Department of Environment
and Resource Management

Third Update on the Water Quality of Port Curtis and Tributaries Including Data Collected in the Weeks of 21 November and 12 December 2011

January 2012

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Acknowledgements

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Executive Summary

During the latter half of 2011 concerns over the health of fish in Gladstone waterways were raised with the Queensland Government. The Department of Environment and Resource Management (DERM), as part of the Queensland Government response to the situation, is investigating whether there have been changes in water quality in Gladstone waterways, whether any spatial pattern exists in water quality which could be explained by dredging, and also whether water quality could be the cause or contribute to the cause of the fish ill-health. DERM has released a series of reports on this topic.

The first DERM report, released on 5th October 2011, concluded that the water quality was consistent with historical trends, apart from the impacts of the extreme wet seasons of 2010–11, which occurred throughout the state. In September 2011, DERM commenced monthly investigations of water quality in Gladstone waterways, including testing for dissolved metal concentrations and metals in sediments. Water quality collected in September and October 2011 showed that none of the water quality properties measured were of significant environmental concern and could be connected to poor fish health.

This report presents the results of water quality sampling that occurred during the weeks of 21 November and 12 December 2011. There was no clear pattern in the water quality results to suggest that dredging was having any impact on water quality. Similarly, there was no evidence of any extreme or unusual physical-chemical parameters that could directly link water quality parameters in Gladstone waterways during November and December 2011 with ongoing concerns with fish health. Very high turbidity (>250 NTU) was measured at Boat Creek during November 2011 and was observed to be caused by tidal currents resuspending sediments off the adjacent intertidal flats. This indicates that transient, localized high turbidity levels occur naturally within Gladstone waterways. High concentrations of organic nutrients (mainly nitrogen) were also measured from a few sites across the region in December 2011. This may have been due to the increased rainfall during December washing organic matter into the estuaries and coastal waters. Based on the available pH data there is no evidence to suggest that acid sulphate soils are deteriorating water quality in Gladstone waterways.

Dissolved metal concentrations were lower in October, November and December 2011 compared to September 2011, with a number of metals (dissolved cadmium, chromium, silver and thallium) not being detected in samples collected since the September 2011 sampling round. However, dissolved aluminium concentrations exceeded the Australian and New Zealand water quality guideline trigger values at 18 of 19 sites in November 2011, but only at two sites in December 2011, indicating a short term elevation. As dissolved aluminium concentrations have been found to be elevated across many sites (including reference sites) over the four months of sampling, the measured concentrations are unlikely to be due dredging. Copper was measured at 8 of the 19 sites surveyed in December 2011 and at 4 of these sites the Australian and New Zealand trigger values were exceeded. Exceedances of the copper trigger value in the Gladstone marina may be related to general marine activities, as copper is a component of antifouling paints. Natural variations in metals at the levels reported in Gladstone are quite common especially following flood events or when there is high natural mineralisation.

The report by the Gladstone Fish Health Scientific Advisory Panel (the Panel) was released on 6 January 2012. The report concluded that water quality data collected by the Queensland Government was appropriately collected and analysed and that the measured water quality was not unusual (compared to historical values and trends), except for extremely low salinity during the 2010–2011 wet season. The Panel also made a number of recommendations with respect to improving the investigation program and these will be incorporated into the February 2012 and subsequent sampling rounds. The results from all investigations into the issue of fish health in Gladstone will be reviewed and, where appropriate, the environmental contaminants investigation program will be modified.

Introduction

As part of the Queensland Government response to reported illness amongst fish in Gladstone waterways, Queensland, the Department of Environment and Resource Management (DERM) commenced monthly sampling and analysis of water quality in the Gladstone waterways area. This was undertaken to determine if changes in water quality had occurred in Gladstone waterways and whether these were likely to cause or contributed to the fish illness.

DERM released its first report on 5 October 2011 (DERM, 2011a) which summarised the historical monitoring data available for Gladstone waterways. This indicated that overall, the water quality in the estuaries, and the Harbour was consistent with the natural variation in water quality. However, the analysis was limited by the lack of dissolved metal (a surrogate for biologically available metal) concentration data.

Dissolved and total concentrations of 28 metals and metalloids as well as physical-chemical properties, and chlorophyll-*a* have subsequently been measured in water samples from Gladstone Harbour in September, October, November and December 2011. Sediment collected from Gladstone Harbour in September were analysed for metals and metalloids. Data and reports associated with each sampling round have been released by DERM. The dissolved concentrations of several metals (aluminium, copper and chromium) have exceeded the Australian and New Zealand water quality guideline trigger values at several sites in September and October 2011. These results indicate that at these sites there was the potential for adverse environmental impacts to occur and that further work was required. However, the lack of any spatial pattern in these exceedances suggested that they were not related to current dredging activity.

The current report presents the results of the third and fourth round of water sampling from Gladstone waterways. These samples were collected during the weeks commencing 21 November and 12 December 2011.

Methods

Sample sites

For this and the previous DERM reports (DERM, 2011a, b, c) Gladstone waterways were defined as all coastal waters from The Narrows down to Rodds Bay, including estuaries. Gladstone Harbour is defined as all coastal waters from The Narrows to Auckland Creek and east to Curtis Island.

The sites for this investigation program were selected to cover the various water bodies in the area and to represent various potential sources of metal contaminants (Tables 1 and 2). Sites in the Boyne and Calliope rivers were monitored as part of a long-term monthly ambient monitoring program for Central Queensland. Additional sites consistent with the Gladstone Ports Corporation (GPC) monitoring program were also monitored.

A total of 34 sites were sampled in the November and December sampling rounds (Figure 1). Gladstone Harbour sites were sampled on the 23 and 24 November and 13 and 14 December 2011. The Rodds Bay reference sites were sampled on 21 November and 12 December 2011. The Boyne and Calliope estuaries, including South Trees Inlet and the anabranch of the Calliope, were sampled on 23 November and 13 December 2011. Two additional sites were sampled in November and December, compared to the previous sampling rounds. The two additional sites (sites 2A, 3B) were located close to sites for potential scallop processing facilities.

Based on the distance sites were from the current dredging activities, the Western Basin Bund and the spoil grounds, they were divided into three zones (Tables 1 and 2 and Figure 1). Zone 1 is the closest to these activities and Zone 3 the furthest away. Thus there is a decreasing likelihood of being affected by dredging and associated activities in moving from Zone 1 to 3.

Sampling

DERM has been monitoring the Boyne and Calliope estuaries in the same way since 1994. The estuaries were always monitored on the same day and always during the ebb tide. The monitoring always started from the river mouth and proceeded along the same sequence of sites upstream. Monitoring always started in the Boyne estuary (just after the high tide) with the

Calliope monitored later in the day. Sub-surface water samples were collected for nutrient analysis from all sites and chlorophyll-*a* (Chl-*a*) analyses from 5 and 8 sites in the Boyne and Calliope estuaries, respectively. From November 2011 onwards, samples were also collected for chlorophyll-*a* analyses from the Harbour, Rodds Bay reference sites and the offshore spoil grounds (Tables 1 and 2). Sampling for physico-chemical parameters were taken throughout the water column, starting at 0.2 m under the surface and then every 2 m until approximately 0.5m above the bottom. Sampling methods are described in more detail in DERM (2011c).

Analyses

Water samples were analysed for chlorophyll-*a*, nutrients (total nitrogen (TN), total phosphorus (TP), filtered reactive phosphorus (FRP), ammonia and nitrogen oxides) and for total recoverable and dissolved concentrations of 18 metals and metalloids (i.e. aluminium, antimony, arsenic, boron, cadmium, chromium, cobalt, copper, iron, lead, manganese, molybdenum, nickel, selenium, silver, thallium, tin, vanadium and zinc). Details of the analytical methods used are provided in DERM (2011c). The limit of reporting (LOR, the lowest concentration that a laboratory will confidently state as occurring) for each of the metals analysed are presented in Appendix 1. This investigation took advantage of the existing DERM Central Queensland Ambient Monitoring Program that occurs in Gladstone waterways and added additional sites. It was not deemed necessary to monitor for metals at multiple locations in the estuaries and the focus was on water quality associated with dredging activities that occurs in Gladstone harbour, therefore metals were only analysed at 19 of the 34 sites (for details, see Table 2).

Comparison of Dissolved Metal and Metalloid Concentrations to Trigger Values and Historical Gladstone Waterways Data

Measured dissolved metal and metalloid concentrations were compared to the trigger values (TVs) for ecosystem protection from the Australia and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC and ARMCANZ, 2000). Trigger values for slightly to moderately modified ecosystems (that aim to protect 95% of all species) are presented in Appendix 1.

Figure 1: Water quality monitoring sites from in and around Gladstone waterways sampled in November and December 2011: Yellow indicates Zone 1 sites, pink, Zone 2 sites and blue, Zone 3 sites (see Tables 1 and 2 for more detailed description of sites).

Table 1: Summary of sites sampled in November 2011 and December 2011 with a site description and samples taken at each site. Zone definition is based on current activity within the port and distance from the dredging and associated activities. Zone 1 has the highest likelihood of being impacted by dredging and associated activities while zone 3 has the lowest likelihood of current impacts.

Locality	Site ID	Site description	Zone	Physico-chemical properties Nov./Dec.	Metals in water total Nov./Dec.	Metals in water dissolved. Nov./Dec.	Nutrients. Nov./Dec.	Chlorophyll-*a*. Nov./Dec.
Gladstone Harbour	QE3	Potential Impact from Dredging Plume	2	X/X	X/X	X/X	X/X	X/X
	QE4	Potential Impact from Dredging Plume	2	X/X	X/X	X/X	X/X	X/X
	ST1	Potential Impact from Dredging Plume	2	X/X	X/X	X/X	X/X	X/X
	BG10	Background Gladstone Harbour	3	X/X	X/X	X/X	X/X	X/X
Marina	MM1	Gladstone marina, shipping	3	X/X	X/X	X/X	X/X	X/X
	MM2	Gladstone marina, shipping	3	X/X	X/X	X/X	X/X	X/X
Auckland Inlet	AUK0.0	Auckland Creek, general industry	3	X/X	X/X	X/X	X/X	X/X
	AUK 1.6	Auckland Creek, general industry	3	X/X	X/X	X/X	X/X	X/X
Calliope River	C0.0	Calliope River Mouth — general industry	3	X/X	-/-[a]	-/-[a]	-/-[b]	X/X
	C1.6	Calliope River Mouth — general industry	3	X/X	X/X	X/X	-/-[b]	-[c]/X
	C3.2	Calliope River 3.2 km upstream from river mouth	3	X/X	-/-[a]	-/-[a]	-/-[b]	X/X

Locality	Site ID	Site description	Zone	Physico-chemical properties Nov./Dec.	Metals in water total Nov./Dec.	Metals in water dissolved. Nov./Dec.	Nutrients. Nov./Dec.	Chlorophyll-*a*. Nov./Dec.
	C4.8	Calliope River 4.8 km upstream from river mouth	3	X/X	-/- [a]	-/- [a]	-/- [b]	X/X
	C6.4	Calliope River 6.4 km upstream from river mouth	3	X/X	X/X	X/X	-/- [b]	X/X
	C11.3	Calliope River 11.3 km upstream from river mouth	3	X/X	-/- [a]	-/- [a]	-/- [b]	X/X
	C12.9	Calliope River 12.9 km upstream from river mouth	3	X/X	-/- [a]	-/- [a]	X/X	X/X
	C14.5	Calliope River 14.5 km upstream from river mouth	3	X/X	-/- [a]	-/- [a]	-/- [b]	X/X
	C16.1	Calliope River 16.1 km upstream from river mouth	3	X/X	-/- [a]	-/- [a]	-/- [b]	X/X
Calliope R. Anabranch	CPA2.8	Calliope River - Anabranch	3	X/X	-/- [a]	-/- [a]	-/- [b]	-/- [c]
Boyne River	B0.0	Boyne River Mouth	3	X/X	-/- [a]	-/- [a]	-/- [b]	X/X
	B2.7	Boyne River 2.7 km upstream from river mouth	3	X/X	-/- [a]	-/- [a]	-/- [b]	X/X
	B5.1	Boyne River 5.1 km upstream from river mouth	3	X/X	X/X	X/X	X/X	X/X
	B8.6	Boyne River 8.6 km upstream from river mouth	3	X/X	-/- [a]	-/- [a]	-/- [b]	X/X
	B12.0	Boyne River 12 km upstream from river mouth	3	X/X	-/- [a]	-/- [a]	X/X	X/X
South Trees Inlet	STI20.0	South Tree Inlet D/S of red mud dam	3	X/X	-/- [a]	-/- [a]	-/- [b]	-/- [c]

Locality	Site ID	Site description	Zone	Physico-chemical properties Nov./Dec.	Metals in water total Nov./Dec.	Metals in water dissolved. Nov./Dec.	Nutrients. Nov./Dec.	Chlorophyll-*a*. Nov./Dec.
Boat Creek	BC	Background water quality input into Gladstone Harbour	3	X/X	X/X	X/X	X/X	X/X
Rodds Bay	RB1	Reference Site in Rodds Bay	3	X/X	X/X	X/X	X/X	X/X
	RB3	Reference Site in Rodds Bay	3	X/X	X/X	X/X	X/X	X/X
Gladstone Harbour	2A	Scallop processing[d]	3	X/X	-/-	-/-	X/-	X/-
	3B	Scallop processing[d]	3	X/X	-/-	-/-	X/-	X/-
Dredge Spoil Ground	SGM1	Reference Site for the Spoil Grounds	3	X/X	X/X	X/X	X/X	X/X
	SGW4	Spoil Grounds	1	X/X	X/X	X/X	X/X	X/X
	SGW5	Spoil Grounds	1	X/X	X/X	X/X	X/X	X/X
Western Basin Bund	BW1	Spoil Disposal Area	1	X/X	X/X	X/X	-/- [b]	X/X
	BW2	Spoil Disposal Area	1	X/X	X/X	X/X	-/- [b]	X/X

[a]. It was not deemed necessary to measure metal concentrations at multiple points in the rivers and creeks that discharge into the Gladstone Harbour. [b.] These sites were monitored as part of the Central Queensland Ambient Monitoring Program which did not measure nutrients at all sites, only representative sites. [c.] These sites were monitored as part of the Central Queensland Ambient Monitoring Program and only physico-chemical properties are usually measured at these locations. [d.] Sites 2a and 3b were additional sites requested to be sampled by the Central Queensland Regional Office of DERM and, while not part of this investigation, they were included for transparency and completeness.

Results and Discussion

Physico-Chemical Water Quality Data for November and December 2011 sampling

Turbidity

Very high subsurface and near bottom turbidity levels (> 250 NTU) were found at Boat Creek (Zone 3) during November 2011 (Figures 2 and 3). The monitoring team collecting the samples observed that this high turbidity was caused by spring tidal (ebb) currents resuspending sediments from adjacent intertidal flats. Boat Creek is a considerable distance from the dredging and this indicates that transient, localized high turbidity levels occur naturally within Gladstone Harbour.

Apart from November 2011, the highest turbidity in the Harbour was usually found at site BG10 (Zone 3) (Figures 2 and 3). An examination of historical turbidity data collected by the GPC at site BG10 since October 2010 suggests that turbidity levels greater than 50 NTU are common at this site around spring tides. Near bottom turbidity levels were often higher than subsurface values (compare Figures 2 and 3). Turbidity often increases with depth because of re-suspension of sediments by tidal currents. Tidal currents have the capacity to mobilise fine sediments (including clays, silts and fine sands) over most of the northern and north-eastern sections of Australia's continental shelf (Porter-Smith et al. 2004).

Turbidity levels in the Boyne and Calliope estuaries during September, October, November and December 2011 were within the long-term ranges previously recorded for these estuaries (DERM 2011a). Subsurface and near bottom turbidity levels in the Boyne waterway ranged between 0–14 NTU and 2–14 NTU, respectively between September and December 2011. The highest turbidity levels were often measured from the site in the South Trees Inlet, which is a tributary off the main Boyne estuary. These turbidity levels are within the long-term turbidity range for the Boyne estuary (across all depths) of 0–388 NTU. The long-term (1994–2011) average turbidity (mean ± 1 standard deviation) is 6 ± 15 NTU at the subsurface and 8 ± 12 NTU for the near bottom turbidity.

The Calliope tends to be a more turbid estuary than the Boyne. Subsurface and near bottom turbidity levels in the Calliope waterway ranged between 1–83 NTU and 1–92 NTU, respectively between September and December 2011. These turbidity levels fall well within the long-term turbidity range for the Calliope estuary (across all depths) of 0–289 NTU. The long-term (1994–2011) average turbidity (mean ± 1 standard deviation) is 16 ± 18 NTU at the subsurface and 21 ± 23 NTU for the near bottom.

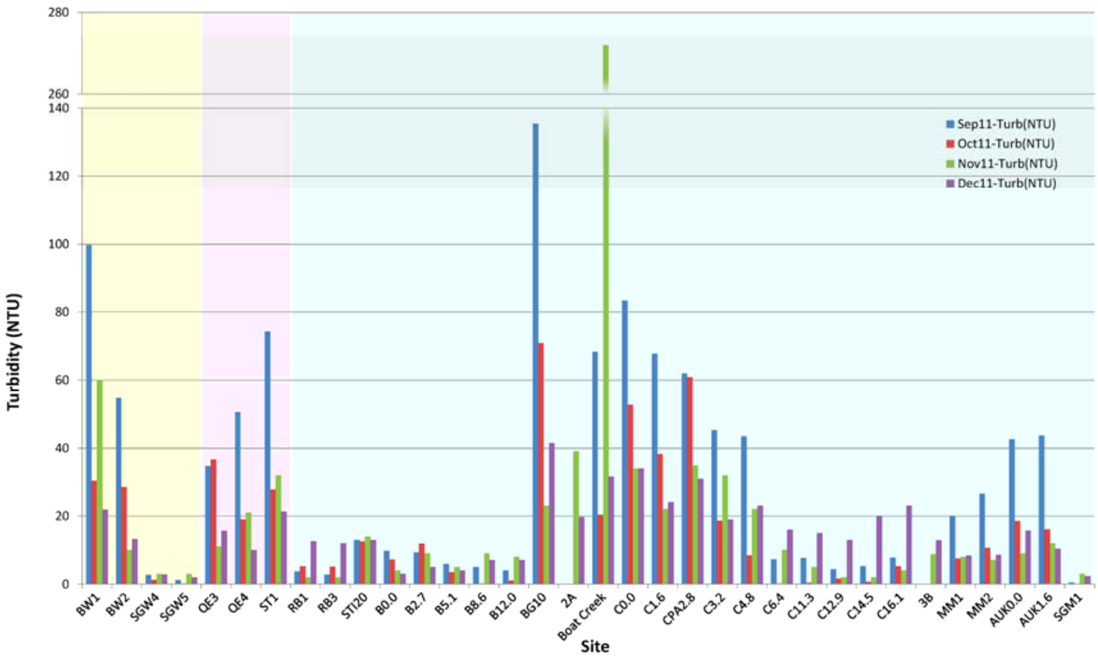

Figure 2: Subsurface turbidity for sites from Gladstone waterways sampled in September (blue bars), October (red bars), November (green bars) and December 2011 (purple bars) based on one observation per site. Sites 2A and 3B were not sampled during September and October 2011. The yellow shading is for Zone 1 sites, pink for Zone 2 sites and blue for Zone 3 sites. The turbidity axis is split to reduce loss of detail of low turbidity values.

