HEAVY METAL DISTRIBUTION AND SEDIMENT QUALITY IN THE BRISBANE WATER ESTUARY, NSW

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Executive Summary

The current Report describes and discusses results of a successful proposal by the Environmental Geology Group at The University of Sydney to the Gosford City Council Environmental Research Sponsorship, 2006 round to undertake an ecosystem health assessment of Brisbane Waters. The project used sedimentary contaminants (heavy metals) to determine the extent and magnitude of human impact on the waterway, to assess risk to benthic fauna by heavy metals and to identify sources of contamination.

Major findings of the research are:

- A strong contaminant gradient is evident in sediments of Brisbane Water with high metal concentrations in the north of the waterway decreasing rapidly southwards

- High concentrations of metals in sediment immediately adjacent to the mouth of Narara Creek, high modelled metal loading and high metal concentrations in fluvial sediment, suggest that this catchment is a major source of heavy metals to the estuary.

- Sediments in the full extent of the estuary are influenced by human activity. In the north of the waterway sediments are approximately four to five times higher than pre-anthropogenic times, whereas in the south sediments are only one and a half to twice as high as the pristine condition.

- Sediments in the northern part of the estuary exceed the lower guideline value indicating the possibility of some adverse biological effects on benthic animals. However, the bioavailable fraction of these chemicals is about 40% of total concentrations and thus the risk to fauna is probably minor. Nevertheless, as metal concentrations exceed the lower guideline value in this area, any interference with

these materials, e. g. wharfs, excavation, sea wall construction, etc. would require additional environmental investigation.

- Although current metal concentrations in sediment of the estuary are at levels which probably pose little risk to benthic animals, vertical profiles through the sediment reveal that metal concentrations continue to increase at a rapid rate in all parts of the estuary.

- Recommendations are to identify primary sources of contamination, especially in the Narara Creek catchment, consider remedial strategies and to undertake follow up investigations of sediment in the northern part of the estuary to improve assessment of possible sediment toxicity.

Introduction

The importance of sediment chemistry in assessment of estuarine health and management is widely acknowledged in the scientific literature (Maher et al., 1999, Birch et al., 2000, Birch & Taylor, 2002). Sediments record and time integrate the environmental status of an aquatic system and they are less time consuming and less expensive to measure, compared to other indicators of estuarine health. Sediments are a major carrier phase for pollutants and provide useful spatial and temporal information (Maher et al., 1999, Birch et al., 2000, Birch, 2003). This report, produced by the Environmental Geology Group of The University of Sydney (USEGG), presents results obtained from chemical and spatial analysis of estuarine, fluvial and core sediment samples obtained from the Brisbane Water estuary, New South Wales. The principal aims of this report are to determine the source and dispersion of heavy metals in sediments of the estuary, to estimate the magnitude of anthropogenic change that has taken place in the waterway and catchment and to assess the quality of sediments in the estuary.

Brisbane Water is located on the Central Coast of New South Wales, within the Gosford LGA (Figure 1). Four main creeks enter the estuary: Woy Woy Creek, Narara Creek, Erina Creek and Kincumber Creek. Woy Woy Creek catchment is mainly bushland; Narara and Kincumber are highly developed industrial and residential, whereas Erina Creek catchment is residential, commercial and agricultural. Total catchment area is approximately 168 km^2 and comprises five major land use types i.e. residential (27% of total catchment area), bushland (35%), agricultural (33%), commercial (4%) and industrial (1%). Narara and Erina Creek catchments comprise 27% and 15% of the total Brisbane Water catchment, respectively.

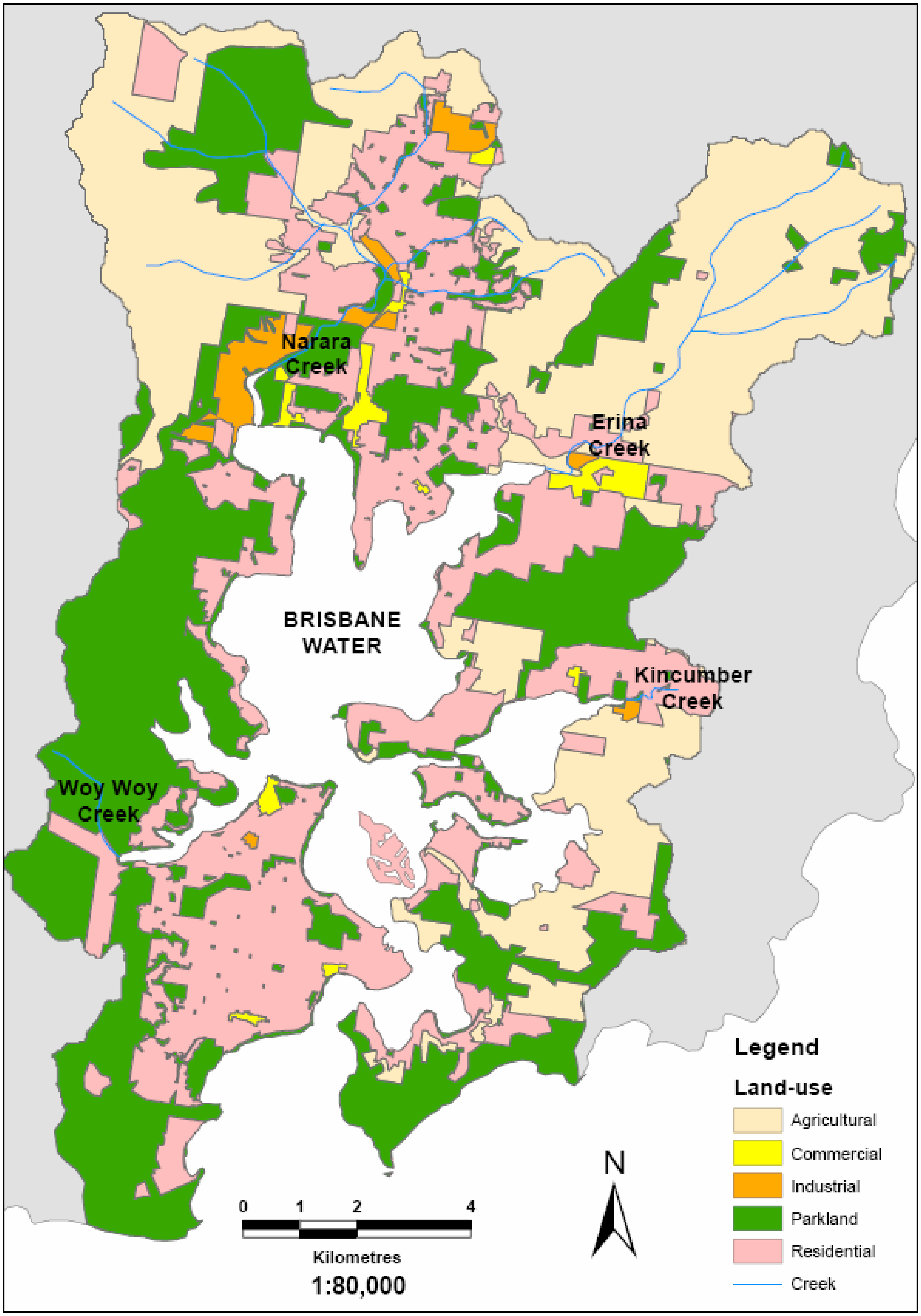


Figure 1. Study Area – Brisbane Water estuary and catchment land-use.

Methods

Samples collected include 40 in Brisbane Water (estuarine), 30 from rivers (fluvial) discharging to the waterway, and 3 estuarine cores taken throughout the study area (Figure 2). A stainless-steel box corer was used for collection of estuarine sediment samples. The top 2 cm of the sediment sample was scrapped off the top of the sample, placed in an airtight polyethylene bag and stored under refrigerated conditions (~4^0C). Fluvial samples were collected by hand with a plastic spatula. Four samples were taken within 1m^2 and pooled to reduce small-scale spatial variance (Birch, et al., 2001). The spatial coordinates, sample and site description were recorded for each estuarine, fluvial and core sample. Sedimentary cores (from 120 to 140 centimetres long) were retrieved using a PVC/aluminium push corer.

Size normalisation of samples was carried out by wet sieving through a <62.5 µm nylon mesh to reduce the confounding effects of variable grain size (Birch, 2003). Samples were digested in an *aqua regia* solution (2ml HNO_3, 2ml HCl, and 10ml MilliQ water 18MΩ/cm) and total recoverable elements were determined using a Varian Vista-AX Inductively Coupled Plasma Optical Emission Spectrometer (ICP-OMS) (modification of the USEPA method 200.8 Rev. 4.4).

Total sediment was analysed for cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), manganese (Mn), nickel (Ni), lead (Pb) and zinc (Zn). The quality of the data analysis was determined through precision and accuracy assessment. Precision, determined by repeated analysis of international reference material AGAL-10, was < 5% RSD for all metals except Zn (9%). Accuracy, established through the use of the same reference material, expressed as recoveries were between 106% (Cr) and 96% (Cd) (Table 1).

Table 1. Precision and accuracy of AGAL10 Reference Standards.

