METAL CONCENTRATIONS IN THE BENTHIC SEDIMENTS OF ROSS RIVER: POST-WET SEASON, 2008

ACTFR Report No. 08/20

October 2008

Prepared by Barry Butler

Australian Centre for Tropical Freshwater Research
James Cook University
Townsville, Qld. 4811
Phone: 07-47814262
Fax: 07-47815589
Email: actfr@jcu.edu.au
Website : www.actfr.jcu.edu.au

EXECUTIVE SUMMARY

The Australian Centre for Tropical Freshwater Research (ACTFR) has conducted event-based water quality monitoring programs for the Black-Ross Water Quality Improvement Plan (WQIP) over the last two wet seasons (2006/07 and 2007/08). This monitoring included some sampling and analysis of trace metals in water. However, because the metal concentrations in water fluctuate enormously over time and between sites, it was not feasible to collect enough water samples to be able to confidently assess the status of metals in the study catchments. Since urban catchments are widely recognised as a potential source of metal contamination in waterways, further more detailed investigations were recommended.

Most metals have limited solubility, so over time they tend to accumulate in the bottom muds of receiving waters. Consequently the metal concentrations in bottom sediment samples can provide an integrated record of recent and past metal inputs, allowing the status of waterways to be assessed without the need for repetitive sampling to account for the kinds of rapid fluctuations that occur in the overlying water. Accordingly a detailed one-off survey to examine the metal composition and distribution of benthic (bottom) sediments in local receiving waters was the most efficient viable means of determining if trace metals are a significant issue in the WQIP area. It was important to ensure that this survey provided information that was sufficiently detailed to be able to reach some definite conclusions, hence the commissioned study focussed on just one catchment, that being Ross River. This report details the methodology and findings of this one-off investigation.

The main objectives of this study were to:

- determine if metal concentrations in the bed sediments of the Ross River drainage system are acceptable for the maintenance of a healthy ecosystem;
- check for any evidence of elevated metal accumulations that could be indicative of pre-existing, current or emerging metal contamination problems, and;
- identify priorities for future management and monitoring of metals in the Ross River catchment.

The work was carried out during the post-wet season months of 2008; after wet season flows had subsided and marine salinity conditions had largely been restored within the estuary. Samples were taken at 34 sites within the river or its tributaries, and at one estuarine control site situated on Cocoa Ck to the south of Ross River. Site locations included headwater streams, the Ross River weirs and Dam, Stuart Creek, Goondi Creek, Gordon Creek, the estuary, and several urban drains. Samples were analysed for the twelve most toxic metals that could potentially be associated with land uses and activities in the catchment area. These comprise antimony, arsenic, cadmium, chromium, cobalt, copper, lead, nickel, selenium, silver, zinc and thallium.

Two different sediment samples were collected at each site. A conventional sediment grab sample was taken from the top 10 to 15 cm of the substratum. This contains comparatively immobile consolidated bed sediment which will generally have been deposited over a number of years. A second sample was taken from the unconsolidated fine sediment layer that lies on or just above the basal sediment. It was collected by using a custom-made device called a turbator to agitate the water at the substratum surface in order to resuspend and capture unconsolidated fines. These highly mobile sediments are easily washed away, so a significant proportion of the material contained in the samples is likely to have been introduced to the waterways during the latter stages of the 2008 wet season, after high flows had subsided.

Metals are known to preferentially accumulate in fine-grained (muddy) sediments. Accordingly, in order to maximise the chances of detecting any potential or emerging contamination problems, samples were collected from the muddiest sections at each site and were sieved to remove particles larger than 63 µm (very fine sand) prior to analysis. Moreover, during analysis the samples were subjected to a strong acid digestion which liberates all of the constituent metals regardless of their chemical form. Since a proportion of these metals will almost certainly have been present in forms that are not bioavailable or toxic, the results presented in this report are likely to have over-estimated the risks of toxicological effects.

Since natural background concentrations and toxic thresholds vary substantially between metals it can be difficult to compare the relative significance of each metal. In this report comparisons of this sort have been facilitated by dividing the concentration results for each metal by the relevant ANZECC guideline to yield index values indicative of the relative risk of toxic effects.

It was originally intended that this study would assign priority ratings to individual sites and subcatchments to aid for determining future monitoring and management directions. However, that proved to be neither feasible nor necessary because the survey found no evidence of any significant existing or emerging metal contamination problems at any site in the Ross River catchment. Some very minor isolated anomalies were detected at a few sites but none of these were large enough to be considered ecologically significant or to warrant management attention.

The possible existence of some localised metal accumulations in very close proximity to point sources can never be completely discounted in a catchment-wide survey such as this. However, the site network was sufficiently extensive to be able to conclude that any undetected sediment contamination must have been confined to relatively small sections of the drainage system.

Also, the possibility of large quantities of metals having passed through the drainage system during high flow events without leaving any evidence in bottom sediments can never be completely discounted. However, the analysis methods employed in this study are capable of detecting quite subtle irregularities in sediment composition, so the probability of this having happened is considered to be quite low.

Specific findings are summarised in the following dot-points:

- All samples complied with the Interim Sediment Quality Guidelines (ISQGs) provided in the current ANZECC (2000) guidelines for the protection of aquatic ecosystems.

- Nickel was the only metal to yield Risk Index scores greater than 0.7, although there were no values larger than one (which would indicate the potential for a compliance breach). However, there was no evidence of any significant anthropogenic enrichment. In fact the estuarine control site registered the second highest score, one of the freshwater controls (site 4) reported a significant index value of 0.6, and all of the reported values were significantly lower than the levels that have been reported at some Queensland EPA reference sites. These observations imply either that nickel naturally occurs at concentrations that are high enough to be ecologically significant, or that the ISQG is too conservative for this region. Regardless of the explanation it is clear that ambient nickel levels are no more of an issue in the Ross River catchment than they are in most other Queensland catchments.

- Urban drains located in the freshwater sections of the catchment (sites 13, 15, 18) contained the largest quantities of mobile metals simply because they contained the largest amounts of fine sediment. This could be indicative of excessive sediment inputs but could also simply indicate that the drains are not as thoroughly flushed as other watercourses in the study area.

- Small quantities of unconsolidated sediment with elevated metal content were detected at a few sites. Site 14 (an urban drain at Riverside Gardens) was the only site that contained enough of this material to measurably affect its ecological risk scores, but it still reported significantly lower index values than several other sites and is not therefore considered to be cause for concern. (The sediment at this site actually exhibited a distinctive trace metal signature suggesting that it may have originated from soils that are of a different type to the rest of the catchment. This could result from the use of imported top-soils for landscaping or from exposure of sub-soils by excavation works and/or erosion).

- Site 34, a drain located on Benwell Road on the reclaim, contained a small quantity of unconsolidated sediment with elevated concentrations of copper, nickel and lead. However, the quantity of enriched sediment that was present at the time of sampling was too small to threaten the health of fauna inhabiting the site, and the sediment composition at Site 33, which was located near the mouth of the drain, provided no evidence of impact.

- The concentrations of mobile metals at each site in the study area were mainly dependent on the amount of fines that were present. However, when differences in the amount of fines are taken into account it is evident that freshwater sites and low salinity tidal sites report significantly lower metal concentrations than high salinity tidal sites. Moreover, the results suggest that none of the sites in the Ross River estuary were completely free of freshwater influences, because they all contained less metals than the control site on Cocoa Ck. Accordingly, even though Cocoa Ck is a relatively undisturbed estuary that has previously been shown to be free of anthropogenic metal enrichment, it is not an ideal control for the Ross River estuary because it simply lacks the necessary riverine/freshwater influences. It would therefore be advisable to attempt to locate an alternative control site if further sediment investigations are ever carried out in the future.

Based on these findings it is concluded that those trace metals investigated in this report are not a significant management issue for the Ross River catchment, and that future monitoring and assessment efforts in this catchment should focus on the other water quality issues raised in earlier monitoring reports. However, it must be stressed that this conclusion applies only to Ross River. There is pre-existing evidence that metal contamination is an issue in the Ross Ck/Townsville Harbour area (Doherty *et al*. 2000, Jones *et al*. 2000, Gibbs 1993, Esslemont 2000, ACTFR 1996, ACTFR unpub.), and the metals status of other catchments in the WQIP area is yet to be determined. It would be particularly worthwhile to investigate the Bohle River using the methods that have been employed in the current study.

TABLE OF CONTENTS

1. INTRODUCTION

The Australian Centre for Tropical Freshwater Research (ACTFR) has conducted event-based water quality monitoring programs for the Black-Ross Water Quality Improvement Plan (WQIP) over the last two wet seasons (2006/07 and 2007/08). This monitoring included some sampling and analysis of trace metals. However, because the metal concentrations in water fluctuate enormously over time and between sites, it was not feasible to collect enough water samples to be able to confidently assess the status of metals in the study catchments. Since urban catchments are widely recognised as a potential source of metal contamination in waterways, further more detailed investigations were recommended.

Most metals have limited solubility, so over time they tend accumulate in the bottom muds of receiving waters. Consequently the metal concentrations in bottom sediment samples can provide an integrated record of recent and past metal inputs, allowing the status of waterways to be assessed without the need for repetitive sampling to account for the kinds of rapid fluctuations that occur in the overlying water. Accordingly a detailed one-off survey to examine the metal composition and distribution of benthic (bottom) sediments in local receiving waters was the most efficient viable means of determining if trace metals are a significant issue in the WQIP area. It was important to ensure that this survey provided information that was sufficiently detailed to be able to reach some definite conclusions, hence the commissioned study focussed on just one catchment, that being Ross River. This report details the methodology and findings of this one-off investigation

The main objectives of this study were to:

- determine if metal concentrations in the bed sediments of the Ross River drainage system are acceptable for the maintenance of a healthy ecosystem;

- check for any evidence of elevated metal accumulations that could be indicative of pre-existing, current or emerging metal contamination problems, and;

- identify priorities for future management and monitoring of metals in the Ross River catchment.