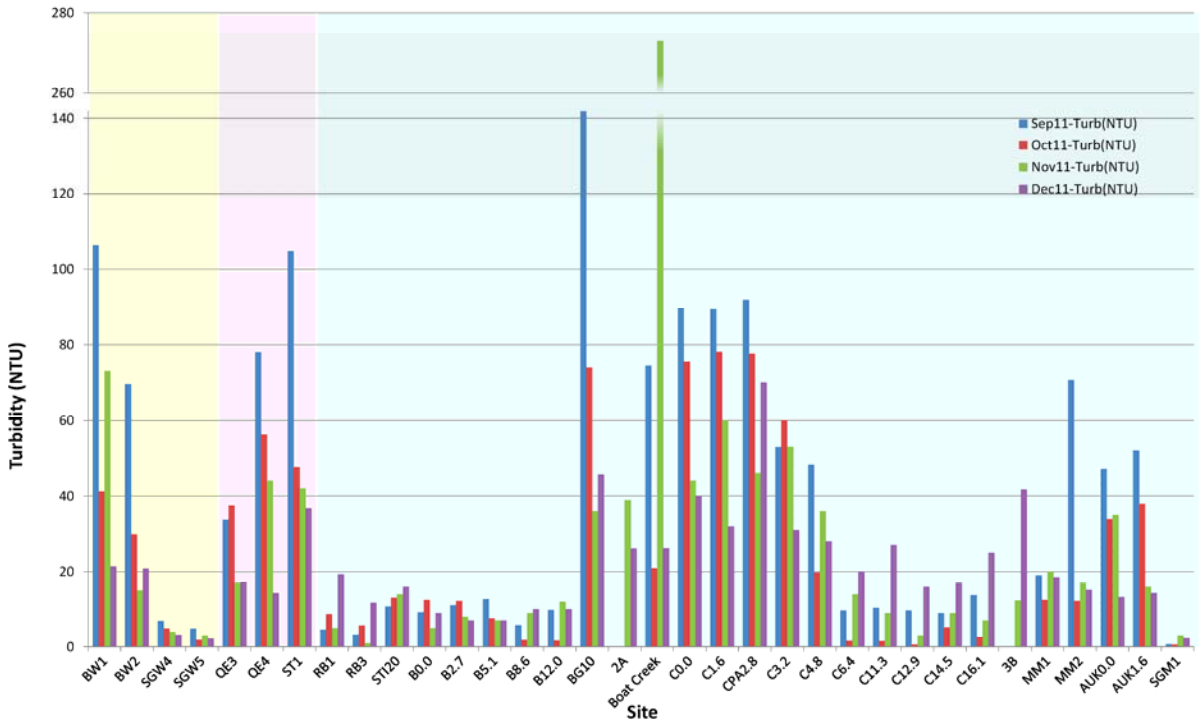

Figure 3: Near bottom turbidity for sites from Gladstone waterways sampled in September (blue bars), October (red bars), November (green bars) and December 2011 (purple bars) based on one observation per site. Sites 2A and 3B were not sampled during September and October 2011. The yellow shading is for Zone 1 sites, pink for Zone 2 sites and blue for Zone 3 sites. The turbidity axis is split to reduce loss of detail of low turbidity values.

Dissolved Oxygen

Subsurface dissolved oxygen (DO) concentrations within Gladstone Harbour were greater than 85% saturation during the November and December sampling (Figure 4). Lower concentrations occurred in the estuaries, especially in the upper reaches of the Boyne River, in the South Trees Inlet and 16.1 km upstream of the mouth of the Calliope River (all sites are from Zone 3). However, even the lowest subsurface DO concentration was still greater than 70% saturation, and the Queensland water quality guidelines (DERM, 2009) indicate that significant impacts on fish are unlikely at DO concentrations greater than 50% saturation. Near bottom DO concentrations were generally slightly lower than subsurface values (compare Figures 4 and 5). This is not unexpected as DO concentrations usually decrease with depth. The lowest DO concentration measured (70% saturation) was from a subsurface sample from the upper reaches of the Boyne estuary during November 2011 (Figure 5). Dissolved oxygen values between 75% and 80% saturation are not uncommon in Queensland estuaries and have never been recorded as affecting fish (DERM, 2009). Dissolved oxygen concentrations above 100% saturation are also not uncommon in Queensland during the summer period. This generally indicates the presence of photosynthesising algal species in the waterways. In December some Calliope River sites were above 100% saturation.

The DO concentrations in the Boyne and Calliope estuaries during September, October, November and December 2011 were within the long-term ranges previously recorded for these estuaries (DERM 2011a). Subsurface and near bottom DO concentrations in the Boyne waterway ranged between 75–103% saturation and 73–101% saturation, respectively between September and December 2011. The lowest DO levels were often measured from the site in the South Trees Inlet, which is a tributary off the main Boyne estuary. These DO concentrations fall within the long-term range for the Boyne estuary (across all depths) of 55–132% saturation.

Subsurface and near bottom DO concentrations in the Calliope waterway ranged between 79–112% saturation and 78–101% saturation, respectively between September and December 2011. These DO concentrations fall within the long-term range for the Calliope estuary (across all depths) of 54–162% saturation. The long-term (1994–2011) average DO concentrations (mean ± 1 standard deviation) for subsurface and near bottom levels are 95 ± 9% saturation and 93 ± 9% saturation, respectively.

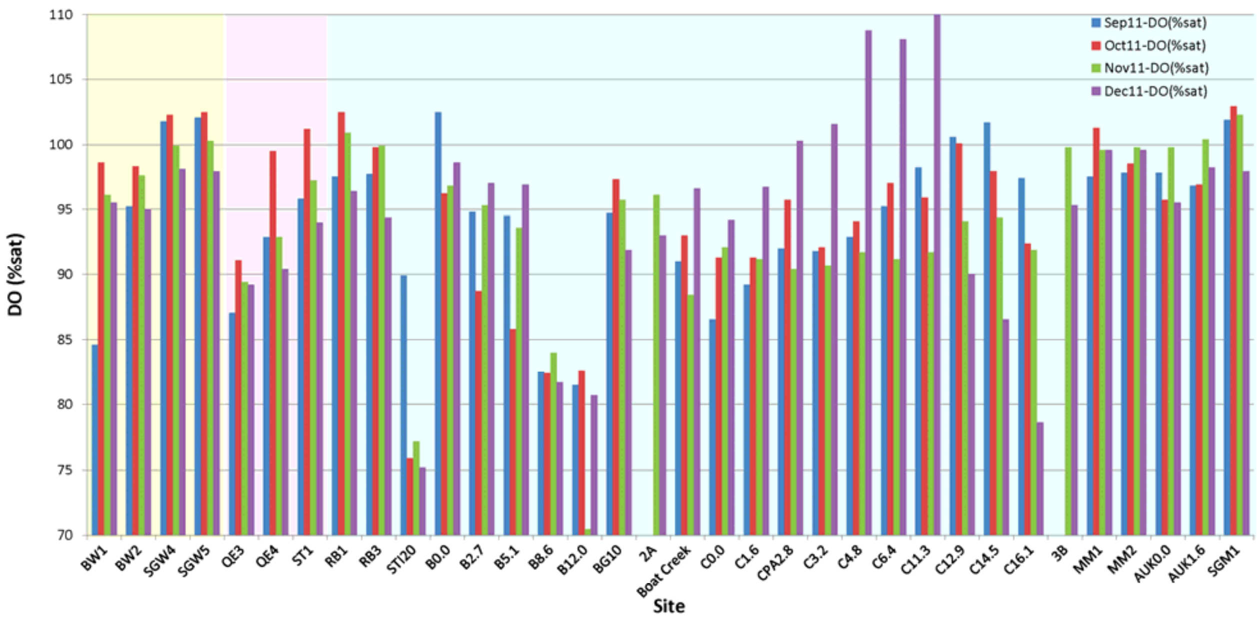

Figure 4: Subsurface dissolved oxygen levels (% saturation) for sites from Gladstone waterways sampled in September (blue bars), October (red bars), November (green bars) and December 2011 (purple bars) based on one observation per site. Sites 2A and 3B were not sampled during September and October 2011. The yellow shading is for Zone 1 sites, pink for Zone 2 sites and blue for Zone 3 sites.

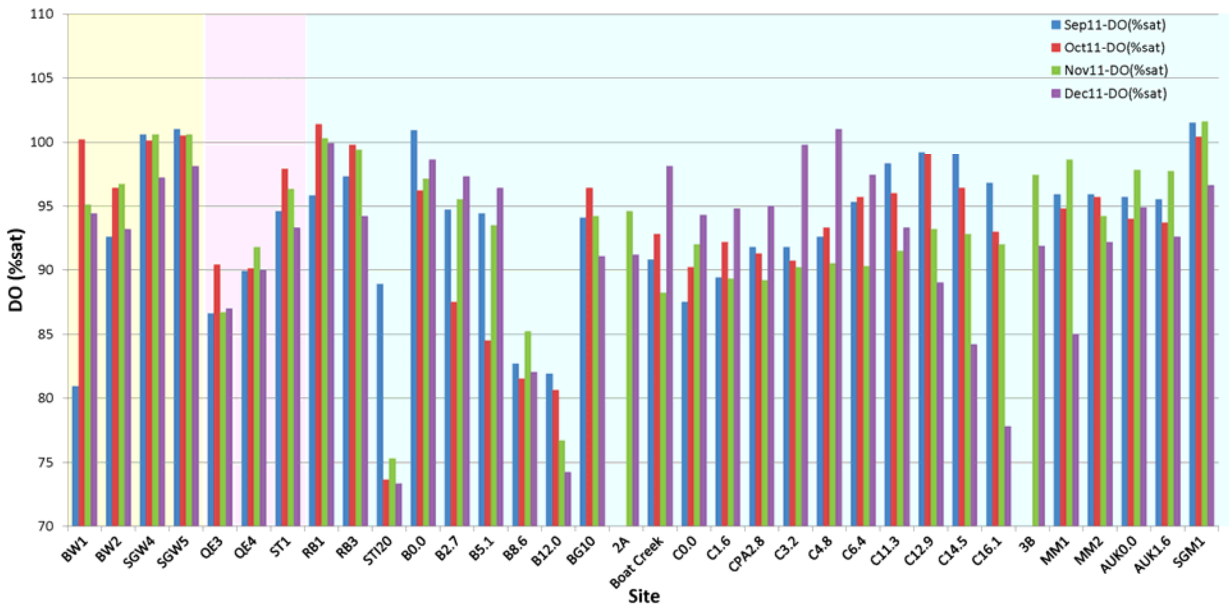

Figure 5: Near bottom dissolved oxygen levels (% saturation) for sites from Gladstone waterways sampled in September (blue bars), October (red bars), November (green bars) and December 2011 (purple bars) based on one observation per site. Sites 2A and 3B were not sampled during September and October 2011. The yellow shading is for Zone 1 sites, pink for Zone 2 sites and blue for Zone 3 sites.

Temperature

Subsurface water temperatures throughout the region continued to increase during November and December 2011, although this warming generally slowed during December (Figure 6). The highest temperatures were generally recorded from the Calliope estuary (sites C0, C1.6, 3.2, C4.8, C6.4, C11.3 – all Zone 3) and its anabranch (site CPA2.8 – Zone 3). Near bottom temperatures also increased during November but in some cases December water temperatures were slightly cooler than during November 2011 (Figure 7). Temperature increases were generally less in the near bottom than the subsurface waters (compare Figures 6 and 7). Water temperatures in the Boyne and Calliope estuaries during September, October, November and December 2011 were within the long-term ranges previously recorded for these estuaries (DERM 2011a).

Subsurface and near bottom temperatures in the Boyne waterway ranged between 22.2–29.2 ^{o}C and 22.2–28.8 ^{o}C, respectively between September and December 2011. These temperatures fall within the long-term range for the Boyne estuary (across all depths) of 15.8–35.5 ^{o}C. Subsurface and near bottom temperatures in the Calliope waterway ranged between 24.3–30.8 ^{o}C and 24.3–31.8 ^{o}C, respectively between September and December 2011. These temperatures fall within the long–term range for the Calliope estuary (across all depths) of 16.8–36.4 ^{o}C.

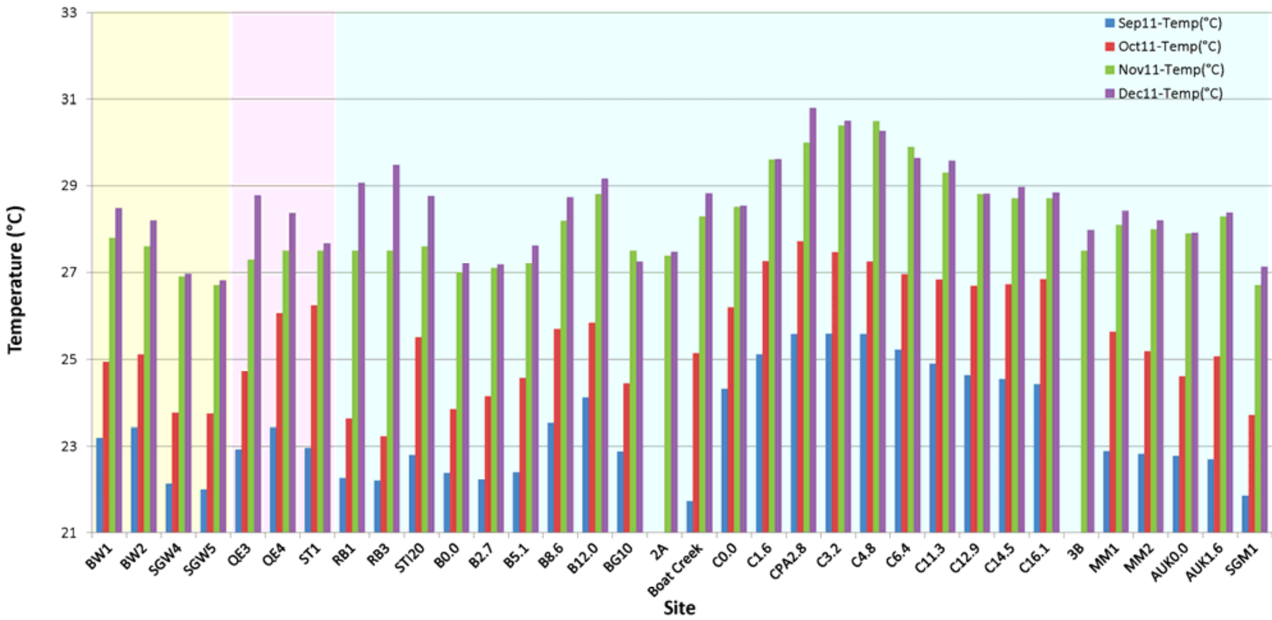

Figure 6: Subsurface temperatures (^{o}C) for sites from Gladstone waterways sampled in September (blue bars), October (red bars), November (green bars) and December 2011 (purple bars) based on one observation per site. Sites 2A and 3B were not sampled during September and October 2011. The yellow shading is for Zone 1 sites, pink for Zone 2 sites, and blue for Zone 3 sites.

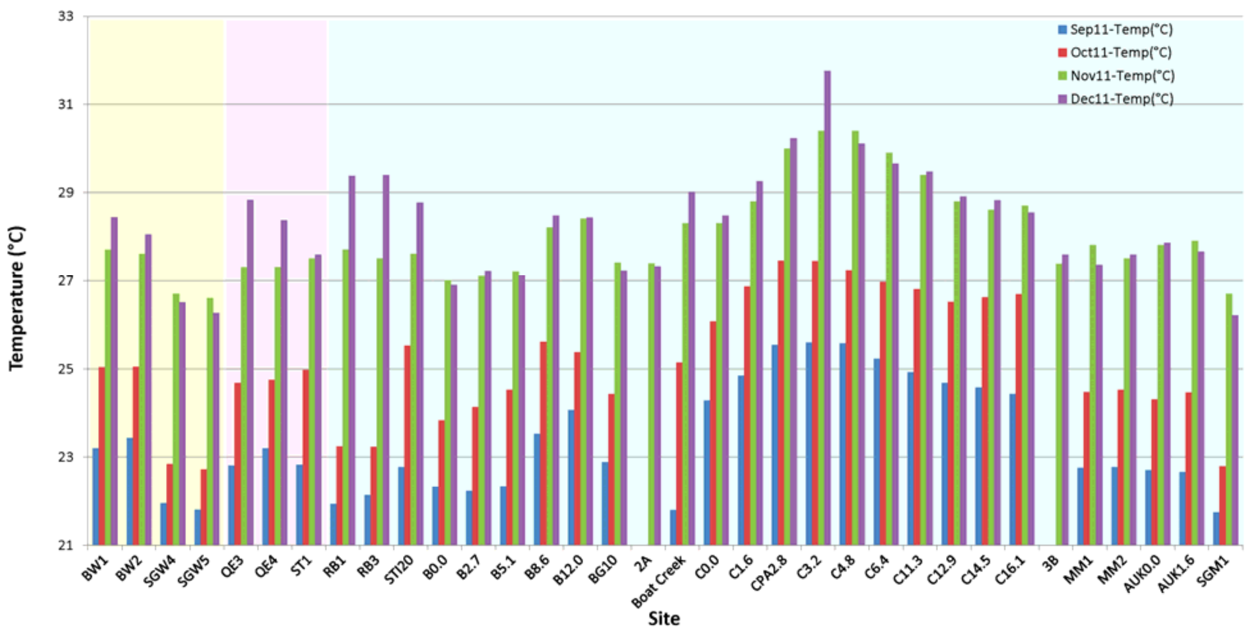

Figure 7: Near bottom temperatures (^{o}C) for sites from Gladstone waterways sampled in September (blue bars), October (red bars), November (green bars) and December 2011 (purple bars) based on one observation per site. Sites 2A and 3B were not sampled during September and October 2011. The yellow shading is for Zone 1 sites, pink for Zone 2 sites, and blue for Zone 3 sites.