Element	Cd	Co	Cr	Cu	Mn	Ni	Pb	Zn
Mean	9	9	87	24	240	19	41	61
SD	0	0	4	0	4	1	1	5
RSD%	**3**	**2**	**4**	**2**	**2**	**5**	**3**	**9**
AGAL10	9	9	82	23	241	18	40	57
SD	1	1	11	2	11	3	3	4
%Recovery	**96**	**102**	**106**	**102**	**99**	**108**	**102**	**107**

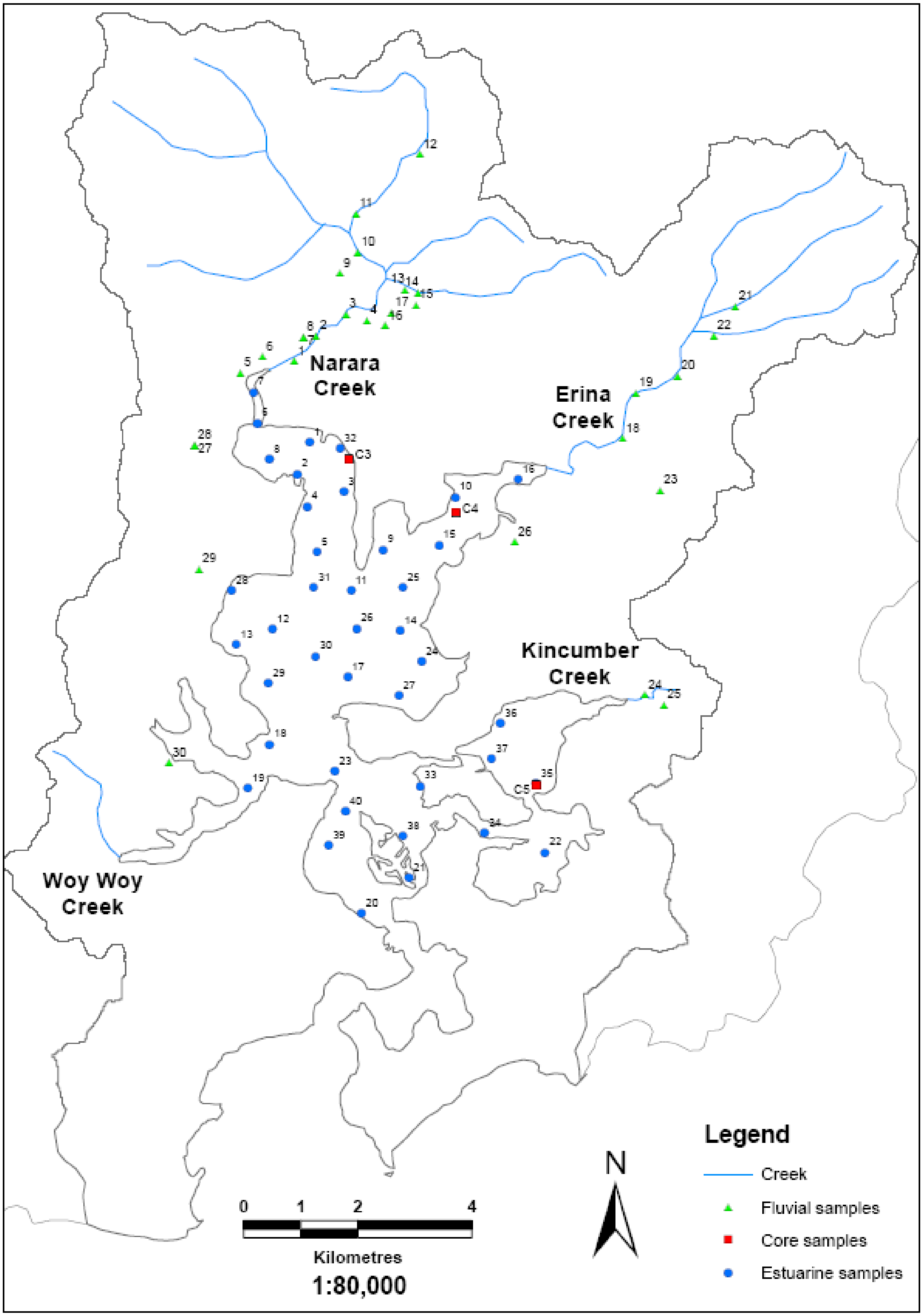


Figure 2. Sample Locations – Estuarine, fluvial and core samples.

Spatial Analysis

In the current study, ArcGIS Version 9 was used for data manipulation, display and spatial analysis. Datasets used included 1:100,000 and 1:250,000 topographic map data from Geoscience Australia covering the study area, whereas catchment boundaries were obtained from the NSW Department of Natural Resources. Land use information was derived from the Australian Bureau of Statistics Mesh Blocks (Draft) dataset. The Kriging interpolation method in ArcGIS Version 9 Spatial Analyst tool was used to display the spatial extent of heavy metal distributions by creating layers identifying heavy metal concentrations, and also for determining areas with contaminant concentrations above sediment quality guidelines. Kriging is a geostatistical interpolation method that assumes a spatial correlation of the data, or spatial relationship between the sample points. It is a weighted-linear-average estimator where the weights are chosen to minimise the estimated variance (Ouyang et al., 2005).

Bioavailability

Twenty estuarine samples were selected to determine the bioavailable fraction of metals using dilute hydrochloric acid (HCl) and Ethylenediaminetetraacetic acid (EDTA) extraction. HCl allowed a partial fractionation of metals in sediments, releasing both inorganic and organic-associated metals (Ying et al., 1992). EDTA is commonly used for this purpose due to its strong chelating ability for heavy metals (Sun et al., 2001). The method used in the current study follows Ying et al. (1992). Approximately 3g of dried sediment sample was weighed into a polypropylene centrifuge tube; 25ml of 0.05 M EDTA was added to each tube then agitated for 2 hours and centrifuged for 10 minutes at 3400 r.p.m. A blank and a duplicate were included with each batch. A similar method was used for the HCl analysis, which involved taking ~3g of sediment sample and mixing with 0.1M HCl (AR Grade) for 2 hours, centrifuged for 10 minutes and analysed by ICP-AES.

Background and Enrichment

Background heavy metal concentrations were obtained from cores taken by the USEGG. The background or pre-anthropogenic concentration was determined by calculating the mean concentration of metals in the fine fraction from the pre-anthropogenic section of the core, i.e. where the metal concentration declined to a consistent minimum (Gillis & Birch, 2006). Through the use of background concentrations, the relative enrichment of the estuary was established by comparing the pre-anthropogenic values with the present-day surficial estuarine sample concentrations. The mean enrichment for the estuary is the average enrichment for all samples in the waterway and the maximum enrichment is the highest enrichment of all samples, respectively

Sediment Quality

Total heavy metal sample concentrations were compared to Interim Sediment Quality Guidelines (ANZECC/ARMCANZ, 2000, Simpson et al, 2005). This scheme provides two values, Interim Sediment Quality Guidelines Low (ISQG L) and ISQG High (ISQG H), which delineate three concentration ranges for a particular chemical. Concentrations below ISQG L values represent a minimal-effects range, which is intended to identify conditions where adverse biological effects would be rarely observed. Concentrations equal to or greater than ISQG L, but below ISQG H, represent a range within which biological effects occur occasionally. Concentrations at or above ISQG H values represent a probable-effects range, above which adverse biological effects frequently occur. Sediment quality guidelines were used to identify conditions under which adverse biological effects may occur (Table 2). ISQG-L also represents a threshold level that triggers the requirement for additional environmental investigative work.

Table 2. Recommended sediment quality guidelines (ANZECC/ARMCANZ, 2000).

Element	ISQG Low	ISQG High
Cd	1.5	10
Cr	80	370
Cu	65	270
Ni	21	52
Pb	50	220
Zn	200	410

Heavy Metal Loadings

Heavy metal catchment loadings for the four main creeks entering Brisbane Water were calculated using the methodology recommended by the CRC for Catchment Hydrology (Fletcher et al., 2004). Annual pollutant load in kg/yr (**L**) can be calculated using the formula:

$$L = PCvCA$$

P = Annual rainfall (mm), data from BoM, Average annual rainfall based on standard 30 year climatology (1961-1990)

Cv = Volumetric runoff coefficient

C = Event Mean concentration (EMC) (mg/L)

A = Catchment area (Km^2)

Results

Heavy Metal Distribution

Heavy metal concentrations for total and normalised sediment samples are presented in Appendices 1 and 2, and a summary of these results is given in Table 3. Mean concentrations of the total fraction were less than those calculated from the fine fraction for both fluvial and estuarine samples. Mean concentrations for fluvial samples were higher than those from estuarine samples, except for Cr.

Table 3. Summary statistics for estuarine and fluvial heavy metal samples, total and fine fractions (µg/g). The fine fraction of the sediment is the <62.5m size material and the total is the whole sediment.

