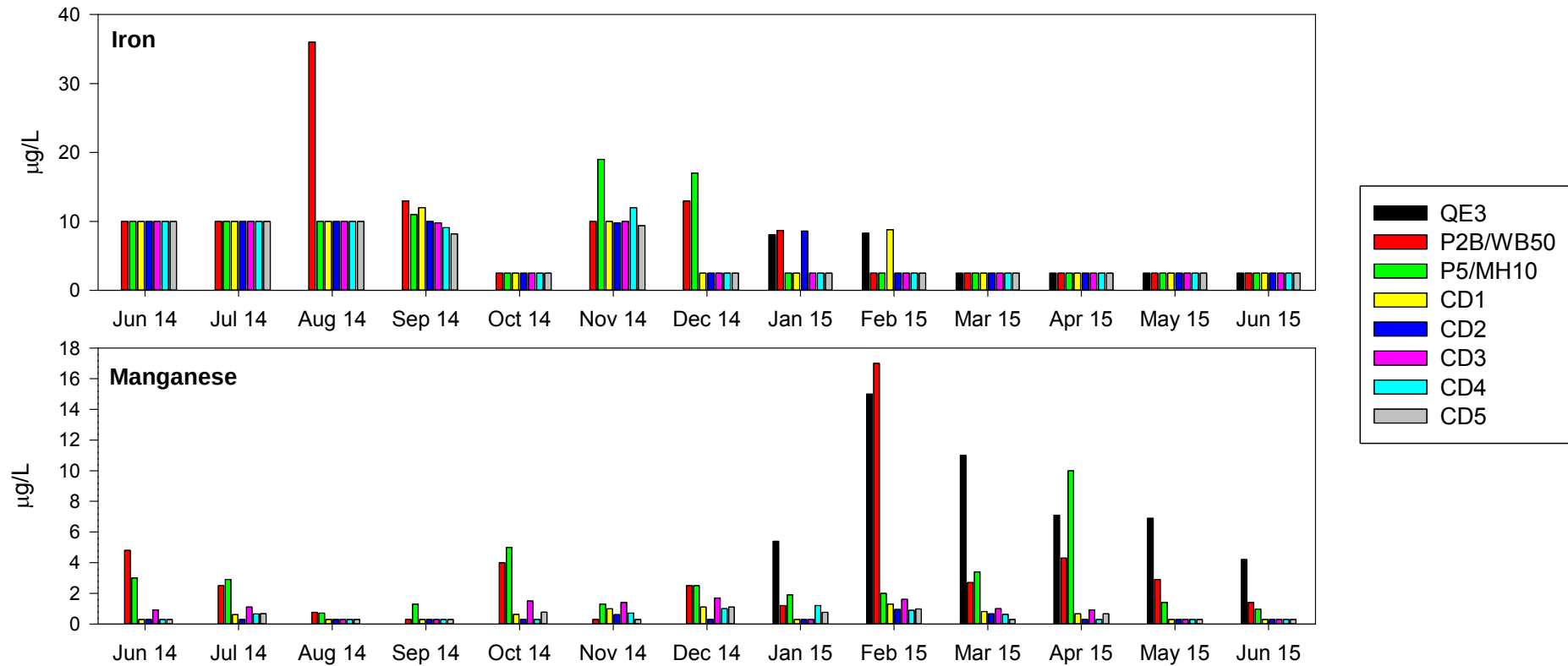


Figure 3.55 Dissolved iron and manganese concentrations at monitoring sites

Figure note: Values which were < LOR, were plotted as half LOR. Gallium, lead and mercury were not plotted as values were generally at or < LOR at all sites each month. Note, iron LOR changed from 20µg/L to 5µg/L in September 2014. Results prior to August were all < LOR.

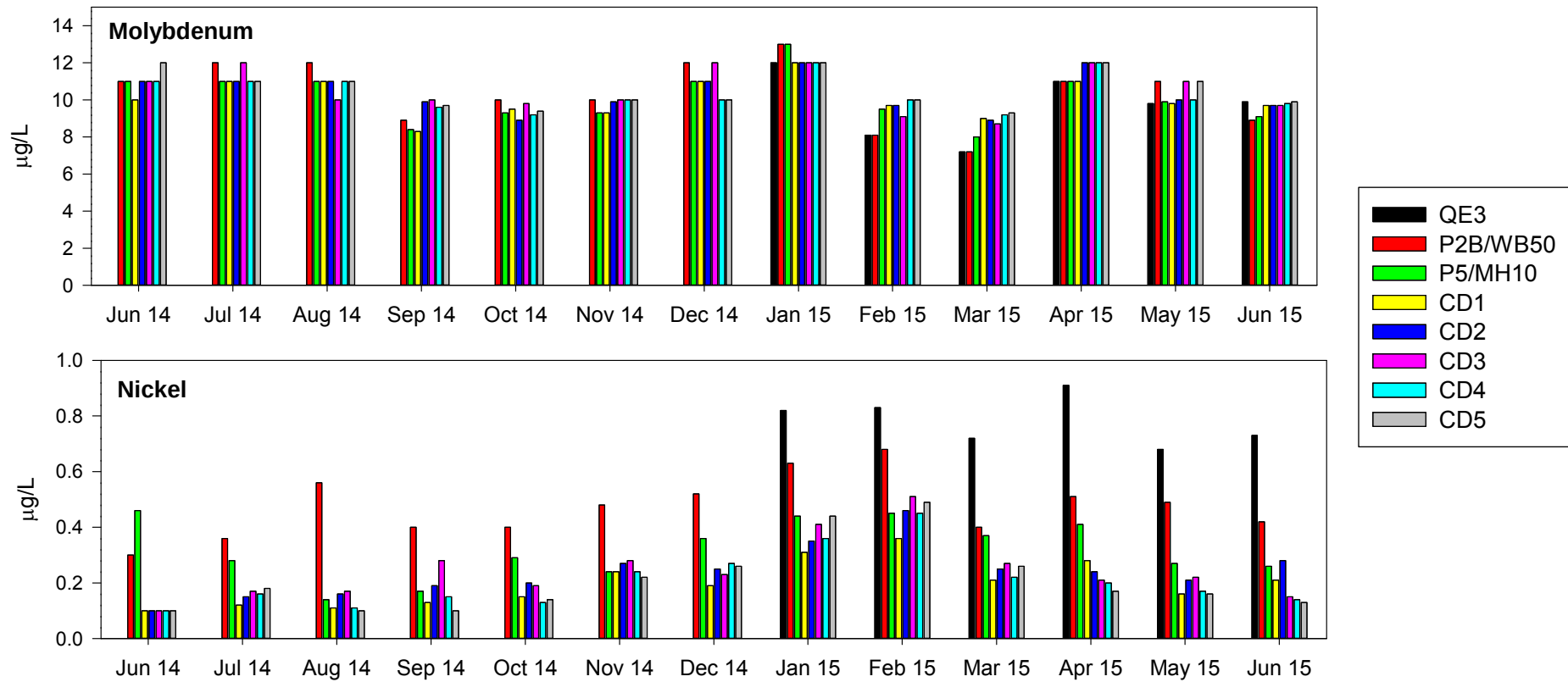


Figure 3.56 Dissolved molybdenum and nickel concentrations at monitoring sites

Figure note: Values which were < LOR, were plotted as half LOR.

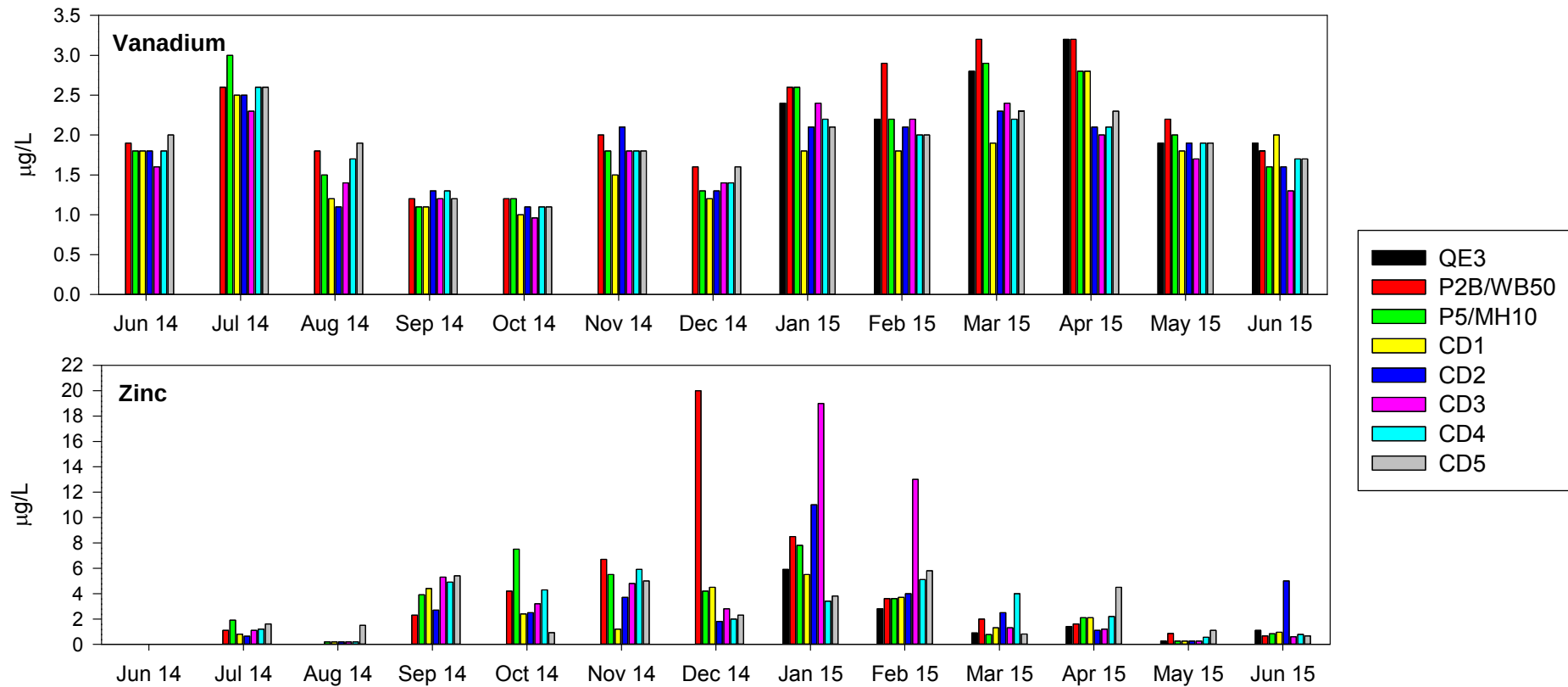


Figure 3.57 Dissolved vanadium and zinc concentrations at monitoring sites

Figure note: Values which were < LOR, were plotted as half LOR. Contamination of dissolved zinc during June and for the P2B/WB50 sample in August was evident; therefore these values have not been included in the long-term plot.

Statistically significant seasonal variation in metal concentrations was not evident for most metals. However, total and dissolved copper, nickel and vanadium, and dissolved manganese were significantly higher in samples collected ($p < 0.05$) during the wet season. Overall there was a general trend for the majority of total and dissolved metals in samples to be more elevated in sampling months after rain events. This has been a historical finding for Port Curtis with elevated total metals in the post January 2011 and 2013 flood events (Vision Environment 2013b). Elevated metals were also recorded in other catchment areas in Queensland following the January 2011 floods (DERM 2011, Vision Environment 2012a).

A number of total metals detected in samples were significantly ($p < 0.05$) correlated with TSS concentrations, indicating that in areas where TSS was higher (such as at the inshore sites of QE3 and P2B/WB50), metal concentrations were also higher. This included aluminium ($r^2 = 0.87$), copper ($r^2 = 0.85$), iron ($r^2 = 0.88$), lead ($r^2 = 0.877$), manganese ($r^2 = 0.80$) and nickel ($r^2 = 0.65$). Similar relationships have been identified previously in Port Curtis with increased turbidity and TSS concentrations highly associated with increased total aluminium, iron, cobalt and manganese (Vision Environment 2012a), indicating metals in the water column are predominately bound to particulates.

For the detectable metals, total concentrations were generally considerably higher than dissolved concentrations. This suggests that most metals were predominantly bound to particulates, as supported by the linear regressions between TSS and total metal concentrations. Certain metals are known to readily adsorb onto iron hydroxides and colloidal particles (Salomons et al. 1995).

Significant spatial variation was also evident for a number of metals. Concentrations of total aluminium, lead, iron and vanadium, and total and dissolved cobalt, copper, nickel, manganese were significantly higher in samples from P2B/WB50 and QE3 than in those samples from offshore sites. Decreasing metal concentrations from lower estuary and enclosed coastal waters to open coastal waters have been a consistent historical finding for Port Curtis (Storey et al. 2007, Vision Environment 2011, Vision Environment 2013f).

WQOs for metals in Port Curtis have been set by EHP (2014), with the majority of these originally established in the National Water Quality Management Strategy (ANZECC/ARMCANZ 2000). EHP have designated the Port Curtis water areas or 'zones' into different levels of ecosystem protection, including 'high ecological value' (HEV), 'slightly disturbed' (SD), 'moderately disturbed' (MD) and 'highly disturbed' (HD). Zones which are designated HEV or SD are proposed to meet the AWQG trigger value for 99% level of species protection for metals and other toxicants, while MD zones are proposed to meet the AWQG trigger value for 95% level of species protection (ANZECC/ARMCANZ 2000). Previously, the 95% AWQG trigger value has been applied to all inshore sites, whereas the 99% AWQG trigger value was considered more appropriate for reference or offshore sites.

Of the current monitoring sites, QE3 (The Narrows zone SD2442) has been classified as HEV/SD, and thus 99% AWQG trigger values for metals are applicable. Zones in which sites P2B/WB50, P5/MH10, CD1 and CD3 are located are classified as MD, indicating that the 95% AWQG are applicable. Sites CD2, CD4 and CD5 are located in coastal waters outside Gladstone Harbour, which are classified as slightly to moderately disturbed (SMD), and thus the 95% AWQG trigger values are considered most appropriate for use.

Due to the use of more stringent guidelines (e.g. use of 99% rather than 95% AWQG trigger value) at QE3, a number of water quality samples collected for this Project at this site were

above the WQOs assigned to these waters, including concentrations of total aluminium in both the wet season and dry season, and total and dissolved cobalt and copper in both seasons. For the remaining sites where the 95% AWQG trigger value has been designated for use, total aluminium sample concentrations from all sites were above the WQO during both wet and dry seasons, with the exception of samples from CD4 and CD5 which exceeded during the wet season only. However, dissolved aluminium sample concentrations remained well below the WQO at each site. Additionally in samples from site P2B/WB50, concentrations of total copper in both the wet and dry season were above the WQO, with dissolved concentrations remaining below the WQO. Although AWQG exceedances of certain total metals in Port Curtis have been recorded previously, the majority of dissolved and therefore potentially bioavailable metals, have generally been below AWQG (Vision Environment 2012a, Vision Environment 2013d, Vision Environment 2013f), and are therefore not considered current contaminants of concern for this Project.

3.5.5 Organics

Organic contaminants are those containing carbon and include herbicides, pesticides, oil and grease, which encompass petroleum hydrocarbons and polycyclic aromatic hydrocarbons (PAH). Potential sources of herbicides and pesticides are thought to be minimal in Port Curtis due to very few agricultural and farming sources within surrounding catchments. Nonetheless, increased industrial and anthropogenic activities indirectly associated with port development may contribute to an increase in some organic compounds in the water column.

Subsurface samples for organics (total recoverable hydrocarbons, benzene, toluene, ethyl benzene, xylene, PAHs, organochlorine pesticides, organophosphate pesticides and multi-residue pesticides) were collected and analysed quarterly in July and October 2014, and January and April 2015. Quarterly results are tabulated in the Appendix 6.5 (refer Tables 6.46 to 6.49). The measured organic substances were not detected in samples from any site, on any occasion.

4 SUMMARY

Water quality monitoring was undertaken by Vision Environment from 1 June 2014 to 4 July 2015 at eight monitoring sites located throughout Port Curtis to provide interpreted baseline data to support the process of the Project EIS. For the purposes of this EIS technical report water quality results, which represent ambient baseline conditions across eight sites in Port Curtis from June 2014 to July 2015, have been compared against WQOs for reference purposes only. A summary of the baseline data results is provided below.

4.1 Physicochemistry

- Surface turbidity at inshore sites (QE3, P2B/WB50 and P5/MH10) was significantly higher than at offshore monitoring sites (CD1 to CD5), with the highest turbidity inshore evident during spring tides. However, mean turbidity at inshore sites was within the 20th to 80th percentile WQOs, indicating similar values to previous studies undertaken within Port Curtis.
- At the offshore sites benthic turbidity was significantly higher and more variable than surface turbidity. However, significant linear regressions were evident between benthic and surface turbidity at each site (although regressions tended to be weak), indicating that both surface and benthic turbidity responded similarly to environmental stimuli.
- Deeper offshore sites (CD4 and CD5) exhibited lower turbidity than their offshore counterparts, with turbidity at these two sites and site CD1 responding primarily to wind

events. Sites CD2 located closer to Port Curtis and CD3 located closer to the main land in comparatively shallower depths, exhibited the highest turbidity of the offshore sites, and were influenced by the tidal regime as well as offshore wind and wave action.

- For sites CD1 and CD3 in Mid and Outer Harbour zones of Port Curtis, mean turbidity during both seasons was within the 20th to 80th percentile WQO. However, of the remaining offshore sites, only surface values at CD5 were consistently below the WQO for coastal waters outside Gladstone Harbour.
- Higher turbidity was evident during the wet season across both inshore and offshore sites. Offshore sites responded to TC Marcia in February 2015 with short term highly elevated turbidity, particularly at the benthos, and inshore sites responded to the significant rain events recorded in mid-January and mid-February 2015.
- A spatial pattern was evident across the eight sites in regard to pH and DO, with inshore sites QE3 and P2B/WB50 exhibiting consistently lower values, similar to what has been previously recorded in other studies in Port Curtis. At these sites, diurnal patterns for DO due to plant photosynthesis and respiration was evident, particularly during the warmer months.
- At the offshore sites, only marginal differences were evident between benthic and surface temperature, conductivity, pH and DO, indicating the offshore water column was generally well-mixed, similar to the inshore sites. This was supported by the depth-profiling data.
- Notable rain events (mid-January and mid-February 2015) consistently generated the following impacts, which often fluctuated tidally at inshore sites and CD3:
 - o Large decline in conductivity with slow recovery to background conditions
 - o Short-lived decline in pH
 - o Short-lived decline in DO due to increased BOD and COD
 - o Salt water stratification at CD3, with a surface layer of freshwater over saltwater
- Preliminary monitoring at P5/MH10 from October 2013 to June 2014 exhibited similar physicochemistry as values recorded during the Project (June 2014 to June 2015).