Salinity

In the vast majority of cases salinity levels peaked across the region during November 2011 (Figures 8 and 9), consistent with increasing summer temperatures and generally lower rainfall during November compared to October and December 2011 (Australian Bureau of Meteorology: http://www.bom.gov.au/climate/data/). As expected, for both the subsurface and near bottom samples, the lowest salinity levels occurred in the upper reaches of the estuaries whereas those from the Harbour, spoil grounds and the reference sites at Rodds Bay were generally closer to oceanic salinity levels (35–36 PSU).

Near bottom salinity levels generally displayed a similar spatial pattern across sites as subsurface salinity levels (compare Figure 8 and 9). There was also little difference between the subsurface salinity levels and the near bottom values, except in the upper estuaries where subsurface salinity levels were lower (compare Figures 8 and 9). The salinity levels of subsurface waters in the upper Calliope estuary were especially low during the December 2011 monitoring, consistent with the higher rainfall during this month (Australian Bureau of Meteorology: http://www.bom.gov.au/climate/data/). The salinity levels measured between the September and December 2011 sampling rounds were mostly within the ranges (22.8–38 PSU) reported for Gladstone waterways in an earlier study by CSIRO (Angel *et al*. (2010)) in December 2003 and 2004. Subsurface salinity levels < 22.8 PSU were measured by DERM in December 2011 from the upper Calliope estuary but this is not inconsistent with Angel *et al*. (2010) where only the lower reaches of this estuary were monitored.

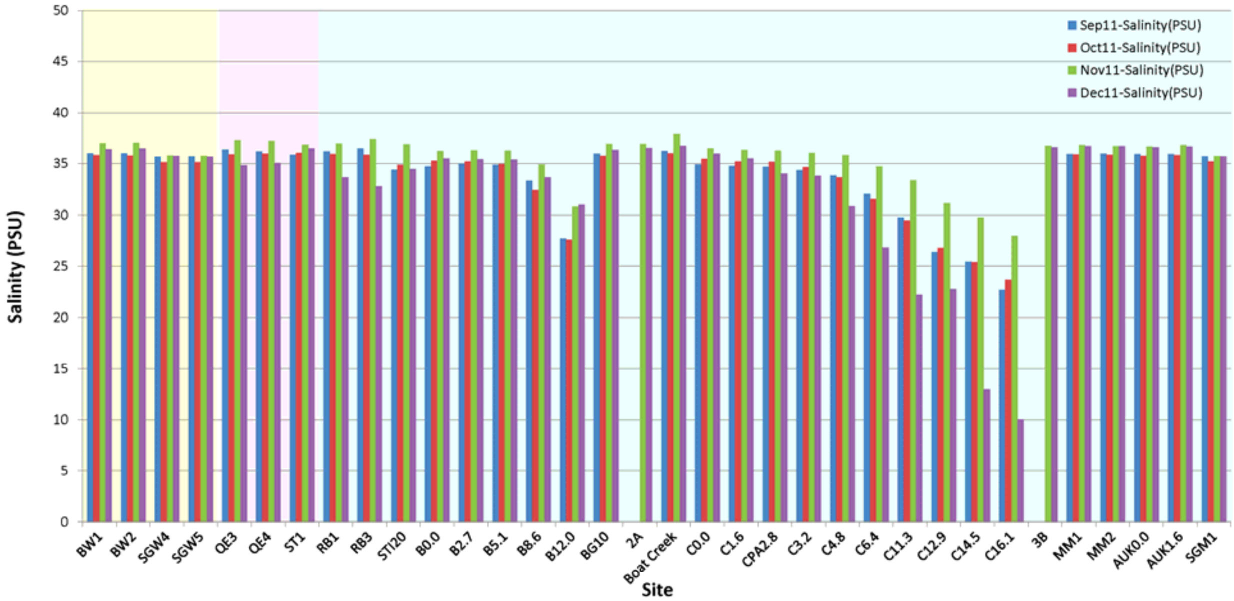

Figure 8: Subsurface salinity levels (practical salinity units—PSU) for sites from Gladstone waterways sampled in September (blue bars), October (red bars), November (green bars) and December 2011 (purple bars) based on one observation per site. Sites 2A and 3B were not sampled during September and October 2011. The yellow shading is for Zone 1 sites, pink for Zone 2 sites and blue for Zone 3 sites.

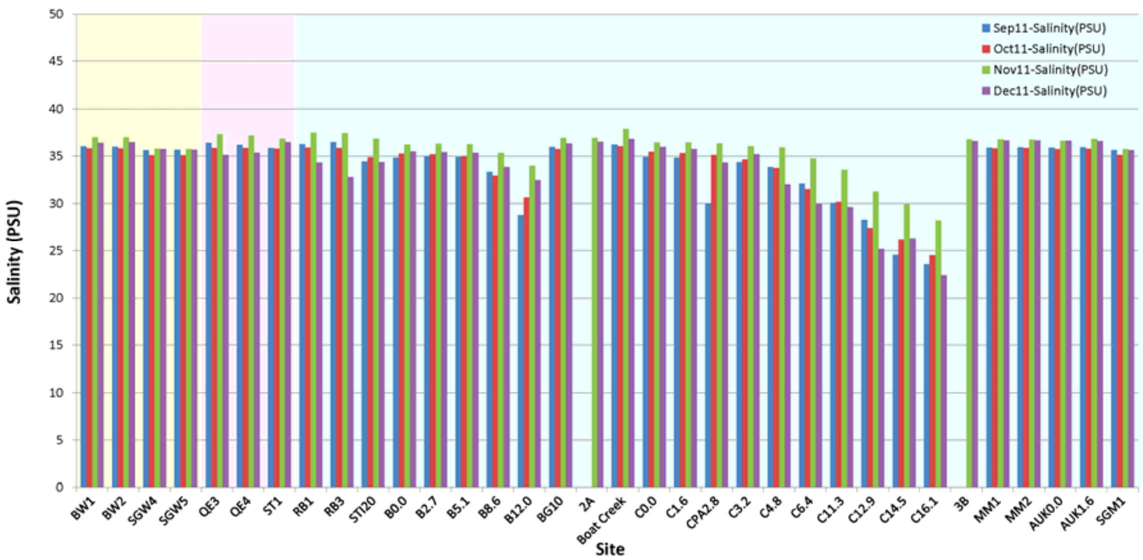

Figure 9: Near bottom salinity levels (practical salinity units—PSU) for sites from Gladstone waterways sampled in September (blue bars), October (red bars), November (green bars) and December 2011 (purple bars) based on one observation per site. Sites 2A and 3B were not sampled during September and October 2011. The yellow shading is for Zone 1 sites, pink for Zone 2 sites and blue for Zone 3 sites.

pH

Subsurface and near bottom pH values were higher across all sites in November and December than October 2011 except for one site in Rodds Bay (Figures 10 and 11). Consistent with previous reports, no acidic pH values were found, with all pHs greater than 7.5. The lowest pH values from the November and December monitoring were found in the upper reaches of the Boyne estuary and in South Trees Inlet in the Boyne River (all Zone 3 sites). There was little difference between subsurface pH values and those measured near the bottom (compare Figure 10 and 11). The vast majority of the pH values measured from the four months of sampling were within the ranges reported for Gladstone waterways by Angel *et al*. (2010) of 7.73–8.24 from their sampling in December 2003 and 2004. Based on the available pH data there is no evidence to suggest that acid sulphate soils are deteriorating water quality in Gladstone waterways.

Subsurface and near bottom pH in the Boyne waterway ranged between 7.6–8.1 between September and December 2011. These pH values fall within the long-term range for the Boyne estuary (across all depths) of 7.2–8.8. The long-term (1994–2011) average pH (mean ± 1 standard deviation) for subsurface and near bottom levels is 8.0 ± 0.2. Subsurface and near bottom pH in the Calliope waterway ranged between 7.8–8.0 between September and December 2011. These pH values fall within the long-term range for the Calliope estuary (across all depths) of 7.1–8.7. The long-term (1994–2011) average pH (mean ± 1 standard deviation) for subsurface and near bottom levels are 8.0 ± 0.2.

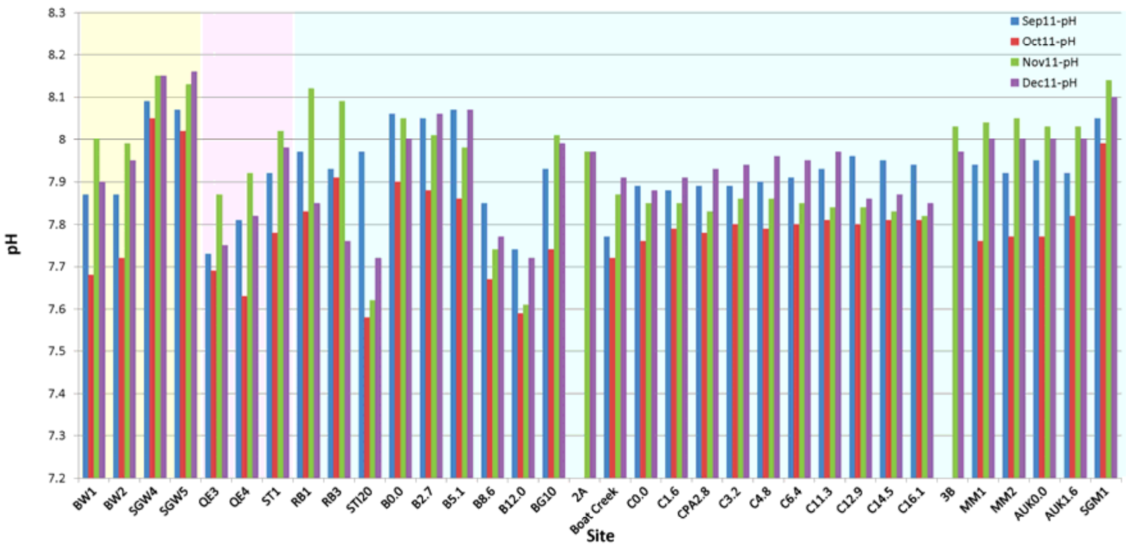

Figure 10: Subsurface pH values for sites from Gladstone waterways sampled in September (blue bars), October (red bars), November (green bars) and December 2011 (purple bars) based on one observation per site. Sites 2A and 3B were not sampled during September and October 2011. The yellow shading is for Zone 1 sites, pink for Zone 2 sites and blue for Zone 3 sites.

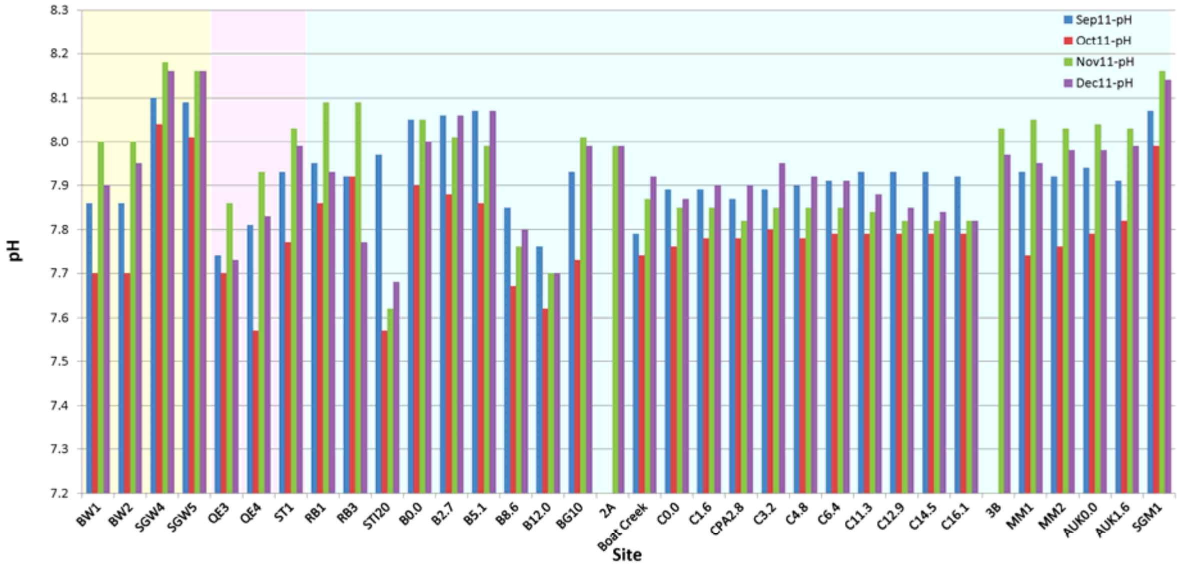

Figure 11: Near bottom pH values for sites from Gladstone waterways sampled in September (blue bars), October (red bars), November (green bars) and December 2011 (purple bars) based on one observation per site. Sites 2A and 3B were not sampled during September and October 2011. The yellow shading is for Zone 1 sites, pink for Zone 2 sites and blue for Zone 3 sites.

Chlorophyll-*a*

Monthly monitoring for November and December 2011 included chlorophyll-*a* sampling from the Gladstone Harbour, Rodds Bay reference sites, offshore spoil grounds and scallop processing sites in addition to the Boyne and Calliope estuaries (Figure 12). Chlorophyll-*a* is an indirect measure of phytoplankton abundance and high concentrations can be used to infer the presence of phytoplankton blooms within a waterway. However, it does not provide any information on the species composition of phytoplankton in the bloom. Throughout the Boyne and Calliope estuaries, the chlorophyll-*a* concentrations monitored during November and December were generally higher than during October 2011 and in many cases during September. All chlorophyll-*a* concentrations from both estuaries were within previously measured ranges from the long-term ambient monitoring program for central Queensland (DERM 2011a). Chlorophyll-*a* concentrations in the Boyne waterway ranged between 0.1–6.0 µg/L between September and December 2011. These concentrations fall within the long-term range for the Boyne estuary of 0.1–37.4 µg/L. The long-term (1994–2011) average chlorophyll-*a* concentration (mean ± 1 standard deviation) is 2.2 ± 3.1 µg/L. Chlorophyll-*a* concentrations in the Calliope waterway ranged between 0.1–7.6 µg/L between September and December 2011. These concentrations fall within the long-term range for the Calliope estuary of 0.2–45.3 µg/L. The long-term (1994–2011) average chlorophyll-*a* concentration (mean ± 1 standard deviation) for the Calliope estuary is 3.3 ± 3.2 µg/L.

Chlorophyll-*a* concentrations measured from the Harbour sites during November and December 2011 were mostly less than 4 µg/L. These concentrations would comply with Central Queensland Coast water quality guideline for marinas and boat harbours (DERM, 2009) and could be expected in waters adjacent to a major population centre such as Gladstone. The offshore sites (SGW4, SGW5 and SGM1) all had lower chlorophyll-*a* concentrations of <1 µg/L (Figure 12) consistent with generally lower nutrient concentrations in these waters (see Table 2). The chlorophyll-*a* concentrations measured at these offshore sites are not unusual within the Great Barrier Reef lagoon (Brodie *et al*. 2011).

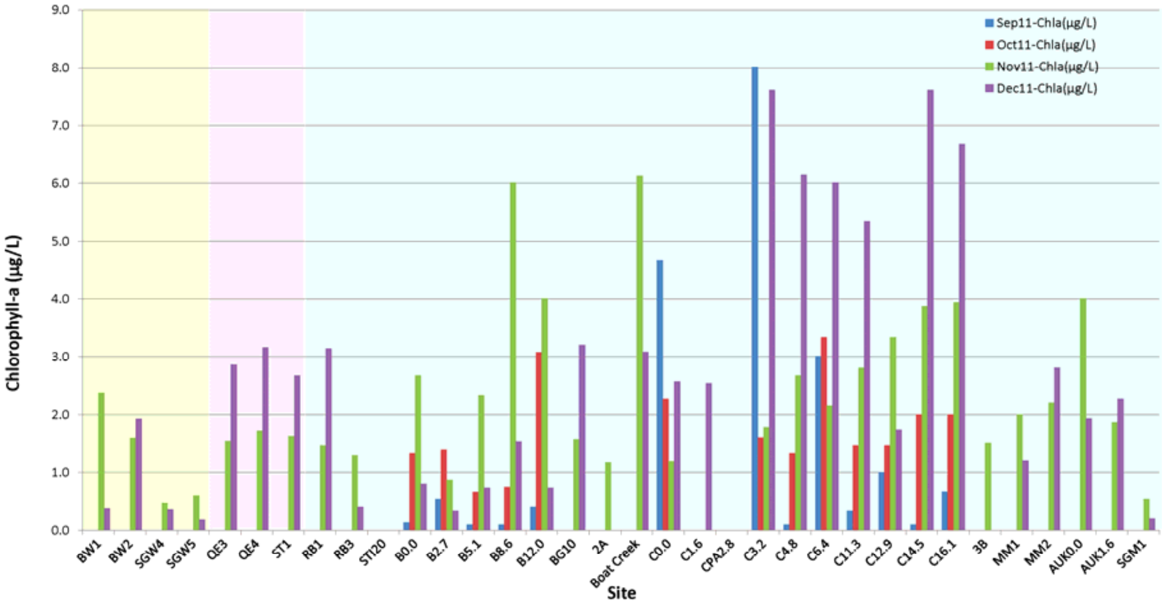

Figure 12: Subsurface chlorophyll-*a* values for sites from Gladstone waterways sampled in September (blue bars), October (red bars), November (green bars) and December 2011 (purple bars) based on one observation per site. Chlorophyll-*a* samples were not collected from Gladstone Harbour sites before November 2011. The yellow shading is for Zone 1 sites, pink for Zone 2 sites and blue for Zone 3 sites.

Nutrients

More sites in November showed a decrease in nutrient concentrations than those that increased. In December, more sites increased in nutrient concentration that those that decreased (Table 2). There was no obvious spatial pattern to these changes. A small number of sites had large increases in total nitrogen (TN) concentrations during December 2011, especially the Harbour site (BG10), a Rodds Bay reference site (RB1) and sites in the Boyne (B5.1) and Calliope estuaries (C12.9). All these nutrient spikes were predominantly composed of organic nitrogen as the inorganic ammonia (NH_3) and nitrogen oxide (NO_x) concentrations remained low (Table 2). There was a corresponding large increase in total phosphorus (TP) at the site in the Calliope estuary. This was also mostly composed of organic form of phosphorus as the concentration of the inorganic phosphorus (filterable reactive phosphorus) remained low (Table 2). It is possible that the higher rainfall in the region during December (Australian Bureau of Meteorology: http://www.bom.gov.au/climate/data/) washed organic material into the estuaries and coastal waters resulting in these sporadic, spikes in organic nutrients. It is unlikely that these transient, sporadic, spikes in organic nutrients are linked to the problems of fish health in the region.