2. STUDY DETAILS

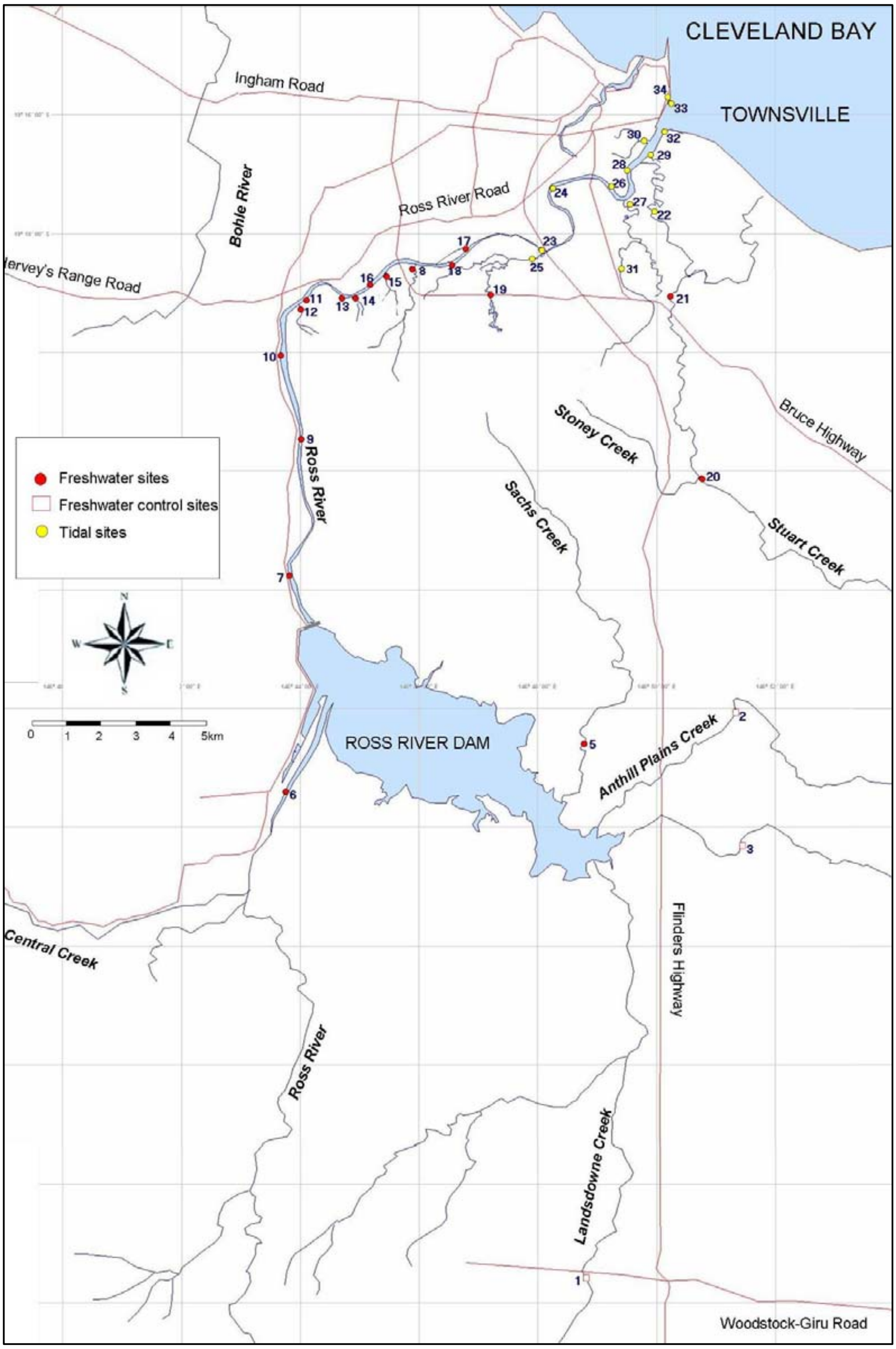
2.1 Monitoring Locations

Bottom sediment samples were collected from the 35 sites listed in Table 2.1. These comprise 21 non-tidal freshwater sites and 13 estuarine or tidally-influenced sites located within the Ross River/Stuart Creek drainage system (Figure 2.1), and one estuarine control site situated on Cocoa Creek to the south of Ross River. A number of the sites were located in tributary streams that serve as urban stormwater drains. These include some unnamed watercourses in Riverside Gardens and Annandale, as well as Gordon Ck, Goondi Ck and Lavarack Ck.

Table 2.1 Sediment sampling site location

SITE	DESCRIPTION	LATITUDE	LONGITUDE	SITE TYPE
S1	Lansdowne Ck	S19°35'34.20"	E146°48'48.84"	Freshwater Control Sites
S2	Anthill Plains Ck	S19°26'02.94"	E146°51'19.92"	
S3	Stonehouse Ck (Toonpan)	S19°28'19.01"	E146°51'26.26"	
S4	Central Ck (Ross River)	S19°28'54.69"	E146°38'47.56"	
S5	Sachs Ck (Oak Valley)	S19°26'36.10"	E146°48'46.30"	Freshwater Monitoring Sites
S6	Central Ck arm of Ross Dam	S19°27'24.30"	E146°43'45.00"	
S7	Black Weir below Ross Dam	S19°23'45.97"	E146°43'48.79"	
S8	Palmetum drain (Aplins W.)	S19°18' 35.35"	E146°45' 52.83"	
S9	Black Weir, Rassmussen	S19°21' 28.17"	E146°44' 00.68"	
S10	Condon drain (Black Weir)	S19°20' 03.59"	E146°43' 39.65"	
S11	Lower end of Black Weir	S19°19' 07.51"	E146°44' 05.93"	
S12	Riverside Gardens drain (Black W.)	S19°19' 16.32"	E146°44' 00.34"	
S13	Mouth of drain at Gleesons Weir	S19°19' 05.04"	E146°44' 41.87"	
S14	Riverside Gardens drain (Aplins W.)	S19°19' 05.42"	E146°44' 55.00"	
S15	Douglas drain (Aplins W.)	S19°18' 43.35"	E146°45' 26.80"	
S16	Aplins Weir (Cranbrook side)	S19°18' 51.59"	E146°45' 9.97"	
S17	Aplins Weir (Aitkenvale side)	S19°18' 15.08"	E146°46' 46.93"	
S18	Annandale drain (Aplins Weir)	S19°18' 31.94"	E146°46' 33.19"	
S19	Lavarack Ck entering Annandale	S19°19' 02.11"	E146°47' 11.56"	
S20	Stuart Ck (upstream)	S19°22'06.54"	E146°50'43.54"	
S21	Stuart Ck near Cluden	S19°19'03.96"	E146°50'13.14"	
S22	Stuart Ck (upper estuary)	S19°17'37.50"	E146°49'58.50"	Estuarine Monitoring Sites
S23	Ross R. near Bowen Rd Bridge	S19°18'14.94"	E146°48'4.80"	
S24	Ross R. below Fairfield Waters	S19°17'13.68"	E146°48'15.05"	
S25	Lavarack Ck (tidal end)	S19°18'25.44"	E146°47'54.48"	
S26	Ross R. below Rooneys Bridge	S19°17'12.48"	E146°49'14.46"	
S27	Gordon Ck near confluence with Ross	S19°17'30.00"	E146°49'33.12"	
S28	Ross R. above National Park ramp	S19°16'56.34"	E146°49'29.28"	
S29	Ross R. opp. mouth of Goondi Ck	S19°16'40.14"	E146°49'51.90"	
S30	Goondi Ck (near mouth)	S19°16'28.92"	E146°49'42.00"	
S31	Gordon Ck near tidal limit	S19°18'35.96"	E146°49'24.44"	
S32	Ross R. @ mouth of Flying Fox Ck	S19°16'17.34"	E146°50'4.86"	
S33	River mouth @ the reclaim	S19°15'47.70"	E146°50'13.92"	
S34	Tidal drain on Benwell Rd (the reclaim)	S19°15'41.82"	E146°50'11.58"	
S35	Cocoa Ck	S19°17'17.43"	E146°50'11.58"	Estuarine Control Sites

Figure 2.1 Benthic sediment sampling sites – post-wet season 2008. (Map sourced from Natmap Raster 2003: Geoscience Australia)



Sites 1 to 4 were located in relatively undisturbed headwater streams in the upper catchment areas where the dominant landuse is free-range cattle grazing. The metals results obtained at these sites provide the best available estimate of natural background concentrations in the catchment; hence these have been used as freshwater control sites. Monitoring sites 5 to 21 were located lower in the freshwater drainage system, within river reaches, weirs, tributary streams and/or drains that are potentially subject to impact from human disturbances such as river regulation, drainage works, excavations, waste disposal and/or urban runoff.

Monitoring sites 22 to 34 were located further downstream in tidally-influenced parts of the river system. At the time of sampling the salinity of the water at the River mouth was only slightly less than normal seawater, but some of the waters in the upper estuary were less saline indicating that they were subject to freshwater influences. This was most evident at Site 31 (near the tidal limit of Gordon Ck) which was only one third seawater, and sites 23 (below Aplins Weir on Ross River) and 25 (the lower end of Lavarack Ck) which were less than half seawater. The waters at all other tidal sites comprised at least two-thirds seawater, with salinity levels increasing with decreasing distance from the coast.

High salt concentrations strongly influence metal solubilities and sedimentation rates, so the natural background concentrations in estuarine bottom sediments are significantly different to those of freshwater sediments. Accordingly it was necessary to establish an estuarine control site, and since tidal flows can potentially carry anthropogenic metals into any section of an estuary, the control site had to be located in a different catchment. Cocoa Creek (site 35) was chosen for this purpose because its catchment area is largely undisturbed and it has previously been shown to be free of any obvious signs of anthropogenic metal enrichment (Doherty *et al* 2000).

A concerted effort was made to collect samples that contain a lot of freshly deposited fine-grained material. Hence sampling was carried out in those parts of each watercourse that naturally tend to trap muddy sediments (e.g. bars, backwaters and waterholes). Streambeds and banks where old sedimentary materials could have been exposed by scouring or erosion were avoided where possible.

2.2 Sampling Regime

This project aimed to examine the distribution of sedimentary metals in the post-wet season – long enough after wet season inflow events to allow normal marine sediment flocculation and deposition processes to occur within the estuaries, but soon enough to minimise the complications caused by prolonged tidal redistribution of sediments during the dry season (which can potentially cause metals to migrate away from their original source). Basically sampling needed to be conducted as soon as possible after marine salinity conditions had been restored within the estuary.

The Ross River catchment experienced unusually prolonged soaking rainfall during the 2007/2008 wet season and this generated more persistent stream flows than normal. As a result the salinity of the estuary was still being partially influenced by freshwater inflows in late April. Nevertheless, as discussed in 2.1, the salinity levels in most parts of the estuary were considered to be close enough to seawater to commence sediment sampling at that time.

Accordingly, all sites were sampled between April 24 and May 8, 2008, except for site 31 which was a brackish water site thought to be influenced by occasional very large spring tides. It was not sampled until June 6 in order to allow saline conditions to develop if they were going to. At the time of sampling the site contained one third seawater.

All estuarine sites were sampled on the ebb of a neap tide and under calm weather conditions so that mobile sediment floccs had an opportunity to settle to the bottom.

Samples collected by grab are identified in this report by prefixing the site number with the letter “G”.

2.3 Sampling Methods and Rationale

Separate samples of consolidated and unconsolidated sediment were collected at each site, except for Site 3 (a control site on Stonehouse Ck) where only consolidated material could be collected because the stream had run dry.

Consolidated sediments were collected by taking numerous grab samples from the top 10 to 15 cm of the substratum, and then mixing them to prepare a single composite sample for each site. As mentioned previously, these samples were not intended to be representative of the entire streambed, but rather of the parts of each waterbody where fine-grained sediment particles from the catchment are most likely to be accumulating (e.g. muddy backwaters and bars). Metals tend to be strongly associated with fine sediment particles hence muddy habitats of this kind will generally be the first places where metal toxicity problems develop if there is any anthropogenic enrichment.

The age of the consolidated bed sediments will vary between sites due to inherent hydrogeomorphological differences, but in most cases they are likely to have been deposited over several years, so their composition will not necessarily reflect recent inputs from the catchment. Nevertheless, the quality of these sediments is important to the health of the existing ecosystem, because many aquatic organisms live deep within the sediment and can be affected by any contaminant residues that it contains, regardless of how recently they were deposited. This is particularly true of metals, most of which have the potential to persist in bioavailable forms for a very long time after deposition.

The unconsolidated sediments lying on the substratum surface are much more likely to have been recently introduced into the aquatic system from the catchment (although they will undoubtedly include some previously deposited materials that have been re-introduced to water through bank erosion and bed scouring, as well as chemical and biological dissolution processes). Many organisms live within, and/or feed on, this thin layer of loose readily-resuspendable sediment and they can be exposed to any contaminants it contains. More significantly, this material will potentially be incorporated into the consolidated substratum during the current dry season, and may influence the quality of benthic habitats for years to come.

These highly mobile surface-sediment layers contain a lot of extremely small, light-weight particles (such as flocculated colloids and clays) that cannot be collected efficiently using conventional sediment grab-samplers. They also hold a lot of interstitial water which, due to its intimate contact with the sediment, can take up significant quantities of dissolved metals. It is extremely difficult to obtain quantitative samples of this water through conventional means.

Accordingly the ACTFR have designed and constructed a customised sediment sampler for the purpose (see Figure 2.2). This device, termed a sediment turbator, comprises a plastic cylindrical chamber (height 19cm, volume 14 L) capable of enclosing a 7.8 dm^2 area of the substratum surface, a plunger which is used to disturb and resuspend fine sediments within the chamber, and a peristaltic sampling pump to extract a sample of the sediment-laden water from the chamber.

Turbator samples were collected by placing the chamber on the streambed, agitating the water in the chamber with three rapid strokes of the plunger, waiting 30 seconds for sand to settle and then pumping a 2 litre sample from the chamber.

These samples generally contain a much higher proportion of very fine particles than the underlying substratum, as well as metal-enriched interstitial water, hence they usually yield higher metal concentrations than normal sediment or water samples. Moreover, the concentration values obtained depend on numerous arbitrary factors such as the volume of the chamber and the amount of agitation applied, and cannot therefore be compared to data collected using other sampling methods.