Total Fraction

	Element	Cd	Co	Cr	Cu	Mn	Ni	Pb	Zn
Estuarine	**Mean**	**0.5**	**3.9**	**22**	**15**	**179**	**8.3**	**30**	**87**
n = 40	Min	0.0	0.5	3	1	19	0.8	3	6
	Max	1.7	7.5	40	41	672	17.6	92	300
Fluvial	**Mean**	**0.4**	**6.9**	**17**	**25**	**259**	**13.7**	**33**	**159**
n = 30	Min	0.1	0.7	3	3	13	2.0	5	20
	Max	0.6	21.5	40	76	783	46.3	88	792

Fine Fraction

	Element	Cd	Co	Cr	Cu	Mn	Ni	Pb	Zn
Estuarine	**Mean**	**1.0**	**7.1**	**40**	**29**	**309**	**16.2**	**53**	**158**
n = 40	Min	0.1	4.0	29	19	105	10.8	37	102
	Max	1.7	9.5	53	44	627	21.7	93	306
Fluvial	**Mean**	**1.9**	**9.9**	**30**	**52**	**373**	**18.8**	**81**	**319**
n = 30	Min	1.5	3.9	14	14	74	6.8	16	94
	Max	2.2	47.1	47	223	1145	37.4	252	957

The spatial distributions of total and normalised results for Cu, Pb and Zn have been illustrated (Figures 3 to 8) as these metals were most abundant toxic heavy metals and were readily liberated by HCl and EDTA extraction.

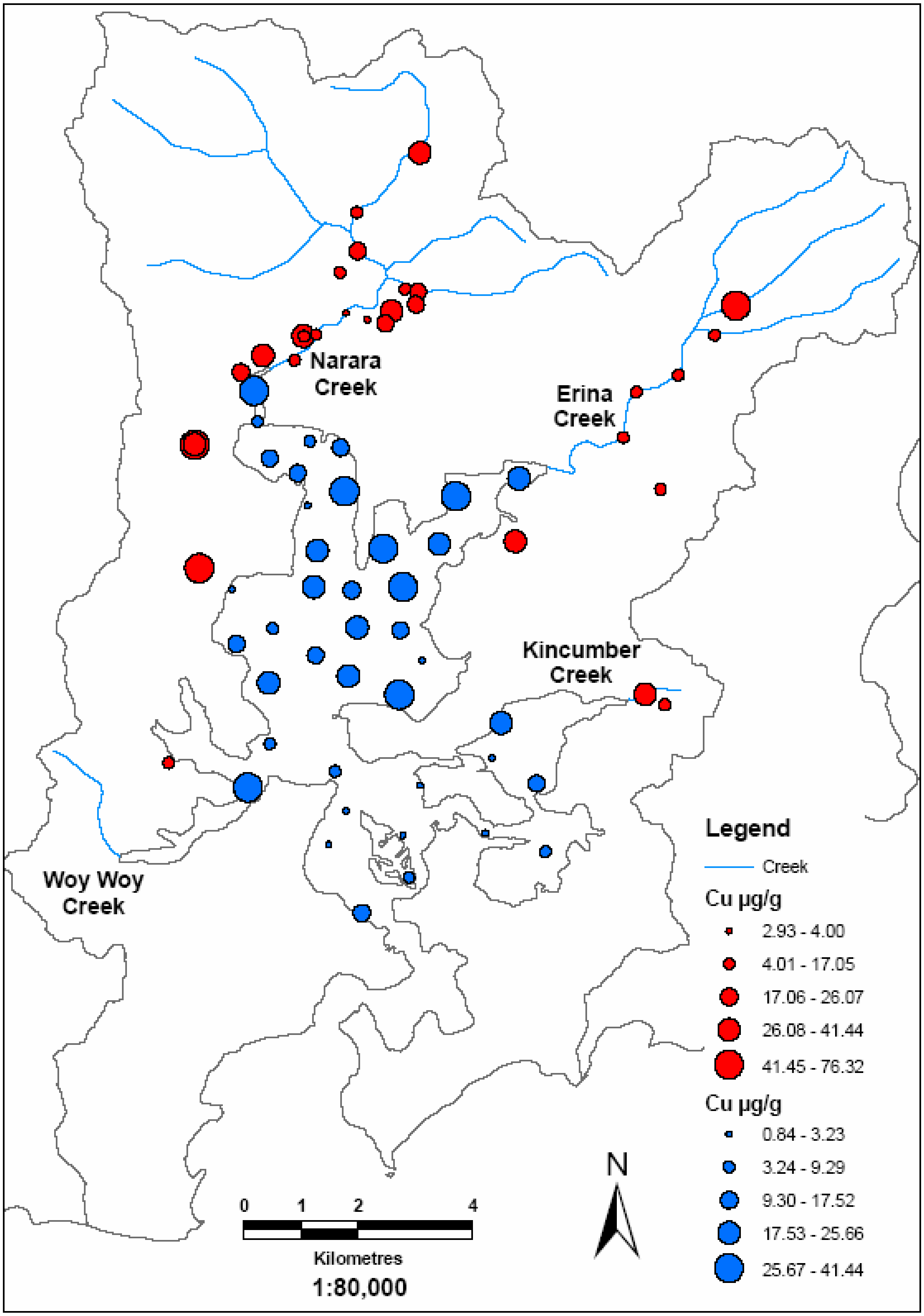


Figure 3. Quantified distribution map of estuarine and fluvial samples – Total Cu concentrations.

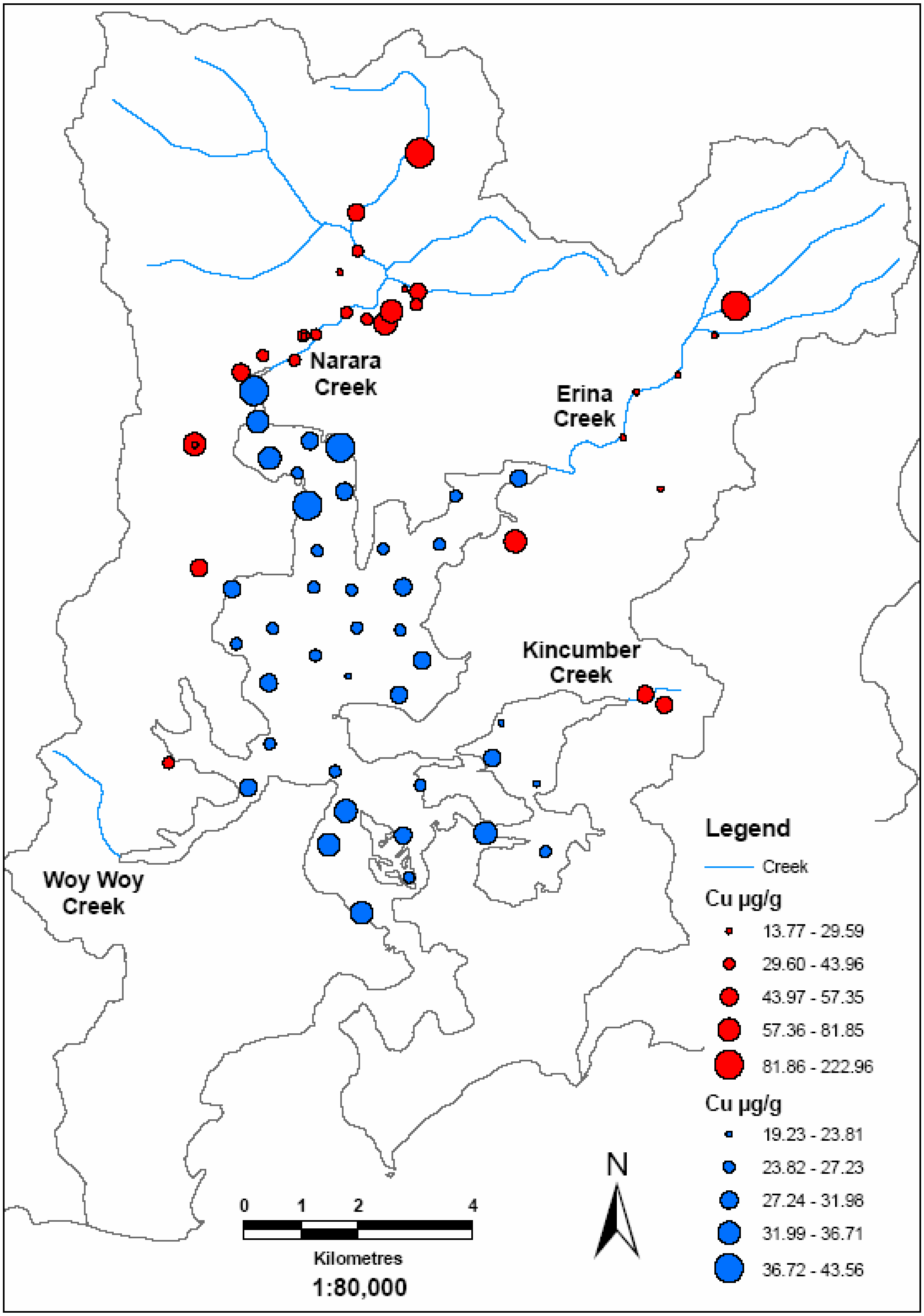


Figure 4. Quantified distribution map of estuarine and fluvial samples – Normalised Cu concentrations.