4.2 Sedimentation

- Two forms of information were provided by altimeters: instantaneous bed level change (bed level flux) and cumulative bed level change over a given period. At inshore sites and offshore sites CD2 and CD3, bed level flux was influenced by significant rain events, and spring tides.
- Bed level flux at offshore sites CD1, CD4 and CD5 was more stable and appeared to be wind driven. This was particularly evident during TC Marcia in February 2015, in which wind direction appeared to highly impact whether sediment was deposited or eroded.
- Erosion and deposition was generally equal at most inshore sites, resulting in low cumulative bed level change. However bed level flux was quite volatile at site CD2 where erosion was most commonly recorded, while overall deposition was primarily recorded at CD3 located at the mouth of the Boyne River, particularly after significant rain events.

4.3 Benthic Photosynthetically Active Radiation

- The main variables found to influence BPAR were ambient light, turbidity, light attenuation and water depth
- Although ambient light was highest during the wet season (October 2014 to March 2015) when daylight periods were longer, BPAR was significantly higher at all five benthic sites in the dry season, suggesting that ambient light was only a partial influence on variation in BPAR at these sites. This is supported by the lack of significant correlations between

ambient PAR and BPAR at three of the five sites, and only weak correlations at the remaining two sites.

- Significant but weak linear regression relationships were evident between turbidity and BPAR at each site, with BPAR increasing with decreasing turbidity. However, BPAR was significantly higher at the shallower offshore sites (CD1 and CD2), which did not record the lowest turbidity values. Despite the shallow depth at CD3, BPAR was lower, most likely due to elevated TSS through the water column therefore increasing the attenuation of light.
- Previous studies have determined light requirements for certain species of seagrass in Port Curtis, which were used as ecological triggers during dredging works for the WBDDP.

4.4 Water analysis

- Across the sites, surface TSS was significantly higher in samples from P2B/WB50 than at offshore sites (CD1 to CD5). Samples from other inshore sites (QE3 and P5/MH10) exhibited intermediate concentrations. However, mean seasonal TSS sample results from inshore sites were below the applicable QWQG.
- At offshore sites, TSS was significantly higher at the benthic depth than at mid and surface depths. Concentrations above the applicable WQOs were found in samples from all depths at sites CD2 and CD3, and at the benthos at remaining sites.
- As expected, a strong and significant correlation was evident between TSS results and turbidity, indicating that as TSS increased, so did turbidity. However, no significant seasonal difference for TSS could be inferred from monthly sample results.
- Nutrients (total phosphorus, total nitrogen and orthophosphate) and chlorophyll *a* were significantly higher in samples from inshore sites P2B/WB50 and QE3 than in samples from offshore sites, with intermediate concentrations in samples from P5/MH10, suggesting a geographical gradient which has been previously recorded in Port Curtis. No significant seasonal variation in nutrient concentrations could be inferred from monthly sample results, but chlorophyll *a* concentrations were significantly higher during the wet season.
- Most nutrients were within their recommended WQO range, but in samples from P2B/WB50 and QE3 concentrations were above the chlorophyll *a* WQO. Total phosphorus concentrations in samples from P2B/WB50 were also above the WQO.
- For those samples from sites located in the coastal waters outside Gladstone Harbour (CD2, CD4 and CD5), concentrations were above the WQOs for: total phosphorus and nitrogen oxides during both seasons; total nitrogen and chlorophyll *a* during the wet season; and ammonia during the dry season
- Concentrations of a number of metals (total aluminium, lead, iron and vanadium, and total and dissolved cobalt, copper, nickel, manganese) were significantly higher in samples from the inshore sites of QE3 and P2B/WB50 than in samples from the offshore sites, with intermediate concentrations found in samples from P5/MH10. This geographical gradient has been historically recorded in Port Curtis.
- Total and dissolved copper, nickel and vanadium and dissolved manganese were the only metals to exhibit seasonal differences, being significantly higher in samples collected during the wet season compared to the dry season
- TSS sample concentrations were strongly correlated with a number of total metals, suggesting that a high proportion of metals are bound to suspended particulates in the water column. This is supported by the considerably lower dissolved concentrations found for most metals.

- QE3 is located in a HEV/SD zone, and thus more stringent WQOs for metals are assigned. The mean total aluminium concentrations, as well as total and dissolved copper and cobalt concentrations in samples from this site in the wet and dry season, were above their WQOs
- The remaining sites are considered to be in SMD or MD zones, and thus WQOs are less stringent. Total aluminium concentrations in samples from both wet and dry seasons from all sites were above the WQOs, with the exception of samples from CD4 and CD5 where concentrations were above WQOs the during wet season only. However, dissolved aluminium concentrations were well below the WQO. Total copper concentrations in samples from P2B/WB50 in both the wet and dry season were above the WQO also.
- Although AWQG exceedances of certain total metals in Port Curtis have been recorded previously, the majority of dissolved and therefore potentially bioavailable metals, have generally been below AWQG, and are therefore considered not current contaminants of concern for this Project
- None of the organic compounds analysed were detected in any samples collected from any sites during the four sampling occasions of the baseline data collection period

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6 APPENDIX

6.1 Preliminary P5/MH10 monitoring

Table 6.1 Water quality parameters at P5/MH10 from October 2013 to May 2014

Statistic	Turbidity (NTU)	Temperature (°C)	pH	Conductivity (mS/cm)	DO (%)
Mean ± se	7.8 ± 0.1	25.8 ± 0.0	8.1 ± 0.0	53.0 ± 0.0	100 ± 0
Range	<1 – 91	20.3 – 30.4	7.9 – 8.5	30.5 – 59.0	75 – 129
20 th percentile	2.6	-	-	-	-
50 th percentile (median)	5.2	26.0	8.1	53.5	99
80 th percentile	12	-	-	-	-
WQO	4, 9, 16	-	7.4 – 8.3	-	94, 97, 101

Table notes:

1. N = 22,651 – 23,305
2. Wet Season WQOs are provided for comparison as the deployment period consisted of one month of dry season, six months of wet season, followed by an additional month of dry season
3. Three values are listed for turbidity and DO WQO denoting the 20th, 50th and 80th percentiles
4. For pH, the 20th to 80th percentile range is listed for the WQO

Table 6.2 Total Suspended Solids, Chlorophyll a and nutrients concentrations at P5/MH10

Parameter	P5/MH10	WQO
TSS (mg/L)	20 ± 6 (14)	20
Chlorophyll a (µg/L)	1.8 ± 0.2 (1.8)	0.5, 1.0, 2.0
Total Phosphorus (µg/L)	14 ± 3 (13)	9, 14, 23
Orthophosphate (µg/L)	<5	1, 2, 3
Total Nitrogen (µg/L)	107 ± 20 (105)	110, 135, 200
Ammonia - N (µg/L)	18 ± 6 (16)	3, 3, 12
Nitrate (µg/L)	5 ± 1 (<5)	1, 3, 9
Nitrite (µg/L)	<5	1, 3, 9

Table notes:

1. Values are means ± se (median), n = 8
2. Specific zone WQOs for TSS have not been specified by DSITIA, therefore QWQG for Central Coast Queensland Region: Mid-Estuarine and Tidal Canals, Constructed Estuaries, Marinas and Boat Harbours have been used (DERM 2009)
3. For chlorophyll a and nutrients, three values are listed for the WQO denoting the 20th, 50th and 80th percentiles

Table 6.3 Total and dissolved metal concentrations at P5/MH10

Metal (µg/L)	Form	P5/MH10	WQO
Aluminium	Total	269 ± 61 (206)	24
	Dissolved	5.7 ± 1.3 (5.6)	
Arsenic	Total	1.8 ± 0.1 (1.9)	-
	Dissolved	1.4 ± 0.0 (1.4)	
Cadmium	Total	<0.1	5.5
	Dissolved	<0.1	
Chromium	Total	<1	CrIII – 27.4, CrVI 4.4
	Dissolved	<1	
Cobalt	Total	<1	1
	Dissolved	<1	
Copper	Total	<1	1.3
	Dissolved	<1	
Gallium	Total	<1	-
	Dissolved	<1	
Iron	Total	284 ± 57 (243)	-
	Dissolved	<5	
Lead	Total	<1	4.4
	Dissolved	<1	
Manganese	Total	10 ± 1 (10)	-
	Dissolved	2.5 ± 0.8 (1.5)	
Mercury	Total	<0.1	0.4
	Dissolved	<0.1	
Molybdenum	Total	12 ± 0 (12)	-
	Dissolved	12 ± 0 (12)	
Nickel	Total	<1	70
	Dissolved	<1	
Selenium	Total	<1	-
	Dissolved	<1	
Silver	Total	<1	1.4
	Dissolved	<1	
Vanadium	Total	3.0 ± 0.2 (2.9)	100
	Dissolved	2.0 ± 0.1 (1.8)	
Zinc	Total	1.1 ± 0.3 (0.5)	15
	Dissolved	<1	

Table notes:

1. Values are means ± se (median), n = 8
2. P5/MH10 is located in a 'moderately disturbed' water area (EHP 2014) and that the 95% AWQG trigger value (ANZECC/ARMCANZ 2000) is appropriate for use

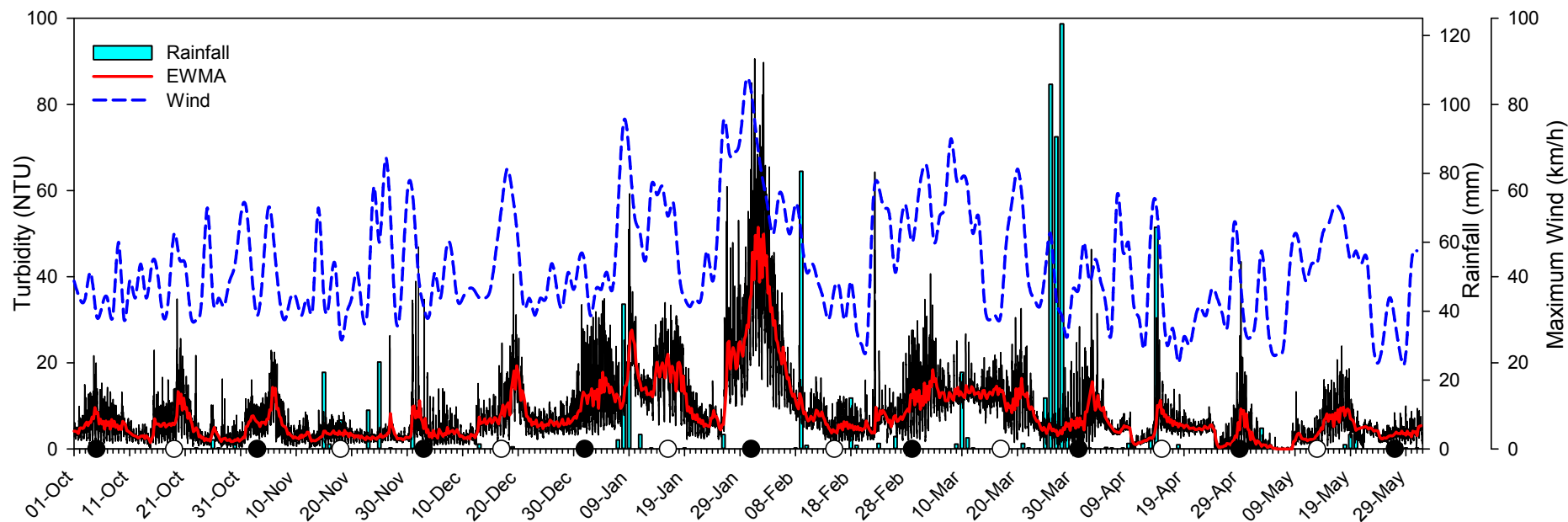


Figure 6.1 Surface turbidity, rainfall and inshore wind speed at site P5/MH10

Figure note: Open and closed circles indicate full and new moons, respectively.

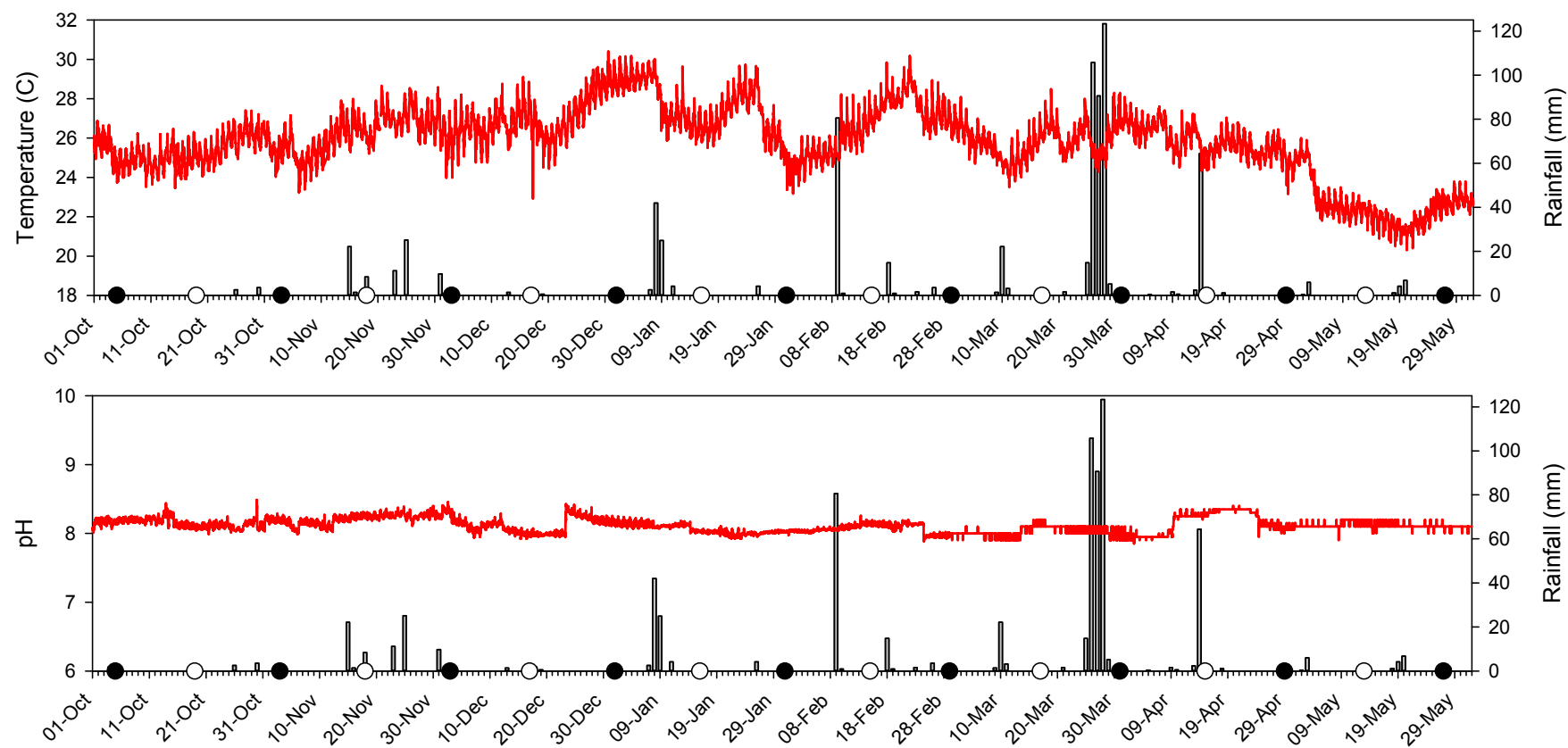


Figure 6.2 Surface temperature and pH at site P5/MH10

Figure note: Open and closed circles indicate full and new moons, respectively.

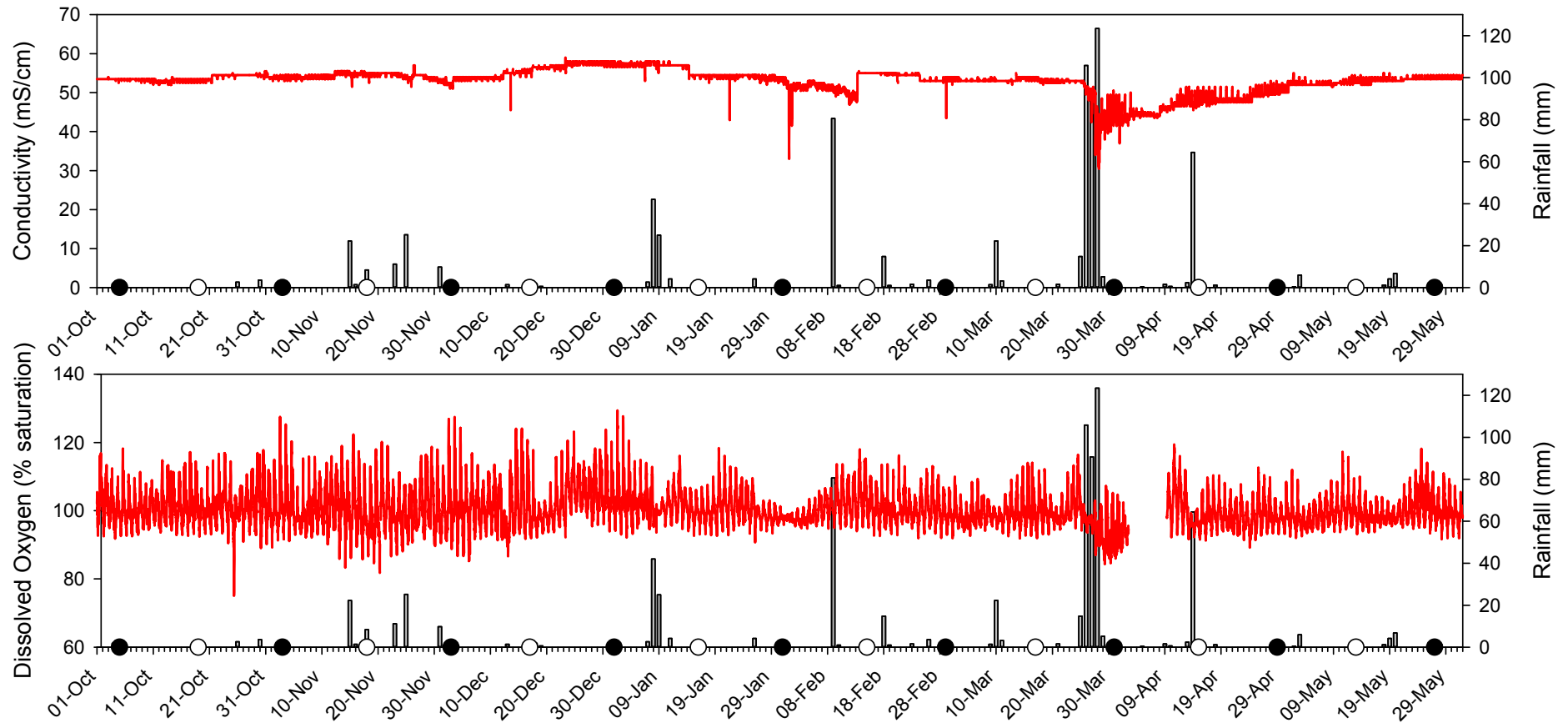


Figure 6.3 Surface conductivity and dissolved oxygen at site P5/MH10

Figure note: Open and closed circles indicate full and new moons, respectively.