Since samples contain all of the metals (both sediment-bound and dissolved) that were released from the sediment surface enclosed by the sampling chamber, metal concentrations are reported in mass per unit area terms (i.e. mg/dm^2).

Turbator samples are identified by prefixing the site number with the letter “T”.

Figure 2.2: Sediment turbator

2.4 Laboratory Analyses

Bioavailable metals are generally concentrated in the fine (muddy) sediment fraction. Coarse particles such as sand and gravel contain very little metal and effectively act as a diluent. Consequently, sandy samples generally report low metal concentrations even if they contain fine sediments that are sufficiently contaminated to cause problems if they were to find their way into a muddier habitat. To allow more meaningful comparisons between sites, especially when attempting to identify metal sources in the catchment, it is common practice to sieve samples to remove sand and grit prior to analysis. The Queensland EPA adopted this approach when assessing the metals status of State reference sites (Moss and Costanzo 1998) and accordingly the same methods have been employed for the analysis of consolidated sediment samples in this study.

Specifically, consolidated sediment samples were sieved to collect the minus 63 micron (-63 μm) sediment fraction for analysis. All washings were retained and evaporated at 105°C to obtain an oven-dry sample for analysis. The dried sample was ground and mixed prior to analysis. Trace metals determinations were conducted by ICP-MS (or Zeeman Graphite AAS) at the Advanced Analytical Centre at JCU after being subjected to nitric acid/microwave digestion. Nitric acid/microwave digestion is a procedure that is expected to recover the majority of metals present in the fine sediment fraction. The nitric acid digestion generates data that are ideal for comparison with QEPA guidelines (Moss and Costanzo 1999).

The analytical suite comprised antimony (Sb), arsenic (As), cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu), lead (Pb), nickel (Ni), selenium (Se), silver (Ag), zinc (Zn) and thallium (Tl). This encompasses all of the toxic metals and metalloids commonly associated with the kinds of urban and light industrial activities that occur in the Ross River catchment, and all of the metals for which ANZECC (2000) aquatic ecosystem protection guidelines are available, other than mercury (which was excluded because it is expensive to analyse and is not considered likely to be a potential issue in the Ross River catchment).

Several metals that are often included in sediment surveys such as aluminium, bismuth, boron, molybdenum, iron and manganese have been intentionally excluded due to existing uncertainties about their ecological significance in aquatic environments and/or because they would have to be studied in considerable detail in order to interpret results. Iron and manganese for example dissolve in anoxic waters but precipitate in the presence of oxygen, hence sedimentary concentrations cannot be interpreted without closely determining the historical oxic status of the sampling sites – a task that would be a major undertaking in its own right.

The strong acid digestions used in this study extract virtually all of the metals from sediment samples including some that are not bioavailable. This needs to be taken into consideration if assessing compliance with ANZECC (2000) Interim Sediment Quality Guideline values (ISQGs) because they only relate to bioavailable metals, the concentrations of which would normally be determined by carrying out weak acid extractions. Moreover, the ISQGs are meant to be used for assessing whole (unsieved) sediments which generally contain lower metal concentrations than minus 63 µm samples (due to dilution by coarser sediment particles such as sand and shell grit).

Basically the methods employed in this study are much more conservative than the methods that are used to assess compliance with ANZECC guidelines. They provide the maximum possible power to detect any potential or emerging problems, and are designed to ensure that ecological risks are never underestimated. This is an appropriate precaution to take when conducting broadscale surveys such as this, which require risks to be assessed based on the results of just one sample per site, but when interpreting findings it is important to remember that risks may have been overestimated. Notably, this means that a failure to comply with ANZECC guidelines is not necessarily indicative of an existing problem, but rather of the need to carry out more detailed investigations in order to able to discount the possibility that a problem exists.

Turbator samples were filtered to collect solids which were dried and subjected to the same digestion and analysis procedures as the consolidated sediment samples. Filtrates were digested and analysed separately, and then the contributions from the filterable and non-filterable fractions were summed to provide an estimate of the total metal content per unit area of substratum.

Previous experience with samples collected using this custom-developed sampling technique indicates that it almost always yields higher metal concentrations than other sampling methods. This enhances its capacity to detect metal enrichment and provides an excellent basis for comparing between sites, but as noted previously, the results cannot be validly compared to results obtained from other sampling methods or existing sediment guideline values.

3. RESULTS AND DISCUSSION

3.1 Consolidated Sediments

The metals concentrations in the minus 63 µm fraction of consolidated sediment samples are shown in Table 3.1. ANZECC (2000) ISQG values and Queensland reference values (Moss and Costanzo 1998) are also shown at the bottom of the table.

Queensland reference values comprise the Reference Median Range (RMR), which encompasses the lowest and highest median concentrations reported at any individual reference site in the State monitoring network, and the RMR-median, which is the median of all the individual site medians in the State database. The sampling and analysis methods employed in this study are essentially the same as those employed in the State ambient monitoring program, except that this study targeted muddy substrata where possible while the State monitoring employed representative sampling of all substratum types. Targeted sampling can sometimes yield slightly elevated concentrations; nevertheless, the results should be generally comparable.

RMR values are only available for half of the metals analysed in this study (Cd, Cr, Cu, Ni, Pb and Zn), but these are the six metals that are most likely to be subject to anthropogenic enrichment in an urban catchment, and are the only metals other than cobalt that reported concentrations significantly greater than the analytical detection limit. Table 3.1 shows that, with the exception of lead, all sites in this study reported metals concentrations that are well within the reference range, and in most cases less than the reference median. Lead values exceeded the reference median at all sites, including the controls, and most results were greater than the maximum reference value.

Notably the second highest lead value of 32 mg/kg was reported at an upstream freshwater control site, and the data as a whole show no obvious signs of hotspots or concentration gradients indicative of potential point sources. This suggests that the results are indicative of natural lead background concentrations in the region. ACTFR (unpub. Data) have found that virtually all of the sediment surveys they have conducted between the Burdekin River and Mitchell catchments in north Queensland report lead concentrations greater than the State RMR values, suggesting that the RMR values for lead are not a valid benchmark to employ in this region.

The ANZECC (2000) ISQGs are toxicity risk-based guideline values which do not take natural background concentrations into consideration. They are only interim values because they are based on quite limited overseas data (on only 2 animal species in many cases) and have also been derived using statistical procedures that are quite different to the methods employed for other ANZECC guidelines. Nevertheless they are currently the best available benchmark for assessing the potential ecological significance of sedimentary metal accumulations. The ISQG-low and high values are indicative of the 10% and 50% effect concentrations, respectively. As explained in Section 2.4, the sampling and analysis techniques employed in this study (i.e. strong acid digestion of the fine sediment fraction) usually yield significantly higher results than the methods that are meant to be used to assess compliance with the ISQGs (weak acid extractions of unsieved sediment). Accordingly, in this study results greater than the ISQG values would not necessarily represent a compliance breach.

The fact that each metal has a different natural concentration range and ISQG value, makes it quite tedious to compare the relative significance of different metals and/or to assess overall cumulative effects from numerous metals. This task can be simplified by dividing the metal concentration values by their respective ISQG values to yield an index score indicative of the relative risks to the ecosystem. This normalises the results allowing direct comparisons to be made between metals. Scores can also be summed to help gauge overall cumulative effects if the concentrations of a number of different metals are elevated. The Risk Index provides a quantitative measure of relative risk (i.e. the higher the index score the higher the risk to the ecosystem), with scores greater than one indicating that concentrations are high enough to potentially breach the ANZECC sediment quality guidelines. Since the sampling and analysis methods employed in this study are likely to over-estimate the concentrations of bioavailable metals, scores less than one suggest a very low probability of adverse ecological effects.

Table 3.1 Metals concentrations in the 63 µm fraction of consolidated sediment grab samples (mg/kg). Freshwater study sites are shaded yellow, estuarine sites are shaded blue and reference sites are shaded grey.

Site	Silver (Ag)	Arsenic (As)	Cadmium (Cd)	Cobalt (Co)	Chromium (Cr)	Copper (Cu)	Nickel (Ni)	Lead (Pb)	Antimony (Sb)	Selenium (Se)	Thallium (Tl)	Zinc (Zn)
G1	<0.1	6	<0.2	11	10	11	9	18	<0.05	<1	0.33	36
G2	<0.1	<5	<0.2	13	18	8	9	20	<0.05	<1	<0.2	32
G3	<0.1	<5	<0.2	11	10	5	4	32	<0.05	<1	0.27	29
G4	<0.1	<5	<0.2	9	19	10	13	13	<0.05	<1	<0.2	45
G5	<0.1	<5	<0.2	8	23	10	12	15	<0.05	<1	<0.2	33
G6	<0.1	<5	<0.2	6	12	11	7	16	<0.05	<1	0.32	39
G7	0.14	<5	<0.2	12	24	14	21	17	<0.05	<1	<0.2	47
G8	<0.1	<5	<0.2	14	13	11	8	36	<0.05	<1	0.21	51
G9	<0.1	<5	<0.2	6	14	14	9	23	<0.05	<1	0.31	54
G10	<0.1	<5	<0.2	6	15	12	11	29	<0.05	<1	0.32	61
G11	<0.1	<5	<0.2	8	15	13	8	22	<0.05	<1	0.43	52
G12	<0.1	<5	<0.2	4	8	6	4	11	<0.05	<1	0.23	26
G13	<0.1	<5	<0.2	9	18	12	10	25	<0.05	<1	0.30	54
G14	<0.1	<5	<0.2	9	31	13	16	23	<0.05	<1	<0.2	43
G15	<0.1	<5	<0.2	7	16	12	9	27	<0.05	<1	<0.2	60
G16	<0.1	<5	<0.2	8	19	13	11	26	<0.05	<1	0.29	57
G17	<0.1	<5	<0.2	8	18	14	11	28	<0.05	<1	0.31	67
G18	<0.1	<5	<0.2	9	14	10	5	24	<0.05	<1	0.23	52
G19	<0.1	<5	<0.2	7	17	11	9	24	<0.05	<1	<0.2	57
G20	<0.1	<5	<0.2	13	21	19	14	25	<0.05	<1	<0.2	57
G21	<0.1	<5	<0.2	8	19	12	10	22	<0.05	<1	<0.2	35
G22	<0.1	5	<0.2	7	21	11	10	15	<0.05	<1	<0.2	40
G23	<0.1	<5	<0.2	6	10	11	6	18	<0.05	<1	<0.2	46
G24	<0.1	7	<0.2	11	30	18	17	28	<0.05	<1	0.31	76
G25	<0.1	<5	<0.2	9	22	13	12	24	<0.05	<1	0.21	66
G26	<0.1	7	<0.2	10	29	18	17	26	<0.05	<1	0.29	69
G27	<0.1	5	<0.2	6	16	10	9	12	<0.05	<1	<0.2	38
G28	<0.1	5	<0.2	7	19	11	11	16	<0.05	<1	0.20	41
G29	<0.1	<5	<0.2	5	18	9	9	11	<0.05	<1	<0.2	34
G30	<0.1	5	<0.2	6	20	18	10	15	<0.05	<1	<0.2	55
G31	<0.1	<5	<0.2	6	17	11	7	10	<0.05	<1	0.20	33
G32	<0.1	<5	<0.2	6	10	6	7	8	<0.05	<1	<0.2	27
G33	<0.1	<5	<0.2	3	9	7	4	7	<0.05	<1	<0.2	23
G34	<0.1	<5	<0.2	5	12	10	8	16	<0.05	<1	<0.2	50
G35	<0.1	10	<0.2	9	31	13	19	16	<0.05	<1	<0.2	47
ISQG low	**1**	**20**	**1.5**		**80**	**65**	**21**	**50**	**2**			**200**
ISQG-high	**3.7**	**70**	**10**		**370**	**270**	**52**	**220**	**25**			**410**
RMR			0.5 -1.5		15 - 240	10 - 64	5 - 40	5 - 20				29 - 130
RMR median			1.5		66	20	20	5				83
RMR			0.5 - 1.5		30 - 95	5 - 23	5 - 23	5 - 13				37 - 110
RMR median			0.5		60	17	10	5				65

***** ISQG values are from ANZECC (2000).
** RMR values are from Moss and Costanzo (1998).

The Risk Index values calculated from the raw results in Table 3.1 are shown in Table 3.2. For most metals these values were obtained by dividing each reported concentration value by the ISQG-low. However, the ANZECC guidelines do not provide ISQG values for cobalt, selenium or thallium. For these metals it was necessary to propose speculative guideline values, based on consideration of natural concentration ranges and relative toxicities as indicated by water quality trigger values and the ecotoxicological information provided in the ANZECC (2000) guidelines. Given the obvious uncertainties involved in this process every effort was made to err on the side of caution and the speculative values were set at the lowest plausible levels. In practice the concentrations of selenium and thallium reported in this study were so low that the index calculations were largely inconsequential. Cobalt concentrations were more significant but they were still consistently low and would not be expected to present any significant ecological risk.