At the offshore sites (sites SGM1 – Zone 3, sites SGW4 and SGW5 – Zone 1), all measured nutrient concentrations remained low, with the inorganic forms (ammonia, nitrogen oxides and filterable reactive phosphorus) being below the limit of reporting. Generally, nutrient concentrations within Gladstone waterways and its tributary estuaries were consistent with a slightly nutrient enriched system, which could be expected given the proximity of the city of Gladstone.

Ammonia concentrations were compared to the appropriate trigger value from the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC and ARMCANZ, 2000). The trigger values is 0.9 mg/L which is significantly higher than any of the concentrations measured in Gladstone waterways in both November and December 2011 (the highest ammonia concentration measured was 0.017 mg/L in the Boyne estuary in December). Given the magnitude of the difference between the measured ammonia and the trigger value, the ammonia present in Gladstone waterways poses a very low risk of toxicity to aquatic life.

Table 2: Concentrations (mg/L) of various forms of phosphorus and nitrogen measured in subsurface waters in Gladstone waterways during September, October, November and December 201
The yellow shading is for Zone 1 sites, pink for Zone 2 sites and blue for Zone 3 sites.

Site	Total Phosphorus mg/L as P				Filterable Reactive Phosphorus mg/L as P				Total Nitrogen mg/L as N				Ammonia Nitrogen mg/L as N				Nitrogen Oxides mg/L as N			
	Sep-11	Oct-11	Nov-11	Dec-11	Sep-11	Oct-11	Nov-11	Dec-11	Sep-11	Oct-11	Nov-11	Dec-11	Sep-11	Oct-11	Nov-11	Dec-11	Sep-11	Oct-11	Nov-11	Dec-11
BW1	-	-	0.05	0.025	-	-	0.005	0.006	-	-	0.3	0.17	-	-	0.003	0.011	-	-	0.01	0.016
BW2	-	-	0.017	0.020	-	-	0.003	0.005	-	-	0.17	0.17	-	-	< 0.002	0.008	-	-	0.004	0.033
SGW4	0.01	0.007	0.007	0.009	< 0.002	< 0.002	< 0.002	< 0.002	0.08	0.09	0.09	0.09	< 0.002	< 0.002	< 0.002	0.003	< 0.002	< 0.002	< 0.002	< 0.002
SGW5	0.009	0.007	0.007	0.008	< 0.002	< 0.002	< 0.002	< 0.002	0.07	0.11	0.09	0.09	< 0.002	< 0.002	< 0.002	0.003	< 0.002	< 0.002	< 0.002	< 0.002
QE3	0.03	0.024	0.023	0.024	0.006	0.003	0.003	0.002	0.17	0.26	0.15	0.19	0.004	0.002	0.005	0.005	0.006	0.009	0.003	0.007
QE4	0.035	0.018	0.030	0.020	0.008	0.003	0.003	0.003	0.22	0.17	0.19	0.18	0.008	< 0.002	0.003	0.006	0.009	0.013	0.004	0.013
ST1	0.039	0.023	0.035	0.033	0.007	0.003	0.002	0.004	0.18	0.20	0.18	0.20	0.009	< 0.002	< 0.002	0.009	0.016	0.009	0.005	0.014
RB1	0.011	0.011	0.012	0.027	< 0.002	< 0.002	< 0.002	< 0.002	0.1	0.15	0.16	0.90	< 0.002	< 0.002	< 0.002	0.007	< 0.002	< 0.002	< 0.002	0.003
RB3	0.011	0.012	0.011	0.019	< 0.002	< 0.002	< 0.002	< 0.002	0.12	0.18	0.14	0.20	< 0.002	< 0.002	0.003	0.012	< 0.002	< 0.002	0.009	0.004
B5.1	0.009	0.049	0.011	0.015	< 0.002	< 0.002	< 0.002	< 0.002	0.11	0.56	0.18	0.52	< 0.002	0.006	< 0.002	0.002	< 0.002	0.005	< 0.002	< 0.002
B12.0	0.017	0.019	0.028	0.031	0.003	< 0.002	0.003	0.007	0.25	0.32	0.33	0.28	0.009	0.007	0.004	0.017	0.003	0.005	0.003	0.013
BG10	0.05	0.036	0.021	0.038	0.007	0.004	0.003	0.004	0.23	0.23	0.15	0.97	0.012	0.005	0.005	0.010	0.015	0.019	0.005	0.014
2A	-	-	0.033	-	-	-	0.003	-	-	-	0.25	-	-	-	0.004	-	-	-	0.005	-
Boat Creek	0.038	0.029	0.14	0.037	0.006	0.004	0.006	0.002	0.19	0.19	0.68	0.22	0.008	0.004	0.008	0.004	0.011	0.014	0.017	< 0.002
C12.9	0.019	0.018	0.020	0.068	0.008	0.007	0.007	0.031	0.15	0.18	0.23	0.45	0.003	0.002	< 0.002	0.008	0.002	< 0.002	0.002	0.022
3B	-	-	0.058	-	-	-	0.002	-	-	-	0.14	-	-	-	< 0.002	-	-	-	0.004	-
MM1	0.025	0.016	0.012	0.017	0.007	0.004	< 0.002	0.004	0.14	0.16	0.12	0.16	0.012	0.006	0.004	0.007	0.014	0.017	0.006	0.012
MM2	0.03	0.018	0.013	0.017	0.007	0.004	0.002	0.003	0.15	0.20	0.12	0.17	0.013	0.008	< 0.002	0.006	0.015	0.015	0.004	0.011
Auk0.0	0.033	0.025	0.015	0.023	0.006	0.004	0.002	0.004	0.16	0.18	0.15	0.17	0.011	0.007	0.006	0.009	0.015	0.018	0.004	0.013
Auk1.6	0.027	0.021	0.016	0.018	0.007	0.005	0.002	0.003	0.14	0.19	0.15	0.16	0.013	0.006	0.004	0.006	0.015	0.019	0.004	0.013
SGM1	0.009	0.007	0.008	0.008	< 0.002	< 0.002	< 0.002	< 0.002	0.07	0.12	0.10	0.10	< 0.002	< 0.002	< 0.002	0.002	< 0.002	< 0.002	< 0.002	< 0.002

Blue record for November and December means that the concentration decreased compared with result of previous month.
Green record for November and December means that the concentration increased compared with result of previous month.
Black record for November and December means no change compared with result of previous month or result of previous month not available.
Samples analysed by NATA accredited laboratory
"<" indicates that the concentration is less than the level of reporting (LOR) which is the lowest concentration that the laboratory will confidently state as being measured.
"-" indicates that the result is not available.

Comparison of Dissolved Metal Concentrations from September, October, November and December 2011

Comparison of the dissolved concentrations for the 18 metals and metalloids collected at all the sites monitored for metals since September are presented as graphs in Appendix 2 and as a Table in Appendix 3. In general, the dissolved concentrations of metals found in November and December 2011 were less than or equal to those measured in October 2011, with the highest overall dissolved metal concentrations detected in September 2011.

No antimony, selenium or tin were detected at or above the LOR at any site at any month (see Appendices 2 and 3). Dissolved cadmium, chromium, silver and thallium were detected at a number of sites in September 2011, but have not been detected since (see Appendices 2 and 3). Cobalt was detected at five sites in September (BW1 and BW2 from Zone 1 and QE3 and QE4 from Zone 2 and C6.4 from Zone 3), and then only at one site in November (Boat Creek, Zone 3) and December (QE3 from Zone 2).

Arsenic was detected at all sites in all months, and was slightly elevated in September 2011 at all sites apart from RB3 and Boat Creek compared to the concentrations in subsequent months. Dissolved iron was detected at all 20 sites in September 2011 compared to one site in October 2011 (SGW5 from Zone 1), seven sites in November 2011 (BW1, BW2 and SGW5 from Zone 1 and B5.1, BG10, C6.4 and MM2 from Zone 3) and two sites in December 2011 (QE4 from Zone 2 and SGM1 from Zone 3) (Appendices 2 and 3). Dissolved lead was detected at the majority of sites monitored in September 2011 (in all three Zones), but only a few sites in October, November and none in December.

Dissolved aluminium was detected at 18 of the 19 monitoring sites sampled for metals in November 2011 (apart from C1.6) compared to a small number of sites in other months (Appendix 3). In September 2011 there were four sites (QE4, ST1, BG10, and MM1) with detected concentrations of dissolved aluminium of 20 µg/L and two sites (QE3 and C6.4) having concentrations of 70 and 80 µg/L, respectively; one site in October 2011 (MM2) having a measured concentration of 20 µg/L; and December 2011 where two sites (MM1 and ST1) had concentrations of 30 and 10 µg/L, respectively.

Boron, molybdenum, manganese and vanadium were detected in all or nearly all sites at all times but there was no consistent pattern in the concentrations.

Measured dissolved zinc concentrations in October and November were not presented as the samples were found to have been possibly contaminated due to the presence of zinc in blank samples. In September 12 sites from all three Zones had detectable concentrations of dissolved zinc while in December only 2 sites had detectable concentrations both from Zone 3.

Measured copper concentrations for November 2011 (total and dissolved) are not presented here as there was possible evidence of copper contamination due to presence of copper in blank samples. Copper was detected at approximately half the sites in September, October and December. The actual sites where copper was detected varied from month to month. Copper was not detected at any of the spoil ground sites which are further out to sea (SGW4, SGW5 or SGM1) or reference site RB3 in any month.

Dissolved nickel was detected at 14 sites in September, 11 sites in October and 9 sites December, but was not detected at any sites in November 2011. Nickel was not detected at any of the spoil ground sites which are further out to sea (SGW4, SGW5 or SGM1), at the Boyne River site (B5.1) or reference site RB1 in any month. Nickel was consistently detected at seven sites in the three months it appeared. These sites were in all three zones; two sites in Zone 1 (BW1, BW2), three sites in Zone 2 (QE3, QE4, ST1) and two sites in Zone 3 (BG10 and C6.4).

In summary, dissolved metals were detected across Gladstone waterways in fluctuating concentrations. Dissolved arsenic, lead and iron were generally elevated in concentration in September 2011 compared to later months at a number of sites. The number of sites where aluminium was detected was the highest in November 2011, although the highest concentrations (at a smaller number of sites) were found in September 2011. The detection of dissolved metals is not necessarily of concern. The next section compares the concentration of dissolved metals with the Australian and New Zealand trigger values (ANZECC and ARMCANZ, 2000).

Comparison of Dissolved Metal Concentrations at Gladstone Waterways Against the Australian and New Zealand Trigger Values

As in the previous DERM report (DERM, 2011c) the concentrations of dissolved aluminium, cadmium, copper, nickel and zinc were compared with the dissolved metal results reported by an earlier CSIRO study (Angel *et al*. 2010) and national and international studies of metal contaminants in estuaries (Denton & Burdon-Jones, 1986;Benoit *et al*., 1994; Bruland *et al*., 1994; Comber *et al*., 1995; Fabris & Monahan, 1995; Laslett & Balls, 1995; Mackey *et al*., 1996; Sañudo-Wilhelmy *et al*., 1996;Owens & Balls, 1997; Apte and Day, 1998; Munksgaard & Parry, 2001; Maceky *et al*., 2002; Hatje *et al*., 2003; Baeyens *et al*., 2005) (Appendix 5). Differences in the limit of reporting between the studies limit the comparability of the metal results. However, some comparisons have been made to put the current results into context.

The range of dissolved aluminium concentrations measured by DERM (September to December, 2011) at offshore sites, in the Harbour and in The Narrows were all within the ranges of values measured in the same categories of sites in December 2003 and 2004 by CSIRO (unpublished data provided by CSIRO). However, the dissolved aluminium concentrations measured by DERM in rivers are greater than the one value measured in the Calliope River by CSIRO of 16.5 µg/L (unpublished data provided by CSIRO). In the majority of other cases, where comparisons could be made, the dissolved metal concentrations reported by DERM (DERM, 2011b, c, and the current study) are generally higher than those reported by CSIRO (Angel *et al*., 2010). Nonetheless, they were within the range of concentrations reported in other estuaries throughout the world (Appendix 5) and therefore are not atypical by world standards. Four metals showed levels in Gladstone that were significantly lower that elsewhere: the maximum dissolved concentrations of cadmium, copper, nickel and zinc found elsewhere in the world were approximately 12 % higher and three-times, seven-times and two-times higher, respectively, than those at Gladstone waterways.

The dissolved concentrations of copper, nickel and zinc measured in Gladstone waterways were invariably higher than those reported for the Great Barrier Reef (Appendix 5). However, this is to be expected as Gladstone Harbour is a busy commercial port near an industrialised city. The dissolved concentrations of cadmium measured in Gladstone waterways were within the range of values measured in the Great Barrier Reef lagoon. Data was not comparable for aluminium and lead (Appendix 5).

In November and December, only three metals (aluminium, copper and zinc) had dissolved concentrations that exceeded the Australian and New Zealand trigger values (ANZECC and ARMCANZ, 2000) (Appendix 2).

Metals that Exceed the Australian and New Zealand Trigger Values

The Australian and New Zealand water quality guideline trigger values (ANZECC and ARMCANZ, 2000) were derived using toxicity data that measure effects of chemicals that are likely to affect the long-term sustainability of species such as reduced reproduction, reduced growth and reduced mobility (hence organisms are more susceptible to predation and starvation) (Warne, 1998; ANZECC and ARMCANZ, 2000; Warne 2001). Symptoms such as the skin lesions, skin flushing of the abdomen and parasitic infections that have been reported for the fish in Gladstone waterways are not considered in setting the trigger values. The information currently available does not demonstrate a link between the elevated metal concentrations and fish concerns in Gladstone.

Aluminium

Dissolved aluminium concentrations exceeded the Australian and New Zealand trigger value for aluminium (ANZECC and ARMCANZ, 2000) at 18 of the 19 sites sampled for metals in November 2011 (Figure 13 and Appendix 3). The highest measured concentration of dissolved aluminium in November 2011 was 50 µg/L at SGW4 in Zone 1 (Appendix 3). Aluminium concentrations at other sites in November ranged from 10–30 µg/L across all three zones. During December, only two sites (MM1 of Zone 3 and ST1 of Zone 2) had detected concentrations of aluminium that exceeded the trigger value. Where results indicated concentrations of dissolved aluminium were less than the LOR, it was not possible to assess whether the TV had been exceeded or not, as the LOR for aluminium was greater than the TV. The dissolved aluminium concentration at MM1 has exceeded the trigger value in three out of the four months sampled. The persistent exceedances of the aluminium trigger values at this site may indicate there is a source of aluminium nearby. However, as has been noted in previous reports (DERM 2011b and c), CSIRO studies undertaken in December 2003 and 2004 measured concentrations of dissolved aluminium up to 83 µg/L (unpublished data provided by CSIRO) which is similar to concentrations measured by DERM in 2011. Monthly dissolved metal and metalloid sampling undertaken by GHD between May and August 2009 at 12 sites in the Gladstone Harbour (GHD 2009) reported concentrations of up to 210 µg/L with half the sites having concentrations of at least 50 µg/L. These data indicate that dissolved aluminium concentrations higher than those measured in November and December 2011 have been reported previously.

Fluctuations in the occurrence of aluminium across Gladstone Harbour have also been noted historically. Monthly dissolved metal and metalloid sampling was undertaken by GHD between May and August 2009 at 12 sites in the Gladstone Harbour (GHD 2009). Dissolved aluminium was not detected during May, June and July 2009 at any of the 12 sites monitored, yet in August 2009 dissolved aluminium was detected at all sites at concentrations ranging from 10 to 210 µg/L. Five of the six sites from the GHD study with the highest dissolved aluminium concentrations (i.e. ≥50 µg/L) were located in what would be classed as Zones 1 and 2 in the DERM studies. The other site would be classed as a Zone 3 site. The GHD data indicate large scale fluctuations in dissolved aluminium concentrations have occurred throughout Gladstone waterways historically and before the current dredging associated with the establishment of the LNG plants on Curtis Island commenced. As well, the aluminium concentrations detected in November 2011 were found at the majority of sites in Gladstone waterways (including reference sites and across all zones). These findings further support the previous conclusion that the large-scale variation in aluminium concentrations observed in Gladstone Harbour are unlikely to be a result of dredging activities. There are a number of alternate sources of aluminium in Gladstone waterways principally natural tidal induced re-suspension of sediments (aluminosilicate minerals) and the aluminium refining and smelting operations.

While dissolved aluminium concentrations have exceeded the trigger value, it should be noted that concentrations of dissolved aluminium measured in Gladstone waterways since September 2011 (DERM et al. 2011b, c and the current report) are consistent with those reported by CSIRO for samples collected in December 2003 and 2004 (Angel et al. 2010) and by GHD as part of the Environmental Impact Statement for the Western Basin Port Development (GHD 2009) collected in May and August 2009. Both the CSIRO (Angel et al. 2010) and GHD (GHD 2009) studies were undertaken before the current dredging of the Western Basin began. It is therefore likely that the same level of environmental protection would have been provided to aquatic ecosystems since September 2011 as in these earlier periods. If the current concentrations of aluminium caused or contributed to the current fish health issues, then it would also be expected that such fish health issues would have occurred previously.