6.2 Physicochemistry

Table 6.4 Mean monthly turbidity data retention rate (validated useable data as opposed to raw data capture) across monitoring sites

Site	Data Retention Rate													
	Jun-15	May-15	Apr-15	Mar-15	Feb-15	Jan-15	Dec-14	Nov-14	Oct-14	Sep-14	Aug-14	Jul-14	Jun-14	Mean
QE3	98%	100%	100%	90%	90%	92%	-	-	-	-	-	-	-	95%
P2B/WB50	100%	100%	100%	100%	85%	83%	100%	100%	98%	100%	96%	100%	100%	97%
P5/MH10	100%	99%	78%	97%	100%	85%	99%	100%	98%	100%	100%	100%	99%	96%
CD1 surface	100%	100%	96%	100%	91%	85%	81%	99%	95%	100%	99%	100%	100%	96%
CD1 benthic	94%	96%	71%	94%	97%	66%	80%	100%	99%	100%	99%	100%	100%	92%
CD2 surface	100%	100%	100%	100%	95%	80%	100%	100%	100%	99%	100%	99%	100%	98%
CD2 benthic	78%	88%	76%	85%	89%	42%	75%	66%	98%	83%	99%	99%	100%	83%
CD3 surface	100%	100%	95%	62%	66%	100%	100%	100%	89%	97%	100%	100%	100%	93%
CD3 benthic	93%	91%	78%	99%	100%	99%	84%	96%	86%	97%	100%	99%	100%	94%
CD4 surface	100%	100%	100%	94%	67%	99%	100%	75%	100%	97%	99%	94%	100%	94%
CD4 benthic	86%	78%	79%	99%	43%	72%	96%	81%	82%	97%	91%	86%	97%	84%
CD5 surface	94%	100%	100%	90%	90%	90%	72%	96%	60%	92%	85%	99%	93%	89%
CD5 benthic	89%	89%	71%	98%	84%	79%	88%	98%	81%	92%	85%	99%	89%	88%

Table 6.5 Mean monthly turbidity values across monitoring sites

	Turbidity (NTU)												
Month	QE3	P2B/WB50	P5/MH10	CD1		CD2		CD3		CD4		CD5	
	Surface	Surface	Surface	Surface	Benthic	Surface	Benthic	Surface	Benthic	Surface	Benthic	Surface	Benthic
Jun-14	-	9.3 ± 0.2	5.7 ± 0.1	1.5 ± 0.0	1.5 ± 0.0	1.7 ± 0.0	4.2 ± 0.1	3.5 ± 0.0	5.8 ± 0.1	1.1 ± 0.0	2.7 ± 0.1	<1	<1
Jul-14	-	9.1 ± 0.1	3.1 ± 0.0	<1	2.4 ± 0.0	1.7 ± 0.0	2.6 ± 0.0	2.6 ± 0.0	2.7 ± 0.1	<1	1.6 ± 0.0	<1	<1
Aug-14	-	11 ± 0	4.1 ± 0.1	1.7 ± 0.0	4.7 ± 0.1	3.0 ± 0.0	6.3 ± 0.1	2.2 ± 0.0	5.1 ± 0.1	1.2 ± 0.0	4.8 ± 0.2	<1	<1
Sep-14	-	8.9 ± 0.1	4.2 ± 0.1	1.1 ± 0.0	3.0 ± 0.1	2.7 ± 0.0	4.7 ± 0.1	4.4 ± 0.1	7.5 ± 0.2	<1	4.0 ± 0.1	1.6 ± 0.0	1.9 ± 0.1
Oct-14	-	7.7 ± 0.7	3.9 ± 0.0	1.3 ± 0.0	3.5 ± 0.1	2.1 ± 0.0	5.5 ± 0.1	3.2 ± 0.1	6.0 ± 0.1	1.3 ± 0.0	3.1 ± 0.1	<1	<1
Nov-14	-	7.7 ± 0.1	3.1 ± 0.0	2.1 ± 0.0	2.3 ± 0.0	1.9 ± 0.0	3.2 ± 0.1	<1	2.0 ± 0.1	<1	1.6 ± 0.0	1.6 ± 0.0	1.4 ± 0.0
Dec-14	-	8.0 ± 0.1	4.9 ± 0.1	2.2 ± 0.0	2.1 ± 0.0	2.7 ± 0.0	4.3 ± 0.1	2.9 ± 0.0	4.6 ± 0.1	<1	1.6 ± 0.0	1.1 ± 0.0	1.3 ± 0.0
Jan-15	6.3 ± 0.3	8.4 ± 0.2	5.5 ± 0.1	1.3 ± 0.1	1.1 ± 0.0	1.7 ± 0.0	3.6 ± 0.0	4.6 ± 0.1	2.0 ± 0.1	1.1 ± 0.0	<1	<1	4.4 ± 0.1
Feb-15	7.6 ± 0.2	4.9 ± 0.1	7.4 ± 0.2	3.1 ± 0.0	17 ± 0.0	4.6 ± 0.1	18 ± 0.3	4.6 ± 0.1	19 ± 0.4	2.4 ± 0.0	7.0 ± 0.1	6.6 ± 0.2	7.9 ± 0.2
Mar-15	11 ± 0.1	9.0 ± 0.2	3.9 ± 0.1	1.5 ± 0.0	2.4 ± 0.1	<1	7.4 ± 0.1	2.5 ± 0.1	8.0 ± 0.2	1.6 ± 0.0	5.1 ± 0.1	<1	1.8 ± 0.0
Apr-15	1.4 ± 0.0	3.7 ± 0.1	3.4 ± 0.1	1.5 ± 0.0	5.8 ± 0.1	<1	4.5 ± 0.1	3.4 ± 0.1	6.5 ± 0.1	2.5 ± 0.0	1.5 ± 0.0	<1	2.1 ± 0.0
May-15	4.4 ± 0.0	7.4 ± 0.1	3.9 ± 0.1	1.8 ± 0.0	3.3 ± 0.1	2.0 ± 0.0	3.8 ± 0.1	6.0 ± 0.1	1.7 ± 0.0	1.9 ± 0.0	4.4 ± 0.1	<1	1.5 ± 0.0
Jun-15	9.4 ± 0.1	9.8 ± 0.1	4.9 ± 0.1	1.8 ± 0.0	4.9 ± 0.1	3.7 ± 0.1	4.3 ± 0.1	6.3 ± 0.1	11 ± 0.1	<1	7.3 ± 0.1	<1	5.4 ± 0.1

Table note: Values are means ± se (n ≤ 2,966)

Table 6.6 Mean monthly temperature values across monitoring sites

Month	Temperature (°C)												
	QE3	P2B/WB50	P5/MH10	CD1		CD2		CD3		CD4		CD5	
	Surface	Surface	Surface	Surface	Benthic	Surface	Benthic	Surface	Benthic	Surface	Benthic	Surface	Benthic
Jun-14	-	21.1 ± 0.0	20.9 ± 0.0	21.4 ± 0.0	21.3 ± 0.0	21.3 ± 0.0	21.3 ± 0.0	20.9 ± 0.0	20.8 ± 0.0	21.7 ± 0.0	21.6 ± 0.0	21.8 ± 0.0	21.7 ± 0.0
Jul-14	-	18.5 ± 0.0	18.6 ± 0.0	19.2 ± 0.0	19.2 ± 0.0	19.0 ± 0.0	19.0 ± 0.0	18.5 ± 0.0	18.4 ± 0.0	19.6 ± 0.0	19.4 ± 0.0	19.7 ± 0.0	19.4 ± 0.0
Aug-14	-	19.8 ± 0.0	19.5 ± 0.0	19.7 ± 0.0	19.7 ± 0.0	19.6 ± 0.0	19.6 ± 0.0	19.4 ± 0.0	19.4 ± 0.0	19.9 ± 0.0	19.8 ± 0.0	19.9 ± 0.0	19.8 ± 0.0
Sep-14	-	22.1 ± 0.0	21.6 ± 0.0	21.3 ± 0.0	21.3 ± 0.0	21.2 ± 0.0	21.2 ± 0.0	21.6 ± 0.0	21.5 ± 0.0	21.0 ± 0.0	21.0 ± 0.0	21.1 ± 0.0	20.9 ± 0.0
Oct-14	-	24.8 ± 0.0	24.1 ± 0.0	23.6 ± 0.0	23.6 ± 0.0	23.6 ± 0.0	23.6 ± 0.0	24.2 ± 0.0	24.2 ± 0.0	23.5 ± 0.0	23.5 ± 0.0	23.2 ± 0.0	23.1 ± 0.0
Nov-14	-	27.6 ± 0.0	26.8 ± 0.0	26.6 ± 0.0	26.5 ± 0.0	26.4 ± 0.0	26.6 ± 0.0	27.1 ± 0.0	27.1 ± 0.0	26.1 ± 0.0	26.0 ± 0.0	25.9 ± 0.0	25.8 ± 0.0
Dec-14	-	28.6 ± 0.0	28.1 ± 0.0	27.7 ± 0.0	27.6 ± 0.0	27.8 ± 0.0	27.7 ± 0.0	28.1 ± 0.0	28.1 ± 0.0	27.6 ± 0.0	27.5 ± 0.0	27.5 ± 0.0	27.4 ± 0.0
Jan-15	29.1 ± 0.0	29.0 ± 0.0	28.8 ± 0.0	28.7 ± 0.0	28.6 ± 0.0	28.8 ± 0.0	28.6 ± 0.0	28.9 ± 0.0	28.9 ± 0.0	28.6 ± 0.0	28.4 ± 0.0	28.6 ± 0.0	28.4 ± 0.0
Feb-15	27.4 ± 0.0	27.6 ± 0.0	27.2 ± 0.0	27.3 ± 0.0	27.1 ± 0.0	27.2 ± 0.0	27.2 ± 0.0	27.5 ± 0.0	27.1 ± 0.0	27.5 ± 0.0	27.1 ± 0.0	27.4 ± 0.0	27.2 ± 0.0
Mar-15	28.7 ± 0.0	28.6 ± 0.0	28.4 ± 0.0	28.1 ± 0.0	27.9 ± 0.0	28.1 ± 0.0	28.0 ± 0.0	28.4 ± 0.0	28.3 ± 0.0	28.1 ± 0.0	27.8 ± 0.0	28.0 ± 0.0	27.7 ± 0.0
Apr-15	25.3 ± 0.0	25.7 ± 0.0	25.3 ± 0.0	25.6 ± 0.0	25.6 ± 0.0	25.7 ± 0.0	26.2 ± 0.0	25.3 ± 0.0	25.5 ± 0.0	26.0 ± 0.0	26.0 ± 0.0	26.1 ± 0.0	26.0 ± 0.0
May-15	21.6 ± 0.0	22.0 ± 0.0	22.1 ± 0.0	22.4 ± 0.0	22.3 ± 0.0	22.5 ± 0.0	22.5 ± 0.0	21.9 ± 0.0	21.9 ± 0.0	22.8 ± 0.0	22.6 ± 0.0	23.0 ± 0.0	22.8 ± 0.0
Jun-15	20.1 ± 0.0	20.3 ± 0.0	20.3 ± 0.0	20.6 ± 0.0	20.6 ± 0.0	20.6 ± 0.0	20.6 ± 0.0	20.2 ± 0.0	20.2 ± 0.0	21.0 ± 0.0	20.8 ± 0.0	21.1 ± 0.0	21.0 ± 0.0

Table note: Values are means ± se (n ≤ 2,966)

Table 6.7 Mean monthly pH values across monitoring sites

	pH												
Month	QE3	P2B/WB50	P5/MH10	CD1		CD2		CD3		CD4		CD5	
	Surface	Surface	Surface	Surface	Benthic	Surface	Benthic	Surface	Benthic	Surface	Benthic	Surface	Benthic
Jun-14	-	8.1 ± 0.0	8.1 ± 0.0	8.2 ± 0.0	8.2 ± 0.0	8.2 ± 0.0	8.2 ± 0.0	8.3 ± 0.0	8.1 ± 0.0	8.3 ± 0.0	8.2 ± 0.0	8.2 ± 0.0	8.2 ± 0.0
Jul-14	-	8.0 ± 0.0	8.2 ± 0.0	8.3 ± 0.0	8.0 ± 0.0	8.4 ± 0.0	8.3 ± 0.0	8.1 ± 0.0	8.2 ± 0.0	8.2 ± 0.0	8.2 ± 0.0	8.2 ± 0.0	8.3 ± 0.0
Aug-14	-	8.1 ± 0.0	8.1 ± 0.0	8.3 ± 0.0	8.3 ± 0.0	8.2 ± 0.0	8.1 ± 0.0	8.1 ± 0.0	8.2 ± 0.0	8.3 ± 0.0	8.2 ± 0.0	8.2 ± 0.0	8.3 ± 0.0
Sep-14	-	8.1 ± 0.0	8.2 ± 0.0	8.2 ± 0.0	8.2 ± 0.0	8.1 ± 0.0	8.2 ± 0.0	8.2 ± 0.0	8.2 ± 0.0	8.2 ± 0.0	8.2 ± 0.0	8.1 ± 0.0	8.2 ± 0.0
Oct-14	-	8.0 ± 0.0	8.2 ± 0.0	8.2 ± 0.0	8.1 ± 0.0	8.2 ± 0.0	8.2 ± 0.0	8.2 ± 0.0	8.2 ± 0.0	8.3 ± 0.0	8.2 ± 0.0	8.3 ± 0.0	8.1 ± 0.0
Nov-14	-	8.1 ± 0.0	8.1 ± 0.0	8.1 ± 0.0	8.1 ± 0.0	8.1 ± 0.0	8.1 ± 0.0	8.2 ± 0.0	8.1 ± 0.0	8.3 ± 0.0	8.1 ± 0.0	8.2 ± 0.0	8.1 ± 0.0
Dec-14	-	8.0 ± 0.0	8.1 ± 0.0	8.1 ± 0.0	8.2 ± 0.0	8.2 ± 0.0	8.1 ± 0.0	8.1 ± 0.0	8.1 ± 0.0	8.2 ± 0.0	8.1 ± 0.0	8.2 ± 0.0	8.1 ± 0.0
Jan-15	7.7 ± 0.0	7.9 ± 0.0	8.1 ± 0.0	8.1 ± 0.0	8.1 ± 0.0	8.1 ± 0.0	8.2 ± 0.0	8.1 ± 0.0	8.2 ± 0.0	8.1 ± 0.0	8.2 ± 0.0	8.2 ± 0.0	8.1 ± 0.0
Feb-15	7.8 ± 0.0	8.0 ± 0.0	8.0 ± 0.0	8.2 ± 0.0	8.2 ± 0.0	8.2 ± 0.0	8.2 ± 0.0	8.1 ± 0.0	8.1 ± 0.0	8.3 ± 0.0	8.2 ± 0.0	8.2 ± 0.0	8.1 ± 0.0
Mar-15	7.8 ± 0.0	8.0 ± 0.0	8.1 ± 0.0	8.2 ± 0.0	8.2 ± 0.0	8.3 ± 0.0	8.2 ± 0.0	8.1 ± 0.0	7.9 ± 0.0	8.2 ± 0.0	8.3 ± 0.0	8.1 ± 0.0	8.1 ± 0.0
Apr-15	7.8 ± 0.0	8.0 ± 0.0	8.1 ± 0.0	8.3 ± 0.0	8.2 ± 0.0	8.3 ± 0.0	8.2 ± 0.0	8.2 ± 0.0	8.1 ± 0.0	8.2 ± 0.0	8.2 ± 0.0	8.2 ± 0.0	8.2 ± 0.0
May-15	8.0 ± 0.0	8.0 ± 0.0	8.1 ± 0.0	8.1 ± 0.0	8.1 ± 0.0	8.3 ± 0.0	8.2 ± 0.0	8.2 ± 0.0	8.2 ± 0.0	8.3 ± 0.0	8.2 ± 0.0	8.3 ± 0.0	8.2 ± 0.0
Jun-15	8.0 ± 0.0	8.0 ± 0.0	8.1 ± 0.0	8.2 ± 0.0	8.1 ± 0.0	8.2 ± 0.0	8.2 ± 0.0	8.1 ± 0.0	8.2 ± 0.0	8.1 ± 0.0	8.2 ± 0.0	8.2 ± 0.0	8.2 ± 0.0