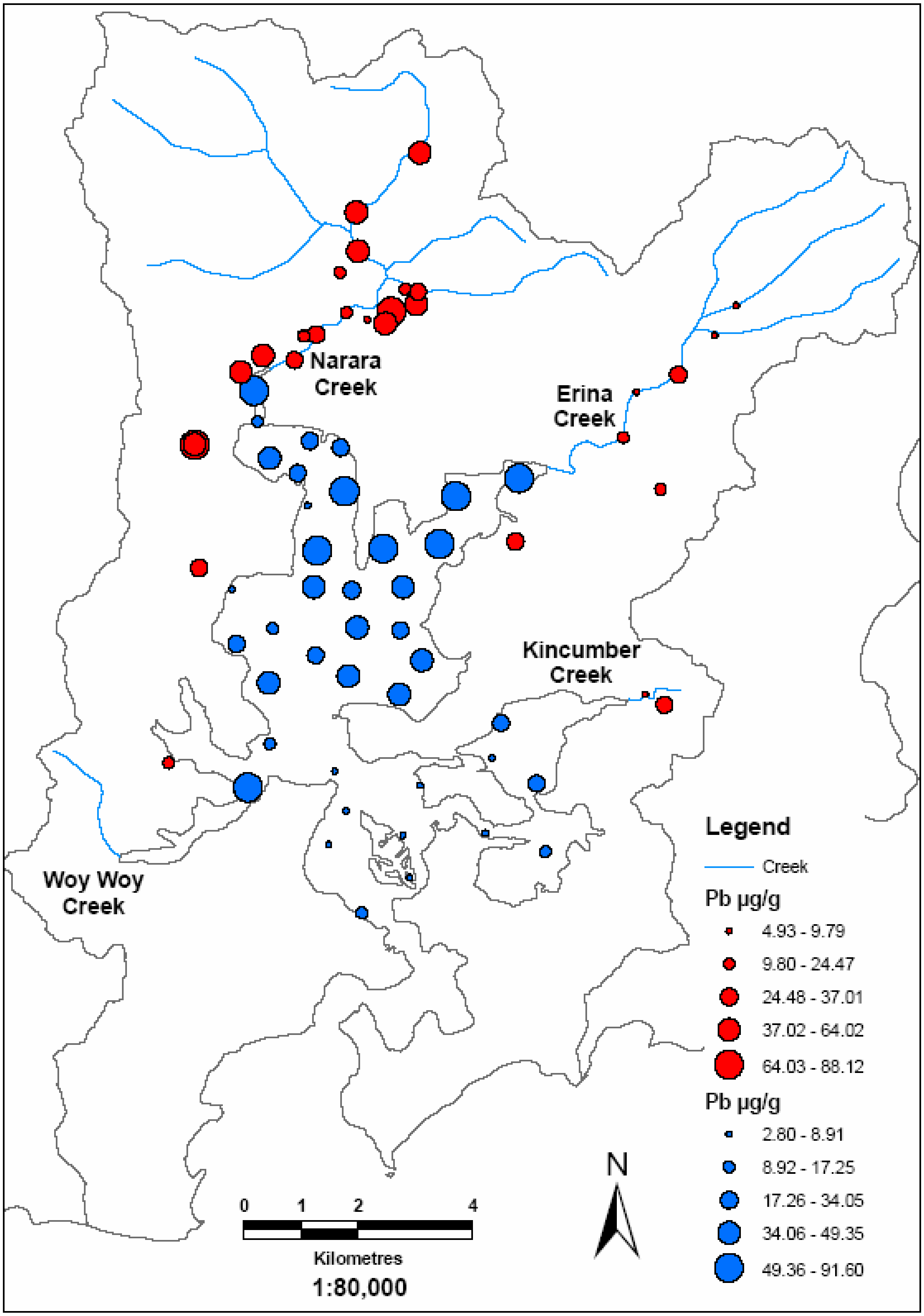


Figure 5. Quantified distribution map of estuarine and fluvial samples – Total Pb concentrations.

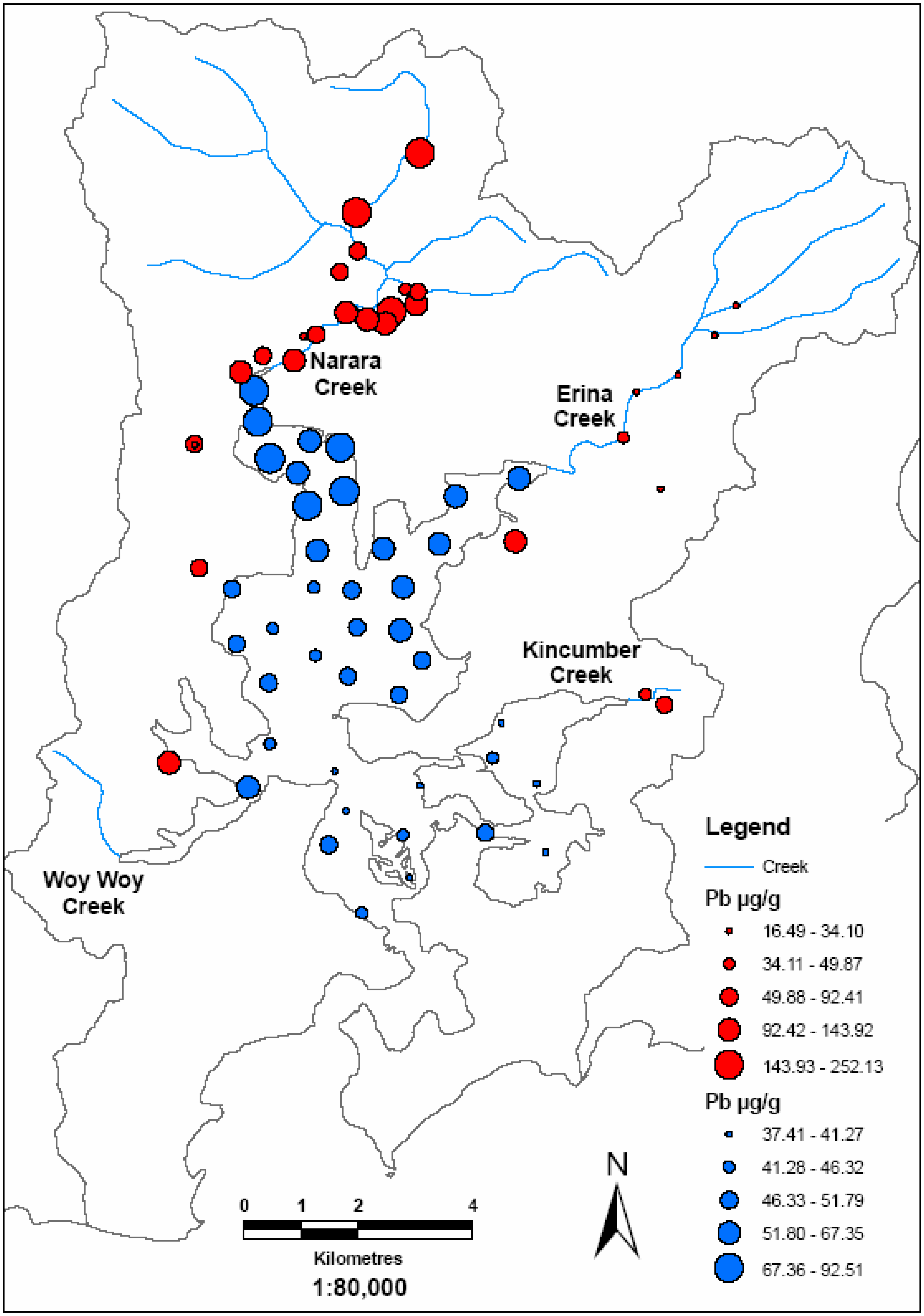


Figure 6. Quantified distribution map of estuarine and fluvial samples – Normalised Pb concentrations.