Overall the Risk Index scores shown in Table 3.2 are very low, especially considering that fine sediment deposition sites and urban drains were targeted, and that due to the use of strong acid digestions, the reported concentrations almost certainly include some non-bioavailable metals. The only results worthy of any discussion are highlighted in blue text in the table. The score of 0.7 recorded for lead at site 8 (the creek that drains runoff from the Palmetum into Aplins Weir) is worth mentioning as it indicates that existing concentrations are high enough to have some potential ecological significance. However, this index value was only slightly higher than the 0.6 score reported at one of the controls (site 3), and in statistical terms the value still falls within the possible natural background range.

All of the other values highlighted in the table relate to nickel which was the only metal to yield a number of scores greater than 0.7, although there were no values larger than one (i.e. no potential compliance breaches). It is noteworthy that the estuarine control site (site 35) registered the second highest score, and one of the freshwater controls (site 4) reported a significant index value of 0.6. Also the State RMR values indicate that the median background nickel concentrations at some Queensland reference sites actually exceed the ISQG-low, in some cases by a factor of two, meaning that some of the individual samples collected at these reference sites would have yielded Risk Index scores greater than two. These observations imply either that nickel naturally occurs at concentrations that are high enough to adversely affect some biological species, or that the ISQG is too conservative for this region. Regardless of the explanation it is clear that ambient nickel levels are no more of an issue in the Ross River catchment than they are in most other Queensland catchments.

The index scores in Table 3.2 provide a convenient means of rapidly evaluating the relative ecological significance of existing metal accumulations, but they do not provide an efficient means of assessing the extent to which metal concentrations have been influenced by anthropogenic inputs. In the scientific literature this has traditionally been facilitated by normalising the results to account for differences in sediment composition, and then dividing the values obtained at study sites by the values recorded at control sites to yield ratios indicative of the level of enrichment. The problem with this approach is that it can produce some fairly misleading ratio values. For example if dealing with a metal such as silver, which naturally occurs at concentrations well below its toxic threshold, a high enrichment value of, say 3 (indicative of a three-fold increase in concentration) would still only represent an extremely minor change and would be of no real practical or ecological consequence. Conversely if dealing with a metal such as lead, which naturally occurs at significant concentrations, enrichment ratio only slightly greater than one could be indicative of increased risks to the ecosystem.

Accordingly this study has employed the alternative approach of using ecological Risk Index scores instead of normalised concentration values, and then calculating deviation values by subtracting the control values rather than performing a division. The resulting scores express deviations from control as a proportion of the ISQG value – for example a result of 0.5 would indicate that the concentration of that metal at that site was higher than the control by an amount equivalent to half of the ISQG.

The Risk Index deviation scores obtained in this study are shown in Table 3.3. For freshwater sites scores were calculated using the median value of the concentrations reported at the four control sites. Since there is some natural random variability in background metal concentrations, some of the control sites report values greater than zero. For marine sites the calculations were performed using the results obtained from the single control site on Cocoa Ck, hence all the control site values in the table are zeroes.

Table 3.2 Risk index scores calculated from the metals concentrations in the minus 63 μm fraction of consolidated bottom sediments. Index values were calculated by dividing metal concentration values by the ISQG-low values shown at the bottom of the table. Freshwater study sites are shaded yellow, estuarine sites are shaded blue and reference sites are shaded grey.

Site	Silver (Ag)	Arsenic (As)	Cadmium (Cd)	Cobalt (Co)	Chromium (Cr)	Copper (Cu)	Nickel (Ni)	Lead (Pb)	Antimony (Sb)	Selenium (Se)	Thallium (Tl)	Zinc (Zn)
G1	0.10	0.3	0.1	0.2	0.1	0.2	0.4	0.4	0.0	0.0	0.2	0.2
G2	0.10	0.3	0.1	0.3	0.2	0.1	0.4	0.4	0.0	0.0	0.1	0.2
G3	0.10	0.3	0.1	0.2	0.1	0.1	0.2	0.6	0.0	0.0	0.1	0.1
G4	0.10	0.3	0.1	0.2	0.2	0.2	0.6	0.3	0.0	0.0	0.1	0.2
G5	0.10	0.3	0.1	0.2	0.3	0.2	0.6	0.3	0.0	0.0	0.1	0.2
G6	0.10	0.3	0.1	0.1	0.1	0.2	0.3	0.3	0.0	0.0	0.2	0.2
G7	0.14	0.3	0.1	0.2	0.3	0.2	**1.0**	0.3	0.0	0.0	0.1	0.2
G8	0.10	0.3	0.1	0.3	0.2	0.2	0.4	**0.7**	0.0	0.0	0.1	0.3
G9	0.10	0.3	0.1	0.1	0.2	0.2	0.4	0.5	0.0	0.0	0.2	0.3
G10	0.10	0.3	0.1	0.1	0.2	0.2	0.5	0.6	0.0	0.0	0.2	0.3
G11	0.10	0.3	0.1	0.2	0.2	0.2	0.4	0.4	0.0	0.0	0.2	0.3
G12	0.10	0.3	0.1	0.1	0.1	0.1	0.2	0.2	0.0	0.0	0.1	0.1
G13	0.10	0.3	0.1	0.2	0.2	0.2	0.5	0.5	0.0	0.0	0.1	0.3
G14	0.10	0.3	0.1	0.2	0.4	0.2	**0.8**	0.5	0.0	0.0	0.1	0.2
G15	0.10	0.3	0.1	0.1	0.2	0.2	0.4	0.5	0.0	0.0	0.1	0.3
G16	0.10	0.3	0.1	0.2	0.2	0.2	0.5	0.5	0.0	0.0	0.1	0.3
G17	0.10	0.3	0.1	0.2	0.2	0.2	0.5	0.6	0.0	0.0	0.2	0.3
G18	0.10	0.3	0.1	0.2	0.2	0.2	0.3	0.5	0.0	0.0	0.1	0.3
G19	0.10	0.3	0.1	0.1	0.2	0.2	0.4	0.5	0.0	0.0	0.1	0.3
G20	0.10	0.3	0.1	0.3	0.3	0.3	0.7	0.5	0.0	0.0	0.1	0.3
G21	0.10	0.3	0.1	0.2	0.2	0.2	0.5	0.4	0.0	0.0	0.1	0.2
G22	0.10	0.2	0.1	0.1	0.3	0.2	0.5	0.3	0.0	0.0	0.1	0.2
G23	0.10	0.3	0.1	0.1	0.1	0.2	0.3	0.4	0.0	0.0	0.1	0.2
G24	0.10	0.4	0.1	0.2	0.4	0.3	**0.8**	0.6	0.0	0.0	0.2	0.4
G25	0.10	0.3	0.1	0.2	0.3	0.2	0.6	0.5	0.0	0.0	0.1	0.3
G26	0.10	0.4	0.1	0.2	0.4	0.3	**0.8**	0.5	0.0	0.0	0.1	0.3
G27	0.10	0.3	0.1	0.1	0.2	0.1	0.4	0.2	0.0	0.0	0.1	0.2
G28	0.10	0.3	0.1	0.1	0.2	0.2	0.5	0.3	0.0	0.0	0.1	0.2
G29	0.10	0.3	0.1	0.1	0.2	0.1	0.4	0.2	0.0	0.0	0.1	0.2
G30	0.10	0.2	0.1	0.1	0.3	0.3	0.5	0.3	0.0	0.0	0.1	0.3
G31	0.10	0.3	0.1	0.1	0.2	0.2	0.3	0.2	0.0	0.0	0.1	0.2
G32	0.10	0.3	0.1	0.1	0.1	0.1	0.3	0.2	0.0	0.0	0.1	0.1
G33	0.10	0.3	0.1	0.1	0.1	0.1	0.2	0.1	0.0	0.0	0.1	0.1
G34	0.10	0.3	0.1	0.1	0.1	0.2	0.4	0.3	0.0	0.0	0.1	0.2
G35	0.10	0.5	0.1	0.2	0.4	0.2	**0.9**	0.3	0.0	0.0	0.1	0.2
ISQG	**1**	**20**	**1.5**	**50***	**80**	**65**	**21**	**50**	**2**	**50***	**2***	**200**

*ANZECC (2000) ISQG-low values have been used for all metals other than Co, Se and Tl, for which no sediment quality guidelines are provided. For these metals speculative values have been proposed based on consideration of existing toxicity data.

Table 3.3 Risk index deviations for minus 63 µm sediment grab samples. Deviations were calculated by subtracting control site risk scores from the raw scores shown in Table 3.2. Freshwater study sites are shaded yellow, estuarine sites are shaded blue and reference sites are shaded grey.

Site	Silver (Ag)	Arsenic (As)	Cadmium (Cd)	Cobalt (Co)	Chromium (Cr)	Copper (Cu)	Nickel (Ni)	Lead (Pb)	Antimony (Sb)	Selenium (Se)	Thallium (Tl)	Zinc (Zn)
G1	0.00	0.0	0.0	-0.01	-0.05	0.03	0.00	-0.03	0.0	0.0	0.0	0.0
G2	0.00	0.0	0.0	0.04	0.05	-0.01	0.00	0.03	0.0	0.0	0.0	0.0
G3	0.00	0.0	0.0	0.01	-0.05	-0.06	-0.22	**0.27**	0.0	0.0	0.0	0.0
G4	0.00	0.0	0.0	-0.04	0.07	0.01	**0.21**	-0.12	0.0	0.0	0.0	0.1
G5	0.00	0.0	0.0	-0.05	0.12	0.01	0.15	-0.09	0.0	0.0	0.0	0.0
G6	0.00	0.0	0.0	-0.10	-0.03	0.03	-0.09	-0.06	0.0	0.0	0.0	0.0
G7	0.04	0.0	0.0	0.01	0.13	0.07	**0.55**	-0.04	0.0	0.0	0.0	0.1
G8	0.00	0.0	0.0	0.05	-0.01	0.03	-0.06	**0.35**	0.0	0.0	0.0	0.1
G9	0.00	0.0	0.0	-0.10	0.00	0.07	0.03	0.09	0.0	0.0	0.0	0.1
G10	0.00	0.0	0.0	-0.10	0.02	0.04	0.08	0.21	0.0	0.0	0.0	0.1
G11	0.00	0.0	0.0	-0.07	0.01	0.06	-0.06	0.07	0.0	0.0	0.1	0.1
G12	0.00	0.0	0.0	-0.14	-0.07	-0.05	-0.22	-0.15	0.0	0.0	0.0	0.0
G13	0.00	0.0	0.0	-0.05	0.05	0.05	0.07	0.12	0.0	0.0	0.0	0.1
G14	0.00	0.0	0.0	-0.04	**0.21**	0.06	**0.35**	0.09	0.0	0.0	0.0	0.0
G15	0.00	0.0	0.0	-0.08	0.03	0.04	0.02	0.17	0.0	0.0	0.0	0.1
G16	0.00	0.0	0.0	-0.07	0.06	0.06	0.12	0.14	0.0	0.0	0.0	0.1
G17	0.00	0.0	0.0	-0.05	0.06	0.08	0.12	0.19	0.0	0.0	0.0	0.2
G18	0.00	0.0	0.0	-0.04	0.00	0.01	-0.16	0.11	0.0	0.0	0.0	0.1
G19	0.00	0.0	0.0	-0.08	0.04	0.03	0.02	0.10	0.0	0.0	0.0	0.1
G20	0.00	0.0	0.0	0.04	0.09	0.15	0.24	0.13	0.0	0.0	0.0	0.1
G21	0.00	0.0	0.0	-0.07	0.06	0.04	0.03	0.07	0.0	0.0	0.0	0.0
G22	0.00	-0.3	0.0	-0.05	-0.12	-0.04	-0.42	-0.02	0.0	0.0	0.0	0.0
G23	0.00	-0.2	0.0	-0.06	-0.26	-0.04	-0.62	0.03	0.0	0.0	0.0	0.0
G24	0.00	-0.1	0.0	0.03	-0.02	0.07	-0.07	**0.24**	0.0	0.0	0.1	0.1
G25	0.00	-0.2	0.0	0.00	-0.10	-0.01	-0.32	0.16	0.0	0.0	0.0	0.1
G26	0.00	-0.1	0.0	0.02	-0.02	0.07	-0.11	0.19	0.0	0.0	0.0	0.1
G27	0.00	-0.2	0.0	-0.07	-0.19	-0.06	-0.47	-0.09	0.0	0.0	0.0	0.0
G28	0.00	-0.2	0.0	-0.04	-0.14	-0.04	-0.38	-0.01	0.0	0.0	0.0	0.0
G29	0.00	-0.2	0.0	-0.08	-0.16	-0.07	-0.45	-0.11	0.0	0.0	0.0	-0.1
G30	0.00	-0.2	0.0	-0.07	-0.13	0.07	-0.40	-0.02	0.0	0.0	0.0	0.0
G31	0.00	-0.2	0.0	-0.06	-0.17	-0.04	-0.59	-0.12	0.0	0.0	0.0	-0.1
G32	0.00	-0.2	0.0	-0.07	-0.25	-0.11	-0.59	-0.16	0.0	0.0	0.0	-0.1
G33	0.00	-0.2	0.0	-0.11	-0.27	-0.09	-0.71	-0.18	0.0	0.0	0.0	-0.1
G34	0.00	-0.2	0.0	-0.07	-0.24	-0.04	-0.53	-0.01	0.0	0.0	0.0	0.0
G35	0.00	0.0	0.0	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0