Table 6.8 Mean monthly conductivity values across monitoring sites

Month	Conductivity (mS/cm)												
	QE3	P2B/WB50	P5/MH10	CD1		CD2		CD3		CD4		CD5	
	Surface	Surface	Surface	Surface	Benthic	Surface	Benthic	Surface	Benthic	Surface	Benthic	Surface	Benthic
Jun-14	-	51.3 ± 0.0	53.8 ± 0.0	54.0 ± 0.0	53.9 ± 0.0	52.6 ± 0.0	54.3 ± 0.0	54.5 ± 0.0	54.6 ± 0.0	53.9 ± 0.0	52.2 ± 0.0	53.6 ± 0.0	54.1 ± 0.0
Jul-14	-	54.8 ± 0.0	54.6 ± 0.0	52.8 ± 0.0	55.0 ± 0.0	52.9 ± 0.0	54.8 ± 0.0	51.5 ± 0.0	53.6 ± 0.0	54.1 ± 0.0	52.9 ± 0.0	53.1 ± 0.0	53.9 ± 0.0
Aug-14	-	52.8 ± 0.0	54.0 ± 0.0	53.8 ± 0.0	54.3 ± 0.0	53.7 ± 0.0	52.0 ± 0.0	52.3 ± 0.0	52.8 ± 0.0	53.1 ± 0.0	51.9 ± 0.0	51.5 ± 0.0	52.7 ± 0.0
Sep-14	-	54.5 ± 0.0	53.4 ± 0.0	53.1 ± 0.0	52.5 ± 0.0	53.2 ± 0.0	53.0 ± 0.0	51.3 ± 0.0	54.5 ± 0.0	52.6 ± 0.0	53.1 ± 0.0	52.6 ± 0.0	52.6 ± 0.0
Oct-14	-	53.6 ± 0.0	53.6 ± 0.0	53.3 ± 0.0	53.4 ± 0.0	54.2 ± 0.0	54.2 ± 0.0	53.6 ± 0.0	53.9 ± 0.0	54.1 ± 0.0	53.3 ± 0.0	54.5 ± 0.0	53.5 ± 0.0
Nov-14	-	56.4 ± 0.0	55.9 ± 0.0	55.1 ± 0.0	54.6 ± 0.0	55.3 ± 0.0	55.5 ± 0.0	55.3 ± 0.0	54.2 ± 0.0	54.1 ± 0.0	55.0 ± 0.0	54.5 ± 0.0	55.0 ± 0.0
Dec-14	-	54.4 ± 0.0	56.0 ± 0.0	54.2 ± 0.0	55.8 ± 0.0	54.0 ± 0.0	56.2 ± 0.0	55.6 ± 0.0	53.8 ± 0.0	54.0 ± 0.0	54.4 ± 0.0	54.5 ± 0.0	54.9 ± 0.0
Jan-15	48.2 ± 0.0	48.9 ± 0.0	53.4 ± 0.0	55.7 ± 0.0	54.6 ± 0.0	54.2 ± 0.0	53.9 ± 0.0	49.7 ± 0.0	55.2 ± 0.0	54.1 ± 0.0	55.1 ± 0.0	54.7 ± 0.0	54.2 ± 0.0
Feb-15	37.8 ± 0.1	42.1 ± 0.1	48.0 ± 0.0	53.3 ± 0.0	54.5 ± 0.0	51.0 ± 0.0	54.8 ± 0.0	42.0 ± 0.2	51.5 ± 0.0	53.8 ± 0.0	54.5 ± 0.0	55.2 ± 0.0	55.4 ± 0.0
Mar-15	43.3 ± 0.1	45.5 ± 0.1	49.1 ± 0.0	54.2 ± 0.0	53.7 ± 0.0	52.1 ± 0.0	52.2 ± 0.0	49.6 ± 0.1	51.7 ± 0.0	52.5 ± 0.0	53.4 ± 0.0	52.6 ± 0.0	53.7 ± 0.0
Apr-15	51.5 ± 0.0	49.4 ± 0.1	51.5 ± 0.0	53.1 ± 0.0	51.6 ± 0.0	52.3 ± 0.0	52.9 ± 0.0	51.9 ± 0.1	50.6 ± 0.0	52.7 ± 0.0	52.6 ± 0.0	52.1 ± 0.0	53.3 ± 0.0
May-15	50.2 ± 0.0	51.6 ± 0.0	51.6 ± 0.0	51.6 ± 0.0	54.1 ± 0.0	53.9 ± 0.0	53.1 ± 0.0	51.7 ± 0.0	54.4 ± 0.0	53.0 ± 0.0	52.8 ± 0.0	51.5 ± 0.0	52.9 ± 0.0
Jun-15	52.6 ± 0.0	53.6 ± 0.0	53.5 ± 0.0	53.0 ± 0.0	54.0 ± 0.0	53.0 ± 0.0	52.3 ± 0.0	52.5 ± 0.0	53.3 ± 0.0	53.3 ± 0.0	53.6 ± 0.0	55.1 ± 0.0	51.9 ± 0.0

Table note: Values are means ± se (n ≤ 2,966)

Table 6.9 Mean monthly dissolved oxygen values across monitoring sites

	Dissolved oxygen (% saturation)												
Month	QE3	P2B/WB50	P5/MH10	CD1		CD2		CD3		CD4		CD5	
	Surface	Surface	Surface	Surface	Benthic	Surface	Benthic	Surface	Benthic	Surface	Benthic	Surface	Benthic
Jun-14	-	95 ± 0	99 ± 0	98 ± 0	99 ± 0	99 ± 0	98 ± 0	98 ± 0	98 ± 0	99 ± 0	98 ± 0	99 ± 0	98 ± 0
Jul-14	-	94 ± 0	99 ± 0	100 ± 0	101 ± 0	100 ± 0	100 ± 0	99 ± 0	99 ± 0	99 ± 0	98 ± 0	100 ± 0	99 ± 0
Aug-14	-	98 ± 0	100 ± 0	100 ± 0	101 ± 0	101 ± 0	100 ± 0	99 ± 0	99 ± 0	101 ± 0	100 ± 0	101 ± 0	99 ± 0
Sep-14	-	97 ± 0	102 ± 0	102 ± 0	101 ± 0	102 ± 0	101 ± 0	101 ± 0	100 ± 0	101 ± 0	100 ± 0	102 ± 0	101 ± 0
Oct-14	-	98 ± 0	101 ± 0	102 ± 0	102 ± 0	102 ± 0	102 ± 0	101 ± 0	101 ± 0	102 ± 0	102 ± 0	103 ± 0	102 ± 0
Nov-14	-	97 ± 0	101 ± 0	102 ± 0	102 ± 0	101 ± 0	101 ± 0	101 ± 0	101 ± 0	102 ± 0	101 ± 0	101 ± 0	101 ± 0
Dec-14	-	96 ± 0	100 ± 0	101 ± 0	98 ± 0	101 ± 0	101 ± 0	101 ± 0	100 ± 0	101 ± 0	100 ± 0	102 ± 0	101 ± 0
Jan-15	87 ± 0	94 ± 0	100 ± 0	100 ± 0	99 ± 0	101 ± 0	101 ± 0	100 ± 0	99 ± 0	102 ± 0	99 ± 0	102 ± 0	99 ± 0
Feb-15	88 ± 0	95 ± 0	100 ± 0	101 ± 0	99 ± 0	101 ± 0	103 ± 0	101 ± 0	97 ± 0	101 ± 0	99 ± 0	102 ± 0	98 ± 0
Mar-15	85 ± 0	95 ± 0	100 ± 0	101 ± 0	98 ± 0	101 ± 0	100 ± 0	99 ± 0	98 ± 0	101 ± 0	100 ± 0	102 ± 0	99 ± 0
Apr-15	91 ± 0	95 ± 0	101 ± 0	100 ± 0	97 ± 0	99 ± 0	100 ± 0	99 ± 0	100 ± 0	99 ± 0	99 ± 0	101 ± 0	98 ± 0
May-15	93 ± 0	97 ± 0	99 ± 0	99 ± 0	99 ± 0	100 ± 0	99 ± 0	100 ± 0	100 ± 0	100 ± 0	99 ± 0	102 ± 0	99 ± 0
Jun-15	92 ± 0	96 ± 0	100 ± 0	99 ± 0	99 ± 0	99 ± 0	99 ± 0	99 ± 0	100 ± 0	100 ± 0	99 ± 0	99 ± 0	99 ± 0

Table note: Values are means ± se (n ≤ 2,966)

Table 6.10 Monthly depth-profiling data across monitoring sites

Site	Sample Date	Turbidity (NTU)	Temperature (°C)	pH	Conductivity (mS/cm)	DO (% saturation)	Light Attenuation (Kd)
P2B/WB50	06/06/2014	2.4 ± 0.0	22.6 ± 0.0	8.0 ± 0.0	54.0 ± 0.0	96 ± 0	0.8
P5/MH10	06/06/2014	2.7 ± 0.1	22.1 ± 0.0	8.1 ± 0.0	54.4 ± 0.0	98 ± 0	1.5
CD1	06/06/2014	1.0 ± 0.0	22.8 ± 0.0	8.2 ± 0.0	54.0 ± 0.1	100 ± 0	0.2
CD2	06/06/2014	1.5 ± 0.0	22.7 ± 0.0	8.2 ± 0.0	54.3 ± 0.0	100 ± 0	0.5
CD3	06/06/2014	2.6 ± 0.4	22.6 ± 0.0	8.1 ± 0.0	54.4 ± 0.0	99 ± 0	0.4
CD4	06/06/2014	<1	22.9 ± 0.0	8.2 ± 0.0	54.5 ± 0.0	100 ± 0	0.2
CD5	06/06/2014	<1	23.0 ± 0.0	8.2 ± 0.0	54.2 ± 0.1	100 ± 0	0.2
P2B/WB50	7/08/2014	2.1 ± 0.0	17.7 ± 0.0	8.0 ± 0.0	51.6 ± 0.0	99 ± 0	0.6
P5/MH10	7/08/2014	4.1 ± 0.0	18.3 ± 0.0	7.9 ± 0.0	51.5 ± 0.0	97 ± 0	0.7
CD1	7/08/2014	<1	19.2 ± 0.0	8.1 ± 0.0	51.7 ± 0.0	100 ± 0	0.2
CD2	7/08/2014	1.4 ± 0.0	18.8 ± 0.0	8.0 ± 0.0	51.6 ± 0.0	100 ± 0	0.3
CD3	7/08/2014	1.5 ± 0.0	17.9 ± 0.0	8.0 ± 0.0	51.8 ± 0.0	99 ± 0	0.3
CD4	7/08/2014	<1	19.8 ± 0.0	8.1 ± 0.0	51.6 ± 0.0	100 ± 0	0.1
CD5	7/08/2014	1.0 ± 0.0	19.7 ± 0.0	8.1 ± 0.0	51.6 ± 0.0	100 ± 0	0.2
P2B/WB50	08/11/2014	21 ± 0	19.3 ± 0.0	7.9 ± 0.0	56.1 ± 0.0	97 ± 0	2.5
P5/MH10	08/11/2014	1.5 ± 0.0	19.6 ± 0.0	8.1 ± 0.0	55.3 ± 0.0	99 ± 0	0.3
CD1	08/11/2014	1.8 ± 0.3	19.5 ± 0.0	8.1 ± 0.0	55.3 ± 0.0	100 ± 0	0.4
CD2	08/11/2014	4.2 ± 0.1	19.3 ± 0.0	8.1 ± 0.0	55.5 ± 0.0	100 ± 0	0.8
CD3	08/11/2014	2.6 ± 0.1	19.0 ± 0.0	8.0 ± 0.0	55.8 ± 0.0	100 ± 0	0.7
CD4	08/11/2014	<1	20.0 ± 0.0	8.1 ± 0.0	55.2 ± 0.0	101 ± 0	0.2
CD5	08/11/2014	<1	20.0 ± 0.0	8.1 ± 0.0	55.2 ± 0.0	101 ± 0	0.3
P2B/WB50	11/09/2014	26 ± 0	21.3 ± 0.0	7.8 ± 0.0	56.0 ± 0.0	94 ± 0	3.8
P5/MH10	11/09/2014	3.9 ± 0.1	21.0 ± 0.0	7.9 ± 0.0	55.3 ± 0.0	98 ± 0	0.8
CD1	11/09/2014	1.4 ± 0.1	20.5 ± 0.0	8.0 ± 0.0	53.6 ± 1.2	101 ± 0	0.3
CD2	11/09/2014	2.6 ± 0.2	21.0 ± 0.0	8.0 ± 0.0	54.4 ± 0.6	102 ± 0	0.5

Site	Sample Date	Turbidity (NTU)	Temperature (°C)	pH	Conductivity (mS/cm)	DO (% saturation)	Light Attenuation (Kd)
CD3	11/09/2014	7.5 ± 0.2	20.9 ± 0.0	7.9 ± 0.0	53.6 ± 1.3	101 ± 0	1.1
CD4	11/09/2014	<1	20.4 ± 0.0	8.0 ± 0.0	54.9 ± 0.0	101 ± 0	0.2
CD5	11/09/2014	<1	20.5 ± 0.0	8.0 ± 0.0	54.5 ± 0.3	102 ± 0	0.2
P2B/WB50	01/10/2014	2.0 ± 0.0	23.4 ± 0.0	7.7 ± 0.0	56.6 ± 0.0	97 ± 0	0.7
P5/MH10	01/10/2014	2.4 ± 0.0	22.6 ± 0.0	8.0 ± 0.0	56.4 ± 0.0	99 ± 0	0.7
CD1	01/10/2014	<1	23.0 ± 0.0	8.1 ± 0.0	55.7 ± 0.0	104 ± 0	0.1
CD2	01/10/2014	<1	22.7 ± 0.0	8.1 ± 0.0	55.8 ± 0.0	103 ± 0	0.3
CD3	01/10/2014	1.0 ± 0.0	23.1 ± 0.0	8.1 ± 0.0	56.0 ± 0.0	102 ± 0	0.4
CD4	01/10/2014	<1	22.2 ± 0.0	8.1 ± 0.0	55.7 ± 0.0	103 ± 0	0.2
CD5	01/10/2014	<1	22.1 ± 0.0	8.1 ± 0.0	55.6 ± 0.0	103 ± 0	0.2
P2B/WB50	06/11/2014	14 ± 0	25.5 ± 0.0	7.9 ± 0.0	58.0 ± 0.0	96 ± 0	2.0
P5/MH10	06/11/2014	2.3 ± 0.2	24.9 ± 0.0	8.1 ± 0.0	56.9 ± 0.0	99 ± 0	0.7
CD1	06/11/2014	1.6 ± 0.0	25.1 ± 0.0	8.2 ± 0.0	56.7 ± 0.0	105 ± 0	0.3
CD2	06/11/2014	4.8 ± 0.2	25.0 ± 0.0	8.1 ± 0.0	56.8 ± 0.0	102 ± 0	0.8
CD3	06/11/2014	2.4 ± 0.1	25.6 ± 0.0	8.1 ± 0.0	57.4 ± 0.0	105 ± 0	0.5
CD4	06/11/2014	1.4 ± 0.1	25.0 ± 0.0	8.1 ± 0.0	56.6 ± 0.0	102 ± 0	0.2
CD5	06/11/2014	1.4 ± 0.0	24.9 ± 0.1	8.1 ± 0.0	56.4 ± 0.0	103 ± 0	0.2
P2B/WB50	03/12/2014	4.3 ± 0.2	27.5 ± 0.0	7.9 ± 0.0	60.6 ± 0.0	97 ± 0	1.1
P5/MH10	03/12/2014	4.7 ± 0.0	26.3 ± 0.0	7.9 ± 0.0	59.9 ± 0.0	97 ± 0	1.1
CD1	03/12/2014	<1	26.5 ± 0.0	8.0 ± 0.0	58.6 ± 0.0	99 ± 0	0.3
CD2	03/12/2014	3.6 ± 0.1	27.0 ± 0.0	8.0 ± 0.0	52.0 ± 7.4	100 ± 0	0.8
CD3	03/12/2014	1.7 ± 0.0	26.9 ± 0.1	8.0 ± 0.0	57.6 ± 2.1	102 ± 0	0.6
CD4	03/12/2014	<1	26.6 ± 0.0	8.0 ± 0.0	58.7 ± 0.1	100 ± 0	0.2
CD5	03/12/2014	<1	26.6 ± 0.0	8.0 ± 0.0	58.3 ± 0.0	100 ± 0	0.2
P2B/WB50	05/01/2015	7.5 ± 0.4	29.3 ± 0.0	7.8 ± 0.0	54.9 ± 0.0	96 ± 0	2.2
P5/MH10	05/01/2015	12 ± 0	29.0 ± 0.0	8.0 ± 0.0	56.3 ± 0.0	101 ± 0	1.3
QE3	05/01/2015	8.6 ± 0.5	29.2 ± 0.0	7.7 ± 0.0	53.3 ± 0.0	93 ± 0	2.0

Site	Sample Date	Turbidity (NTU)	Temperature (°C)	pH	Conductivity (mS/cm)	DO (% saturation)	Light Attenuation (Kd)
CD1	05/01/2015	<1	28.6 ± 0.0	8.0 ± 0.0	56.7 ± 0.0	102 ± 0	0.2
CD2	05/01/2015	5.2 ± 0.2	28.9 ± 0.0	8.0 ± 0.0	56.7 ± 0.0	99 ± 0	0.8
CD3	05/01/2015	3.2 ± 0.1	29.0 ± 0.0	8.0 ± 0.0	57.0 ± 0.0	101 ± 0	0.5
CD4	05/01/2015	<1	29.0 ± 0.0	8.1 ± 0.0	56.7 ± 0.0	102 ± 0	0.7
CD5	05/01/2015	<1	28.8 ± 0.0	8.1 ± 0.0	56.5 ± 0.0	102 ± 0	0.3
QE3	02/02/2015	5.5 ± 0.0	25.0 ± 0.0	7.7 ± 0.0	46.2 ± 0.0	86 ± 0	1.2
P2B/WB50	02/02/2015	7.3 ± 0.2	25.3 ± 0.0	8.0 ± 0.0	46.5 ± 0.2	106 ± 1	1.1
P5/MH10	02/02/2015	1.0 ± 0.2	23.4 ± 0.0	7.9 ± 0.0	58.4 ± 0.0	98 ± 0	0.4
CD1	02/02/2015	<1	23.8 ± 0.1	8.1 ± 0.0	58.1 ± 0.1	101 ± 0	0.3
CD2	02/02/2015	<1	23.4 ± 0.0	8.2 ± 0.0	57.5 ± 0.0	104 ± 0	0.3
CD3	02/02/2015	1.7 ± 0.4	24.4 ± 0.0	8.2 ± 0.0	53.3 ± 0.1	108 ± 0	0.6
CD4	02/02/2015	<1	23.2 ± 0.0	8.1 ± 0.0	59.1 ± 0.0	104 ± 0	0.1
CD5	02/02/2015	<1	23.3 ± 0.0	8.2 ± 0.0	58.8 ± 0.0	105 ± 0	0.2
QE3	02/03/2015	16 ± 2	28.8 ± 0.1	7.7 ± 0.0	37.4 ± 0.0	85 ± 1	1.3
P2B/WB50	02/03/2015	10 ± 0	28.1 ± 0.0	8.1 ± 0.0	43.1 ± 0.0	100 ± 0	1.6
P5/MH10	02/03/2015	4.9 ± 0.2	28.0 ± 0.0	8.1 ± 0.0	46.1 ± 0.0	99 ± 0	1.3
CD1	02/03/2015	<1	27.0 ± 0.0	8.2 ± 0.0	54.4 ± 0.0	99 ± 0	0.3
CD2	02/03/2015	<1	27.2 ± 0.0	8.2 ± 0.0	52.0 ± 0.0	99 ± 0	0.3
CD3	02/03/2015	1.8 ± 0.2	27.6 ± 0.0	8.1 ± 0.0	48.9 ± 0.1	97 ± 0	0.8
CD4	02/03/2015	<1	27.5 ± 0.0	8.1 ± 0.0	51.8 ± 0.0	101 ± 0	0.3
CD5	02/03/2015	<1	26.9 ± 0.0	8.2 ± 0.0	52.0 ± 0.0	99 ± 0	0.3
QE3	13/04/2015	2.1 ± 0.0	24.8 ± 0.0	7.8 ± 0.0	49.4 ± 0.0	97 ± 0	0.6
P2B/WB50	13/04/2015	3.1 ± 0.1	25.2 ± 0.0	7.9 ± 0.0	49.6 ± 0.0	98 ± 0	0.8
P5/MH10	13/04/2015	2.5 ± 0.0	24.3 ± 0.0	8.0 ± 0.0	50.6 ± 0.0	100 ± 0	0.7
CD1	13/04/2015	1.4 ± 0.0	24.7 ± 0.0	8.1 ± 0.0	51.5 ± 0.0	100 ± 0	0.4
CD2	13/04/2015	1.3 ± 0.0	24.9 ± 0.0	8.0 ± 0.0	51.6 ± 0.0	101 ± 0	0.4
CD3	13/04/2015	3.0 ± 0.0	24.2 ± 0.0	8.0 ± 0.0	51.1 ± 0.0	99 ± 0	0.6