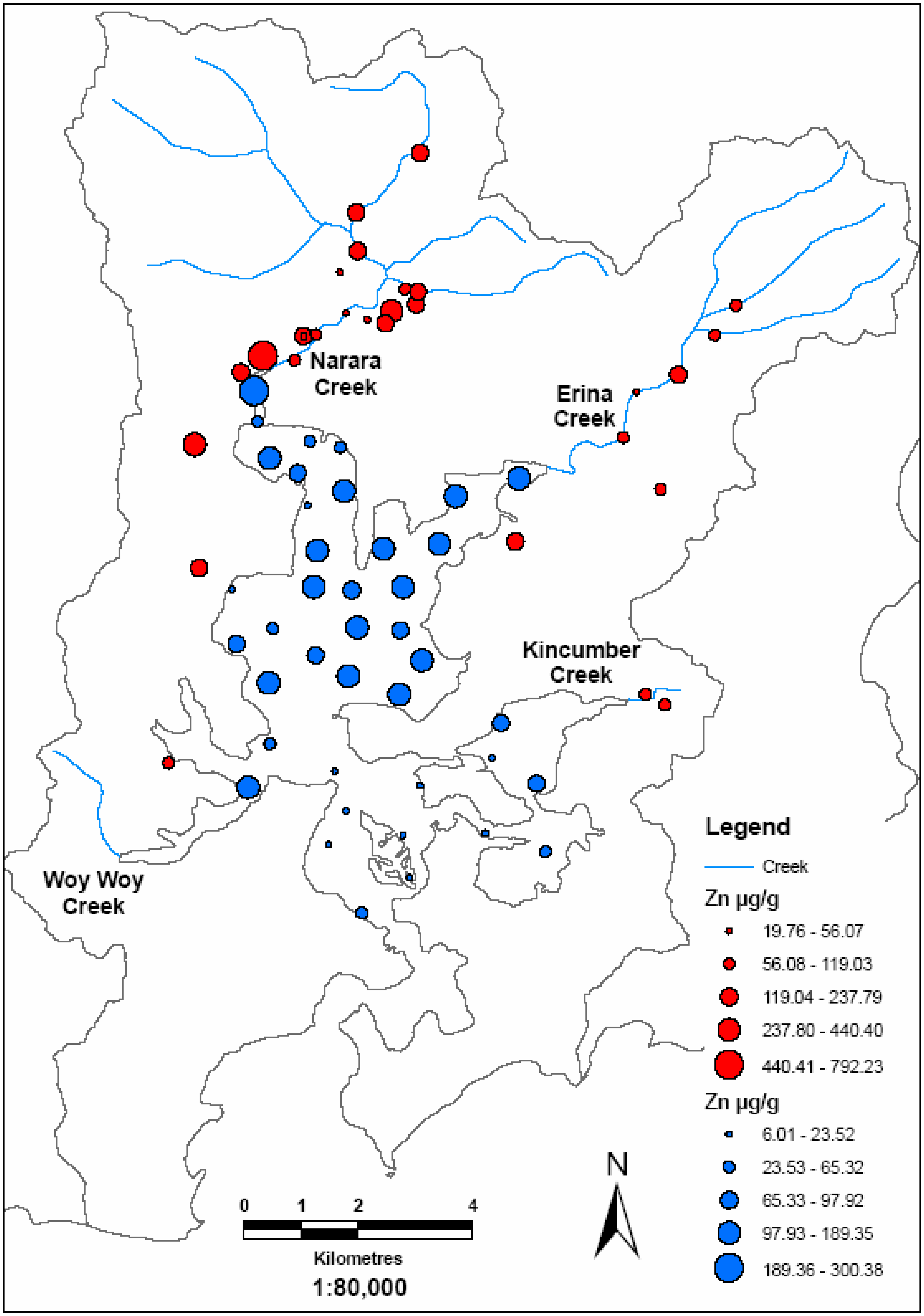


Figure 7. Quantified distribution map of estuarine and fluvial samples – Total Zn concentrations.

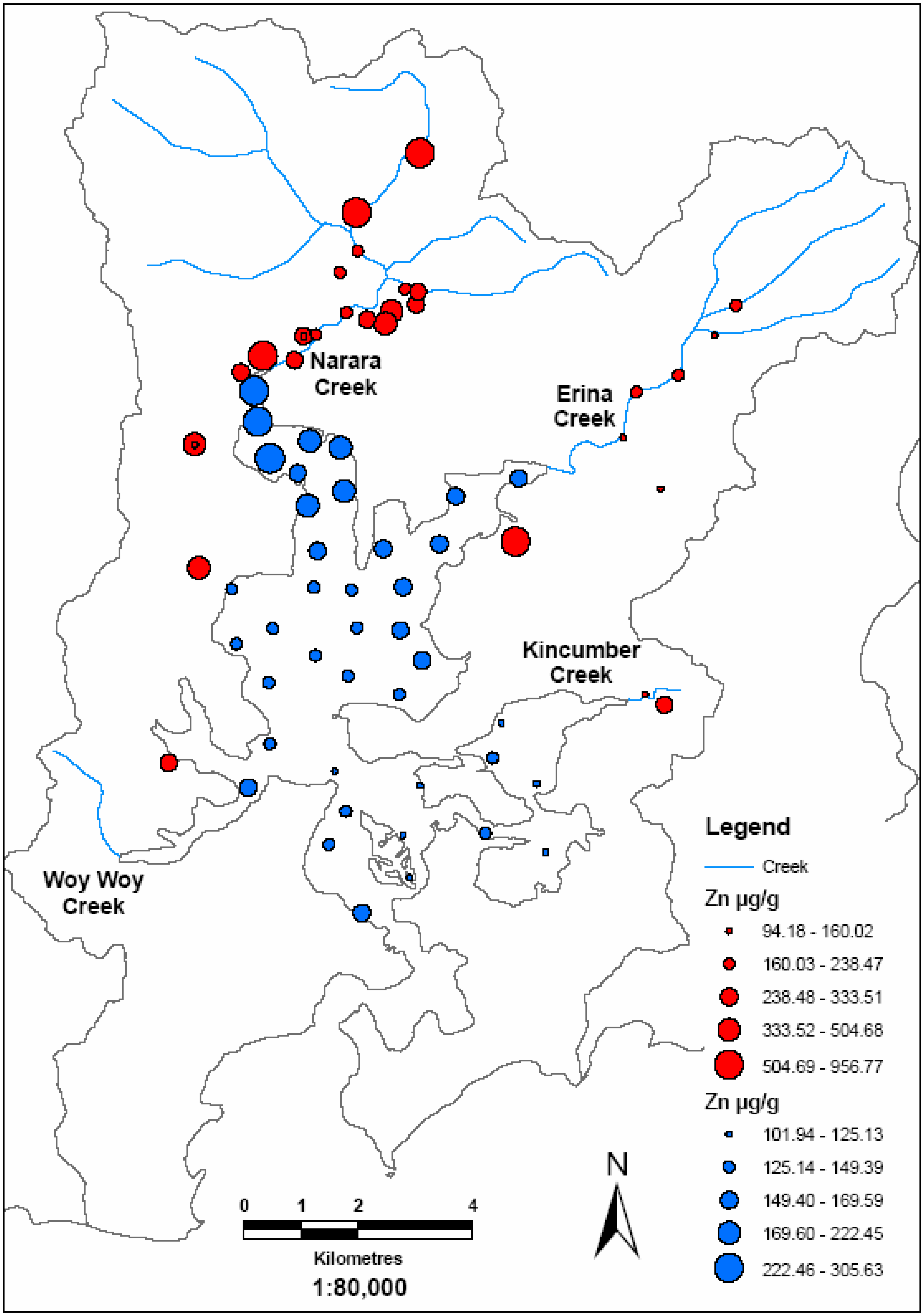
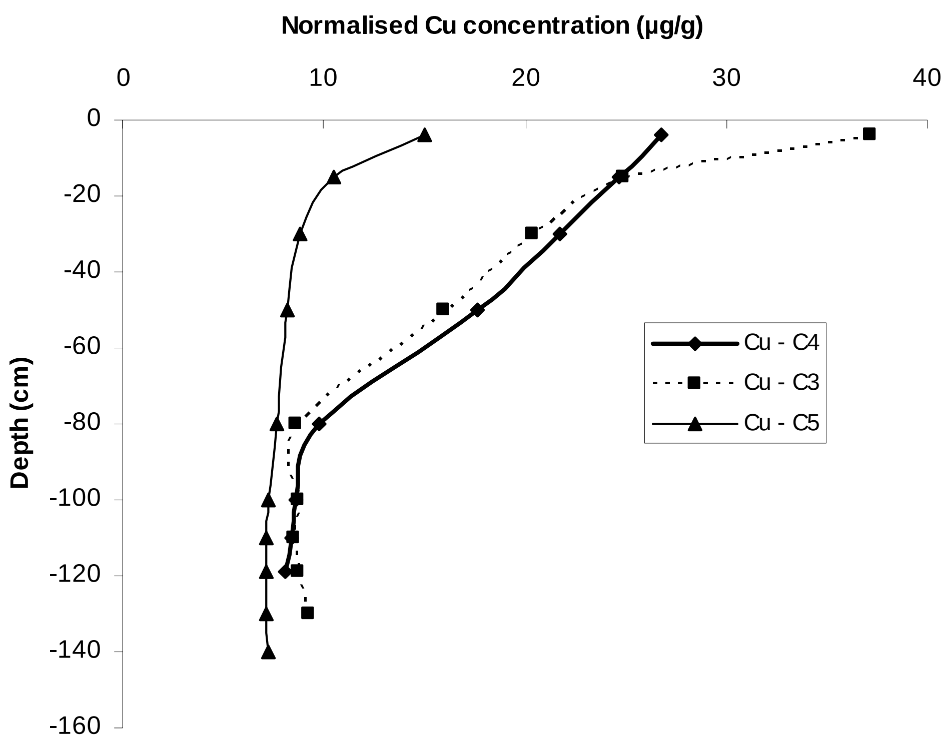
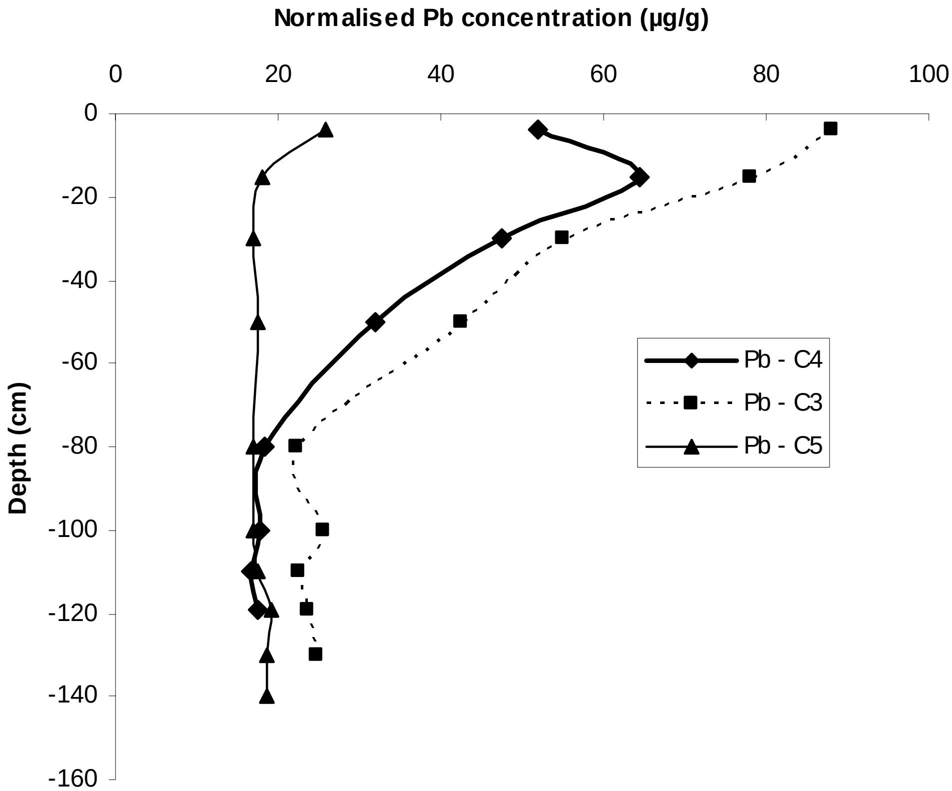


Figure 8. Quantified distribution map of estuarine and fluvial samples – Normalised Zn concentrations.