The deviation scores in Table 3.3 are all quite moderate and provide no indications of any significant anthropogenic enrichment. The most significant scores are highlighted in blue text. The fact that control sites reported some of the highest values for nickel and lead confirms that natural background variations of these metals may be large enough to carry some potential ecological significance. It would be necessary to collect a lot more control data to be able to confidently determine if the results for non-control sites actually fall outside the natural variability range. Based on the limited data available, it is obvious that the highlighted values are the only results that could potentially be indicative of significant anthropogenic enrichment. However, none of the values are high enough to be cause for concern and there is no evidence of effects downstream of any of these sites, so at worst the results would indicate mild localised enrichment. It is noteworthy that site 14 (a drain at Riverside Gardens) was the only site that reported significant values for more than one metal (chromium and nickel).

If controls and study sites are a good match then the dataset should contain an equal mix of negative and positive deviation scores (or at least values that are consistently close to zero). In this case the tidal sites have consistently registered negative values for several metals indicating that background concentrations at the estuarine control site at Cocoa Ck were significantly higher than they were in the study area. Hence Cocoa Ck is obviously not an ideal control for the Ross River estuary and it would be advisable to attempt to locate an alternative site if further investigations of this sort are carried out in the future. The reasons for the apparent mismatch are discussed in the next section.

3.2 Unconsolidated Sediments

Turbator samples evaluate the total quantities of resuspendable sediment and metals per unit area of substratum. The results obtained in this study are shown in Table 3.4. Turbator results vary depending on the amount and type of agitation applied to the sediment surface during sampling. They do not therefore provide an absolute measure of sediment concentration and cannot be compared to data obtained using any other sampling method. Nevertheless, since the same sampling method was employed at each site in this study, the results provide a valid basis for comparing the quantity and quality of mobile resuspendable sedimentary materials present on the substratum surface at each site.

Turbator results are expressed in mass per unit area terms (mg/m^2) and cannot be directly compared to ISQG concentration values (which are given in mg/kg). Nevertheless, it is still feasible to use the ISQGs to calculate index values analogous to the Risk Indices used in the preceding section. The main difference in this case is that although the values are still indicative of relative risk – i.e. the higher the index score the higher the risk – there is no way of knowing what the maximum acceptable index value would be. The Relative Risk Index scores calculated from the results in Table 3.4 are shown in Table 3.5.

Since the index scores normalise the results, the values for different metals can validly be summed to provide a single score indicative of the overall risks at each site. The summed scores for this dataset are shown in the rightmost column of Table 3.5. It can be seen that the values in this column span a range of more than an order of magnitude, from a minimum of 0.2 to a maximum of 4.2, suggesting that the risks associated with sedimentary metals accumulations vary substantially between sites. These variations are driven by two interacting factors; the amount of fine resuspendable sediment present and the concentrations of metals attached to that fine sediment.

The total amount of solids (i.e. fine sediment) that was resuspended by the turbator at each site is shown in the leftmost column of Tables 3.4 and 3.5. Results varied widely between sites, ranging from 0.02 kg/m^2 to 1.24 kg/m^2, and are obviously strongly correlated to risk index score. This correlation is more easily seen in the red regression line on Figure 3.1 which, for freshwater sites, plots the cumulative (summed) risk scores against mobile (resuspendable) sediment quantity. The correlation is very strong indeed ($R^2 = 0.9797$), demonstrating that the amount of fine sediment present was the main determinant of metal-related risks at most sites.

The quantities of fine sediment retained on the bottom of a waterbody are primarily a function of its hydrodynamics because small particles can only settle in areas where the water is relatively free of turbulence and where flows are slow enough to allow them to settle before they are washed away. Hence there are certain parts of a drainage system where fine sedimentary materials (and concomitantly metals) tend to naturally accumulate, and these will always be the sites that are most likely to experience sediment contamination problems. There are three types of anthropogenic influences that can potentially increase the contamination levels at these fine sediment trap sites: 1) hydrodynamic alterations such as the introduction of flow obstructions which can increase sedimentation rates; 2) elevated fine sediment inputs (due mainly to increased catchment erosion), and; 3) metal enrichment due to increased inputs of metals and subsequent attachment to fine sediment particles.

The potential for adverse effects from increased fine sediment accumulation (i.e. influences 1 and 2 above) must be assessed on a case by case basis because natural sediment trapping capacities can vary substantially between sites. Nevertheless, it is noteworthy that in this study all but one of the freshwater samples with sediment concentrations greater than 0.5 kg/m^2 were collected from drains (sites 13, 15, 18) and the only other value that high was reported at site 6 within the Central Ck arm of Ross Dam. The latter result is to be expected because dams almost always trap some fine sediment.

The substratum at some freshwater sites contains very few fine sediment particles. However, these lower abundance particles often have unusually high metal sorption capacity and tend to accumulate metals more efficiently than other sediments. Hence the solids in turbator samples from sites that contain only small amounts of fine sediment often report elevated metal concentrations.

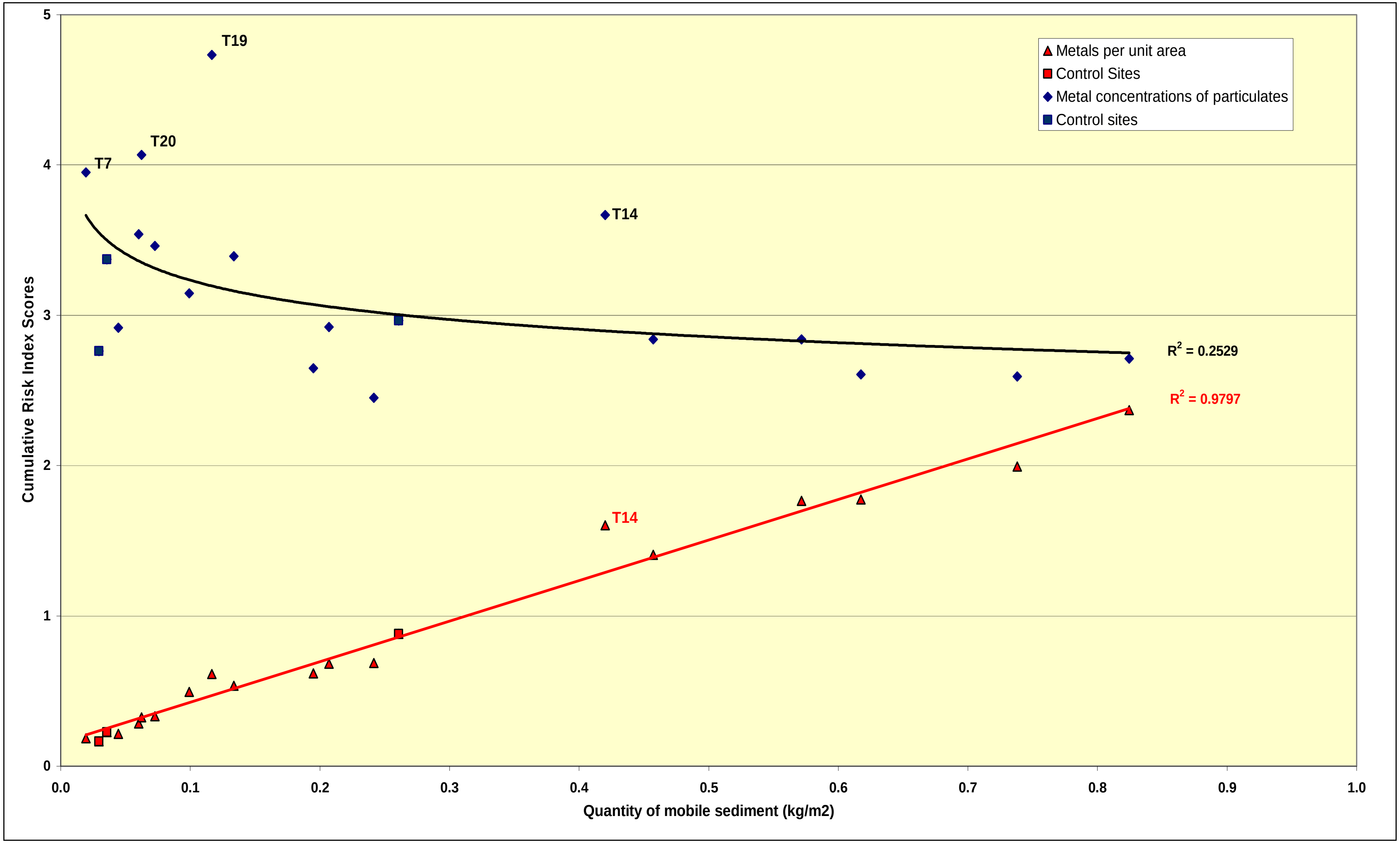
Figure 3.4: The total metal content of turbator samples (including contributions from both particulate and dissolved metals) expressed as mg/m^2. Note that results are a function of the sampling method employed and can only be compared to values obtained using precisely the same sampling equipment and method. Freshwater study sites are shaded yellow, estuarine sites are shaded blue and reference sites are shaded grey.