Site	Sample Date	Turbidity (NTU)	Temperature (°C)	pH	Conductivity (mS/cm)	DO (% saturation)	Light Attenuation (Kd)
CD4	13/04/2015	<1	25.4 ± 0.0	8.1 ± 0.0	52.5 ± 0.0	100 ± 0	0.3
CD5	13/04/2015	<1	25.5 ± 0.0	8.1 ± 0.0	52.4 ± 0.0	100 ± 0	0.2
QE3	05/05/2015	3.5 ± 0.1	22.1 ± 0.0	7.8 ± 0.0	52.5 ± 0.0	95 ± 0	1.1
P2B/WB50	05/05/2015	6.9 ± 0.1	22.3 ± 0.0	7.9 ± 0.0	52.9 ± 0.0	97 ± 0	1.4
P5/MH10	05/05/2015	2.0 ± 0.0	22.2 ± 0.0	8.0 ± 0.0	54.3 ± 0.0	95 ± 0	0.8
CD1	05/05/2015	<1	22.6 ± 0.0	8.1 ± 0.0	55.0 ± 0.0	99 ± 0	0.3
CD2	05/05/2015	<1	22.8 ± 0.0	8.1 ± 0.0	54.8 ± 0.0	100 ± 0	0.4
CD3	05/05/2015	1.6 ± 0.1	22.3 ± 0.0	8.1 ± 0.0	54.4 ± 0.0	101 ± 0	0.8
CD4	05/05/2015	<1	22.6 ± 0.0	8.1 ± 0.0	54.8 ± 0.0	99 ± 0	0.3
CD5	05/05/2015	<1	23.0 ± 0.0	8.1 ± 0.0	54.9 ± 0.0	99 ± 0	0.3
QE3	17/06/2015	12 ± 0	20.7 ± 0.0	7.9 ± 0.0	55.3 ± 0.0	95 ± 0	1.0
P2B/WB50	17/06/2015	27 ± 0	20.7 ± 0.0	8.0 ± 0.0	55.0 ± 0.0	97 ± 0	2.9
P5/MH10	17/06/2015	14 ± 0	20.9 ± 0.0	8.1 ± 0.0	55.1 ± 0.0	101 ± 0	1.8
CD1	17/06/2015	12 ± 0	20.9 ± 0.0	8.2 ± 0.0	54.9 ± 0.0	101 ± 0	0.7
CD2	17/06/2015	10 ± 0	21.1 ± 0.0	8.2 ± 0.0	54.9 ± 0.0	102 ± 0	0.5
CD3	17/06/2015	18 ± 0	20.5 ± 0.0	8.1 ± 0.0	55.3 ± 0.0	100 ± 0	1.7
CD4	17/06/2015	10 ± 0	21.4 ± 0.0	8.2 ± 0.0	54.9 ± 0.0	102 ± 0	0.2
CD5	17/06/2015	10 ± 0	21.2 ± 0.0	8.2 ± 0.0	54.9 ± 0.0	102 ± 0	0.3

Table note: Values are means ± se of sub-surface values (n ≤ 6)

6.3 Sedimentation

Table 6.11 Cumulative bed level change as recorded by altimeter at QE3

Deployment Period	Cumulative bed level change (mm)
16 January to 2 February 2015	12.4
2 to 12 February 2015	39.5
13 to 26 February 2015	17.4
26 February to 8 April 2015	Unit missing upon retrieval
8 April to 24 April 2015	Unit missing upon retrieval
24 April to 5 July 2015	-4.2

Table note: Positive change indicates deposition, while negative change indicates erosion

Table 6.12 Cumulative bed level change as recorded by altimeter at P2B/WB50

Deployment Period	Cumulative bed level change (mm)
6 to 17 June 2014	1.0
17 June to 1 July 2014	10.5
1 to 24 July 2014	-6.3
24 July to 11 August 2014	-14.4
11 August to 10 September 2014	-5.8
10 to 30 September 2014	3.8
30 September to 31 October 2014	-10.1
31 October to 2 December 2014	12.6
2 December 2014 to 12 January 2015	2.9
12 January to 26 February 2015	-2.7
26 February to 8 April 2015	-13.2
8 April to 28 April 2015	1.0
28 April to 5 July 2015	50.5

Table note: Positive change indicates deposition, while negative change indicates erosion

Table 6.13 Cumulative bed level change as recorded by altimeter at P5/MH10

Deployment Period	Cumulative bed level change (mm)
6 to 17 June 2014	23.2
17 June to 1 July 2014	5.7
1 to 24 July 2014	12.3
24 July to 11 August 2014	-3.0
11 August to 10 September 2014	0.5
10 to 30 September 2014	-2.0
30 September to 31 October 2014	8.8
31 October to 3 December 2014	-3.0
3 December 2014 to 12 January 2015	-15.8
12 January to 26 February 2015	-21.1
26 February to 8 April 2015	4.1
8 April to 28 April 2015	-4.1
28 April to 5 July 2015	-11.6

Table note: Positive change indicates deposition, while negative change indicates erosion

Table 6.14 Cumulative bed level change as recorded by altimeter at CD1

Deployment Period	Cumulative bed level change (mm)
27 May to 14 June 2014	5.5
14 June to 1 July 2014	14.4
1 to 24 July 2014	18.9
24 July to 11 August 2014	-1.2
11 August to 10 September 2014	6.8
30 September to 8 October 2014	-3.6
8 to 31 October 2014	5.5
31 October to 2 December 2014	-4.5
2 December 2014 to 12 January 2015	-5.2
28 March to 28 April 2015	-12.8
28 April to 5 July 2015	-11.9

Table note: Positive change indicates deposition, while negative change indicates erosion

Table 6.15 Cumulative bed level change as recorded by altimeter at CD2

Deployment Period	Cumulative bed level change (mm)
27 May to 13 June 2014	65.2
13 June to 1 July 2014	-10.6
1 to 24 July 2014	-13.5
24 July to 12 August 2014	-30.5
12 August to 10 September 2014	16.4
10 to 30 September 2014	-10.2
30 September to 31 October 2014	-3.9
31 October to 2 December 2014	22.8
12 January to 28 March 2015	-18.8
28 March to 28 April 2015	-63.1
28 April to 5 July 2015	-40.7

Table note: Positive change indicates deposition, while negative change indicates erosion

Table 6.16 Cumulative bed level change as recorded by altimeter at CD3

Deployment Period	Cumulative bed level change (mm)
5 to 13 June 2014	48.8
13 June to 1 July 2014	5.5
1 to 24 July 2014	11.9
24 July to 11 August 2014	-4.0
11 August to 10 September 2014	-0.3
10 to 30 September 2014	16.3
30 September to 31 October 2014	1.5
31 October to 2 December 2014	4.1
2 December 2014 to 12 January 2015	12.0
12 January to 28 March 2015	27.5
28 March to 28 April 2015	1.9
28 April to 5 July 2015	4.1

Table note: Positive change indicates deposition, while negative change indicates erosion

Table 6.17 Cumulative bed level change as recorded by altimeter at CD4

Deployment Period	Cumulative bed level change (mm)
27 May to 13 June 2014	-12.1
13 June to 1 July 2014	1.5
1 to 24 July 2014	23.5
24 July to 11 August 2014	-9.7
11 August to 10 September 2014	-2.3
10 to 30 September 2014	-3.7
30 September to 31 October 2014	-6.9
31 October to 2 December 2014	9.4
2 December 2014 to 12 January 2015	3.0
12 January to 25 March 2015	-20.0
28 April to 5 July 2015	5.9

Table note: Positive change indicates deposition, while negative change indicates erosion

Table 6.18 Cumulative bed level change as recorded by altimeter at CD5

Deployment Period	Cumulative bed level change (mm)
27 May to 13 June 2014	16.0
13 June to 1 July 2014	19.5
1 to 24 July 2014	33.3
24 July to 11 August 2014	-1.9
11 August to 10 September 2014	9.8
10 to 30 September 2014	-3.2
30 September to 31 October 2014	-5.0
31 October to 2 December 2014	-0.3
2 December 2014 to 10 January 2015	-2.4
10 January to 27 February 2015	-0.04
27 February to 8 April 2015	-5.4
8 to 28 April 2015	6.4
28 April to 5 July 2015	-11.7

Table note: Positive change indicates deposition, while negative change indicates erosion

6.4 Benthic Photosynthetically Active Radiation

Table 6.19 Mean monthly total daily PAR at monitoring sites

Month	Mean monthly total daily PAR (mol/m ² /day)					
	VB	CD1	CD2	CD3	CD4	CD5
June 2014	29.2	2.4	1.4	0.1	0.8	1.0
July 2014	33.6	4.8	2.8	0.3	2.1	2.2
August 2014	37.6	2.3	1.5	0.7	0.8	1.3
September 2014	45.6	4.2	*2.4	2.8	*1.0	2.1
October 2014	55.2	3.0	1.2	*1.8	*1.5	*1.8
November 2014	56.9	2.8	2.4	1.5	*1.9	0.4
December 2014	55.8	2.3	*1.1	0.9	*1.4	1.3
January 2015	50.8	0.7	0.7	0.4	0.6	0.6
February 2015	51.2	0.2	0.2	0.1	0.0	0.0
March 2015	50.7	1.2	0.4*	0.3	0.4*	*
April 2015	41.2	1.0	0.6	0.5	0.4	0.4
May 2015	35.9	1.2	0.8	0.8	0.5	0.4
June – July 04 th 2015	29.0	0.6	0.4	0.3	0.3	0.4

Table note: *Values represent a portion of the month due to instrument malfunction

6.5 Water sampling

Table 6.20 Total Suspended Solids concentrations at monitoring sites

Sample Date	Depth	QE3	P2B/WB50	P5/MH10	CD1	CD2	CD3	CD4	CD5
6/06/2014	Surface	-	2	2	<2	<2	2	<2	<2
	Mid	-	-	-	3	<2	3	<2	<2
	Benthic	-	-	-	2	<2	4	<2	<2
8/07/2014	Surface	-	4	<2	<2	<2	2	<2	<2
	Mid	-	-	-	3	3	3	<2	2
	Benthic	-	-	-	<2	<2	<2	<2	<2
11/08/2014	Surface	-	27	<2	<2	3	2	<2	<2
	Mid	-	-	-	5	3	5	<2	<2
	Benthic	-	-	-	<2	6	8	<2	<2
11/09/2014	Surface	-	23	2	<2	2	13	<2	<2
	Mid	-	-	-	<2	2	10	<2	<2
	Benthic	-	-	-	<2	3	4	<2	<2
1/10/2014	Surface	-	<2	<2	<2	<2	<2	<2	<2
	Mid	-	-	-	<2	2	<2	<2	<2
	Benthic	-	-	-	2	<2	<2	<2	<2
6/11/2014	Surface	-	16	<2	2	5	2	2	<2
	Mid	-	-	-	2	10	3	<2	<2
	Benthic	-	-	-	9	10	8	9	3
3/12/2014	Surface	-	5	6	<2	<2	<2	<2	4
	Mid	-	-	-	2	4	5	<2	5
	Benthic	-	-	-	5	4	5	3	4
5/01/2015	Surface	9	6	16	<2	3	5	<2	<2
	Middle	-	-	-	<2	2	5	<2	<2
	Benthic	-	-	-	6	25	32	8	3
2/02/2015	Surface	5	10	3	3	2	3	<2	2
	Middle	-	-	-	2	<2	<2	2	3
	Benthic	-	-	-	<2	<2	24	<2	<2
2/03/2015	Surface	16	12	4	<2	2	4	<2	<2
	Middle	-	-	-	<2	<2	8	<2	<2
	Benthic	-	-	-	<2	7	11	4	<2
13/04/2015	Surface	4	<2	6	<2	2	7	<2	2
	Middle	-	-	-	<2	<2	4	<2	<2
	Benthic	-	-	-	6	2	5	<2	7
5/05/2015	Surface	10	9	15	<2	<2	2	<2	<2
	Middle	-	-	-	<2	5	10	<2	3
	Benthic	-	-	-	8	7	9	<2	10
17/06/2015	Surface	4	44	12	8	3	31	3	4
	Middle	-	-	-	4	6	24	3	<2
	Benthic	-	-	-	5	5	25	3	2

Table note: N = 1

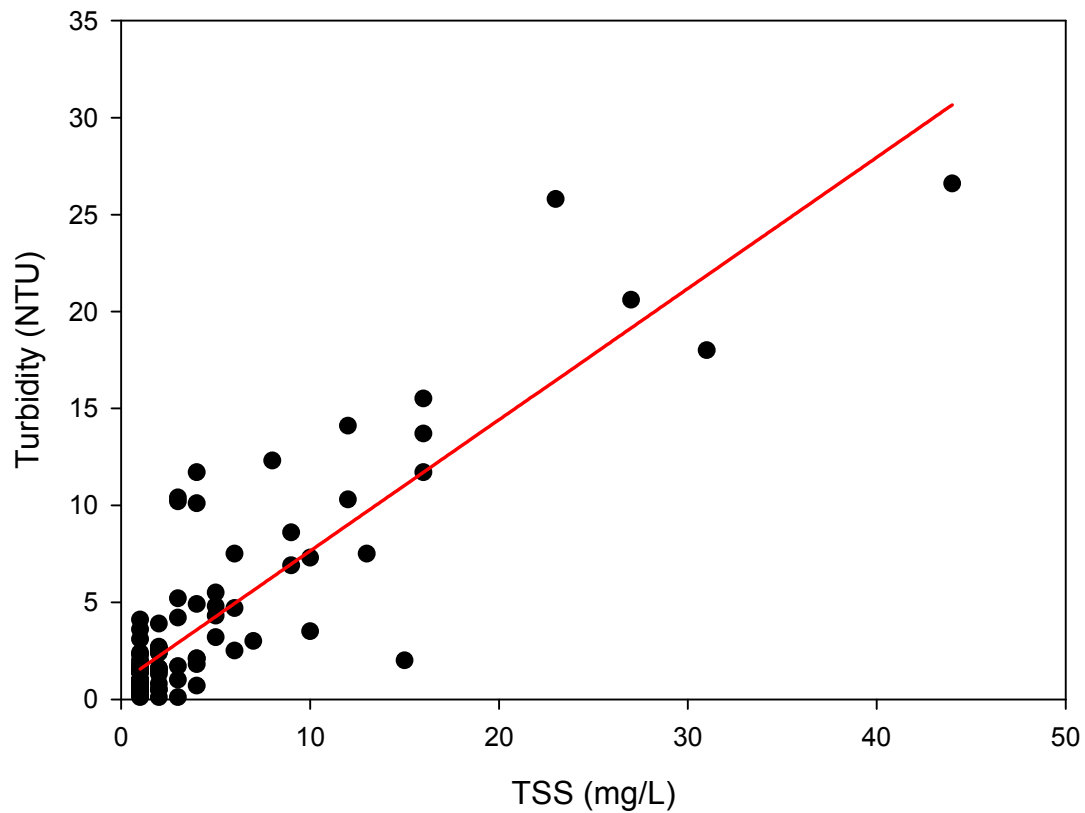


Figure 6.4 Linear regression relationship between TSS and turbidity

Figure note: N = 96, $R^2 = 0.87$, $p < 0.001$. Samples from across all monitoring sites and sample occasions.

Table 6.21 Chlorophyll a concentrations at monitoring sites

Sample Date	Chlorophyll a (µg/L)							
	QE3	P2B/WB50	P5/MH10	CD1	CD2	CD3	CD4	CD5
6/06/2014	-	0.6	0.7	0.3	0.3	0.6	0.3	0.2
8/07/2014	-	0.7	0.3	0.2	0.3	0.3	<0.1	<0.1
11/08/2014	-	0.4	0.2	0.5	0.6	1.5	0.1	<0.1
11/09/2014	-	0.5	0.2	<0.1	<0.1	0.2	<0.1	<0.1
1/10/2014	-	0.3	0.6	0.2	0.3	0.2	0.1	0.1
6/11/2014	-	1.1	0.8	0.5	0.9	1.2	1.7	0.9
3/12/2014	-	1.1	0.9	<0.2	0.6	<0.2	<0.2	<0.2
5/01/2015	2.1	1.7	0.9	<0.2	0.6	0.4	0.7	0.3
2/02/2015	3.3	5.3	0.5	0.3	0.5	0.7	0.2	0.2
2/03/2015	4.3	3.9	1.7	0.5	<0.2	0.8	0.9	0.7
13/04/2015	0.7	1.1	0.5	0.3	0.3	0.6	0.4	<0.2
5/05/2015	1.4	2.5	0.7	0.5	0.4	0.4	0.3	<0.2
17/06/2015	<2	<2	<2	<2	<2	<2	<2	<2

Table 6.22 Total Phosphorus concentrations at monitoring sites

Sample Date	Total Phosphorus (µg/L)							
	QE3	P2B/WB50	P5/MH10	CD1	CD2	CD3	CD4	CD5
6/06/2014	-	15	15	10	10	11	10	9
8/07/2014	-	14	13	9	9	9	8	9
11/08/2014	-	43	11	11	15	14	10	10
11/09/2014	-	56	15	11	11	23	11	11
1/10/2014	-	14	15	10	11	10	11	12
6/11/2014	-	31	11	12	18	16	11	12
3/12/2014	-	17	19	11	18	12	10	9
5/01/2015	29	26	28	11	16	13	12	10
2/02/2015	27	31	13	11	11	12	11	10
2/03/2015	38	33	21	10	12	16	13	11
13/04/2015	16	17	15	13	12	14	10	10
5/05/2015	18	24	16	11	12	12	11	9
17/06/2015	15	42	18	12	7	25	5	9

Table note: N = 1

Table 6.23 Orthophosphate concentrations at monitoring sites

Sample Date	Orthophosphate (µg/L)							
	QE3	P2B/WB50	P5/MH10	CD1	CD2	CD3	CD4	CD5
6/06/2014	-	3	3	<2	<2	<2	<2	<2
8/07/2014	-	3	<2	<2	<2	<2	<2	2
11/08/2014	-	3	<2	<2	2	<2	<2	<2
11/09/2014	-	4	3	<2	<2	3	2	<2
1/10/2014	-	<2	<2	<2	<2	<2	<2	<2
6/11/2014	-	4	<2	<2	<2	<2	<2	<2
3/12/2014	-	<2	<2	<2	<2	<2	<2	<2
5/01/2015	2	2	<2	<2	<2	<2	<2	<2
2/02/2015	<2	2	<2	<2	<2	<2	<2	<2
2/03/2015	4	4	4	3	3	3	3	2
13/04/2015	2	3	<2	<2	<2	<2	<2	<2
5/05/2015	<2	2	<2	<2	<2	<2	<2	<2
17/06/2015	3	3	2	<2	2	<2	<2	<2