Sediment Cores

Figure 9 illustrates the results from the three sediment cores taken in the estuary for Cu, Pb and Zn. Core locations are provided in Figure 2. Core C3, located in the northern part of the estuary, had the highest top-core concentration for all metals and Core C5, located in the south, had the lowest top-core metal concentrations. Concentrations of all three heavy metals attained a relatively constant minimal value at a depth of about 80 centimetres in Cores C3 and C4 and at approximately 15 cm in core C5.





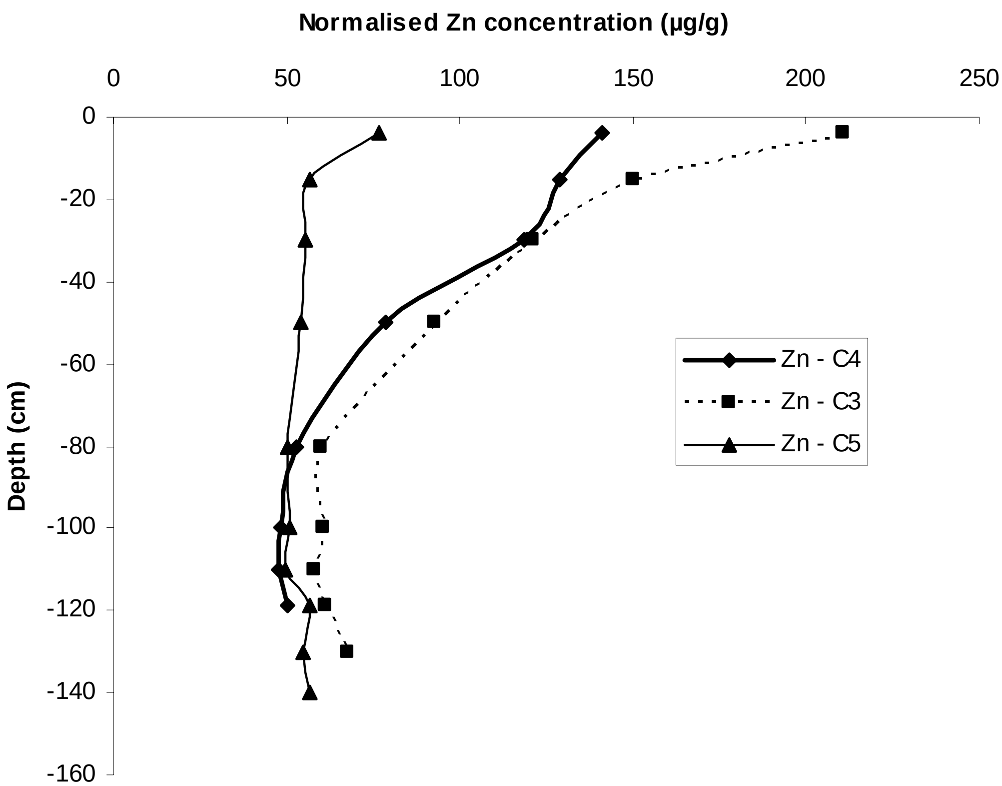


Figure 9. Heavy metal concentrations of normalised core samples for Cores 3, 4 and 5.

Sediment Quality

Only Cd, Pb and Zn exceeded ISQG Low values in the estuarine samples (Appendix 1) and Cu, Ni, Pb and Zn were above ISQG Low values for fluvial samples, with one sample (BWR06) exceeding the ISQG High value for Zn (Appendix 1). No mean concentrations of heavy metals exceeded guideline values. Figure 10 shows the location of those samples having metals greater than ISQG Low values.

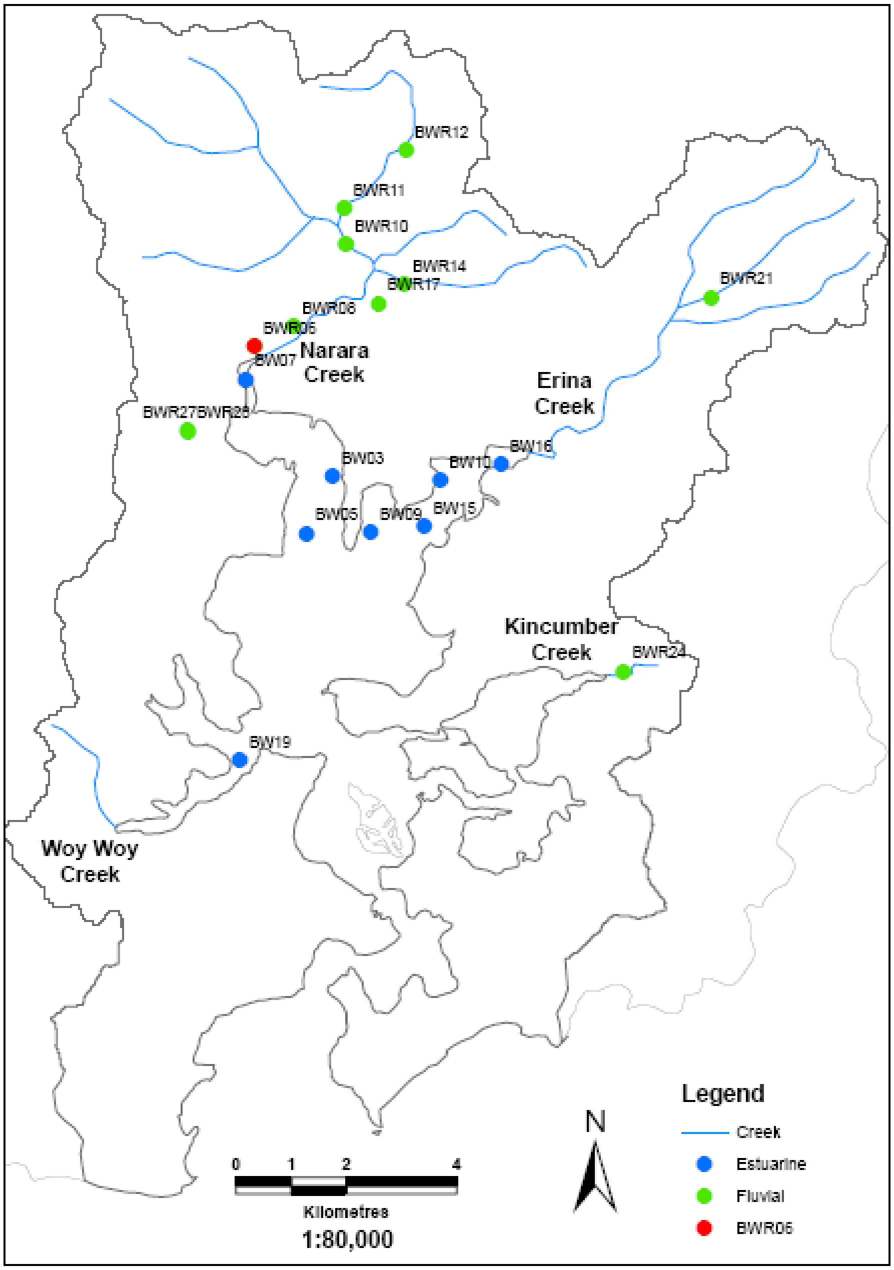


Figure 10. Estuarine and fluvial samples exceeding ISQG Low values.

Bioavailability

The fraction removed by HCl varied between a mean of 19.1% for Ni and 44.3% for Cu. Metals most readily liberated were Cu, Pb and Zn. HCl extraction results are presented in Table 4. The extractable portion for EDTA varied from 8.4% for Cr to 75.7% for Zn, with Cu, Pb and Zn being most readily liberated.

Table 4. Extractability (% of total concentration) of selected heavy metals from total sediment samples of Brisbane Water estuary with 0.05 M EDTA and 0.1 M HCl.

HCl (n=14)

Element	Co	Cr	Cu	Ni	Pb	Zn
Mean %	24.1	22.6	44.3	19.1	42.9	39.1
SD	19.8	13.5	38.2	11.5	26.9	26.9

EDTA (n=17)

Element	Co	Cr	Cu	Ni	Pb	Zn
Mean %	19.5	8.4	75.7	20.5	42.2	36.3
SD	19.1	9.7	47.7	20.5	24.4	21.3

Heavy Metal Loadings

The event mean concentration (EMC) and runoff coefficients used for calculating heavy metal loadings from the four main creeks and catchments are provided in Table 5 and were derived from Fletcher et al., 2004.