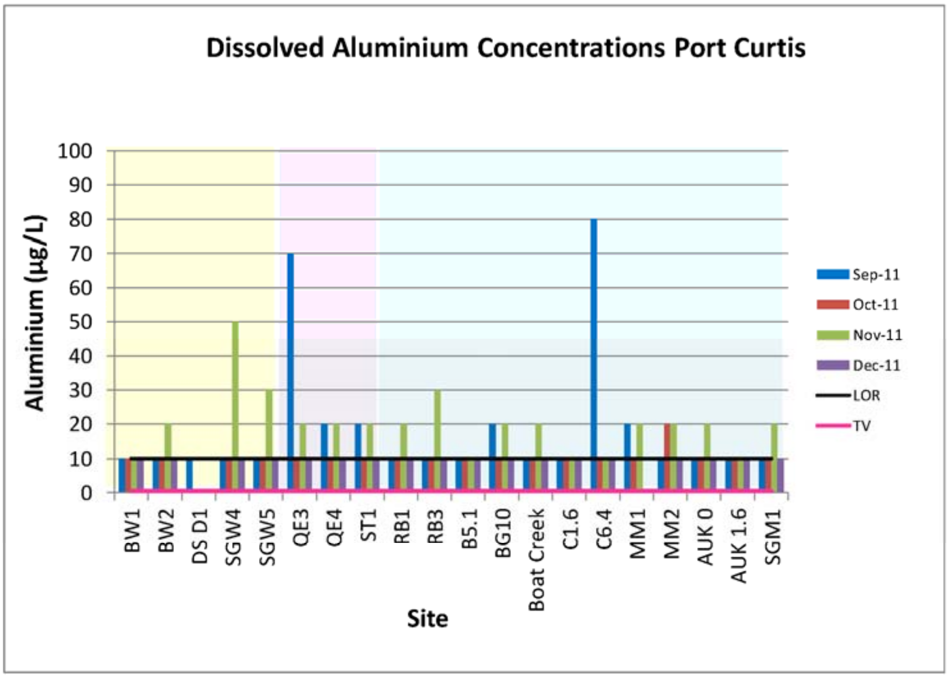

Figure 13: Measured concentrations of dissolved aluminium in water samples collected in September, October, November and December 2011 from Gladstone waterways. Yellow shading indicates Zone 1 sites, pink, Zone 2 sites and blue, Zone 3 sites. TV (red line) indicates the Australian and New Zealand Water Quality Guidelines Cu trigger value and LOR (blue line) indicates the limit of reporting (LOR).

Copper

No copper data are presented for the November sampling round due to possible contamination issues. Quantifiable concentrations of copper (i.e., concentrations greater than the limit of reporting) were, however, measured at 8 of the 19 sites surveyed in December 2011 (Appendix 3) and at 4 of these sites the Australian and New Zealand trigger values (ANZECC and ARMCANZ 2000) were exceeded (Figure 14). All of these four sites were in Zone 3 (sites MM1, MM2, AUK 0.0 and BG10). Two of these sites were in the Gladstone Marina, one was at the mouth of Auckland Creek and one site was in Gladstone Harbour.

In December 2011 the dissolved copper concentrations at four sites exceeded the trigger value (sites MM1, MM2, AUK 0.0, BG10) compared to seven sites (BW2, QE4, MM1, MM2, AUK1.6 Boat Creek, C1.6) in October 2011 and three sites in September 2011 (B5.1, Boat Creek, MM1). In December sites MM1, AUK0.0 and Boat Creek had concentrations of 2 µg/L, and MM2 had a concentration of 3 µg/L.

Copper concentrations measured in the Gladstone Marina (sites MM1 and MM2) have exceeded the trigger value in two of the three months where data are available. Copper was detected at MM1 in September, October and December at 2 µg/L, and at MM2 in October and December at 3 µg/L. Copper is widely used an algicide and has been used as an antifoulant for ships and marine infrastructure (Dafforn *et al*. 2011), and the elevated concentrations of copper in the marina may reflect the high boat traffic in this area. There were no patterns in the detection of copper above the trigger value at other sites, apart from Boat Creek where copper concentrations exceeded trigger value in both September and October.

The level of protection for slightly to moderately impacted ecosystems is 95% of species. At concentrations of 2–3 µg/L, it was estimated that between 90% and 92% of species[1] would be protected from experiencing sub-lethal chronic effects such as reduced reproduction, reduced growth and reduced mobility (DERM 2012 b, c).

[1] The Australian and New Zealand TV for copper in marine waters was derived using the BurrliOZ Species Sensitivity Distribution (SSD) method (Campbell *et al*., 2000) and therefore the percentage of species that should theoretically be protected at the measured dissolved copper concentrations could be determined.

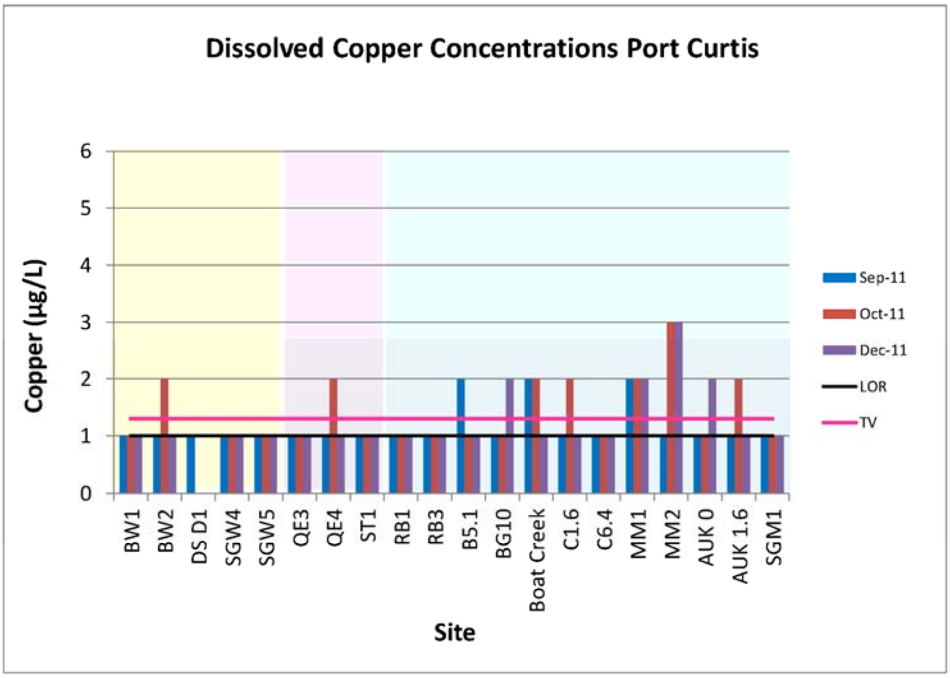

Figure 14: Measured concentrations of dissolved copper (Cu) in water samples collected from Gladstone waterways in September, October, November and December 2011. Yellow shading indicates Zone 1 sites, pink, Zone 2 sites and blue, Zone 3 sites. TV (red line) indicates the Australian and New Zealand Water Quality Guidelines Cu trigger value and LOR (blue line) indicates the limit of reporting (LOR).

Zinc

The Australian and New Zealand trigger value (ANZECC and ARMCANZ, 2000) for zinc was not exceeded at any site during September or December (Figure 15) which were the only months with dissolved zinc concentration data. As measured dissolved zinc concentrations were not available from the October and November 2011 sampling rounds, due to possible contamination, total recoverable zinc concentrations were compared to the trigger values (ANZECC and ARMCANZ, 2000) (Appendix 4). Total zinc concentrations in October and November 2011 did not exceed the trigger value at any site except for Boat Creek in November 2011 (See Appendix 4). The use of total metal concentrations to assess potential impacts will most probably overestimate the impacts as total metal concentrations contain both particulate and dissolved metals and total metals are generally not biologically available

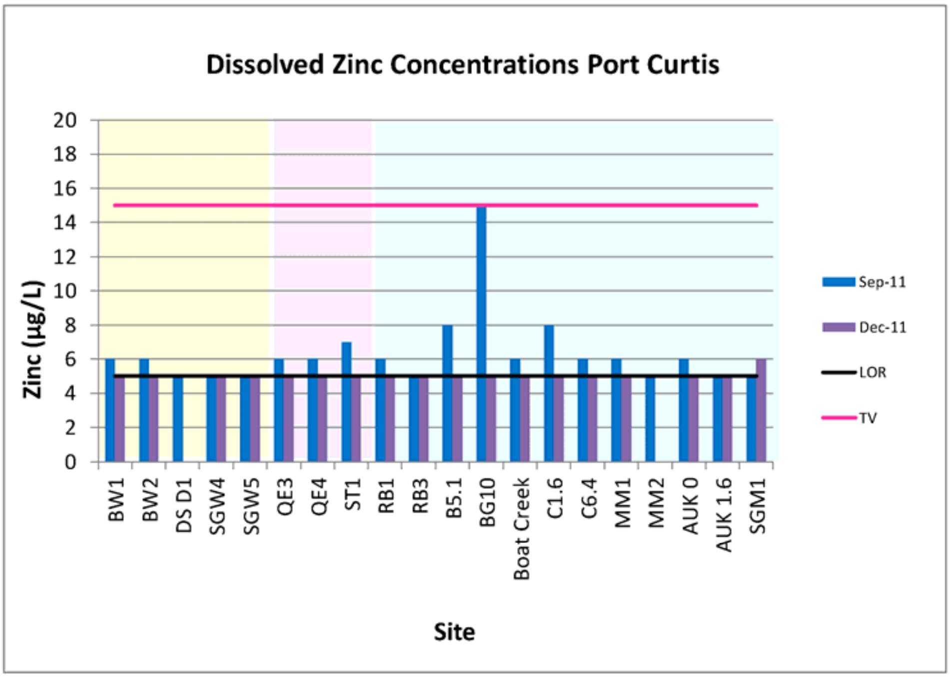

Figure 15: Measured concentrations of dissolved Zinc (Zn) in water samples collected from Gladstone waterways in September and December 2011. Yellow shading indicates Zone 1 sites, pink, Zone 2 sites and blue, Zone 3 sites. TV (red line) indicates the Australian and New Zealand Water Quality Guidelines Zn trigger value and LOR (blue line) indicates the limit of reporting (LOR).

Spatial Distribution of Sites that Exceed the Trigger Values for Metals

The sites that exceed the Australian and New Zealand trigger values (ANZECC and ARMCANZ, 2000) from the November and December sampling rounds are presented in Figures 16 and 17, respectively. Aluminium exceeded the trigger values at all sites (including the reference sites) and all Zones apart from C1.6 in November 2011. However, in December 2011 aluminium only exceeded trigger values at sites ST1 (Zone 2) and MM1 (Zone 3). Copper exceeded the trigger values at four sites in December 2011 (BG10 from Zone 2 and MM1, MM2 and Auk0.0 from Zone 3). As noted in DERM (2011 c), it is not unexpected to detect relatively higher copper concentrations in areas with high boating activity and little water exchange, as copper is used as an antifoulant for boats, and copper toxicity has been identified as a potential problem in these types of waters (Dafforn *et al*. 2011).

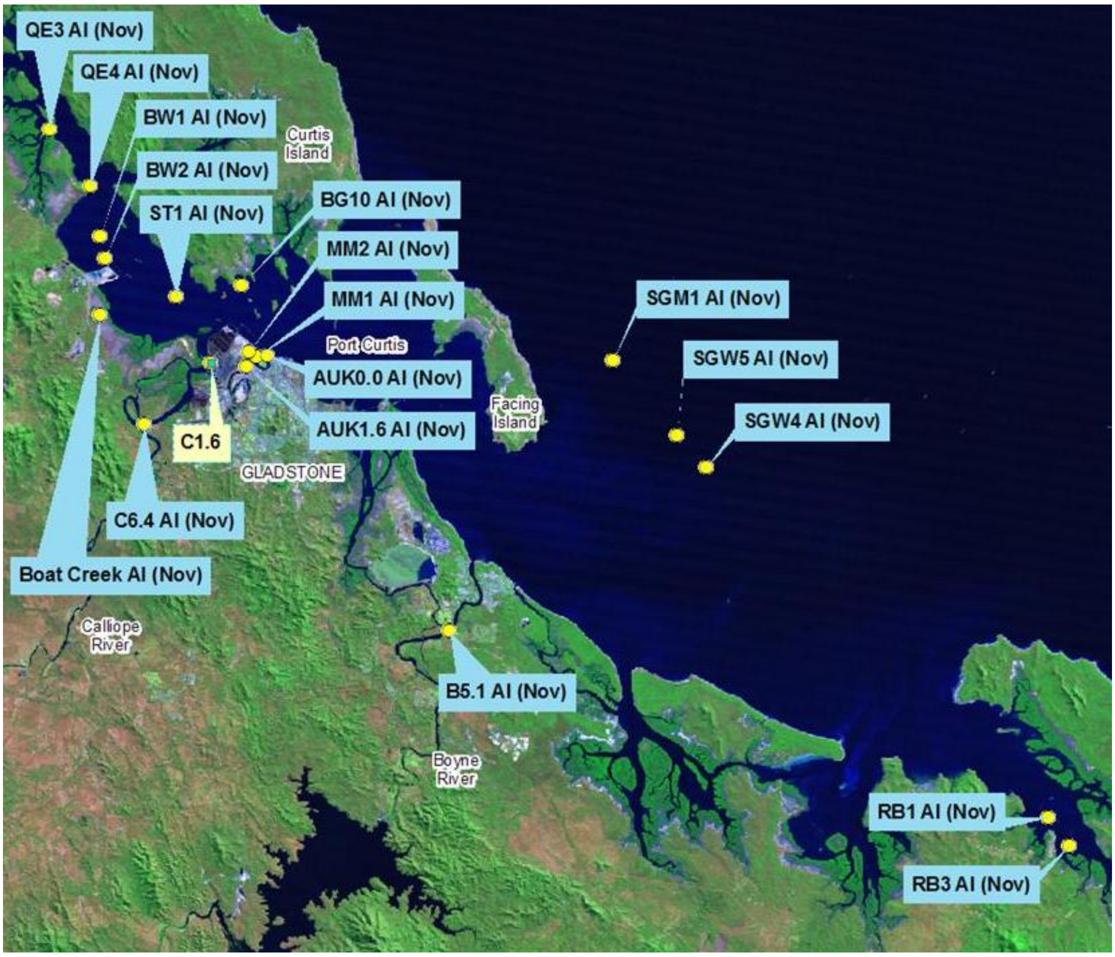

Figure 16: Sites in Gladstone waterways where dissolved metal concentrations exceeded the Australian and New Zealand water quality guidelines trigger values (TVs) in November 2011. Sites where values were below TV are white; sites that exceeded the TVs are blue. Metals within the site flags are the metals that exceeded the TVs (aluminium = Al).

Figure 17: Sites in Gladstone waterways where dissolved metal concentrations exceeded the Australian and New Zealand water quality guidelines trigger values (TVs) in December 2011. Sites where values were below TV are white; sites that exceeded the TVs are blue. Metals within the site flags are the metals that exceeded the TVs (aluminium = Al).

Dredging and Tidal Influences

Dredging can lead to the re-suspension of sediments, decreases in pH and increases in dissolved metal concentrations particularly if the sediments contain acid sulphate soils or potential acid sulphate soils. No decreased pH values at sites close to dredging or dredging associated activities have been observed. Visual observation indicates that plumes of re-suspended dredging sediment only persist, at least visually from the surface, for very limited distances. It is very difficult to plausibly attribute the elevation of aluminium concentrations that occurred in November at all monitored sites within Gladstone waterways (a distance of approximately 60 kms), including the reference sites at Rodds Bay, to dredging.

Conclusions

There was no discernable evidence of atypical physical-chemical parameters (turbidity, dissolved oxygen, temperature, pH, salinity, nutrients) or chlorophyll-*a* that could be attributed to dredging, nor that these measures were related to the fish health issues at Gladstone. Very high turbidity (>250 NTU) was measured at Boat Creek (Zone 3) during November 2011 and was observed to be caused by tidal currents resuspending sediments off the adjacent intertidal flats. This indicates that transient, localized high turbidity levels occur naturally within Gladstone Harbour. High concentrations of organic nutrients (mainly nitrogen) were also measured at a few sites across the region in December 2011. This may have been due to the increased rainfall during December washing organic matter into the estuaries and coastal waters.

Dissolved metal concentrations were generally lower in October, November and December 2011 compared to September 2011, with a number of metals (dissolved cadmium, chromium, silver and thallium) not being detected in samples collected since the September 2011 sampling round. Dissolved aluminium concentrations exceeded the trigger value throughout Gladstone waterways in November 2011, but only exceeded at two sites in December 2011, indicating a short term elevation. As dissolved aluminium concentrations were found to be elevated across all Zones (including reference sites), the measured concentrations are unlikely to be due to dredging. Copper concentrations exceeded the trigger value in the Gladstone Marina in three out of four months measurements were made, and is probably a result of the boat traffic in the marina. There remains no clear association between metal concentrations and the fish health issues at Gladstone waterways.

To obtain copies of data used in this report

Send an email to water.data@derm.qld.gov.au

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Appendices

Appendix 1

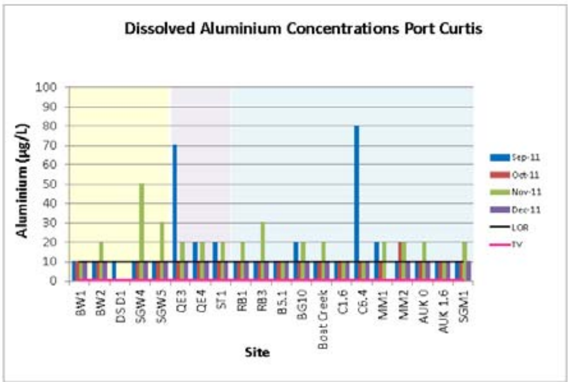
Summary of metal measured in water samples in both the DERM and Gladstone Port Corporation (GPC) sampling programs, the limit of reporting (LOR) for each metal and the ANZECC and ARMCANZ 2000 trigger value (TV) for each metal (where available).

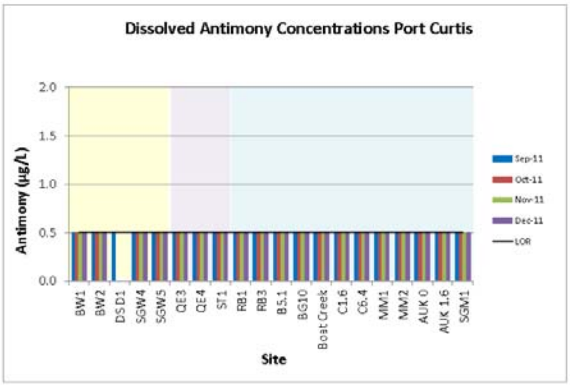
Metal	DERM Sampling Program, September 2011	GPC Monitoring Program	LOR	TV
aluminium	TM/DM	TM	10	0.5
antimony	TM/DM		0.5	270
arsenic	TM/DM	TM	0.5	2.3
boron	TM/DM		100	5100
cadmium	TM/DM	TM	0.2	0.7
chromium	TM/DM	TM (Cr III)	0.5	4.4 (Cr VI); 27.4 (Cr III)
cobalt	TM/DM	TM	0.2	1
copper	TM/DM	TM	1	1.3
iron	TM/DM	TM	5	300
lead	TM/DM	TM	0.2	4.4
manganese	TM/DM	TM	0.5	80
molybdenum	TM/DM	TM	0.1	23
nickel	TM/DM	TM	0.5	7
selenium	TM/DM	TM	2	3
silver	TM/DM	TM	0.1	1.4
thallium	TM/DM		0.1	17
tin	TM/DM		5	10
vanadium	TM/DM	TM	0.5	100
zinc	TM/DM	TM	5	15

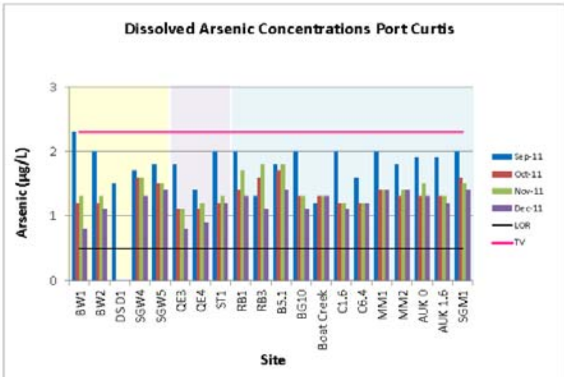
Note: TM stands for total recoverable metal; DM stands for dissolved metal.