Site	Solids(kg/m^2)	Silver (Ag)	Arsenic (As)	Cadmium (Cd)	Cobalt (Co)	Chromium (Cr)	Copper (Cu)	Nickel (Ni)	Lead (Pb)	Antimony (Sb)	Selenium (Se)	Thallium (Tl)	Zinc (Zn)
T1	0.04	<0.05	<1	<0.2	0.4	0.6	3.1	0.4	0.6	<0.05	<1	<0.1	18
T2	0.26	<0.05	1	<0.2	2.7	4.7	7.2	2.7	4.8	0.1	<1	<0.1	46
T4	0.03	<0.05	<1	<0.2	0.2	0.4	1.4	0.4	0.6	<0.05	<1	<0.1	13
T5	0.20	<0.05	1	<0.2	1.9	4.7	3.9	3.2	3.8	<0.05	<1	<0.1	25
T6	0.62	<0.05	3	<0.2	5.3	10.8	15.1	7.0	14.8	0.1	<1	0.2	38
T7	0.02	<0.05	<1	<0.2	0.1	0.4	1.4	0.3	0.3	<0.05	<1	<0.1	17
T8	0.06	<0.05	<1	<0.2	2.1	0.8	1.1	0.7	1.8	<0.05	<1	<0.1	17
T9	0.10	<0.05	2	<0.2	1.2	1.4	5.7	1.3	2.1	<0.05	<1	<0.1	24
T10	0.07	<0.05	<1	<0.2	0.4	1.0	6.4	0.9	2.1	<0.05	<1	<0.1	14
T11	0.24	<0.05	1	<0.2	1.6	4.2	4.3	3.1	5.9	<0.05	<1	<0.1	20
T12	0.04	<0.05	<1	<0.2	0.3	0.7	1.0	0.6	1.1	<0.05	<1	<0.1	17
T13	0.74	<0.05	4	<0.2	6.0	14.8	12.3	9.3	20.0	0.1	<1	0.2	44
T14	0.42	0.08	2	<0.2	6.0	13.7	9.4	9.6	15.1	<0.05	<1	<0.1	22
T15	0.57	0.07	3	<0.2	4.3	12.6	10.3	7.8	21.5	0.1	<1	0.1	32
T16	0.21	<0.05	<1	<0.2	1.9	4.4	6.8	3.3	5.5	<0.05	<1	<0.1	21
T17	0.46	<0.05	2	<0.2	3.6	9.5	10.9	6.8	14.4	<0.05	<1	0.1	33
T18	0.82	0.08	4	0.2	5.3	15.4	20.5	8.6	24.4	0.1	<1	0.2	59
T19	0.12	<0.05	<1	<0.2	1.4	3.6	9.3	2.2	6.3	<0.05	<1	<0.1	16
T20	0.06	<0.05	<1	<0.2	0.6	1.3	7.2	0.9	1.6	<0.05	<1	<0.1	14
T21	0.13	<0.05	<1	<0.2	1.5	3.4	6.2	2.3	4.3	<0.05	<1	<0.1	17
T22	0.93	0.12	7	0.2	9.2	29.2	24.1	15.6	24.0	0.1	1	0.2	51
T23	0.38	0.05	3	<0.2	3.5	8.9	10.1	5.1	13.6	0.1	<1	0.1	19
T24	0.11	<0.05	1	<0.2	1.6	4.5	3.3	3.2	2.8	0.1	<1	<0.1	14
T25	0.19	<0.05	2	<0.2	1.9	4.7	8.5	2.9	7.4	0.1	<1	<0.1	15
T26	1.24	<0.05	9	0.3	13.6	40.4	27.6	24.1	34.6	0.1	2	0.3	51
T27	0.49	0.07	6	<0.2	5.3	16.1	12.2	9.0	11.8	0.2	1	<0.1	28
T28	0.19	<0.05	3	<0.2	1.9	5.6	6.0	3.6	4.6	0.1	1	<0.1	20
T29	0.38	<0.05	4	<0.2	2.5	8.7	7.2	5.9	5.7	0.1	1	<0.1	19
T30	0.25	0.05	4	<0.2	2.6	9.1	15.0	6.1	6.8	0.1	1	<0.1	18
T31	0.54	<0.05	3	<0.2	5.0	9.4	8.4	6.2	11.5	0.1	2	<0.1	31
T32	0.47	0.07	5	<0.2	6.9	17.1	11.5	10.5	10.8	0.1	2	0.1	41
T33	0.18	<0.05	2	<0.2	1.9	6.5	10.4	10.1	4.8	0.4	2	<0.1	14
T34	0.21	0.07	4	<0.2	2.4	8.6	18.2	10.1	22.0	0.3	2	<0.1	35
T35	0.62	<0.05	8	<0.2	7.0	26.4	18.4	15.3	13.3	0.6	2	0.2	53

Table 3.5: Relative Risk index scores calculated from the total metal content of turbator samples. Freshwater study sites are shaded yellow, estuarine sites are shaded blue and reference sites are shaded grey.

Site	Solids(kg/m^2)	Silver (Ag)	Arsenic (As)	Cadmium (Cd)	Cobalt (Co)	Chromium (Cr)	Copper (Cu)	Nickel (Ni)	Lead (Pb)	Antimony (Sb)	Selenium (Se)	Thallium (Tl)	Zinc (Zn)	Sum of Scores
T1	0.04	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2
T2	0.26	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.2	0.9
T4	0.03	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2
T5	0.20	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.1	0.0	0.0	0.0	0.1	0.6
T6	0.62	0.1	0.2	0.1	0.1	0.1	0.2	**0.3**	**0.3**	0.0	0.0	0.1	0.2	1.8
T7	0.02	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2
T8	0.06	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3
T9	0.10	0.0	0.1	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.5
T10	0.07	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.3
T11	0.24	0.0	0.1	0.0	0.0	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.1	0.7
T12	0.04	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2
T13	0.74	0.0	0.2	0.1	0.1	0.2	0.2	**0.4**	**0.4**	0.0	0.0	0.1	0.2	2.0
T14	0.42	0.1	0.1	0.1	0.1	0.2	0.1	**0.5**	**0.3**	0.0	0.0	0.0	0.1	1.6
T15	0.57	0.1	0.1	0.1	0.1	0.2	0.2	**0.4**	**0.4**	0.0	0.0	0.1	0.2	1.8
T16	0.21	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.1	0.0	0.0	0.0	0.1	0.7
T17	0.46	0.0	0.1	0.1	0.1	0.1	0.2	**0.3**	**0.3**	0.0	0.0	0.1	0.2	1.4
T18	0.82	0.1	0.2	0.1	0.1	0.2	**0.3**	**0.4**	**0.5**	0.0	0.0	0.1	**0.3**	**2.4**
T19	0.12	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.0	0.0	0.0	0.1	0.6
T20	0.06	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.3
T21	0.13	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.0	0.0	0.0	0.1	0.5
T22	0.93	0.1	**0.3**	0.1	0.2	**0.4**	**0.4**	**0.7**	**0.5**	0.1	0.0	0.1	0.3	3.2
T23	0.38	0.0	0.1	0.1	0.1	0.1	0.2	0.2	0.3	0.0	0.0	0.0	0.1	1.3
T24	0.11	0.0	0.1	0.0	0.0	0.1	0.1	0.2	0.1	0.0	0.0	0.0	0.1	0.6
T25	0.19	0.0	0.1	0.0	0.0	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.1	0.8
T26	1.24	0.0	**0.5**	0.2	0.3	**0.5**	**0.4**	**1.1**	**0.7**	0.1	0.0	0.2	0.3	4.2
T27	0.49	0.1	0.3	0.1	0.1	0.2	0.2	**0.4**	0.2	0.1	0.0	0.1	0.1	1.9
T28	0.19	0.0	0.1	0.0	0.0	0.1	0.1	0.2	0.1	0.0	0.0	0.0	0.1	0.8
T29	0.38	0.0	0.2	0.1	0.1	0.1	0.1	0.3	0.1	0.1	0.0	0.0	0.1	1.2
T30	0.25	0.1	0.2	0.0	0.1	0.1	0.2	0.3	0.1	0.1	0.0	0.0	0.1	1.3
T31	0.54	0.0	0.2	0.1	0.1	0.1	0.1	0.3	0.2	0.1	0.0	0.0	0.2	1.4
T32	0.47	0.1	0.3	0.1	0.1	0.2	0.2	**0.5**	0.2	0.1	0.0	0.1	0.2	2.0
T33	0.18	0.0	0.1	0.0	0.0	0.1	0.2	**0.5**	0.1	0.2	0.0	0.0	0.1	1.4
T34	0.21	0.1	0.2	0.1	0.0	0.1	0.3	**0.5**	**0.4**	0.1	0.0	0.0	0.2	2.1
T35	0.62	0.0	**0.4**	0.1	0.1	**0.3**	0.3	**0.7**	0.3	0.3	0.0	0.1	0.3	2.9

Figure 3.1 Cumulative (summed) Relative Risk Index scores obtained from the metal concentrations in turbator solids (mg/kg) and turbator estimates of the total amount of metals per unit area, each plotted against the total quantity of mobile (unconsolidated) sediment per unit area



This contaminated material is not usually hazardous to the ecosystem at the site being sampled, simply because there is so little of it present. (The existence of small quantities of metal-enriched sediment of this sort cannot always be disregarded because there could be muddier habitats nearby that contain much greater amounts of the material and/or significant quantities could have been carried downstream to other habitats. In this case, however, sampling was carried out in the muddiest part of each site, and the site network that has been employed is sufficiently extensive to be able to detect any downstream impacts. Hence this report is able to focus mainly on evaluating the status of individual sites without needing to be unduly concerned about predicting the potential for downstream effects.

The concentrations of metals contained in the fine sediments (i.e. just the solids fraction) of turbator samples are shown in Table 3.6 and the associated Relative Risk Index scores are presented in Table 3.7. The summed index scores for freshwater sites are plotted (in blue) on Figure 3.1. The two plots on Figure 3.1 can be used in combination to detect and assess the significance of any potential metals enrichment. Points that lie significantly above the blue regression are indicative of the presence of metal-enriched fine sediment. As noted above, enriched sediment of this kind may have some significance even if it is only present in very small quantities. However, it only presents a direct risk to the site being sampled if it is present in sufficient quantity to significantly increase the overall (mass per unit area) risk scores shown on the red plot. Hence a site should only be considered to exhibit significant metal enrichment if it lies above the regression line on both the blue and red plots.

The blue plot exhibits the pattern discussed earlier, with the three highest concentration index scores being reported at sites that contained very little fine resuspendable sediment. Site 19 (in the creek immediately below Lavarack Dam spillway) yielded the highest score due to elevated Cu (1.2), Pb (1.1) and Ni (0.8) values. This site lies slightly above the red regression line, so the effect was detectable, but the overall risk score was still low, and was actually less than one of the control sites.

The high value at Site 7 (on Ross River immediately downstream of the dam) can be attributed mainly to a very high Zn index score of 2.1, which could possibly be related to recent construction works on the dam spillway. However, as can be seen on the red plot, the total quantities of fine sediment present were low enough for risks to be negligible. The elevated score at Site 20 (on the upstream end of Stuart Ck) was due mainly to a high Cu value (1.7), but again the total quantities present were negligible.

Site 14, a drain in Riverside Gardens, stands out as the only site that lies significantly above both of the regression lines on Figure 3.1, indicating that it contained potentially significant quantities of metal-enriched fine sediment. The sediment at this site did not contain high concentrations of any particular metal but compared to other sites it reported slightly elevated levels of several metals including Ni, Pb, Cu, Cr, Co, As and Ag. There are few urban contamination sources that would involve such a broad range of metals, although it is possible that topsoil from a different catchment has been used for landscaping purposes and that this has given the stream sediments a distinctive metal signature. It is also possible that the sediment at site 14 simply has a greater capacity to adsorb metals than the sediments at other sites in the region. This would happen if it contained an unusually high proportion of certain clays that are found in subsoils, and could therefore result from deeper soils being exposed by erosion and/or excavation works.

There are no indications of metal-enrichment at any other freshwater sites, the total amounts of mobile metals at these sites being dependent almost entirely on the amount of fine resuspendable sediment that was present, which as mentioned previously, is largely a function of site hydrodynamics.

Marine sediments are inherently different to those that are found in fresh water, so the results obtained in the estuarine parts of the drainage system must be interpreted somewhat differently. One of the main differences is that, due to the combined effects of high salt concentrations and mucous-secreting marine microbes, most fine sediment particles flocculate in seawater (i.e. they stick together to form large aggregates called floccs which may be visible to the naked eye - these are sometimes referred to as marine snow). The constituent particles within floccs retain their high affinity for metals and still behave like fine sediment in most respects, but they settle to the bottom much more rapidly than the dispersed sediment particles that typically occur in fresh waters. The other major difference is that in an estuary, when freshwater flows are absent, tidal currents constantly carry fine sediments floccs backwards and forwards, so they have many opportunities to settle and often become intermixed with other sediments before they finally come to rest.