Table note: N = 1

Table 6.24 Total Nitrogen concentrations at monitoring sites

Sample Date	Total Nitrogen (µg/L)							
	QE3	P2B/WB50	P5/MH10	CD1	CD2	CD3	CD4	CD5
6/06/2014	-	130	120	80	80	100	100	90
8/07/2014	-	110	100	70	90	90	80	80
11/08/2014	-	160	80	80	100	110	70	70
11/09/2014	-	200	110	90	90	120	90	90
1/10/2014	-	120	100	100	90	100	90	80
6/11/2014	-	160	110	120	130	150	110	150
3/12/2014	-	160	150	120	140	120	90	100
5/01/2015	210	190	180	100	120	110	160	120
2/02/2015	230	240	130	110	110	140	110	100
2/03/2015	270	210	160	100	120	150	150	120
13/04/2015	140	140	130	100	110	130	100	100
5/05/2015	170	190	140	120	110	120	120	110
17/06/2015	90	170	90	70	60	130	<50	70

Table note: N = 1

Table 6.25 Ammonia concentrations at monitoring sites

Sample Date	Ammonia (µg/L)							
	QE3	P2B/WB50	P5/MH10	CD1	CD2	CD3	CD4	CD5
6/06/2014	-	4	5	<3	<3	<3	<3	<3
8/07/2014	-	3	<3	<3	8	<3	<3	11
11/08/2014	-	<3	<3	<3	<3	<3	<3	<3
11/09/2014	-	5	<3	<3	4	<3	<3	<3
1/10/2014	-	12	5	8	<3	4	12	17
6/11/2014	-	7	<3	<3	<3	<3	5	<3
3/12/2014	-	<3	<3	<3	<3	<3	<3	<3
5/01/2015	<3	4	<3	<3	<3	<3	<3	<3
2/02/2015	7	3	<3	<3	<3	3	3	<3
2/03/2015	7	3	<3	<3	<3	3	<3	<3
13/04/2015	6	4	3	<3	<3	<3	7	<3
5/05/2015	4	4	4	<3	4	<3	7	<3
17/06/2015	<3	12	3	<3	<3	<3	<3	<3

Table note: N = 1

Table 6.26 NOx concentrations at monitoring sites

Sample Date	NOx (µg/L)							
	QE3	P2B/WB50	P5/MH10	CD1	CD2	CD3	CD4	CD5
6/06/2014	-	3	<2	<2	<2	<2	<2	<2
8/07/2014	-	3	<2	<2	10	3	25	58
11/08/2014	-	3	2	<2	<2	<2	<2	3
11/09/2014	-	7	3	3	<2	2	3	2
1/10/2014	-	6	<2	6	<2	3	19	11
6/11/2014	-	10	3	13	2	6	6	<2
3/12/2014	-	5	3	10	3	5	<2	2
5/01/2015	2	6	2	3	3	<2	<2	<2
2/02/2015	6	3	2	5	2	2	<2	12
2/03/2015	4	<2	<2	3	34	<2	9	<2
13/04/2015	20	3	<2	<2	<2	<2	12	<2
5/05/2015	<2	3	<2	<2	<2	<2	<2	<2
17/06/2015	7	9	5	6	4	5	3	<2

Table note: N = 1

Table 6.27 Nitrite concentrations at monitoring sites

Sample Date	NOx (µg/L)							
	QE3	P2B/WB50	P5/MH10	CD1	CD2	CD3	CD4	CD5
8/07/2014	-	<2	<2	<2	<2	<2	<2	<2
11/08/2014	-	<2	<2	<2	<2	<2	<2	<2
11/09/2014	-	<2	<2	<2	<2	<2	<2	<2
1/10/2014	-	<2	<2	<2	<2	<2	<2	<2
6/11/2014	-	<2	<2	<2	<2	<2	<2	<2
3/12/2014	-	2	<2	<2	<2	<2	<2	<2
5/01/2015	<2	<2	<2	<2	<2	<2	<2	<2
2/02/2015	<2	<2	<2	<2	<2	<2	<2	<2
2/03/2015	<2	<2	<2	<2	<2	<2	<2	<2
13/04/2015	<2	<2	<2	<2	<2	<2	<2	<2
5/05/2015	<2	2	<2	<2	<2	<2	<2	<2
17/06/2015	<2	<2	<2	<2	<2	<2	<2	12

Table note: N = 1

Table 6.28 Total and dissolved aluminium concentrations at monitoring sites

Sample Date	QE3		P2B/WB50		P5/MH10		CD1		CD2		CD3		CD4		CD5	
	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total
6/06/2014			<10	150	<10	190	<10	20	<10	57	<10	66	<10	<10	<10	<10
8/07/2014			<5	220	<5	110	<5	<10	<5	79	<5	40	<5	<10	<5	<10
11/08/2014			<5	2000	<5	100	<5	56	<5	390	<5	210	<5	24	<5	37
11/09/2014			9.8	2300	10	310	7.4	67	6.6	99	8.1	500	5.5	27	5.2	13
1/10/2014			8.5	46	<5	110	<5	8.6	<5	22	<5	35	<5	7.8	<5	7.7
6/11/2014			<5	1200	<5	100	<5	30	<5	240	<5	100	<5	35	<5	22
3/12/2014			8.3	350	7	400	<5	42	5.3	260	<5	110	<5	23	<5	30
5/01/2015	6	530	8.2	1200	8	850	6.5	40	7.9	280	15	250	7.9	22	6.1	15
2/02/2015	<5	530	6.3	750	8.6	110	<5	40	<5	80	<5	100	<5	24	<5	9.2
2/03/2015	6	1100	13	860	7.5	500	12	52	<5	56	<5	180	<5	45	7.5	62
13/04/2015	<5	220	<5	360	<5	190	<5	79	<5	96	<5	230	<5	37	<5	36
5/05/2015	<5	310	6.3	800	<5	290	5.1	54	<5	78	5.5	120	<5	61	<5	37
17/06/2015	<5	440	<5	2100	<5	580	<5	330	<5	110	<5	810	<5	40	<5	33

Table note: N = 1

Table 6.29 Total and dissolved arsenic concentrations at monitoring sites

Sample Date	QE3		P2B/WB50		P5/MH10		CD1		CD2		CD3		CD4		CD5	
	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total
6/06/2014			1	1.4	1.2	1.4	1.3	1.5	1.3	1.6	1.1	1.7	1.3	1.7	1.4	1.8
8/07/2014			0.92	1.6	1	1.7	1.4	2.1	1.2	1.8	1.2	1.8	1.5	2.1	1.5	2.2
11/08/2014			0.68	1.8	1	1.6	1.2	1.8	1.1	1.6	1	1.5	1.3	2	1.4	1.9
11/09/2014			0.53	1.7	0.75	1.2	0.87	1.4	0.9	1.5	0.77	1.6	1	1.5	1	1.6
1/10/2014			0.68	0.75	0.78	0.86	0.85	0.9	1.1	1	1	0.95	1.1	1.1	1.1	1.1
6/11/2014			0.78	1.2	1	1.3	0.98	1.1	0.97	1.1	1	1.1	0.97	1.2	0.89	4.2
3/12/2014			0.95	1.2	1	1.2	1	1.2	1.1	1.3	1.1	1.3	1.2	1.4	1.3	1.4
5/01/2015	1	1.4	1.1	1.4	1.3	1.5	1.1	1.2	1.2	1.4	1.3	1.7	1.3	1.8	1.4	2
2/02/2015	0.58	0.78	0.78	1	1	0.94	0.91	0.96	0.98	1	0.99	1.1	0.96	1	1	1.1
2/03/2015	0.74	1.2	1	1.5	1.1	1.3	1.1	1.2	1.1	1.2	1.1	1.3	1.2	1.5	1.2	1.3
13/04/2015	0.81	1.1	0.86	1.1	0.87	1.3	1.2	1.5	0.92	1.1	0.93	1.3	1.1	1.2	1.2	1.2
5/05/2015	0.66	0.96	0.86	1.2	0.99	1.1	1.2	1.3	1.1	1.3	1.2	1.2	1.1	1.4	1.2	1.2
17/06/2015	0.94	1.6	0.89	2.6	0.89	1.4	1.6	1.9	0.94	1.2	0.94	1.6	1.2	1.2	1.2	1.3

Table note: N = 1

Table 6.30 Total and dissolved cadmium concentrations at monitoring sites

Sample Date	QE3		P2B/WB50		P5/MH10		CD1		CD2		CD3		CD4		CD5	
	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total
6/06/2014			<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
8/07/2014			<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
11/08/2014			<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
11/09/2014			<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
1/10/2014			<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
6/11/2014			<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
3/12/2014			<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
5/01/2015	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
2/02/2015	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
2/03/2015	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
13/04/2015	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
5/05/2015	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
17/06/2015	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1

Table note: N = 1

Table 6.31 Total and dissolved chromium concentrations at monitoring sites

Sample Date	QE3		P2B/WB50		P5/MH10		CD1		CD2		CD3		CD4		CD5	
	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total
6/06/2014			<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4
8/07/2014			<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3
11/08/2014			<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4
11/09/2014			<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4
1/10/2014			<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4
6/11/2014			<1	1.2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
3/12/2014			<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
5/01/2015	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
2/02/2015	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
2/03/2015	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
13/04/2015	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
5/05/2015	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
17/06/2015	<1	<1	<1	1.8	<1	<1	<1	<1	<1	<1	<1	1	<1	<1	<1	<1

Table note: N = 1

Table 6.32 Total and dissolved cobalt concentrations at monitoring sites

Sample Date	QE3		P2B/WB50		P5/MH10		CD1		CD2		CD3		CD4		CD5	
	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total
6/06/2014			<0.1	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
8/07/2014			0.14	0.12	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
11/08/2014			<0.1	0.69	<0.1	<0.1	<0.1	<0.1	<0.1	0.13	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
11/09/2014			<0.1	0.69	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.19	<0.1	<0.1	<0.1	<0.1
1/10/2014			<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
6/11/2014			<0.1	0.49	<0.1	<0.1	<0.1	<0.1	<0.1	0.11	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
3/12/2014			<0.1	0.14	<0.1	0.17	<0.1	<0.1	<0.1	0.11	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
5/01/2015	0.14	0.34	<0.1	0.27	<0.1	0.37	<0.1	<0.1	<0.1	0.13	<0.1	0.12	<0.1	<0.1	<0.1	<0.1
2/02/2015	0.21	0.39	0.22	0.44	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
2/03/2015	0.16	0.5	<0.1	0.43	<0.1	0.19	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
13/04/2015	0.13	0.22	<0.1	0.17	<0.1	0.13	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
5/05/2015	0.13	0.24	<0.1	0.34	<0.1	0.12	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
17/06/2015	0.11	0.29	<0.1	0.83	<0.1	0.24	<0.1	0.12	<0.1	<0.1	<0.1	0.26	<0.1	<0.1	<0.1	<0.1

Table note: N = 1

Table 6.33 Total and dissolved copper concentrations at monitoring sites

Sample Date	QE3		P2B/WB50		P5/MH10		CD1		CD2		CD3		CD4		CD5	
	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total
6/06/2014			0.96	1.1	0.43	0.78	<0.2	0.36	0.23	0.49	0.3	0.47	0.32	0.39	0.38	0.43
8/07/2014			0.54	0.84	0.56	0.56	0.2	0.25	0.26	0.37	0.27	0.37	0.24	0.28	<0.2	0.22
11/08/2014			0.52	2.1	<0.2	0.33	<0.2	<0.2	<0.2	0.35	<0.2	0.22	<0.2	<0.2	<0.2	1.8
11/09/2014			0.7	2.2	<0.2	0.51	0.23	0.26	0.87	0.66	0.43	0.74	0.47	0.29	0.35	0.27
1/10/2014			0.49	0.58	0.32	0.5	<0.2	0.49	<0.2	0.41	<0.2	<0.2	<0.2	<0.2	<0.2	0.56
6/11/2014			0.58	1.5	<0.2	0.29	<0.2	<0.2	0.72	0.8	0.42	0.32	<0.2	<0.2	<0.2	0.25
3/12/2014			0.66	0.97	0.89	0.9	<0.2	0.25	0.29	0.51	<0.2	0.33	<0.2	0.25	<0.2	<0.2
5/01/2015	0.78	1.4	1.1	1.5	0.8	1.4	0.33	0.5	0.7	0.69	0.59	0.89	0.32	1.6	0.28	0.28
2/02/2015	0.69	4.6	1	1.8	0.39	0.62	0.28	0.43	0.42	0.86	1.3	0.52	0.6	0.48	0.54	0.32
2/03/2015	0.85	1.9	0.88	2.1	0.68	1.1	<0.2	<0.2	0.3	0.33	0.36	0.59	0.27	0.38	0.3	0.4
13/04/2015	0.85	1.2	0.89	1.4	0.64	1.2	0.2	0.26	0.33	0.46	0.25	0.42	<0.2	0.24	<0.2	0.25
5/05/2015	0.52	0.89	0.71	1.5	0.4	0.73	<0.2	0.25	0.24	0.36	0.24	0.5	<0.2	0.26	<0.2	<0.2
17/06/2015	0.61	0.96	0.56	2.5	0.36	0.83	<0.2	0.28	0.29	<0.2	<0.2	0.44	<0.2	<0.2	<0.2	<0.2

Table note: N = 1

Table 6.34 Total and dissolved gallium concentrations at monitoring sites

Sample Date	QE3		P2B/WB50		P5/MH10		CD1		CD2		CD3		CD4		CD5	
	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total
6/06/2014			<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
8/07/2014			<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
11/08/2014			<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
11/09/2014			<0.5	0.52	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
1/10/2014			<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
6/11/2014			<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
3/12/2014			<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
5/01/2015	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
2/02/2015	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
2/03/2015	<0.5	0.57	<0.5	0.63	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
13/04/2015	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
5/05/2015	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
17/06/2015	<0.5	<0.5	<0.5	0.98	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5

Table note: N = 1

Table 6.35 Total and dissolved iron concentrations at monitoring sites

Sample Date	QE3		P2B/WB50		P5/MH10		CD1		CD2		CD3		CD4		CD5	
	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total
6/06/2014			<20	170	<20	180	<20	38	<20	76	<20	75	<20	21	<20	<20
8/07/2014			<20	230	<20	120	<20	<20	<20	72	<20	37	<20	<20	<20	<20
11/08/2014			36	1500	<20	110	<20	100	<20	310	<20	160	<20	21	<20	30
11/09/2014			13	2200	11	250	12	46	10	82	9.8	470	9.1	28	8.2	16
1/10/2014			<5	47	<5	86	<5	7.2	<5	15	<5	33	<5	8.4	<5	9
6/11/2014			10	1100	19	100	10	39	9.8	240	10	97	12	36	9.4	28
3/12/2014			13	280	17	410	<5	46	<5	240	<5	89	<5	28	<5	31
5/01/2015	8.1	540	8.7	690	<5	750	<5	29	8.6	280	<5	200	<5	16	<5	12
2/02/2015	8.3	560	<5	730	<5	65	8.8	27	<5	54	<5	63	<5	16	<5	9.4
2/03/2015	<5	1000	<5	820	<5	360	<5	38	<5	53	<5	140	<5	53	<5	56
13/04/2015	<5	130	<5	210	<5	230	<5	120	<5	80	<5	170	<5	48	<5	60
5/05/2015	<5	280	<5	700	<5	270	<5	42	<5	71	<5	100	<5	48	<5	27
17/06/2015	<5	370	<5	1900	<5	550	<5	270	<5	100	<5	720	<5	35	<5	39

Table note: N = 1

Table 6.36 Total and dissolved lead concentrations at monitoring sites

Sample Date	QE3		P2B/WB50		P5/MH10		CD1		CD2		CD3		CD4		CD5	
	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total
6/06/2014			<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
8/07/2014			<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
11/08/2014			<0.1	0.5	<0.1	0.21	<0.1	<0.1	<0.1	0.11	<0.1	<0.1	<0.1	<0.1	<0.1	0.29
11/09/2014			<0.1	0.52	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.18	<0.1	<0.1	<0.1	<0.1
1/10/2014			<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
6/11/2014			<0.1	0.28	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
3/12/2014			<0.1	<0.1	<0.1	0.33	<0.1	<0.1	<0.1	<0.1	<0.1	0.18	<0.1	<0.1	<0.1	<0.1
5/01/2015	<0.1	0.18	<0.1	0.15	<0.1	0.24	<0.1	<0.1	<0.1	0.1	<0.1	0.12	<0.1	<0.1	<0.1	<0.1
2/02/2015	<0.1	0.3	<0.1	0.17	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.35	<0.1	<0.1
2/03/2015	<0.1	0.33	<0.1	0.25	<0.1	0.12	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
13/04/2015	<0.1	<0.1	<0.1	0.11	<0.1	<0.1	<0.1	<0.1	<0.1	0.11	<0.1	0.15	<0.1	<0.1	<0.1	<0.1
5/05/2015	<0.1	<0.1	<0.1	0.21	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
17/06/2015	<0.1	0.17	<0.1	0.54	<0.1	0.21	<0.1	0.11	<0.1	<0.1	<0.1	0.26	<0.1	<0.1	<0.1	<0.1

Table note: N = 1

Table 6.37 Total and dissolved manganese concentrations at monitoring sites

Sample Date	QE3		P2B/WB50		P5/MH10		CD1		CD2		CD3		CD4		CD5	
	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total
6/06/2014			4.8	7.1	3	6	<0.6	1.2	<0.6	1.5	0.92	2	<0.6	0.77	<0.6	0.87
8/07/2014			2.5	7.8	2.9	4.5	0.61	0.9	<0.6	1.8	1.1	2.2	0.65	0.78	0.67	0.86
11/08/2014			0.76	34	0.71	2.5	<0.6	1.3	<0.6	6.4	<0.6	3.7	<0.6	0.9	<0.6	1.1
11/09/2014			<0.6	30	1.3	4.9	<0.6	0.96	<0.6	1.8	<0.6	8.4	<0.6	1.1	<0.6	0.81
1/10/2014			4	7	5	7.7	0.63	0.77	<0.6	1.1	1.5	2.8	<0.6	0.69	0.77	0.76
6/11/2014			<0.6	24	1.3	3.2	0.99	1.7	0.61	5.4	1.4	3.8	0.71	1.4	<0.6	1.3
3/12/2014			2.5	11	2.5	13	1.1	2	<0.6	7.1	1.7	5.1	1	1.7	1.1	1.7
5/01/2015	5.4	16	1.2	14	1.9	20	<0.6	1.7	<0.6	6.6	<0.6	4.9	1.2	1.9	0.76	1.9
2/02/2015	15	22	17	26	2	3.3	1.3	1.9	0.95	2.4	1.6	3.9	0.89	1.6	0.98	1.5
2/03/2015	11	29	2.7	29	3.4	11	0.82	1.6	0.66	2	1	5.4	0.63	1.8	<0.6	1.9
13/04/2015	7.1	12	4.3	12	10	14	0.66	2.7	<0.6	2.2	0.92	5.3	<0.6	1.9	0.66	1.7
5/05/2015	6.9	14	2.9	20	1.4	5.7	<0.6	1.4	<0.6	1.8	<0.6	2.2	<0.6	1.3	<0.6	0.96
17/06/2015	4.2	12	1.4	38	0.97	9.6	<0.6	4.8	<0.6	1.7	<0.6	11	<0.6	0.8	<0.6	0.81