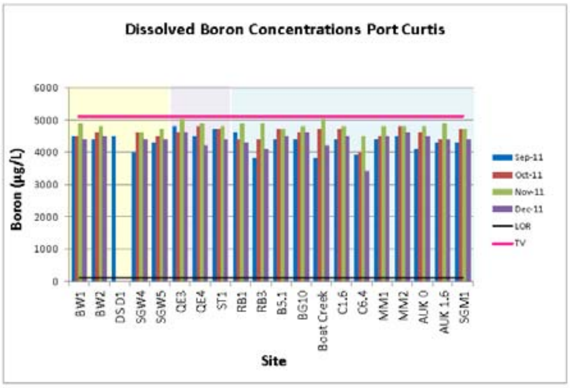
Appendix 2

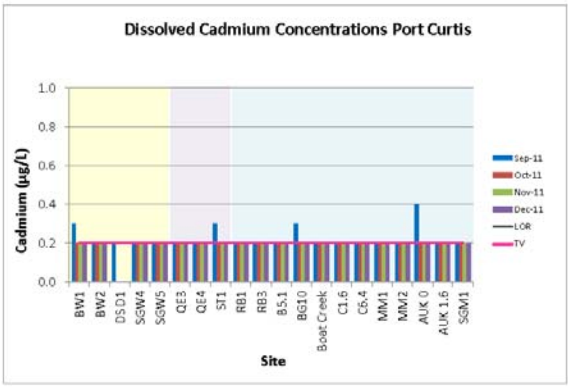
Dissolved metal concentrations from samples collected during the weeks of 26 September 2011, 24 October 2011, 21 November 2011 and 12 December 2011, compared with trigger values (TV) from the ANZECC and ARMCANZ Water Quality Guidelines and the limit of reporting (LOR) which is the lowest concentration of the metal that the laboratory can confidently state that the metal occurs. Not all metals have TVs in the guidelines. Yellow panels indicate sites in Zone 1, pink panels indicate sites in Zone 2 and blue panels indicate sites in Zone 3. The trigger value for antimony is 270 µg/L.

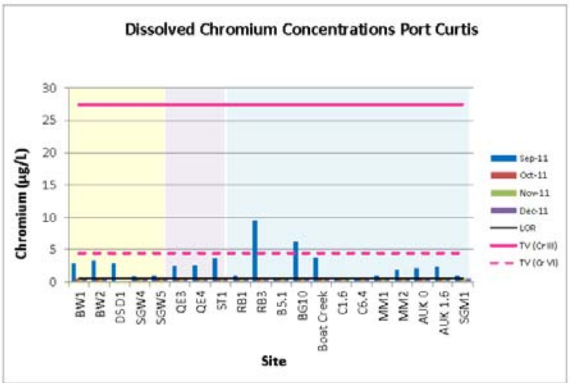


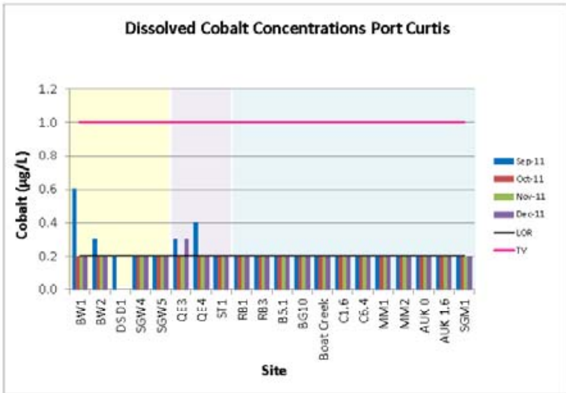


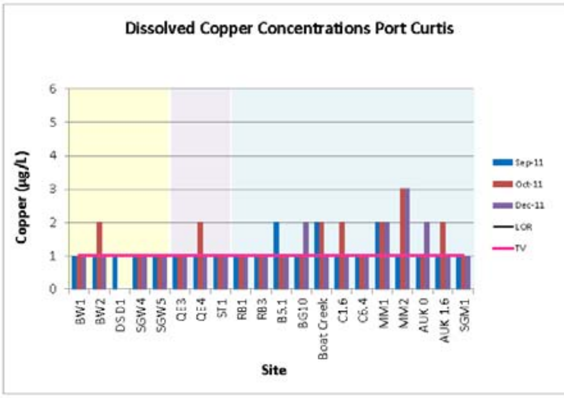


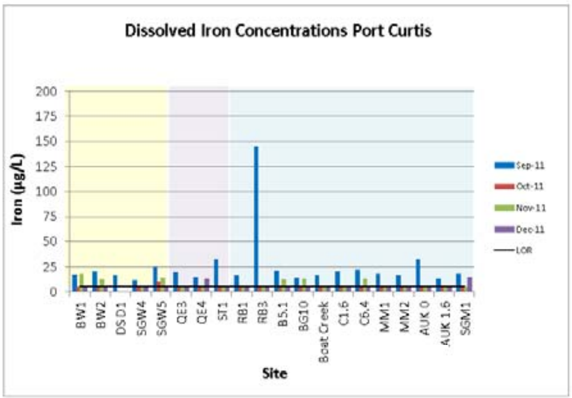


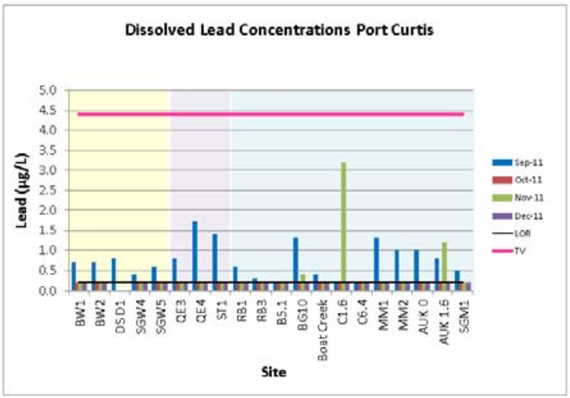


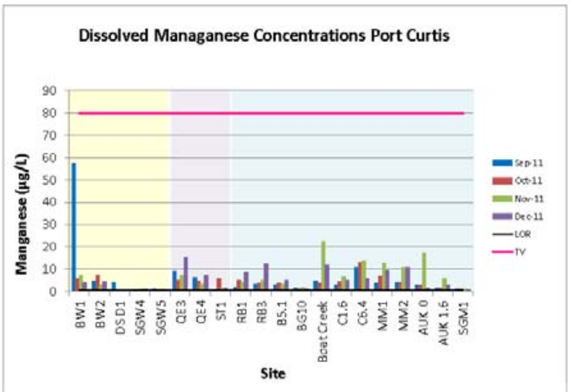


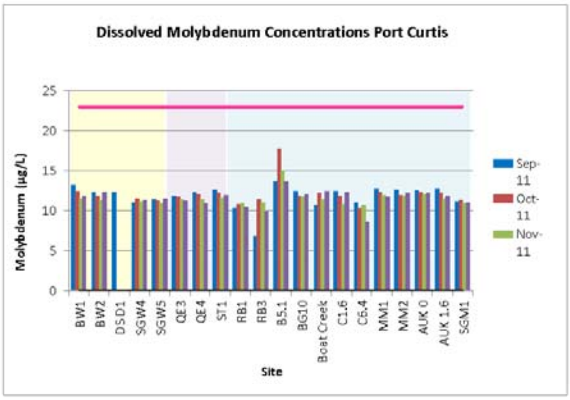

Dissolved Cobalt Concentrations Port Curtis
Cobalt (µg/L)
Site
BW1 BW2 DS D1 SGW4 SGW5 QE3 QE4 ST1 RB1 RB3 B5.1 BG10 Boat Creek C1.6 C6.4 MM1 MM2 AUK 0 AUK 1.6 SGM1
Sep-11
Oct-11
Nov-11
Dec-11
LOR
TV

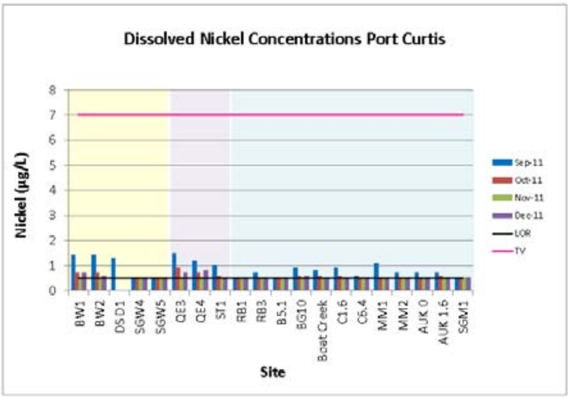

Dissolved Copper Concentrations Port Curtis
Copper (µg/L)
Site
BW1 BW2 DS D1 SGW4 SGW5 QE3 QE4 ST1 RB1 RB3 B5.1 BG10 Boat Creek C1.6 C6.4 MM1 MM2 AUK 0 AUK 1.6 SGM1
Sep-11
Oct-11
Dec-11
LOR
TV

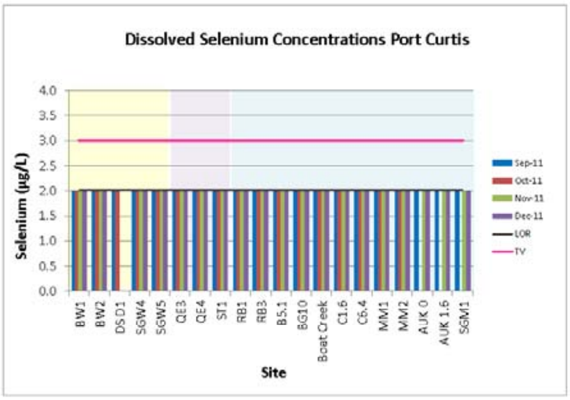

Dissolved Iron Concentrations Port Curtis
Iron (µg/L)
Site
BW1 BW2 DS D1 SGW4 SGW5 QE3 QE4 ST1 RB1 RB3 B5.1 BG10 Boat Creek C1.6 C6.4 MM1 MM2 AUK 0 AUK 1.6 SGM1
Sep-11
Oct-11
Nov-11
Dec-11
LOR

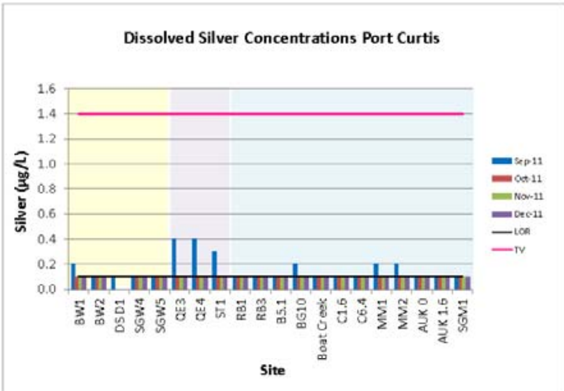

Dissolved Lead Concentrations Port Curtis
Lead (µg/L)
Site
BW1 BW2 DS D1 SGW4 SGW5 QE3 QE4 ST1 RB1 RB3 B5.1 BG10 Boat Creek C1.6 C6.4 MM1 MM2 AUK 0 AUK 1.6 SGM1
Sep-11
Oct-11
Nov-11
Dec-11
LOR
TV

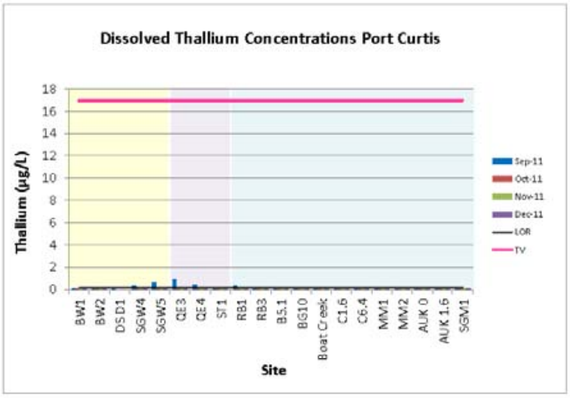

Dissolved Managanese Concentrations Port Curtis
Manganese (µg/L)
Site
BW1 BW2 DS D1 SGW4 SGW5 QE3 QE4 ST1 RB1 RB3 B5.1 BG10 Boat Creek C1.6 C6.4 MM1 MM2 AUK 0 AUK 1.6 SGM1
Sep-11
Oct-11
Nov-11
Dec-11
LOR
TV

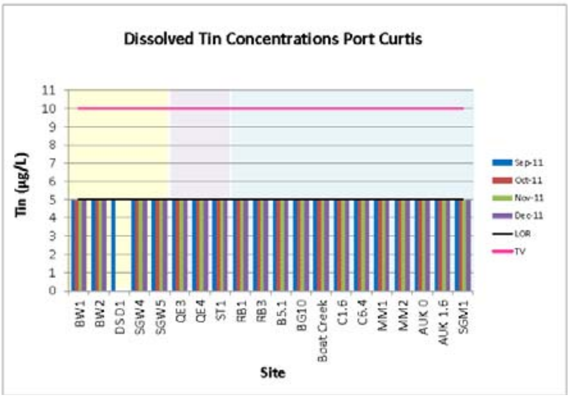

Dissolved Molybdenum Concentrations Port Curtis
Molybdenum (µg/L)
Site
BW1 BW2 DS D1 SGW4 SGW5 QE3 QE4 ST1 RB1 RB3 B5.1 BG10 Boat Creek C1.6 C6.4 MM1 MM2 AUK 0 AUK 1.6 SGM1
Sep-11
Oct-11
Nov-11

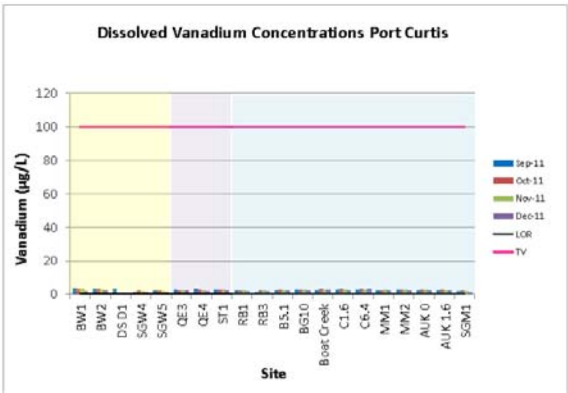

Dissolved Nickel Concentrations Port Curtis
Nickel (µg/L)
Site
Sep-11
Oct-11
Nov-11
Dec-11
LOR
TV
BW1
BW2
DS D1
SGW4
SGW5
QE3
QE4
ST1
RB1
RB3
B5.1
BG10
Boat Creek
C1.6
C6.4
MM1
MM2
AUK 0
AUK 1.6
SGM1

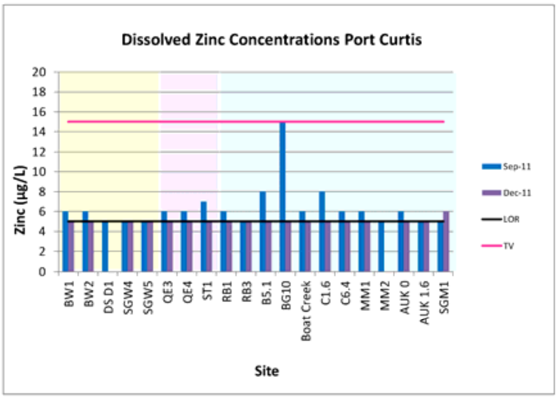

Dissolved Selenium Concentrations Port Curtis
Selenium (µg/L)
Site


Dissolved Silver Concentrations Port Curtis
Silver (µg/L)
Site


Dissolved Thallium Concentrations Port Curtis
Thallium (µg/L)
Site


Dissolved Tin Concentrations Port Curtis
Tin (µg/L)
Site


Dissolved Vanadium Concentrations Port Curtis
Vanadium (µg/L)
Site



Dissolved Zinc Concentrations Port Curtis
Zinc (µg/L)
20
18
16
14
12
10
8
6
4
2
0
BW1
BW2
DS D1
SGW4
SGW5
QE3
QE4
ST1
RB1
RB3
B5.1
BG10
Boat Creek
C1.6
C6.4
MM1
MM2
AUK 0
AUK 1.6
SGM1
Site
Sep-11
Dec-11
LOR
TV

Appendix 3

Dissolved metal concentrations (based on one observation per site) from samples collected during the weeks of 26 September 2011, 24 October 2011, 21 November 2011 and 12 December 2011. Note: "<" indicates that the concentration is less than the limit of reporting (LOR) which is the lowest concentration that the laboratory will confidently state as being measured. Yellow shaded cells indicate sites in Zone 1, pink in Zone 2 and green in Zone 3. [1.] Data not included due to contamination issues which would bias the data.