Consequently, other factors being equal, marine-influenced estuarine sediments contain a larger amount and variety of fine readily-suspendable particles than freshwater sediments, and this significantly affects the results obtained from turbator samples. Notably turbator samples collected from freshwater sites located in sandy riverbeds may contain ten times less sediment than estuary sites which rarely yield less than 0.2 kg/m^2 of fine sediment. Moreover, fine sediments collected from marine sites do not exhibit the natural metal enrichment that is often evident at freshwater sites that contain very small amounts of fine sediment.

Due to inherent differences of this kind it is necessary to employ different benchmarks and control sites when assessing the quality of marine and/or estuarine sediments. However, the Ross River estuary is complicated in this regard because it behaves like a freshwater system when flows are present in the river, but essentially becomes a marine estuary during the dry season. Freshwater flows seldom last more than a few months but due to the water detention capacity of the weirs, they are significantly more prolonged than the flows in most unregulated streams in the region. This makes it very difficult to identify control and/or reference sites capable of providing accurate indications of the natural expectations of the system.

As mentioned previously, the sites surveyed during this study were classified as tidal if they contained water that was more than one third seawater. The overall risk scores obtained from the turbator samples collected at these sites are plotted on Figure 3.2. (In this case the metal-concentration-based index values have not been plotted as they were in Figure 3.1 because they do not exhibit any trends). Nine sites reported salinity levels greater than 75% seawater suggesting a predominately marine character. These are shown on the figure in red. The five remaining sites were less saline suggesting that they could have retained some freshwater characteristics. These low salinity tidal sites are shown in blue. The red regression line was obtained using all of the red points other than site 34 which is a small artificial drain that would not be expected to be indicative of natural trends within the estuary. The dashed blue line is a reproduction of the regression line obtained from the freshwater sites in Figure 3.1.

The following features are obvious in Figure 3.2:

- The quantities of metals contained in samples from low salinity tidal sites were very close to the levels predicted by the freshwater regression line and substantially lower than would be expected at more saline sites.
- Samples collected at high salinity sites contained significantly more metals than freshwater samples containing equivalent amounts of sediment. This can be partially attributed to the presence of floccules containing a lot of very small particles with high metal sorption capacity, although for some metals at least, reduced solubility in seawater may also be a significant contributing factor.
- Taking salinity differences into consideration, there are only two sites that reported potentially anomalous results, and one of those is the control site on Cocoa Ck (discussed below).
- The result recorded for Site 34, a drain located on the reclaim, is the only obvious anomaly that could be indicative of anthropogenic effects. The plot shows that this site contained significantly larger quantities of metals than would be expected under natural conditions, and the index scores in Table 3.7 confirm that the turbator solids at this site were enriched in Cu (1.2), Ni (1.9) and Pb (2.1). Furthermore, the results obtained at Site 33, which is located quite close to the outlet of the drain, were within normal expectations. Hence impacts appear to be minor and localised.

It was suggested in the previous section that Site 35 on Cocoa Creek is not an ideal control site for the Ross River estuary. The post-wet season turbator sediment results support this contention and provide further evidence of inherent differences between the two estuaries. Based on consideration of the relative catchment sizes and hydrology of the two estuaries it seems likely that the existing dissimilarities in sediment composition stem mainly from differences in the intensity and duration of freshwater inflows. Much more distinctly marine conditions would have been established in the Ross River estuary over the course of the dry season, and in view of the trends that are evident in Figure 3.2, it seems likely that the metal content of the unconsolidated sediments would have gradually risen to levels much more similar to those in Cocoa Ck. However, fundamental differences in the composition of the older consolidated sedimentary materials are almost certainly a much more permanent feature of the two estuaries.

Figure 3.2 Cumulative (summed) Relative Risk Index scores obtained from turbator estimates of the total amounts of metal per unit area, plotted against the total quantity of mobile (unconsolidated) sediment per unit area

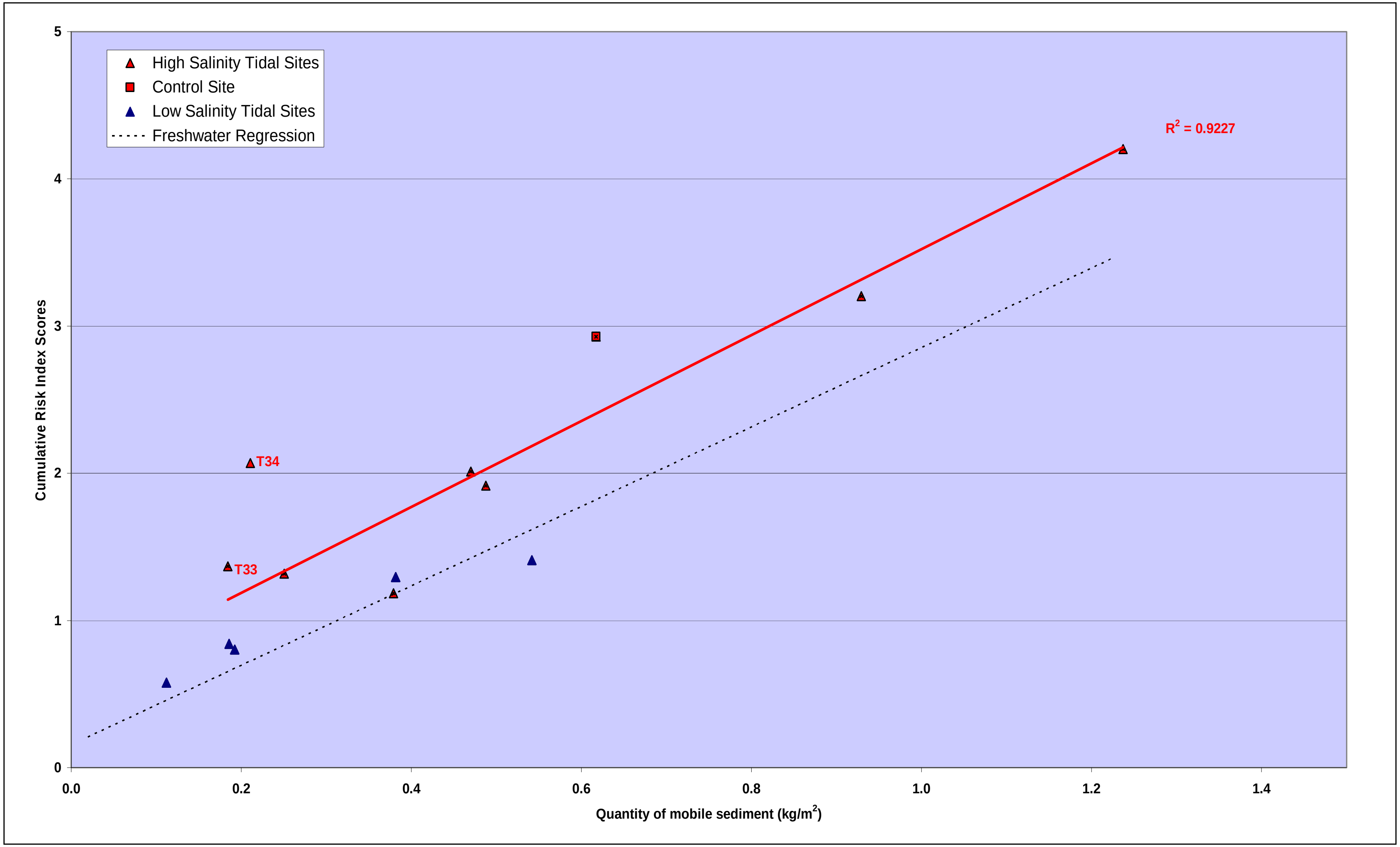


Figure 3.6: Metals concentrations (mg/kg) contained in the suspended sediment particles collected by the sediment turbator. Freshwater study sites are shaded yellow, estuarine sites are shaded blue, estuarine sites are shaded blue and reference sites are shaded grey

Site	Solids(kg/m^2)	Silver (Ag)	Arsenic (As)	Cadmium (Cd)	Cobalt (Co)	Chromium (Cr)	Copper (Cu)	Nickel (Ni)	Lead (Pb)	Antimony (Sb)	Selenium (Se)	Thallium (Tl)	Zinc (Zn)
T1	0.04	<0.1	<5	<0.2	9	13	55	9	15	<0.05	<1	0.2	168
T2	0.26	<0.1	<5	0.48	10	18	26	10	18	<0.05	<1	<0.2	125
T4	0.03	0.1	<5	<0.2	7	9	35	11	16	<0.05	<1	0.3	90
T5	0.20	<0.1	<5	<0.2	10	23	13	15	19	<0.05	<1	<0.2	73
T6	0.62	0.1	<5	<0.2	8	17	23	11	22	<0.05	<1	0.4	38
T7	0.02	<0.1	<5	<0.2	5	9	39	9	8	<0.05	<1	<0.2	422
T8	0.06	<0.1	6.1	0.27	36	12	16	11	28	<0.05	<1	<0.2	152
T9	0.10	<0.1	13.1	0.22	11	12	38	10	19	<0.05	<1	0.2	80
T10	0.07	<0.1	5.3	<0.2	6	13	77	11	26	<0.05	<1	0.2	79
T11	0.24	<0.1	<5	<0.2	7	17	17	12	24	<0.05	<1	0.3	41
T12	0.04	0.1	5.9	0.20	6	16	17	13	24	<0.05	<1	0.2	117
T13	0.74	<0.1	<5	<0.2	8	20	16	13	27	<0.05	<1	0.3	43
T14	0.42	0.2	<5	<0.2	14	33	22	23	36	<0.05	<1	0.2	33
T15	0.57	0.1	<5	0.20	8	22	17	13	37	<0.05	<1	0.2	21
T16	0.21	<0.1	4.6	<0.2	9	21	31	16	26	<0.05	<1	0.2	40
T17	0.46	<0.1	<5	<0.2	8	20	23	15	31	<0.05	<1	0.3	36
T18	0.82	0.1	<5	<0.2	6	19	24	10	30	<0.05	<1	0.3	47
T19	0.12	0.1	4.9	0.25	12	29	75	18	54	<0.05	<1	0.2	78
T20	0.06	<0.1	<5	0.30	10	18	108	13	25	<0.05	<1	<0.2	66
T21	0.13	0.1	<5	<0.2	11	24	43	16	32	<0.05	<1	<0.2	34
T22	0.93	0.1	6.0	<0.2	10	31	23	15	26	<0.05	<1	0.2	32
T23	0.38	0.1	5.5	<0.2	9	22	23	12	36	<0.05	<1	0.3	29
T24	0.11	0.1	<5	<0.2	10	28	18	16	25	<0.05	<1	0.2	61
T25	0.19	0.1	6.4	<0.2	10	23	36	12	38	<0.05	<1	0.2	49
T26	1.24	<0.1	6.8	<0.2	11	32	21	19	28	<0.05	<1	0.3	25
T27	0.49	0.1	10.0	<0.2	11	32	21	17	24	<0.05	<1	0.3	32
T28	0.19	0.1	9.0	<0.2	9	28	22	15	25	<0.05	<1	0.2	35
T29	0.38	0.0	7.3	<0.2	6	22	13	12	14	<0.05	<1	0.2	31
T30	0.25	0.2	10.6	<0.2	10	35	50	19	27	<0.05	<1	0.3	41
T31	0.54	<0.1	<5	0.25	9	15	13	9	21	<0.05	<1	0.2	20
T32	0.47	0.1	8.4	<0.2	14	35	20	20	23	<0.05	<1	0.2	45
T33	0.18	0.1	6.7	<0.2	9	33	26	19	26	<0.05	<1	0.2	37
T34	0.21	0.3	12.3	<0.2	11	39	75	39	104	<0.05	<1	0.3	79
T35	0.62	<0.1	12.4	<0.2	11	42	18	23	22	<0.05	<1	0.3	54

Table 3.7: Risk index scores calculated from the metals concentrations in suspended sediments collected by sediment turbation. Freshwater study sites are shaded yellow, estuarine sites blue and reference sites are shaded grey. Index values were calculated by dividing each metal concentration value by the Interim Sediment Quality Guideline (ISQG) value shown at the bottom of the table.