Table note: N = 1

Table 6.38 Total and dissolved mercury concentrations at monitoring sites

Sample Date	QE3		P2B/WB50		P5/MH10		CD1		CD2		CD3		CD4		CD5	
	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total
6/06/2014			<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
8/07/2014			<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
11/08/2014			<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
11/09/2014			<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
1/10/2014			<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
6/11/2014			<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
3/12/2014			<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
5/01/2015	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
2/02/2015	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
2/03/2015	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
13/04/2015	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
5/05/2015	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
17/06/2015	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1

Table note: N = 1

Table 6.39 Total and dissolved mercury concentrations at monitoring sites

Sample Date	QE3		P2B/WB50		P5/MH10		CD1		CD2		CD3		CD4		CD5	
	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total
6/06/2014			<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
8/07/2014			<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
11/08/2014			<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
11/09/2014			<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
1/10/2014			<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
6/11/2014			<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
3/12/2014			<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
5/01/2015	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
2/02/2015	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
2/03/2015	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
13/04/2015	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
5/05/2015	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
17/06/2015	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1

Table note: N = 1

Table 6.40 Total and dissolved molybdenum concentrations at monitoring sites

Sample Date	QE3		P2B/WB50		P5/MH10		CD1		CD2		CD3		CD4		CD5	
	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total
6/06/2014			11	18	11	11	10	15	11	18	11	28	11	24	12	23
8/07/2014			12	12	11	11	11	11	11	11	12	13	11	12	11	12
11/08/2014			12	11	11	10	11	11	11	10	10	11	11	11	11	11
11/09/2014			8.9	8.6	8.4	8.5	8.3	8.3	9.9	9.7	10	10	9.6	9.8	9.7	9.7
1/10/2014			10	9.7	9.3	9	9.5	9.4	8.9	9.1	9.8	9.1	9.2	8.7	9.4	8.7
6/11/2014			10	10	9.3	9.4	9.3	9.8	9.9	10	10	11	10	10	10	10
3/12/2014			12	12	11	11	11	11	11	11	12	12	10	11	10	11
5/01/2015	12	12	13	13	13	12	12	13	12	12	12	13	12	13	12	13
2/02/2015	8.1	8.7	8.1	9	9.5	11	9.7	10	9.7	11	9.1	9.8	10	11	10	11
2/03/2015	7.2	7	7.2	7.7	8	7.5	9	9.1	8.9	9.1	8.7	8.8	9.2	9.4	9.3	9.4
13/04/2015	11	11	11	11	11	11	11	11	12	12	12	12	12	12	12	12
5/05/2015	9.8	10	11	11	9.9	10	9.8	11	10	11	11	11	10	11	11	11
17/06/2015	9.9	9.6	8.9	9.7	9.1	8.7	9.7	10	9.7	10	9.7	9.9	9.8	10	9.9	10

Table note: N = 1

Table 6.41 Total and dissolved nickel concentrations at monitoring sites

Sample Date	QE3		P2B/WB50		P5/MH10		CD1		CD2		CD3		CD4		CD5	
	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total
6/06/2014			0.3	0.4	0.46	0.51	<0.2	<0.2	<0.2	0.53	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
8/07/2014			0.36	0.48	0.28	0.36	0.12	0.15	0.15	0.21	0.17	0.21	0.16	0.17	0.18	0.14
11/08/2014			0.56	1.5	0.14	0.5	0.11	0.95	0.16	0.38	0.17	0.31	0.11	0.11	<0.1	0.13
11/09/2014			0.4	1.5	0.17	0.26	0.13	0.16	0.19	0.22	0.28	0.48	0.15	0.18	0.1	0.15
1/10/2014			0.4	0.42	0.29	0.33	0.15	0.15	0.2	0.21	0.19	0.19	0.13	0.15	0.14	0.17
6/11/2014			0.48	1.2	0.24	0.4	0.24	0.25	0.27	0.81	0.28	0.31	0.24	0.29	0.22	0.38
3/12/2014			0.52	0.57	0.36	0.51	0.19	0.23	0.25	0.42	0.23	0.37	0.27	0.23	0.26	0.29
5/01/2015	0.82	1.2	0.63	1	0.44	0.88	0.31	0.34	0.35	0.47	0.41	1.7	0.36	0.43	0.44	0.37
2/02/2015	0.83	1.3	0.68	1.1	0.45	0.52	0.36	0.39	0.46	0.56	0.51	0.49	0.45	0.48	0.49	0.46
2/03/2015	0.72	1.5	0.4	0.97	0.37	0.6	0.21	0.2	0.25	0.28	0.27	0.35	0.22	0.24	0.26	0.28
13/04/2015	0.91	0.96	0.51	0.7	0.41	0.52	0.28	0.31	0.24	0.27	0.21	0.35	0.2	0.21	0.17	0.22
5/05/2015	0.68	0.9	0.49	0.88	0.27	0.43	0.16	0.23	0.21	0.3	0.22	0.28	0.17	0.26	0.16	0.2
17/06/2015	0.73	1	0.42	1.5	0.26	0.54	0.21	0.43	0.28	0.18	0.15	0.53	0.14	0.14	0.13	0.15

Table note: N = 1

Table 6.42 Total and dissolved selenium concentrations at monitoring sites

Sample Date	QE3		P2B/WB50		P5/MH10		CD1		CD2		CD3		CD4		CD5	
	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total
6/06/2014			<2	<2	<2	2.1	<2	<2	<2	<2	<2	<2	<2	<2	2.1	<2
8/07/2014			0.46	0.34	1.4	1.1	0.31	0.25	0.56	0.31	0.27	0.24	0.26	<0.2	0.2	<0.2
11/08/2014			<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
11/09/2014			<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
1/10/2014			<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
6/11/2014			<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
3/12/2014			<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
5/01/2015	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
2/02/2015	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
2/03/2015	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
13/04/2015	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
5/05/2015	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
17/06/2015	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5

Table note: N = 1

Table 6.43 Total and dissolved silver concentrations at monitoring sites

Sample Date	QE3		P2B/WB50		P5/MH10		CD1		CD2		CD3		CD4		CD5	
	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total
6/06/2014			<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
8/07/2014			<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
11/08/2014			<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
11/09/2014			<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
1/10/2014			<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
6/11/2014			<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
3/12/2014			<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
5/01/2015	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
2/02/2015	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
2/03/2015	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
13/04/2015	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
5/05/2015	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
17/06/2015	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5

Table note: N = 1

Table 6.44 Total and dissolved vanadium concentrations at monitoring sites

Sample Date	QE3		P2B/WB50		P5/MH10		CD1		CD2		CD3		CD4		CD5	
	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total
6/06/2014			1.9	2.1	1.8	2.4	1.8	1.8	1.8	1.9	1.6	1.9	1.8	1.8	2	2
8/07/2014			2.6	2.6	3	2.8	2.5	2.1	2.5	2.2	2.3	1.7	2.6	2.1	2.6	2.1
11/08/2014			1.8	4.8	1.5	1.6	1.2	1.4	1.1	1.6	1.4	1.9	1.7	2	1.9	1.9
11/09/2014			1.2	4.1	1.1	1.4	1.1	1.1	1.3	1.3	1.2	2	1.3	1.3	1.2	1.3
1/10/2014			1.2	1.3	1.2	1.2	1	0.98	1.1	1.1	0.96	1	1.1	1	1.1	1
6/11/2014			2	4.1	1.8	1.8	1.5	1.7	2.1	2.2	1.8	2	1.8	1.7	1.8	1.7
3/12/2014			1.6	1.9	1.3	1.7	1.2	1.2	1.3	1.6	1.4	1.5	1.4	1.5	1.6	1.6
5/01/2015	2.4	3.3	2.6	3.6	2.6	3.9	1.8	2	2.1	2.3	2.4	2.7	2.2	2.1	2.1	2.1
2/02/2015	2.2	3.5	2.9	4.6	2.2	2.2	1.8	1.8	2.1	2.1	2.2	2.3	2	2.1	2	2.1
2/03/2015	2.8	5.2	3.2	5.2	2.9	3.6	1.9	1.9	2.3	2.3	2.4	2.7	2.2	2.3	2.3	2.4
13/04/2015	3.2	3.6	3.2	3.8	2.8	3.1	2.8	2.8	2.1	2.2	2	2.3	2.1	2.2	2.3	2.3
5/05/2015	1.9	2.5	2.2	3.7	2	2.4	1.8	1.9	1.9	2.1	1.7	2	1.9	2	1.9	1.9
17/06/2015	1.9	2.8	1.8	6.2	1.6	2.7	2	2.6	1.6	1.7	1.3	2.5	1.7	1.6	1.7	1.6

Table note: N = 1

Table 6.45 Total and dissolved zinc concentrations at monitoring sites

Sample Date	QE3		P2B/WB50		P5/MH10		CD1		CD2		CD3		CD4		CD5	
	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total
6/06/2014			5.7	2.5	420	1.4	1.7	1.2	1.5	1.3	1.1	1.1	11	1.2	15	1.4
8/07/2014			1.1	2.5	1.9	2.2	0.8	1.7	0.64	2.1	1.1	2	1.2	2.4	1.6	2
11/08/2014			32	4.8	<0.4	2.4	<0.4	0.95	<0.4	2.1	<0.4	2.1	<0.4	1.7	1.5	4
11/09/2014			2.3	8.8	3.9	4.1	4.4	3.3	2.7	4.3	5.3	5.7	4.9	5.4	5.4	3.2
1/10/2014			4.2	5.5	7.5	3.5	2.4	3.3	2.5	4.8	3.2	2.8	4.3	3.8	0.92	2.5
6/11/2014			6.7	9.6	5.5	5.1	1.2	4.1	3.7	5.9	4.8	5.5	5.9	6.5	5	5.8
3/12/2014			20	4.3	4.2	62	4.5	3.2	1.8	2.5	2.8	2.8	2	2.1	2.3	2.1
5/01/2015	5.9	5.9	8.5	5.5	7.8	5	5.5	6.4	11	4.8	19	8.7	3.4	14	3.8	3.5
2/02/2015	2.8	6.4	3.6	5.2	3.6	5.6	3.7	3.5	4	7	13	3.1	5.1	4	5.8	4.3
2/03/2015	0.9	2.9	2	3.1	0.76	2.6	1.3	0.89	2.5	1.2	1.3	1.5	4	1.9	0.81	0.97
13/04/2015	1.4	2.3	1.6	1.8	2.1	16	2.1	2	1.1	1.2	1.2	5.5	2.2	1.2	4.5	2.4
5/05/2015	<0.5	1.5	0.85	3.2	<0.5	2.2	<0.5	1.7	<0.5	1.2	<0.5	<0.5	0.55	1.4	1.1	2.2
17/06/2015	1.1	1.7	0.66	4.6	0.83	1.7	0.95	1.4	5	0.81	0.6	1.8	0.78	0.69	0.66	0.84

Table note: N = 1

Table 6.46 TRH and BTEX concentrations at CD monitoring sites during July 2014, October 2014, January 2015 and April 2015

Parameter (µg/L)		QE3	P2B/WB50	P5/MH10	CD1	CD2	CD3	CD4	CD5
TRH	TRH C6-C10	<25	<25	<25	<25	<25	<25	<25	<25
	TRH >C10-C16	<50	<50	<50	<50	<50	<50	<50	<50
	TRH >C16-C34	<100	<100	<100	<100	<100	<100	<100	<100
	TRH >C34-C40	<100	<100	<100	<100	<100	<100	<100	<100
BTEX	Benzene	<1	<1	<1	<1	<1	<1	<1	<1
	Toluene	<2	<2	<2	<2	<2	<2	<2	<2
	Ethyl Benzene	<2	<2	<2	<2	<2	<2	<2	<2
	m+p xylenes	<4	<4	<4	<4	<4	<4	<4	<4
	o-xylene	<2	<2	<2	<2	<2	<2	<2	<2
	Total BTEX	<11	<11	<11	<11	<11	<11	<11	<11

Table note: N = 1

Table 6.47 PAH concentrations at CD monitoring sites during July 2014, October 2014, January 2015 and April 2015.

Parameter (µg/L)	QE3	P2B/WB50	P5/MH10	CD1	CD2	CD3	CD4	CD5
Naphthalene	<4	<4	<4	<4	<4	<4	<4	<4
Acenaphthylene	<1	<1	<1	<1	<1	<1	<1	<1
Acenaphthene	<1	<1	<1	<1	<1	<1	<1	<1
Fluorene	<1	<1	<1	<1	<1	<1	<1	<1
Phenanthrene	<1	<1	<1	<1	<1	<1	<1	<1
Anthracene	<1	<1	<1	<1	<1	<1	<1	<1
Fluoranthene	<1	<1	<1	<1	<1	<1	<1	<1
Pyrene	<1	<1	<1	<1	<1	<1	<1	<1
Benz(a)anthracene	<1	<1	<1	<1	<1	<1	<1	<1
Chrysene	<1	<1	<1	<1	<1	<1	<1	<1
Benzo(b)&(k)fluoranthene	<1	<1	<1	<1	<1	<1	<1	<1
Benzo(a)pyrene	<2	<2	<2	<2	<2	<2	<2	<2
Indeno(1,2,3-cd)pyrene	<1	<1	<1	<1	<1	<1	<1	<1
Dibenz(a,h)anthracene	<1	<1	<1	<1	<1	<1	<1	<1
Benzo(g,h,i)perylene	<1	<1	<1	<1	<1	<1	<1	<1
Coronene*	<1	<1	<1	<1	<1	<1	<1	<1
Benzo(e)pyrene*	<1	<1	<1	<1	<1	<1	<1	<1
Perylene*	<1	<1	<1	<1	<1	<1	<1	<1

Table note: N = 1

Table 6.48 Organochlorine and organophosphate pesticide concentrations at CD monitoring sites during July 2014, October 2014, January 2015 and April 2015

Parameter (µg/L)	QE3	P2B/WB50	P5/MH10	CD1	CD2	CD3	CD4	CD5
Aldrin	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
<i>alpha</i> -BHC	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
<i>beta</i> -BHC	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
<i>γ</i> -BHC (Lindane)	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
<i>delta</i> -BHC	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
<i>cis</i> -Chlordane	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
<i>trans</i> -Chlordane	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
<i>p,p'</i> -DDD	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
<i>p,p'</i> -DDE	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
<i>p,p'</i> -DDT	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Dieldrin	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
<i>alpha</i> -Endosulfan	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
<i>beta</i> -Endosulfan	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Endosulfan SO ₄	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Endrin	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Endrin ketone	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Endrin aldehyde	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Heptachlor	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Heptachlor epoxide	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Hexachlorobenzene	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Methoxychlor	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Mirex	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Azinphos-methyl	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Bromophos-ethyl	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Carbophenothion	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Chlorfenvinphos	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Chlorpyrifos	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015
Chlorpyrifos-methyl	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015
Diazinon	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015
Demeton-S-methyl	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Demeton-S	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Dimethoate	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Dichlorvos	<2	<2	<2	<2	<2	<2	<2	<2
Ethion	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Fenitrothion	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Fenthion	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Fenamiphos	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Malathion	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Methidathion	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Parathion	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015
Parathion-methyl	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Phosalone	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03

Parameter (µg/L)	QE3	P2B/WB50	P5/MH10	CD1	CD2	CD3	CD4	CD5
Pirimiphos-methyl	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Profenofos	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Prothiofos	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Trifluralin	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03

Table note: N = 1

Table 6.49 Multiresidue pesticide concentrations at CD monitoring sites during July 2014, October 2014, January 2015 and April 2015

Parameter (µg/L)	P2B/WB50	P5/MH10	QE3	CD1	CD2	CD3	CD4	CD5
Bromophos-ethyl	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Carbophenothion	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Chlorfenvinphos	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Chlorpyrifos	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015
Chlorpyrifos-methyl	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015
Diazinon	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015
Demeton-S-methyl	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Demeton-S	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Dimethoate	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Dichlorvos	<2	<2	<2	<2	<2	<2	<2	<2
Ethion	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Fenitrothion	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Fenthion	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Fenamiphos	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Malathion	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Methidathion	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Parathion	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015
Parathion-methyl	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Phosalone	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Pirimiphos-methyl	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Profenofos	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Prothiofos	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Trifluralin	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
4-CPA	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
2,4,5-T	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
2,4,6-T	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
2,4,5-TP	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
2,4-D	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
2,6-D	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
2,4-DB	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Abamectin	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Acephate	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Acetamiprid	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Acetochlor	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Parameter (µg/L)	P2B/WB50	P5/MH10	QE3	CD1	CD2	CD3	CD4	CD5
Acifluorfen	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Alachlor	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Aldicarb	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Ametryn	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Aminobenzimidazole-2	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Asulam	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Atraton	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Atrazine	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Atrazine Desethyl	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Atrazine Desisopropyl	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Azamethiphos	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Azinphos ethyl	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Azoxystrobin	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Benalaxyl	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Bendiocarb	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Bensulfuron-methyl	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Bentazone	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Bitertanol	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Boscalid	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Bromacil	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Bromoxynil	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Bupirimate	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Buprofezin	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cadusafos	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Carbaryl	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Carbendazim	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Carbofuran	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Carboxin	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Carfentrazone-ethyl	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Chlorantraniliprole	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Chlorfluazuron	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Chloridazon	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Chlorpropham	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Chlorsulfuron	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Clethodim	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Clofentezine	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Clomazone	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Clothianidin	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cyanazine	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cyproconazole 1+2	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cyprodinil	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cyromazine	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Parameter (µg/L)	P2B/WB50	P5/MH10	QE3	CD1	CD2	CD3	CD4	CD5
Dicamba	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Dichlorprop	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Difenoconazole	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Diflubenzuron	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Diflufenican	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Dimethenamid	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Dimethomorph 1+2	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Dinoseb	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Disulfoton	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Diuron	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Dodine	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Emamectin	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Epoxiconazole	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Ethofumesate	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Ethoprophos	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Etoxazole	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Fenarimol	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Fenbuconazole	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Fenhexamid	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Fenoxycarb	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Fenpyroximate	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Fenthion sulfone	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Fenthion sulfoxide	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Fipronil	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Fluazifop-p-butyl	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Fluazinam	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Flubendamide	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Fludioxonil	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Fluometuron	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Fluquinconazole	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Fluoxypyr	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Flusilazole	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Flutriafol	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Fonofos	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Forchlorfenuron	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Furaloxyl	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Haloxypop	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Haloxypop methyl	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Hexaconazole	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Hexaflumuron	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Hexazinone	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Hexythiazox	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Imazalil	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Parameter (µg/L)	P2B/WB50	P5/MH10	QE3	CD1	CD2	CD3	CD4	CD5
Imazapyr	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Imazethapyr	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Imidacloprid	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Indoxacarb	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Ioxynil	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Iprodione	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Irgarol	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Kresoxim-methyl	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Linuron	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Lufenuron	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Mandipropamid	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
MCPA	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
MCPB	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
MCPP	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Metalaxyl	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Methabenzthiazuron	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Methamidophos	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Methiocarb	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Methomyl	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Methomyl Oxime	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4
Methoxyfenozide	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Metolachlor	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Metosulam	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Metrafenone	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Metribuzin	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Metsulfuron-methyl	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Mevinphos	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Monochrotophos	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Myclobutanil	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Omethoate	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Oryzalin	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Oxadixyl	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Oxamyl	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Paclobutrazol	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Penconazole	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Pencycuron	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Pendimethalin	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Phenmedipham	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Phosmet	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Picloram	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Picolinafen	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Piperonyl Butoxide	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Pirimicarb	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Parameter (µg/L)	P2B/WB50	P5/MH10	QE3	CD1	CD2	CD3	CD4	CD5
Prochloraz	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Prometon	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Prometryn	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Propachlor	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Propamocarb	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Propargite	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Propazine	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Propetamphos	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Propiconazole	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Propoxur	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Propyzamide	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Pymetrozine	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Pyraclostrobin	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Pyrimethanil	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Pyriproxyfen	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Quinoxifen	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Rotenone	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Secbumeton	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Sethoxydim	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Siduron	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Simazine	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Simetryn	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Spinosad A	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Spinosad D	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Spirotetramat	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Spirotetramat-enol	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Spiroxamine	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Stirofos	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Tebuconazole	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Tebufenozide	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Tebufenpyrad	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Tebuthiuron	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Terbacil	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Terbufos	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Terbuthylazine	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Terbutryn	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Tetraconazole	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Thiabendazole	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Thiacloprid	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Thiamethoxam	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Thiodicarb	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Tolclofos methyl	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Triadimefon	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Parameter (µg/L)	P2B/WB50	P5/MH10	QE3	CD1	CD2	CD3	CD4	CD5
Triadimenol	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Triazophos	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Trichlorfon	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Triclopyr	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Trifloxystrobin	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Triflumizole	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Triflumuron	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Vamidothion	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Sum of Pyrethrins	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6