	Aluminium (µg/L)				Iron (µg/L)				Arsenic (µg/L)				Boron (µg/L)				Cadmium (µg/L)			
Site	Sep	Oct	Nov	Dec	Sep	Oct	Nov	Dec	Sept	Oct	Nov	Dec	Sep	Oct	Nov	Dec	Sep	Oct	Nov	Dec
BW1	<10	<10	10	<10	17	<5	18	<5	2.3	1.2	1.3	0.8	4500	4500	4900	4400	0.3	<0.2	<0.2	<0.2
BW2	<10	<10	20	<10	20	<5	12	<5	2.0	1.2	1.3	1.1	4400	4600	4800	4500	0.2	<0.2	<0.2	<0.2
SGW4	<10	<10	50	<10	11	<5	<5	<5	1.7	1.6	1.6	1.3	4000	4600	4600	4400	0.2	<0.2	<0.2	<0.2
SGW5	<10	<10	30	<10	24	10	14	<5	1.8	1.5	1.5	1.4	4300	4500	4700	4400	<0.2	<0.2	<0.2	<0.2
QE3	70	<10	20	<10	19	<5	<5	<5	1.8	1.1	1.1	0.8	4800	4600	5000	4600	0.2	<0.2	<0.2	<0.2
QE4	20	<10	20	<10	15	<5	<5	13	1.4	1.1	1.2	0.9	4500	4800	4900	4200	<0.2	<0.2	<0.2	<0.2
ST1	20	<10	20	10	32	<5	<5	<5	2.0	1.2	1.3	1.2	4700	4700	4800	4400	0.3	<0.2	<0.2	<0.2
RB1	<10	<10	20	<10	16	<5	<5	<5	2.0	1.4	1.7	1.3	4600	4400	4900	4300	0.2	<0.2	<0.2	<0.2
RB3	<10	<10	30	<10	145	<5	<5	<5	1.3	1.6	1.8	1.1	3800	4400	4900	4100	<0.2	<0.2	<0.2	<0.2
B5.1	<10	<10	10	<10	21	<5	12	<5	1.8	1.7	1.8	1.4	4400	4700	4700	4500	0.2	<0.2	<0.2	<0.2
BG10	20	<10	20	<10	14	<5	13	<5	2.0	1.3	1.3	1.1	4400	4600	4800	4600	0.3	<0.2	<0.2	<0.2
Boat Creek	<10	<10	20	<10	16	<5	<5	<5	1.2	1.3	1.3	1.3	3800	4700	5000	4200	<0.2	<0.2	<0.2	<0.2
C1.6	<10	<10	<10	<10	20	<5	<5	<5	2.0	1.2	1.2	1.1	4400	4700	4800	4500	<0.2	<0.2	<0.2	<0.2
C6.4	80	<10	10	<10	22	<5	13	<5	1.6	1.2	1.2	1.2	3900	4000	4500	3400	<0.2	<0.2	<0.2	<0.2
MM1	20	<10	20	30	18	<5	<5	<5	2.0	1.4	1.4	1.4	4400	4500	4800	4500	0.2	<0.2	<0.2	<0.2
MM2	<10	20	20	<10	16	<5	6	<5	1.8	1.3	1.4	1.4	4500	4800	4800	4600	0.2	<0.2	<0.2	<0.2
Auk0.0	<10	<10	20	<10	32	<5	<5	<5	1.9	1.3	1.5	1.3	4100	4600	4800	4500	0.4	<0.2	<0.2	<0.2
Auk1.6	<10	<10	10	<10	13	<5	<5	<5	1.9	1.3	1.3	1.2	4300	4400	4900	4400	<0.2	<0.2	<0.2	<0.2
SGM1	<10	<10	20	<10	18	<5	<5	15	2.0	1.6	1.5	1.4	4300	4700	4700	4400	<0.2	<0.2	<0.2	<0.2

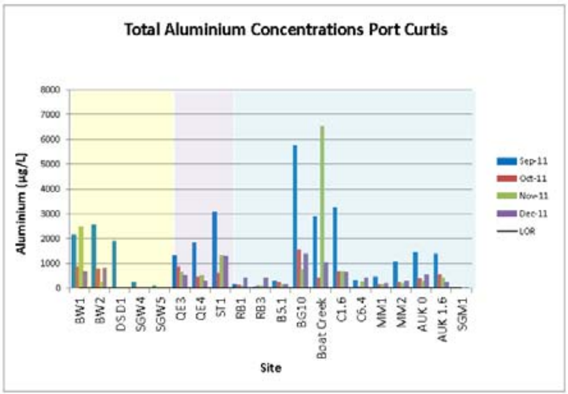
	Chromium (µg/L)				Cobalt (µg/L)				Copper (µg/L)				Lead (µg/L)				Manganese (µg/L)			
Site	Sep	Oct	Nov	Dec	Sep	Oct	Nov	Dec	Sep	Oct	Nov	Dec	Sep	Oct	Nov	Dec	Sep	Oct	Nov	Dec
BW1	2.8	<0.5	<0.5	<0.5	0.6	<0.2	<0.2	<0.2	<1	1		<1	0.7	<0.2	<0.2	<0.2	57.7	5.7	6.9	3.8
BW2	3.2	<0.5	<0.5	<0.5	0.3	<0.2	<0.2	<0.2	1	2		<1	0.7	0.2	<0.2	<0.2	4.6	6.9	2.6	4.4
SGW4	0.9	<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<1	<1		<1	0.4	<0.2	<0.2	<0.2	0.6	<0.5	1.1	1.0
SGW5	1.0	<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<1	<1		<1	0.6	<0.2	<0.2	<0.2	1.1	0.5	1.0	0.7
QE3	2.4	<0.5	<0.5	<0.5	0.3	<0.2	<0.2	0.3	1	1		1	0.8	<0.2	<0.2	<0.2	9.0	4.9	7.2	15.2
QE4	2.6	<0.5	<0.5	<0.5	0.4	<0.2	<0.2	<0.2	1	2		1	1.7	<0.2	0.2	<0.2	6.1	4.6	3.1	7.2
ST1	3.6	<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	1	1		<1	1.4	<0.2	<0.2	<0.2	<0.5	5.6	1.5	1.3
RB1	1.0	<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<1	1		<1	0.6	<0.2	<0.2	<0.2	1.8	5.1	3.9	8.6
RB3	9.5	<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<1	<1		<1	0.3	<0.2	<0.2	<0.2	3.2	3.7	5.2	12.3
B5.1	<0.5	<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	2	<1		<1	<0.2	<0.2	0.2	<0.2	2.6	3.5	3.1	5.2
BG10	6.2	<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	1	1		2	1.3	<0.2	0.4	<0.2	1.3	0.9	1.7	1.1
Boat Creek	3.8	<0.5	<0.5	<0.5	<0.2	<0.2	0.2	<0.2	2	2		<1	0.4	<0.2	<0.2	<0.2	4.5	3.4	22.4	11.9
C1.6	<0.5	<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<1	2		1	<0.2	<0.2	3.2	<0.2	3.0	4.1	6.3	4.9
C6.4	<0.5	<0.5	<0.5	<0.5	0.2	<0.2	<0.2	<0.2	1	1		1	<0.2	<0.2	<0.2	<0.2	10.7	13.1	13.7	5.8
MM1	1.0	<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	2	2		2	1.3	<0.2	<0.2	<0.2	3.7	6.7	12.6	9.5
MM2	1.8	<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	1	3		3	1.0	<0.2	<0.2	<0.2	3.8	3.9	10.8	10.8
Auk0.0	2.0	<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<1	1		2	1.0	<0.2	<0.2	<0.2	3.0	2.9	17.4	1.4
Auk1.6	2.3	<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<1	2		<1	0.8	<0.2	1.2	<0.2	1.5	1.5	5.8	2.8
SGM1	1.0	<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<1	<1		<1	0.5	<0.2	<0.2	<0.2	1.0	0.9	1.0	0.7

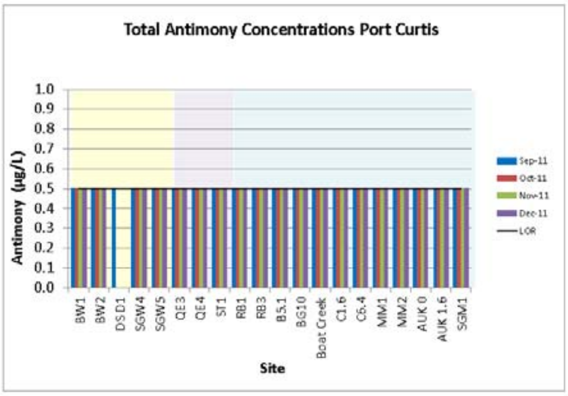
	Molybdenum (µg/L)				Nickel (µg/L)				Silver (µg/L)				Thallium (µg/L)			
Site	Sep	Oct	Nov	Dec	Sep	Oct	Nov	Dec	Sep	Oct	Nov	Dec	Sep	Oct	Nov	Dec
BW1	13.2	12.4	11.5	11.8	1.4	0.7	<0.5	0.7	0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
BW2	12.3	11.8	11.3	12.3	1.4	0.7	<0.5	0.6	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
SGW4	11.0	11.5	11.1	11.3	<0.5	<0.5	<0.5	<0.5	<0.1	<0.1	<0.1	<0.1	0.3	<0.1	<0.1	<0.1
SGW5	11.4	11.2	10.9	11.5	<0.5	<0.5	<0.5	<0.5	<0.1	<0.1	<0.1	<0.1	0.6	<0.1	<0.1	<0.1
QE3	11.8	11.7	11.4	11.2	1.5	0.9	<0.5	0.7	0.4	<0.1	<0.1	<0.1	0.9	<0.1	<0.1	<0.1
QE4	12.3	12.0	11.4	10.9	1.2	0.7	<0.5	0.8	0.4	<0.1	<0.1	<0.1	0.4	<0.1	<0.1	<0.1
ST1	12.6	12.2	11.6	11.9	1.0	0.6	<0.5	0.5	0.3	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
RB1	10.3	10.8	10.9	10.4	<0.5	<0.5	<0.5	<0.5	<0.1	<0.1	<0.1	<0.1	0.3	<0.1	<0.1	<0.1
RB3	6.8	11.4	11.0	9.9	0.7	<0.5	<0.5	<0.5	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
B5.1	13.6	17.7	15.0	13.6	<0.5	<0.5	<0.5	<0.5	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
BG10	12.4	11.8	11.7	12.0	0.9	0.6	<0.5	0.6	0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Boat Creek	10.7	12.2	11.4	12.4	0.8	0.6	<0.5	<0.5	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
C1.6	12.4	11.8	10.8	12.3	0.9	0.6	<0.5	<0.5	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
C6.4	11.0	10.3	10.7	8.6	0.6	0.5	<0.5	0.5	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
MM1	12.7	12.3	11.9	11.7	1.1	0.5	<0.5	<0.5	0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
MM2	12.6	11.9	11.8	12.2	0.7	<0.5	<0.5	0.5	0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Auk0.0	12.5	12.3	12.0	12.2	0.7	<0.5	<0.5	0.5	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Auk1.6	12.7	12.2	11.5	11.8	0.7	0.6	<0.5	<0.5	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
SGM1	11.1	11.3	10.9	11.0	<0.5	<0.5	<0.5	<0.5	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1

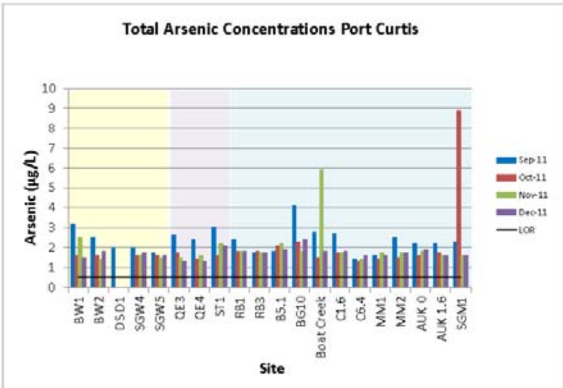
	Vanadium (µg/L)				Selenium (µg/L)				Antimony (µg/L)				Tin (µg/L)				Zinc (µg/L)			
Site	Sep	Oct	Nov	Dec	Sep	Oct	Nov	Dec	Sep	Oct	Nov	Dec	Sep	Oct	Nov	Dec	Sep	Oct	Nov	Dec
BW1	3.4	2.9	3.3	1.6	<2	<2	<2	<2	0.5	<0.5	<0.5	<0.5	<5	<5	<5	<5	6			<5
BW2	3.0	3.1	2.5	2.2	<2	<2	<2	<2	<0.5	<0.5	<0.5	<0.5	<5	<5	<5	<5	6			<5
SGW4	1.1	2.0	1.6	1.4	<2	<2	<2	<2	<0.5	<0.5	<0.5	<0.5	<5	<5	<5	<5	<5			<5
SGW5	1.9	1.9	1.5	1.3	<2	<2	<2	<2	<0.5	<0.5	<0.5	<0.5	<5	<5	<5	<5	<5			<5
QE3	2.4	2.3	2.1	1.9	<2	<2	<2	<2	<0.5	<0.5	<0.5	<0.5	<5	<5	<5	<5	6			<5
QE4	2.8	2.6	2.3	1.5	<2	<2	<2	<2	<0.5	<0.5	<0.5	<0.5	<5	<5	<5	<5	6			<5
ST1	2.4	2.5	2.5	2.0	<2	<2	<2	<2	<0.5	<0.5	<0.5	<0.5	<5	<5	<5	<5	7			<5
RB1	1.9	2.0	2.1	1.7	<2	<2	<2	<2	<0.5	<0.5	<0.5	<0.5	<5	<5	<5	<5	6			<5
RB3	1.2	2.0	2.2	1.5	<2	<2	<2	<2	<0.5	<0.5	<0.5	<0.5	<5	<5	<5	<5	<5			<5
B5.1	1.9	2.7	2.2	1.9	<2	<2	<2	<2	<0.5	<0.5	<0.5	<0.5	<5	<5	<5	<5	8			<5
BG10	2.6	2.4	2.5	1.9	<2	<2	<2	<2	<0.5	<0.5	<0.5	<0.5	<5	<5	<5	<5	15			<5
Boat Creek	2.2	2.8	2.5	2.5	<2	<2	<2	<2	<0.5	<0.5	<0.5	<0.5	<5	<5	<5	<5	6			<5
C1.6	2.6	2.8	2.5	2.1	<2	<2	<2	<2	<0.5	<0.5	<0.5	<0.5	<5	<5	<5	<5	8			<5
C6.4	2.6	2.8	2.5	2.8	<2	<2	<2	<2	<0.5	<0.5	<0.5	<0.5	<5	<5	<5	<5	6			<5
MM1	2.2	2.3	2.4	2.0	<2	<2	<2	<2	<0.5	<0.5	<0.5	<0.5	<5	<5	<5	<5	6			<5
MM2	2.4	2.4	2.4	2.2	<2	<2	<2	<2	<0.5	<0.5	<0.5	<0.5	<5	<5	<5	<5	<5			7
Auk0.0	2.3	2.5	2.4	2.1	<2	<2	<2	<2	<0.5	<0.5	<0.5	<0.5	<5	<5	<5	<5	6			<5
Auk1.6	2.2	2.4	2.3	2.0	<2	<2	<2	<2	<0.5	<0.5	<0.5	<0.5	<5	<5	<5	<5	<5			<5
SGM1	1.7	2.0	1.6	1.4	<2	<2	<2	<2	<0.5	<0.5	<0.5	<0.5	<5	<5	<5	<5	<5			6

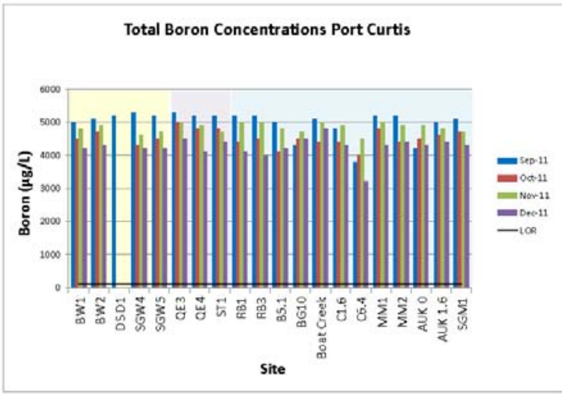
Appendix 4

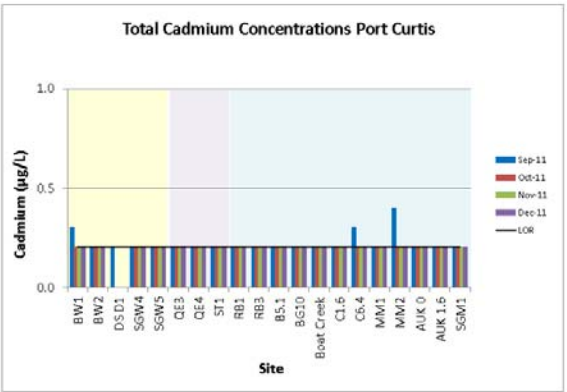
Total metal concentrations (based on one observation per site) from samples collected during the weeks of 26 September 2011, 24 October 2011, 21 November 2011 and 12 December 2011. Note: The limit of reporting (LOR) is the lowest concentration of the metal that the laboratory can confidently state that the metal occurs. Yellow panels indicate sites in Zone 1, pink panels indicate sites in Zone 2 and blue panels indicate sites in Zone 3.