Site	Solids(kg/m^2)	Silver (Ag)	Arsenic (As)	Cadmium (Cd)	Cobalt (Co)	Chromium (Cr)	Copper (Cu)	Nickel (Ni)	Lead (Pb)	Antimony (Sb)	Selenium (Se)	Thallium (Tl)	Zinc (Zn)	Sum of Scores
T1	0.04	0.1	0.3	0.1	0.2	0.2	0.8	0.4	0.3	0.0	0.0	0.1	0.8	3.4
T2	0.26	0.0	0.3	0.3	0.2	0.2	0.4	0.5	0.4	0.0	0.0	0.1	0.6	3.0
T4	0.03	0.1	0.3	0.1	0.1	0.1	0.5	0.5	0.3	0.0	0.0	0.1	0.4	2.8
T5	0.20	0.0	0.3	0.1	0.2	0.3	0.2	0.7	0.4	0.0	0.0	0.1	0.4	2.6
T6	0.62	0.1	0.3	0.1	0.2	0.2	0.4	0.5	0.4	0.0	0.0	0.2	0.2	2.6
T7	0.02	0.0	0.3	0.1	0.1	0.1	0.6	0.4	0.2	0.0	0.0	0.0	**2.1**	4.0
T8	0.06	0.0	0.3	0.2	0.7	0.1	0.2	0.5	0.6	0.0	0.0	0.1	0.8	3.5
T9	0.10	0.0	0.7	0.1	0.2	0.1	0.6	0.5	0.4	0.0	0.0	0.1	0.4	3.1
T10	0.07	0.0	0.3	0.1	0.1	0.2	**1.2**	0.5	0.5	0.0	0.0	0.1	0.4	3.5
T11	0.24	0.0	0.3	0.1	0.1	0.2	0.3	0.6	0.5	0.0	0.0	0.2	0.2	2.5
T12	0.04	0.1	0.3	0.1	0.1	0.2	0.3	0.6	0.5	0.0	0.0	0.1	0.6	2.9
T13	0.74	0.0	0.3	0.1	0.2	0.2	0.3	0.6	0.5	0.0	0.0	0.2	0.2	2.6
T14	0.42	0.2	0.3	0.1	0.3	0.4	0.3	**1.1**	0.7	0.0	0.0	0.1	0.2	3.7
T15	0.57	0.1	0.3	0.1	0.2	0.3	0.3	0.6	0.7	0.0	0.0	0.1	0.1	2.8
T16	0.21	0.0	0.2	0.1	0.2	0.3	0.5	0.7	0.5	0.0	0.0	0.1	0.2	2.9
T17	0.46	0.0	0.3	0.1	0.2	0.3	0.4	0.7	0.6	0.0	0.0	0.1	0.2	2.8
T18	0.82	0.1	0.3	0.1	0.1	0.2	0.4	0.5	0.6	0.0	0.0	0.1	0.2	2.7
T19	0.12	0.1	0.2	0.2	0.2	0.4	**1.2**	0.8	**1.1**	0.0	0.0	0.1	0.4	4.7
T20	0.06	0.0	0.3	0.2	0.2	0.2	**1.7**	0.6	0.5	0.0	0.0	0.1	0.3	4.1
T21	0.13	0.1	0.3	0.1	0.2	0.3	0.7	0.8	0.6	0.0	0.0	0.1	0.2	3.4
T22	0.93	0.1	0.3	0.1	0.2	0.4	0.4	0.7	0.5	0.0	0.0	0.1	0.2	3.0
T23	0.38	0.1	0.3	0.1	0.2	0.3	0.3	0.6	0.7	0.0	0.0	0.1	0.1	2.9
T24	0.11	0.1	0.3	0.1	0.2	0.4	0.3	0.8	0.5	0.0	0.0	0.1	0.3	3.1
T25	0.19	0.1	0.3	0.1	0.2	0.3	0.5	0.6	0.8	0.0	0.0	0.1	0.2	3.3
T26	1.24	0.0	0.3	0.1	0.2	0.4	0.3	0.9	0.6	0.0	0.0	0.1	0.1	3.2
T27	0.49	0.1	0.5	0.1	0.2	0.4	0.3	0.8	0.5	0.0	0.0	0.1	0.2	3.3
T28	0.19	0.1	0.5	0.1	0.2	0.3	0.3	0.7	0.5	0.0	0.0	0.1	0.2	3.1
T29	0.38	0.0	0.4	0.1	0.1	0.3	0.2	0.6	0.3	0.0	0.0	0.1	0.2	2.3
T30	0.25	0.2	0.5	0.1	0.2	0.4	0.8	0.9	0.5	0.0	0.0	0.1	0.2	4.0
T31	0.54	0.0	0.3	0.2	0.2	0.2	0.2	0.4	0.4	0.0	0.0	0.1	0.1	2.1
T32	0.47	0.1	0.4	0.1	0.3	0.4	0.3	0.9	0.5	0.0	0.0	0.1	0.2	3.5
T33	0.18	0.1	0.3	0.1	0.2	0.4	0.4	0.9	0.5	0.0	0.0	0.1	0.2	3.3
T34	0.21	0.3	0.6	0.1	0.2	0.5	**1.2**	**1.9**	**2.1**	0.0	0.0	0.1	0.4	7.4
T35	0.62	0.0	0.6	0.1	0.2	0.5	0.3	**1.1**	0.4	0.0	0.0	0.1	0.3	3.8
ISQG		**1**	**20**	**1.5**	**50**	**80**	**65**	**21**	**50**	**2**	**50**	**2**	**200**	

4. CONCLUSIONS AND RECOMMENDATIONS

It was originally intended that this study would assign priority ratings to individual sites and subcatchments to aid for determining future monitoring and management directions. However, that proved to be neither feasible nor necessary because the survey found no evidence of any significant existing or emerging metal contamination problems at any site in the Ross River catchment. Some very minor isolated anomalies were detected at a few sites but none of these were large enough to be considered ecologically significant or to warrant management attention.

The possible existence of some localised metal accumulations in very close proximity to point sources can never be completely discounted in a catchment-wide survey such as this. However, the site network was sufficiently extensive to be able to conclude that any undetected sediment contamination must have been confined to relatively small sections of the drainage system.

Also, the possibility of large quantities of metals having passed through the drainage system during high flow events without leaving any evidence in bottom sediments can never be completely discounted. However, the analysis methods employed in this study are capable of detecting quite subtle irregularities in sediment composition, so the probability of this having happened is considered to be quite low.

Specific findings are summarised in the following dot-points:

- All samples complied with the Interim Sediment Quality Guidelines (ISQGs) provided in the current ANZECC (2000) guidelines for the protection of aquatic ecosystems.

- Nickel was the only metal to yield Risk Index scores greater than 0.7, although there were no values larger than one (which would indicate the potential for a compliance breach). However, there was no evidence of any significant anthropogenic enrichment. In fact the estuarine control site registered the second highest score, one of the freshwater controls (site 4) reported a significant index value of 0.6, and all of the reported values were significantly lower than the levels that have been reported at some Queensland EPA reference sites. These observations imply either that nickel naturally occurs at concentrations that are high enough to be ecologically significant, or that the ISQG is too conservative for this region. Regardless of the explanation it is clear that ambient nickel levels are no more of an issue in the Ross River catchment than they are in most other Queensland catchments.

- Urban drains located in the freshwater sections of the catchment (sites 13, 15, 18) contained the largest quantities of mobile metals simply because they contained the largest amounts of fine sediment. This could be indicative of excessive sediment inputs but could also simply indicate that the drains are not as thoroughly flushed other watercourses in the study area.

- Small quantities of unconsolidated sediment with elevated metal content were detected at a few sites. Ste 14 (an urban drain at Riverside Gardens) was the only site that contained enough of this material to measurably affect its ecological risk scores, but it still reported significantly lower index values than several other sites and is not therefore considered to be cause for concern. (The sediment at this site actually exhibited a distinctive trace metal signature suggesting that it may have originated from soils that are of a different type to the rest of the catchment. This could result from the use of imported top-soils for landscaping or from exposure of sub-soils by excavation works and/or erosion).

- The concentrations of mobile metals at each site in study area were mainly dependent on the amount of fines that were present. However, when differences in the amount of fines are taken into account it is evident that freshwater sites and low salinity tidal sites report significantly lower metal concentrations than high salinity tidal sites. Moreover, the results suggest that none of the sites in the Ross River estuary were completely free of freshwater influences, because they all contained less metals than the control site on Cocoa Ck. Accordingly, even though Cocoa Ck is a relatively undisturbed estuary that has previously been shown to be free of anthropogenic metal enrichment, it is not an ideal control for the Ross River estuary because it simply lacks the necessary riverine/freshwater influences. It were therefore be advisable to attempt to locate an alternative control site if further sediment investigations are ever carried out in the future.

- Site 34, a drain located on Benwell Road (the reclaim), contained a small quantity of unconsolidated sediment with elevated concentrations of copper, nickel and lead. However, the quantity of enriched sediment that was present at the time of sampling was too small to threaten the health of fauna inhabiting the site, and the sediment composition at Site 33, which was located near the mouth of the drain, provided no evidence of impact.

Based on these findings it is concluded that the trace metals tested in this study are not a significant management issue for the Ross River catchment, and that future monitoring and assessment efforts in this catchment should focus on the other water quality issues raised in earlier monitoring reports. However, it must be stressed that this conclusion applies only to Ross River. There is pre-existing evidence that metal contamination is an issue in the Ross Ck/Townsville Harbour area (Doherty *et al*. 2000, Jones *et al*. 2000, Gibbs 1993, Esslemont 2000, ACTFR 1996, ACTFR unpub.), and the metals status of other catchments in the WQIP area is yet to be determined. It would be particularly worthwhile to investigate the Bohle River using the methods that have been employed in the current study.

5. REFERENCES

ACTFR (1996) *10 Terminal Regiment Site Baseline Dry Season Water Quality Survey*. ACTFR Report No. 96/30 for Thiess Contractors.

American Public Health Association (1998) *Standard Methods for the Examination of Water and Wastewater*. 20th Edition. American Public Health Association. American Water Works Association and Water Environment Federation. Washington, U.S.A.

ANZECC (2000) Australian and New Zealand Guidelines for Fresh and Marine Water Quality. *National Water Quality Management Strategy.* ANZECC and ARMCANZ. Canberra. Australia. ISBN 09578245 0 5

Doherty, G.B., Brunskill, G.J. and M.J. Ridd (2000) Natural and enhanced concentrations of trace metals in sediments of Cleveland Bay, Great Barrier Reef Lagoon, Australia. *Marine Pollution Bulletin*. **41(7-12):** 337-344.

Esslemont (2000) Heavy metals in seawater, marine sediments and corals from the Townsville section, Great Barrier Reef Marine Park, Queensland. *Marine Chemistry* **71 (3-4)**: 215-231

Jones, G.B, Mercurio, P and F Olivier (2000) Zinc in Fish, Crabs, Oysters, and Mangrove Flora and Fauna from Cleveland Bay *Marine Pollution Bulletin* 41 (7-12): 345-352

Gibbs, R.J. (1993) Metals of the bottom muds in Townsville Harbour, Australia. *Environmental Pollution* 81: 297-300.

Inglis, G.J. and J. E. Kross (2000) Evidence for systematic changes in benthic fauna of tropical estuaries as a result of urbanisation. *Marine Pollution Bulletin*. **41(7):** 367-376.

Knauer, G.A. (1977) Immediate industrial effects on sediment metals in a clean coastal environment. *Marine Pollution Bulletin.* **8(11):** 249-254.

Moss, A. and S. Costanzo (1998) *Levels of Heavy Metals in the Sediments of Queensland Rivers, Estuaries and Coastal Waters.* Department of Environment Technical Report No. 20. Brisbane.