Table 5. Annual rainfall (mm), Runoff coefficient and Event Mean Concentration (mg/L) for different land-use types.

			EMC (mg/L)		
Land-use	**Annual rainfall (mm)**	**Runoff coefficient**	Cu	Pb	Zn
RESIDENTIAL	1200	0.78	0.0875	0.135	0.28
PARK	1200	0.05	0.08	0.045	0.22
COMMERCIAL	1200	0.95	0.08	0.15	0.3
INDUSTRIAL	1200	0.95	0.08	0.15	0.3
AGRICULTURAL	1200	0.15	0.08	0.07	0.3

The loadings of Cu, Pb and Zn for the four main catchments and respective contribution percentages are shown in Table 6. Narara Creek catchment had the highest loadings for all three heavy metals. Residential areas contributed from 55% up to 88% of heavy metal loadings, with the exception Erina Creek catchment where Agricultural areas contributed between 40% and 58% of heavy metal loadings. Although metals derived from industrial areas are greater than that of residential land per unit area (higher EMCs), the size of residential land use is considerably larger than industrial areas. This results in higher total metals loading from residential land use areas than industrial. However, runoff from residential areas is highly diffuse, whereas discharge from industrial areas is generally considerably more concentrated. Management of contaminants derived from industrial areas are thus substantially easier to manage than highly diffuse sources associated with residential areas.

Table 6. Heavy metal loadings and contribution percentages according to land-use types in the four main sub-catchments of Brisbane Water – Narara Creek, Erina Creek, WoyWoy Creek and Kincumber Creek.

		LOADING (kg/yr)			Contribution %		
Narara Creek Catchment	km^2	Cu	Pb	Zn	Cu	Pb	Zn
RESIDENTIAL	10.9	891.2	1374.9	2851.7	**58.5**	**62.8**	**55.1**
PARK	9.2	44.0	24.8	121.0	**2.9**	**1.1**	**2.3**
COMMERCIAL	0.5	45.2	84.8	169.6	**3.0**	**3.9**	**3.3**
INDUSTRIAL	2.5	229.8	430.8	861.6	**15.1**	**19.7**	**16.6**
AGRICULTURAL	21.8	313.5	274.3	1175.6	**20.6**	**12.5**	**22.7**
TOTAL	**44.8**	**1523.6**	**2189.6**	**5179.5**			
Erina Creek Catchment	km^2	Cu	Pb	Zn	**Cu**	**Pb**	**Zn**
RESIDENTIAL	1.7	135.3	208.8	433.0	**26.7**	**34.6**	**23.9**
PARK	3.1	14.8	8.3	40.6	**2.9**	**1.4**	**2.2**
COMMERCIAL	0.7	65.6	123.1	246.1	**13.0**	**20.4**	**13.6**
INDUSTRIAL	0.1	9.0	16.9	33.9	**1.8**	**2.8**	**1.9**
AGRICULTURAL	19.6	281.8	246.5	1056.6	**55.6**	**40.8**	**58.4**
TOTAL	**25.1**	**506.5**	**603.6**	**1810.2**			
WoyWoy Creek Catchment	km^2	Cu	Pb	Zn	**Cu**	**Pb**	**Zn**
RESIDENTIAL	0.5	37.2	57.4	119.0	**73.0**	**88.1**	**75.9**
PARK	2.9	13.8	7.8	37.9	**27.0**	**11.9**	**24.1**
TOTAL	**3.3**	**51.0**	**65.1**	**156.9**			
Kincumber Creek Catchment	km^2	Cu	Pb	Zn	**Cu**	**Pb**	**Zn**
RESIDENTIAL	1.8	148.1	228.5	474.0	**78.9**	**83.7**	**76.2**
PARK	0.2	0.8	0.5	2.2	**0.4**	**0.2**	**0.4**
INDUSTRIAL	0.1	10.1	19.0	38.0	**5.4**	**7.0**	**6.1**
AGRICULTURAL	2.0	28.8	25.2	107.8	**15.3**	**9.2**	**17.3**
TOTAL	**4.1**	**187.8**	**273.2**	**622.1**			

Discussion

Comparison to other estuaries

The National Land and Water Resources Audit published the first comprehensive assessment of catchments, rivers and estuaries in Australia in 2002 (NLWRA, 2002). Four estuary conditions were identified using a number of criteria such as catchment land cover, land use, catchment hydrology, estuary use and ecology. The four estuary condition types are Near-pristine, Largely Unmodified, Modified and Extensively Modified. Brisbane Water was classified as an Extensively Modified estuary in this audit. Figure 11 compares Brisbane Water with other estuaries in NSW classified as Near-pristine (Durras Lake), Largely Unmodified (Burril Lake and Myall Lakes), Modified (St Georges Basin and Pittwater) and Extensively Modified (Port Jackson).

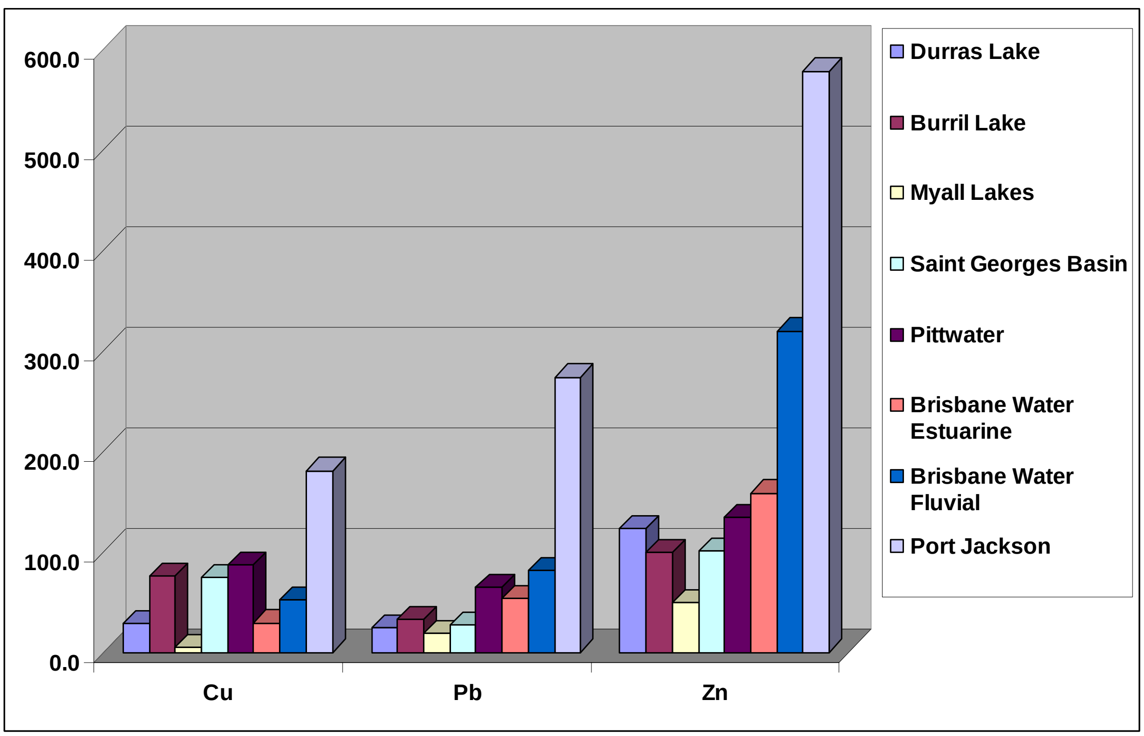


Figure 11. Mean normalised heavy metal concentrations (µg/g) for selected estuaries of New South Wales.

Brisbane Water estuarine sediments contained a surprisingly high concentration of Zn and ranked second behind Port Jackson. Pb concentrations were higher in fluvial samples than in estuarine sediments and mean concentrations were second to Port Jackson. Cu, however, was relatively low compared to other estuaries that were classified as Modified and Largely Unmodified, and were similar to Durras Lake, a Near-pristine estuary.

Heavy Metal Distribution and Sources

The highest metal concentrations in Brisbane Water sediment were in the north of the estuary adjacent to Narara Creek, which drains a moderately industrialised catchment and includes Gosford City (Figures 12 to 14). Metal concentrations were also slightly elevated adjacent to Erina Creek suggesting that this river also contributes metals to the estuary. Metal concentrations decreased rapidly southwards away from the mouths of these two rivers.

Heavy metal loadings also suggested that the northern part of the estuary was receiving high metal discharges. Narara Creek catchment provided approximately 70% of the total Cu, Pb and Zn discharged to Brisbane Water, whereas Erina Creek supplied about 20% of these metals to the waterway. Kincumber and Woy Woy Creeks provided the remaining 8% and 2% of total metals reaching the estuary, respectively. In the Narara Creek catchment, residential land use (~60%) produced the major proportion of metal loading, followed by agricultural (~20%) and industrial (~15%) land uses. Within Erina Creek catchment, the main source of metals was agricultural land use (~55%) followed by residential (~25%) and commercial (~10%) land use.