Table note: N = 1



C

Organics
sample results

Appendix C

Organics sample results

Table C1 Organochlorine and organophosphate pesticide concentrations

Parameter (µg/L)	QE3	P2B/ WB50	P5/MH10	CD1	CD2	CD3	CD4	CD5
Aldrin	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
<i>alpha</i> -BHC	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
<i>beta</i> -BHC	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
<i>g</i> -BHC (Lindane)	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
<i>delta</i> -BHC	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
<i>cis</i> -Chlordane	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
<i>trans</i> -Chlordane	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
<i>p,p'</i> -DDD	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
<i>p,p'</i> -DDE	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
<i>p,p'</i> -DDT	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Dieldrin	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
<i>alpha</i> -Endosulfan	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
<i>beta</i> -Endosulfan	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Endosulfan SO ₄	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Endrin	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Endrin ketone	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Endrin aldehyde	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Heptachlor	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Heptachlor epoxide	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Hexachlorobenzene	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Methoxychlor	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Mirex	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Azinphos-methyl	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Bromophos-ethyl	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Carbophenothion	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Chlorfenvinphos	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Chlorpyrifos	< 0.015	< 0.015	< 0.015	< 0.015	< 0.015	< 0.015	< 0.015	< 0.015
Chlorpyrifos-methyl	< 0.015	< 0.015	< 0.015	< 0.015	< 0.015	< 0.015	< 0.015	< 0.015
Diazinon	< 0.015	< 0.015	< 0.015	< 0.015	< 0.015	< 0.015	< 0.015	< 0.015
Demeton-S-methyl	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Demeton-S	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Dimethoate	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Dichlorvos	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2
Ethion	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Fenitrothion	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Fenthion	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Fenamiphos	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1

Parameter (µg/L)	QE3	P2B/ WB50	P5/MH10	CD1	CD2	CD3	CD4	CD5
Malathion	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Methidathion	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Parathion	< 0.015	< 0.015	< 0.015	< 0.015	< 0.015	< 0.015	< 0.015	< 0.015
Parathion-methyl	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Phosalone	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Pirimiphos-methyl	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Profenofos	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Prothiofos	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Trifluralin	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03

Table C2 Multiresidue pesticide sample concentrations

Parameter (µg/L)	P2B/ WB50	P5/MH10	QE3	CD1	CD2	CD3	CD4	CD5
Bromophos-ethyl	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Carbophenothion	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Chlorfenvinphos	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Chlorpyrifos	< 0.015	< 0.015	< 0.015	< 0.015	< 0.015	< 0.015	< 0.015	< 0.015
Chlorpyrifos-methyl	< 0.015	< 0.015	< 0.015	< 0.015	< 0.015	< 0.015	< 0.015	< 0.015
Diazinon	< 0.015	< 0.015	< 0.015	< 0.015	< 0.015	< 0.015	< 0.015	< 0.015
Demeton-S-methyl	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Demeton-S	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Dimethoate	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Dichlorvos	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2
Ethion	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Fenitrothion	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Fenthion	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Fenamiphos	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Malathion	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Methidathion	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Parathion	< 0.015	< 0.015	< 0.015	< 0.015	< 0.015	< 0.015	< 0.015	< 0.015
Parathion-methyl	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Phosalone	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Pirimiphos-methyl	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Profenofos	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Prothiofos	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Trifluralin	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
4-CPA	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
2,4,5-T	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
2,4,6-T	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
2,4,5-TP	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
2,4-D	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
2,6-D	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
2,4-DB	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01

Parameter (µg/L)	P2B/ WB50	P5/MH10	QE3	CD1	CD2	CD3	CD4	CD5
Abamectin	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Acephate	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Acetamiprid	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Acetochlor	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Acifluorfen	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Alachlor	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Aldicarb	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Ametryn	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Aminobenzimidazole-2	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Asulam	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Atraton	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Atrazine	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Atrazine Desethyl	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Atrazine Desisopropyl	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Azamethiphos	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Azinphos ethyl	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Azoxystrobin	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Benalaxyl	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Bendiocarb	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Bensulfuron-methyl	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Bentazone	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Bitertanol	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Boscalid	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Bromacil	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Bromoxynil	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Bupirimate	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Buprofezin	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Cadusafos	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Carbaryl	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Carbendazim	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Carbofuran	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Carboxin	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Carfentrazone-ethyl	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Chlorantraniliprole	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Chlorfluazuron	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Chloridazon	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Chlorpropham	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Chlorsulfuron	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Clethodim	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Clofentezine	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Clomazone	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01

Parameter (µg/L)	P2B/ WB50	P5/MH10	QE3	CD1	CD2	CD3	CD4	CD5
Clothianidin	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Cyanazine	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Cyproconazole 1+2	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Cyprodinil	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Cyromazine	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Dicamba	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
Dichlorprop	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Difenoconazole	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Diflubenzuron	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Diflufenican	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Dimethenamid	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Dimethomorph 1+2	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Dinoseb	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Disulfoton	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Diuron	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Dodine	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Emmamectin	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Epoxiconazole	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Ethofumesate	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Ethoprophos	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Etoxazole	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Fenarimol	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Fenbuconazole	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Fenhexamid	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Fenoxycarb	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Fenpyroximate	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Fenthion sulfone	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Fenthion sulfoxide	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Fipronil	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Fluazifop-p-butyl	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Fluazinam	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Flubendamide	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Fludioxonil	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Fluometuron	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Fluquinconazole	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Fluoxypyr	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Flusilazole	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Flutriafol	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Fonofos	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Forchlorfenuron	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Furaloxyl	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Haloxypop	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Haloxypop methyl	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01

Parameter (µg/L)	P2B/ WB50	P5/MH10	QE3	CD1	CD2	CD3	CD4	CD5
Hexaconazole	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Hexaflumuron	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Hexazinone	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Hexythiazox	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Imazalil	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Imazapyr	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Imazethapyr	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Imidacloprid	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Indoxacarb	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Ioxynil	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Iprodione	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Irgarol	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Kresoxim-methyl	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Linuron	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Lufenuron	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Mandipropamid	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
MCPA	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
MCPB	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
MCPP	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Metalaxyl	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Methabenzthiazuron	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Methamidophos	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Methiocarb	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Methomyl	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Methomyl Oxime	< 0.4	< 0.4	< 0.4	< 0.4	< 0.4	< 0.4	< 0.4	< 0.4
Methoxyfenozide	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Metolachlor	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Metosulam	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Metrafenone	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Metribuzin	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Metsulfuron-methyl	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Mevinphos	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Monochrotophos	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Myclobutanil	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Omethoate	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Oryzalin	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Oxadixyl	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Oxamyl	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Paclobutrazol	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Penconazole	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Pencycuron	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Pendimethalin	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01

Parameter (µg/L)	P2B/ WB50	P5/MH10	QE3	CD1	CD2	CD3	CD4	CD5
Phenmedipham	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Phosmet	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Picloram	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
Picolinafen	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Piperonyl Butoxide	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Pirimicarb	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Prochloraz	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Prometon	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Prometryn	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Propachlor	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Propamocarb	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Propargite	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Propazine	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Propetamphos	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Propiconazole	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Propoxur	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Propyzamide	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Pymetrozine	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Pyraclostrobin	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Pyrimethanil	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Pyriproxyfen	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Quinoxifen	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Rotenone	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Sebumeton	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Sethoxydim	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Siduron	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Simazine	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Simetryn	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Spinosad A	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Spinosad D	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Spirotetramat	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Spirotetramat-enol	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Spiroxamine	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Stirofos	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Tebuconazole	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Tebufenozide	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Tebufenpyrad	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Tebuthiuron	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Terbacil	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Terbufos	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Terbuthylazine	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Terbutryn	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Tetraconazole	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01

Parameter (µg/L)	P2B/ WB50	P5/MH10	QE3	CD1	CD2	CD3	CD4	CD5
Thiabendazole	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Thiacloprid	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Thiamethoxam	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Thiodicarb	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Tolclofos methyl	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Triadimefon	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Triadimenol	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Triazophos	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Trichlorfon	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Triclopyr	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Trifloxystrobin	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Triflumizole	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Triflumuron	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Vamidotion	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Sum of Pyrethrins	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6

Table note:

N = 1



D

Responses to
independent review
recommendations

Appendix D

Table 1 Key recommendations from the Independent Review of the Port of Gladstone

	Description of findings and recommendations	Channel Duplication Project response	EIS section containing additional information
Recommendations			
14	That proponents of developments within the Port of Gladstone ensure that any voluntary independent audits are conducted consistent with best practice standards and seek to obtain the department's agreement to the criteria	The Project EMPs contain a requirement for independent audits. Commonwealth and Queensland Government agencies will be involved in the review and approval of the Project EMPs prior to the commencement of construction. The department's agreement to the criteria for independent audits will be addressed during this review process.	Appendix Q1 (Dredging EMP), Sections 6.11 and 6.12 Appendix Q2 (Project EMP), Sections 6.11 and 6.12
15	That all confirmed cases of non-compliance be publicly announced on both the department's and proponent's website along with details of any remedial actions	The Project EMP and Dredging EMP will operate within the framework provided by the existing GPC EMS, which is an overarching framework for managing environmental risk at all GPC managed sites. GPC staff and relevant contractors are directed to follow reporting, incident and record keeping procedures outlined in the EMS, while also following the site specific management actions and monitoring outlined in the Project EMP and Dredging EMP.	Appendix Q1 (Dredging EMP), Section 6.14 Appendix Q2 (Project EMP), Section 6.14
18	That, as dredging operations transition from capital to maintenance works, monitoring and reporting be continued in a transparent and consistent manner	Maintenance dredging will generally be required annually for the Gatcombe and Golding Cutting duplicated channels, and the Project barge access channel following the Project dredging works as the sediments stabilise. The Port-wide maintenance dredging and offshore placement will be subject to the relevant Commonwealth Government approval process (e.g. Sea Dumping Permit) and other approvals as required at the time of dredging.	Chapter 2 (Project description), Section 2.11.4 GPC contribute to the monitoring undertaken by PCIMP within the Port of Gladstone. This monitoring program continues between capital and maintenance dredging programs.

Source: Australian Government (2013)

Table 2 Key findings and recommendations from independent review of the bund wall performance (design, construction and functioning of the outer bund wall)

	Description of findings and recommendations	Channel Duplication Project design response	EIS section containing additional information
Findings			
1	Modelling to understand potential consequences of the change in size and shape of the reclamation area on tidal velocities, bed shear stress and associated sediment transport should have been undertaken prior to final approval of the design and commencement of construction	Hydrodynamic and coastal processes modelling have included the WBE reclamation area detailed in the EIS Project description. If the size and/or shape of the reclamation area changes post EIS approval, additional modelling will be undertaken and mitigation measures adopted to minimise the potential changes to environmental impacts	Chapter 7 (coastal processes and hydrodynamics) Appendix G (coastal processes and hydrodynamics) Appendix Q2 (Project EMP)
2	The overall design of the bund wall was consistent with industry best practice for addressing the known geological and/or geomorphic variation of the adjacent seabed	The detailed design phase of the WBE reclamation area and BUF bund walls will adopt industry best practice and incorporate the findings of the Project EIS geotechnical investigation into the design and construction methodology process An additional geotechnical investigation will be undertaken for the WBE reclamation area and BUF during the detailed design phase of the Project	Chapter 7 (coastal processes and hydrodynamics) Appendix G (coastal processes and hydrodynamics) Appendix Q2 (Project EMP)
3	While additional groundwater modelling could have been undertaken by the proponent to better understand the likely consequences of piping to inform the final design and construction method of the bund wall, it would have been difficult for the designers to anticipate the observed piping failure	The Project EIS geotechnical investigation for the WBE reclamation area found no evidence of palaeo channels within the reclamation area footprint	Appendix E2 (DMPA geotechnical investigations) Appendix Q2 (Project EMP)
4	The design of the bund wall with respect to the technical specifications of the geotextile liner did meet industry best practice and/or recognised industry standards	The detailed design phase of the WBE reclamation area and BUF bund walls will adopt industry best practice and incorporate the findings of the Project EIS geotechnical investigation into the design and construction methodology process	Chapter 7 (coastal processes and hydrodynamics) Appendix G (coastal processes and hydrodynamics) Appendix Q2 (Project EMP)
5	The design of the bund wall with respect to the placement and restraint of the geotextile liner did not meet industry best practice and/or recognised industry standards	The detailed design phase of the WBE reclamation area and BUF bund walls will adopt industry best practice and incorporate the findings of the Project EIS geotechnical investigation into the design and construction methodology process	Chapter 7 (coastal processes and hydrodynamics) Appendix G (coastal processes and hydrodynamics) Appendix Q2 (Project EMP)

	Description of findings and recommendations	Channel Duplication Project design response	EIS section containing additional information
6	The observed elevated turbidity in the vicinity of the bund wall was due to a combination of factors, including changed water velocities that occurred as a result of the bund's presence, the poor initial sealing of the bund resulting from the structurally compromised geotextile liner, the unexpected piping resulting from the physical characteristics of paleochannels, and the erosion of mud on the outside of the bund wall	The detailed design phase of the WBE reclamation area and BUF bund walls will adopt industry best practice and incorporate the findings of the Project EIS geotechnical investigation into the design and construction methodology process The Project EIS geotechnical investigation for the WBE reclamation area found no evidence of palaeo channels within the reclamation area footprint Groundwater modelling and piping investigation to be undertaken during the detailed design phase of the Project. The findings of the modelling and investigation will be incorporated into the design and construction methodology and specification.	Chapter 7 (coastal processes and hydrodynamics) Appendix G (coastal processes and, hydrodynamics) Appendix Q2 (Project EMP)
7	The observed impacts of constructing and sealing the bund were greater than predicted during the environmental impact statement phase of the project	Project EIS has addressed potential water quality and ecological impacts of constructing and sealing of the bund walls. The detailed design phase of the WBE reclamation area and BUF bund walls will adopt industry best practice and incorporate the findings of the Project EIS geotechnical investigation into the design and construction methodology process Hydrodynamic modelling will be undertaken during the detailed design phase to determine the least impact options for construction of the bund walls and sealing of the enclosure	Chapter 8 (water quality) Chapter 9 (nature conservation) Appendix I1 (Ecology Technical Report) Appendix Q2 (Project EMP)
8	Gladstone Ports Corporation consulted in a timely and extensive manner with stakeholders, consultants and the Dredge Technical Reference Panel once turbidity exceedances were observed	GPC has consulted with Government stakeholders and community representatives during the preparation of the Project EIS	Appendix N2 (engagement report)
9	Gladstone Ports Corporation's response to seal the inside of the bund wall with settled dredged material was appropriate under the circumstances	Core material (up to 300mm) and dredged material to be used against the outer bund wall geotextile material	Section 2.5.8
Recommendations			
1	For the construction of bund walls in coastal environments with high geological and/or geomorphic variation, governments should require proponents to explicitly assess the risk of piping and to implement appropriate controls	The potential geological and geomorphic variation within and adjoining the WBE reclamation area have been addressed in the EIS geotechnical investigations and reporting	Appendix E2 (DMPA geotechnical investigation) Appendix Q2 (Project EMP)

	Description of findings and recommendations	Channel Duplication Project design response	EIS section containing additional information
2	For constructions of bund walls in coastal environments, any geotextile materials designed to filter sediment should: ■ be placed on the inner bund wall material and then be overlaid and secured by core material ■ be keyed into the rock armour material to prevent slippage and deformation from occurring prior to placement of the core material ■ be laid on the bund wall such that no wrinkles, gaps, folds or deformations occur in the material, with all joints sewn to create seams and to conform to the requirements of Australian Standards 3706: Geotextiles – Methods of Test. Overlaps in the fabric should be directed vertically down the slope of the armour material	The geotextile material design and installation requirements have been incorporated into the EIS project description (refer Section 2.5) and Project EMP These design requirements will be incorporated into the detailed design and construction specifications for the reclamation component of the Project	Chapter 2 (Project description, Section 2.5.8) Appendix Q2 (Project EMP)
3	Governments should require proponents of bund wall structures to ensure that potential impacts on sediment transport from the construction phase of a bund wall be understood prior to final approval	The potential impacts from the establishment of the WBE reclamation area and BUF bund walls have been addressed in the Project EIS. Additional hydrodynamic and coastal processes modelling will be undertaken during the detailed design phase of the Project. The findings of this modelling will be incorporated into the design and updating of the Project EMP.	Chapter 9 (nature conservation) Appendix I1 (Ecology Technical Report) Appendix Q2 (Project EMP)
4	Gladstone Ports Corporation, its contractors and the Queensland and Australian Governments should publish in the peer-reviewed literature the lessons from an engineering perspective on the construction of the bund wall to inform future design and impact assessment	Not applicable to Project EIS	

Source: Australian Government (2014)

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