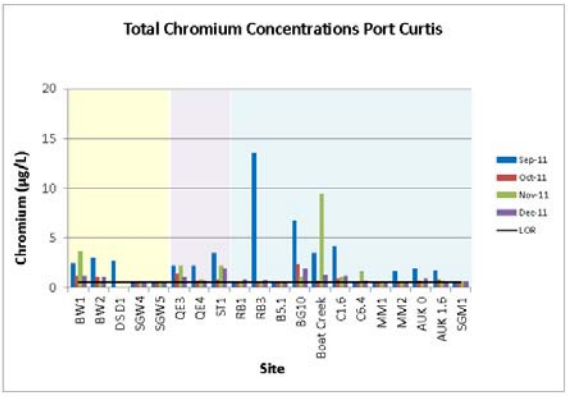


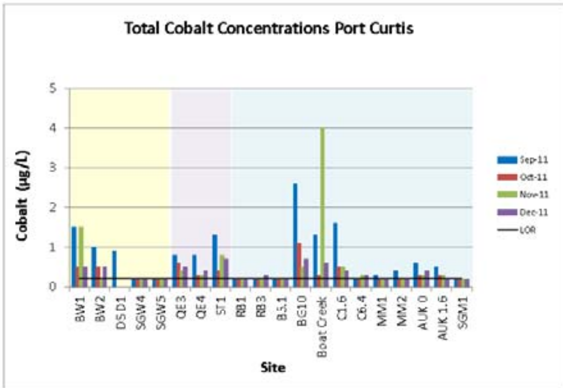


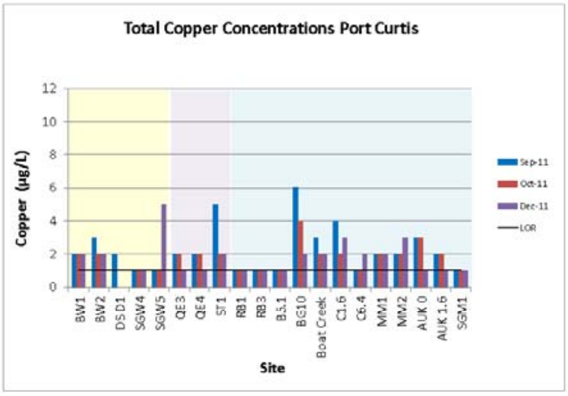


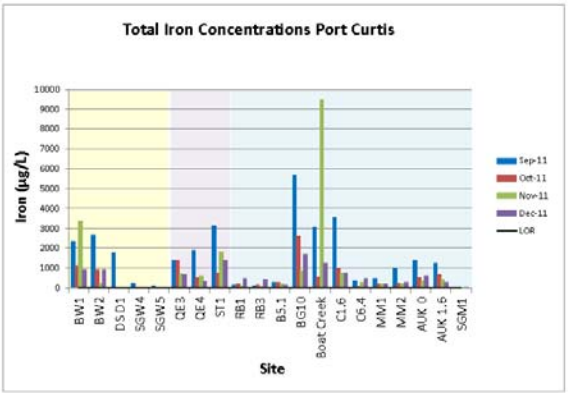


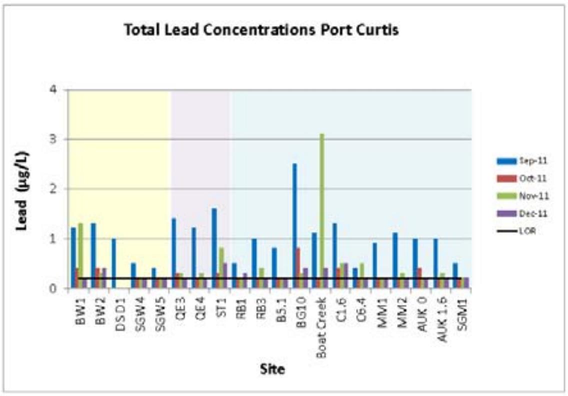


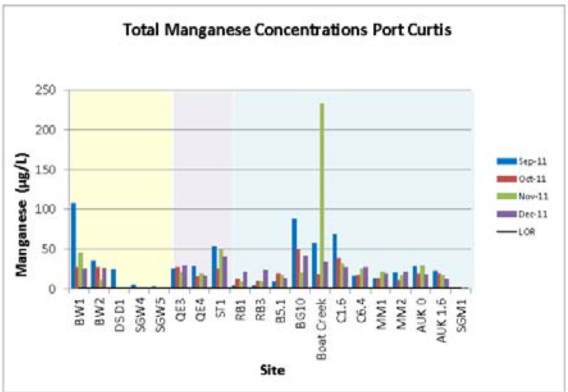


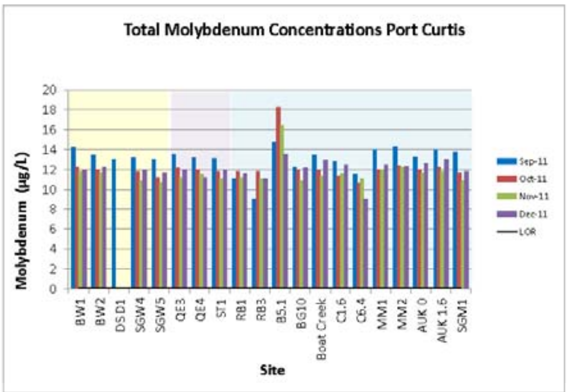

Total Cobalt Concentrations Port Curtis
Cobalt (µg/L)
Site
BW1 BW2 DS D1 SGW4 SGW5 QE3 QE4 ST1 RB1 RB3 B5.1 BG10 Boat Creek C1.6 C6.4 MM1 MM2 AUK 0 AUK 1.6 SGM1
Sep-11
Oct-11
Nov-11
Dec-11
LOR

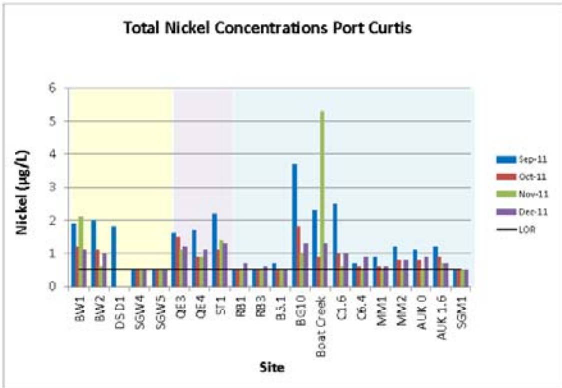

Total Copper Concentrations Port Curtis
Copper (µg/L)
Site
BW1 BW2 DS D1 SGW4 SGW5 QE3 QE4 ST1 RB1 RB3 B5.1 BG10 Boat Creek C1.6 C6.4 MM1 MM2 AUK 0 AUK 1.6 SGM1
Sep-11
Oct-11
Dec-11
LOR

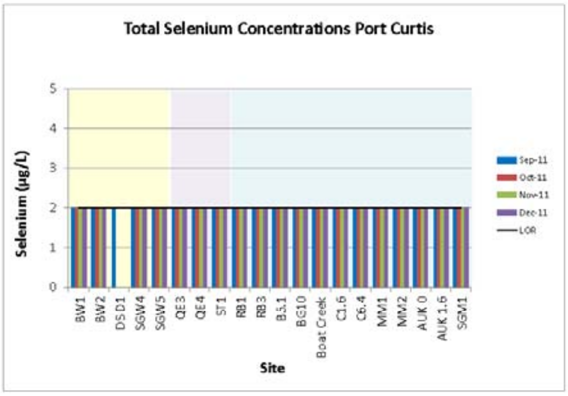

Total Iron Concentrations Port Curtis
Iron (µg/L)
Site
BW1 BW2 DS D1 SGW4 SGW5 QE3 QE4 ST1 RB1 RB3 B5.1 BG10 Boat Creek C1.6 C6.4 MM1 MM2 AUK 0 AUK 1.6 SGM1
Sep-11
Oct-11
Nov-11
Dec-11
LOR

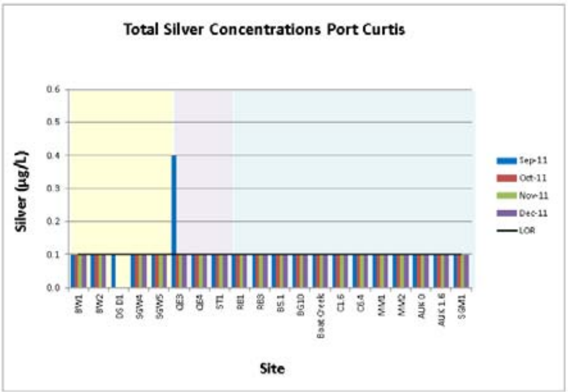

Total Lead Concentrations Port Curtis
Lead (µg/L)
Site
BW1 BW2 DS D1 SGW4 SGW5 QE3 QE4 ST1 RB1 RB3 B5.1 BG10 Boat Creek C1.6 C6.4 MM1 MM2 AUK 0 AUK 1.6 SGM1
Sep-11
Oct-11
Nov-11
Dec-11
LOR

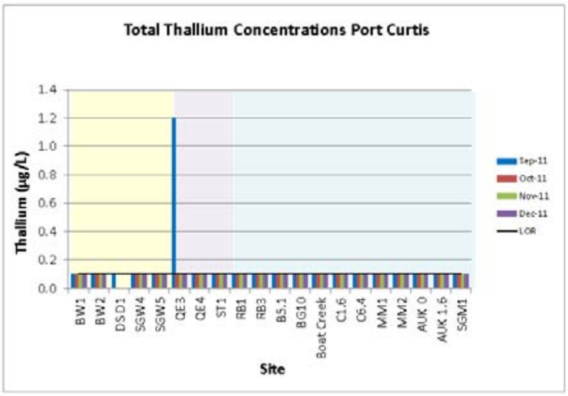

Total Manganese Concentrations Port Curtis
Manganese (µg/L)
Site
BW1 BW2 DS D1 SGW4 SGW5 QE3 QE4 ST1 RB1 RB3 B5.1 BG10 Boat Creek C1.6 C6.4 MM1 MM2 AUK 0 AUK 1.6 SGM1
Sep-11
Oct-11
Nov-11
Dec-11
LOR

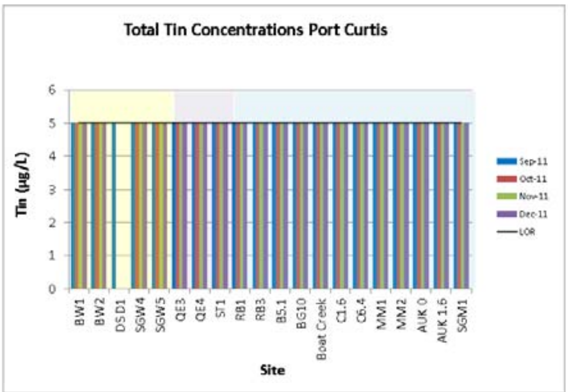

Total Molybdenum Concentrations Port Curtis
Molybdenum (µg/L)
Site
BW1 BW2 DS D1 SGW4 SGW5 QE3 QE4 ST1 RB1 RB3 B5.1 BG10 Boat Creek C1.6 C6.4 MM1 MM2 AUK 0 AUK 1.6 SGM1
Sep-11
Oct-11
Nov-11
Dec-11
LOR

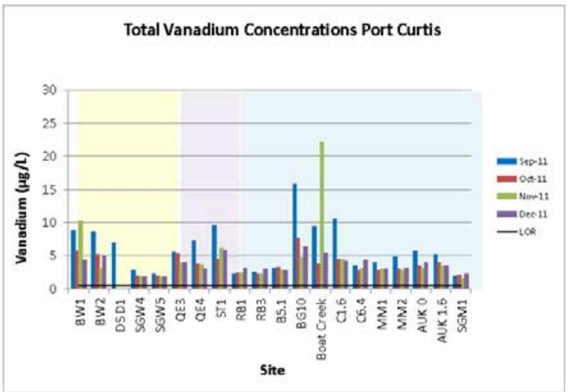

Total Nickel Concentrations Port Curtis
Nickel (µg/L)
Site
Sep-11
Oct-11
Nov-11
Dec-11
LOR

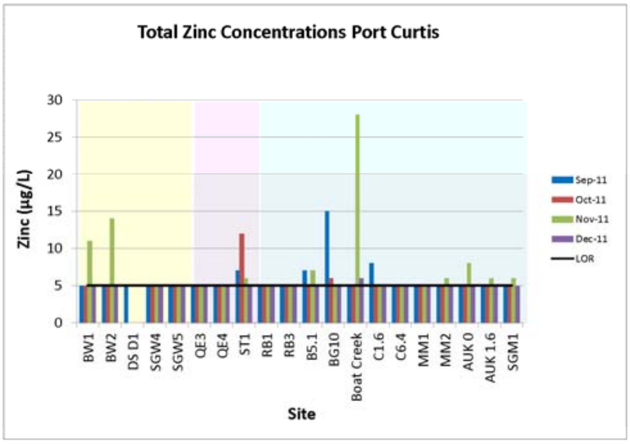

Total Selenium Concentrations Port Curtis
Selenium (µg/L)
Site
Sep-11
Oct-11
Nov-11
Dec-11
LOR


Total Silver Concentrations Port Curtis
Silver (µg/L)
Site


Total Thallium Concentrations Port Curtis
Thallium (µg/L)
Site
Sep-11
Oct-11
Nov-11
Dec-11
LOR


Total Tin Concentrations Port Curtis
Tin (µg/L)
Site


Total Vanadium Concentrations Port Curtis
Vanadium (µg/L)
Site


Total Zinc Concentrations Port Curtis
Zinc (µg/L)
Site
Sep-11
Oct-11
Nov-11
Dec-11
LOR
BW1
BW2
DS D1
SGW4
SGW5
QE3
QE4
ST1
RB1
RB3
B5.1
BG10
Boat Creek
C1.6
C6.4
MM1
MM2
AUK 0
AUK 1.6
SGM1

Appendix 5

Ranges of dissolved metal concentrations measured in Gladstone waterways and other estuaries. The values in parentheses state the percentage of samples that were less than the limit of reporting (LOR), the non-percentage value being the LOR (µg/L).

Location	Date	Al (µg/L)	Cd (µg/L)	Cu (µg/L)	Ni (µg/L)	Pb (µg/L)	Zn (µg/L)	Reference
Aus and NZ TV		**0.5**	**0.7**	**1.3**	**7**	**4.4**	**15**	ANZECC and ARMCANZ, 2000
Offshore	Nov & Dec	<LOR–50 (50% < 10)	<LOR	<LOR	<LOR	<LOR	<LOR–0.6 (80% < 5)	This study
	Sept - Dec	<LOR–50 (75% < 10)	<LOR	<LOR–1 (93% < 1)	<LOR–0.7 (95% < 0.5)	<LOR–0.6 (75% < 0.2)	0 –6 (80% < 5)	This study
The Narrows	Nov & Dec	<LOR–20 (50% < 10)	<LOR	1 (0% < 0.5)	<LOR–0.8 (50% < 0.5)	<LOR–0.2 (75% < 0.2)	<LOR	This study
	Sept - Dec	<LOR–70 (50% < 10)	<LOR	1–2 (0% < 1)	<LOR–1.5 (25% < 0.5)	<LOR–1.7 (63% < 0.2)	<LOR–6 (50% < 5)	This study
Gladstone Harbour	Nov & Dec	<LOR–20 (37.5% < 10)	<LOR	<LOR–2 (75% < 1)	<LOR–0.9 (50% < 0.5)	<LOR–0.4 (87% < 0.2)	<LOR	This study
	Sept - Dec	<LOR–20 (57% < 10)	0–0.3 (75% < 0.2)	1–3 (75% < 1)	<LOR–1.4 (25% < 0.5)	<LOR–1.4 (63% < 0.2)	<LOR–15 (50% < 5)	This study

Location	**Date**	**Al (µg/L)**	**Cd (µg/L)**	**Cu (µg/L)**	**Ni (µg/L)**	**Pb (µg/L)**	**Zn (µg/L)**	**Reference**
Aus and NZ TV		**0.5**	**0.7**	**1.3**	**7**	**4.4**	**15**	ANZECC and ARMCANZ, 2000
Rivers	Nov & Dec	<LOR–20 (50% < 10)	<LOR	< LOR–3 (43% < 1)	<LOR–0.5 (81% < 0.5)	<LOR–3.2 (82% < 0.2)	<LOR–7 (75% < 5)	This study
	Sept - Dec	<LOR–80 (61% < 10)	<LOR–0.4 (88% < 0.2)	<LOR–2 (29% < 1)	<LOR–1.1 (56% < 0.5)	<LOR–3.2 (75% < 0.2)	<LOR–8 (56% < 5)	This study
Offshore[1]		0–200	0–0.004	0–0.085	0.011–0.19		0–0.14	Angel *et al.,* 2010
The Narrows[1]		0–82.8	0.003–0.0065	0.52–0.64	0.47–0.91		0.06–0.21	Angel *et al.*, 2010
Gladstone Harbour[1]		0–44.1.	0.002–0.015	0–0.64	0.011–0.91		0–0.23	Angel *et al.*, 2010
Calliope River[1]		16.5	0.0056–0.0092	0.67–0.73	0.33–0.43		0.34–0.5	Angel *et al.*, 2010
NSW Coast		-	0.025	0.03	0.18	-	<0.022	Apte & Day, 1998
Western Pacific Ocean		-	0.001–0.1	0.04–0.28	0.12–0.52	-	-	Mackey *et al.*, 2002
North Pacific Ocean		-	0.0003–0.11	-	-	-	0.015–0.52	Bruland *et al.*, 1994

Location	Date	Al (µg/L)	Cd (µg/L)	Cu (µg/L)	Ni (µg/L)	Pb (µg/L)	Zn (µg/L)	Reference
Aus and NZ TV		**0.5**	**0.7**	**1.3**	**7**	**4.4**	**15**	ANZECC and ARMCANZ, 2000
Great Barrier Reef			<0.01–0.06	0.11–0.24	0.06–0.16	-	0.03–0.35	Denton & Burdon-Jones, 1986
Bathurst Harbour, Tasmania		-	0.002	0.14	0.14	-	0.39	Mackey *et al*., 1996
Port Jackson, NSW		-	0.006–0.104	0.93–2.55	0.175–1.61	-	3.27–9.66	Hatje *et al*., 2003
Torres Strait and Papua New Guinea		-	0.001–0.029	0.036–0.986	0.94–4.6	-	-	Apte & Day, 1998
Port Phillip Bay, Victoria			<0.005–0.07	0.4–0.63	0.54–1.1	-	0.25–1.05	Fabris & Monahan, 1995
Nine estuaries, Northern Territory		-	0.0014–0.07	0.15–5.5	0.12–4.25	-	<0.001–11.3	Munksgaard & Parry, 2001
Tweed Estuary, UK		-	0.007–0.033	0.49–4.7	-	-	0.43–1.9	Laslett & Balls, 1995
Humber estuary, UK		-	0.08–0.45	0.18–10.1	2.5–12	-	3–20.5	Comber *et al*., 1995
Mersey estuary, UK		-	0.01–0.11	0.8–4.95	2–10.5	-	6.5–28	Comber *et al*., 1995

Location	Date	Al (µg/L)	Cd (µg/L)	Cu (µg/L)	Ni (µg/L)	Pb (µg/L)	Zn (µg/L)	Reference
Aus and NZ TV		**0.5**	**0.7**	**1.3**	**7**	**4.4**	**15**	ANZECC and ARMCANZ, 2000
Tay estuary, UK		-	<0.003–0.085	0.25–1.55	0.25–0.90	-	<0.1–3.2	Owens & Balls, 1997
Forth estuary, UK		-	-	-	0.29–1.47	-	0.46–10.13	Laslett & Balls, 1995
Scheldt estuary, Netherlands		-	0.015–0.1	0.75–1.8	1–6.8	-	1–10	Baeyens *et al*., 2005
San Francisco Bay estuary, USA		-	0.022–0.123	0.315–2.23	0.14–2.41	-	0.16–1.96	Sañudo-Wilhelmy *et al*., 1996
Six estuaries, Texas, USA		-	-	0.1–3.2	-	-	0.3–18	Benoit *et al*., 1994

1. Aluminium concentrations from the CSIRO study of Gladstone waterways were not published in either Angel *et al.* (2010) or in Apte *et al*. (2006). They were provided to DERM by Brad Angel.