Mean Cu, Pb and Zn concentrations of fluvial samples collected from Narara, Erina and Kincumber Creeks are provided in Table 7. Copper concentrations in all three creeks are similar (47-57 g/g) and sediments in these creeks are enriched about 7-8 times over background. Lead is high in Narara and Erina Creeks with enrichment at about 4-5 times background and slightly less enriched in sediments of Kincumber Creek. Erina Creek sediments are over 7 times enriched over background in Zn. High concentrations of especially Pb and Zn in Narara and Erina Creeks combined with large catchment areas and runoff volumes results in these two northern catchments playing a major role in the contribution of these metals to Brisbane Water.

Enrichment levels and results from the sediment cores also suggested that the northern part of the estuary has been affected to a greater degree by anthropogenic influences than the southern area. The results from the sediment quality analysis indicated that the northern part of the estuary may be an area of concern. All samples exceeding ISQG Low values (Figure 10) were located in the northern part of the estuary, with the exception of one estuarine sample in the south of the estuary.

Table 7. Mean metal concentrations and enrichment in three creeks.

	n	Cu	Pb	Zn
Mean concentration				
Narara Creek	16	47	96	355
Erina Creek	5	54	84	410
Kincumber Creek	2	57	63	242
Background		8	20	55
Mean enrichment				
Narara Creek	16	5.9	4.8	6.5
Erina Creek	5	6.8	4.2	7.5
Kincumber Creek	2	7.1	7.9	4.4

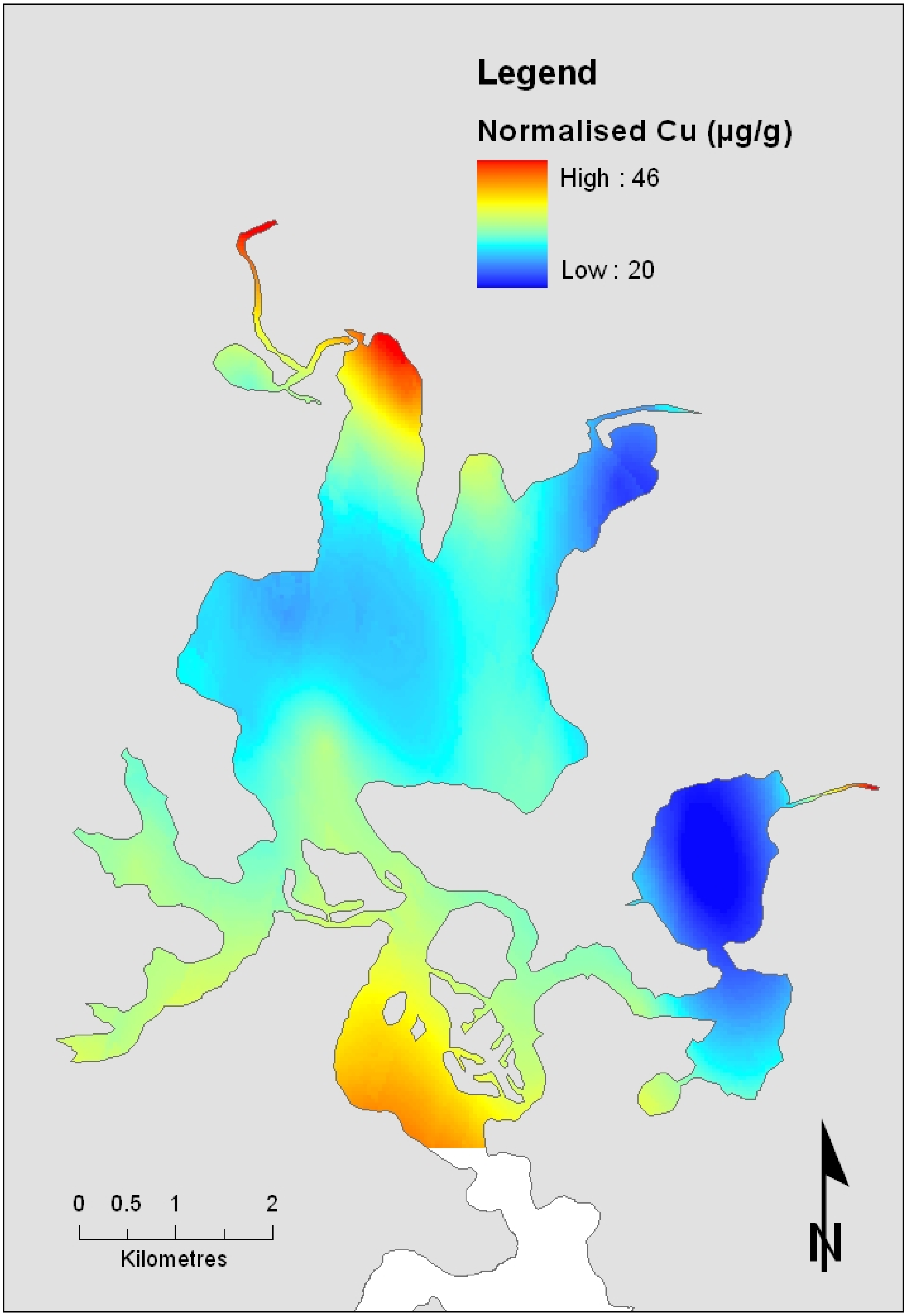


Figure 12. Normalised Cu concentrations for Brisbane Water estuary and the surrounding catchment land use.

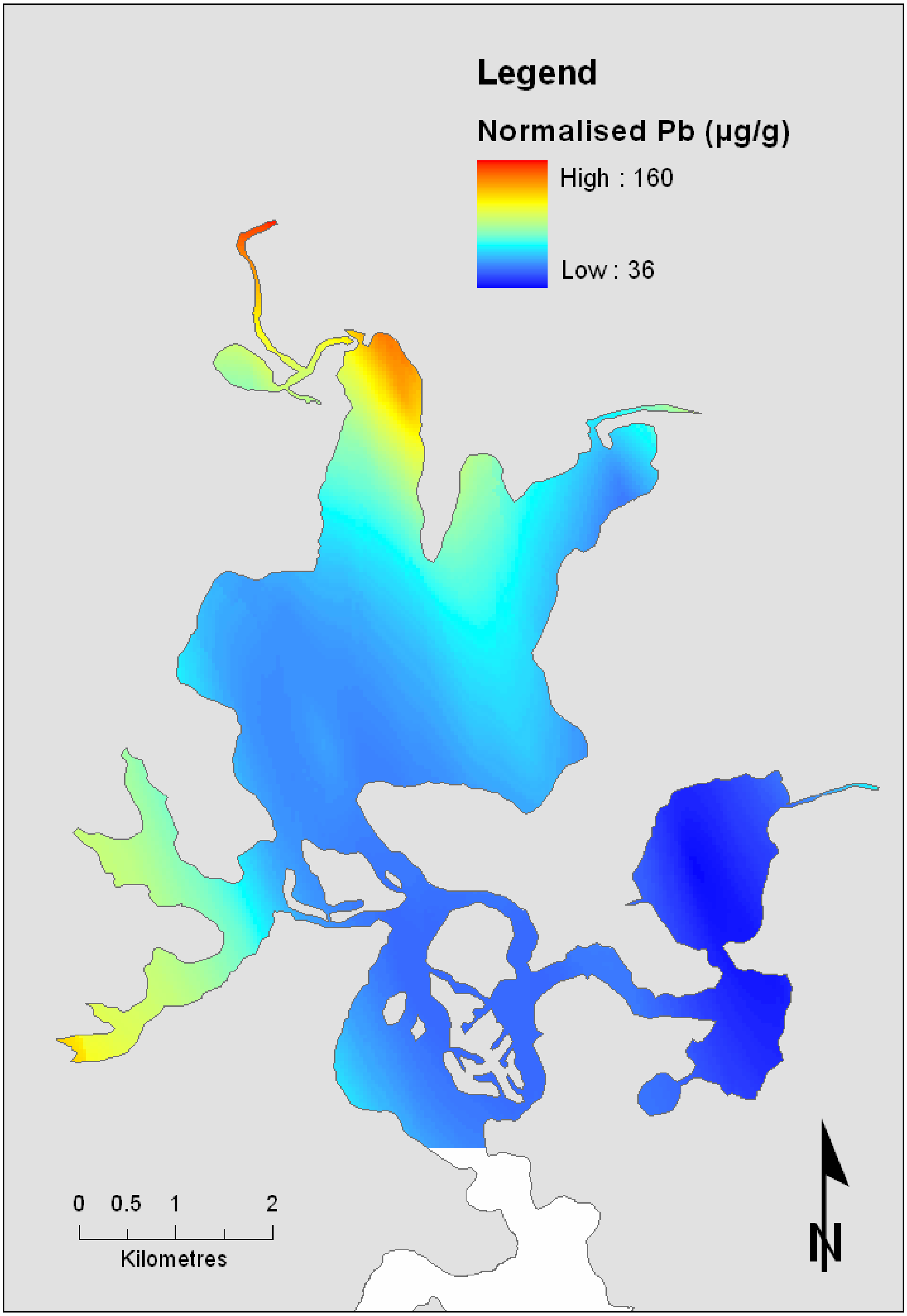


Figure 13. Normalised Pb concentrations for Brisbane Water estuary and the surrounding catchment land use.

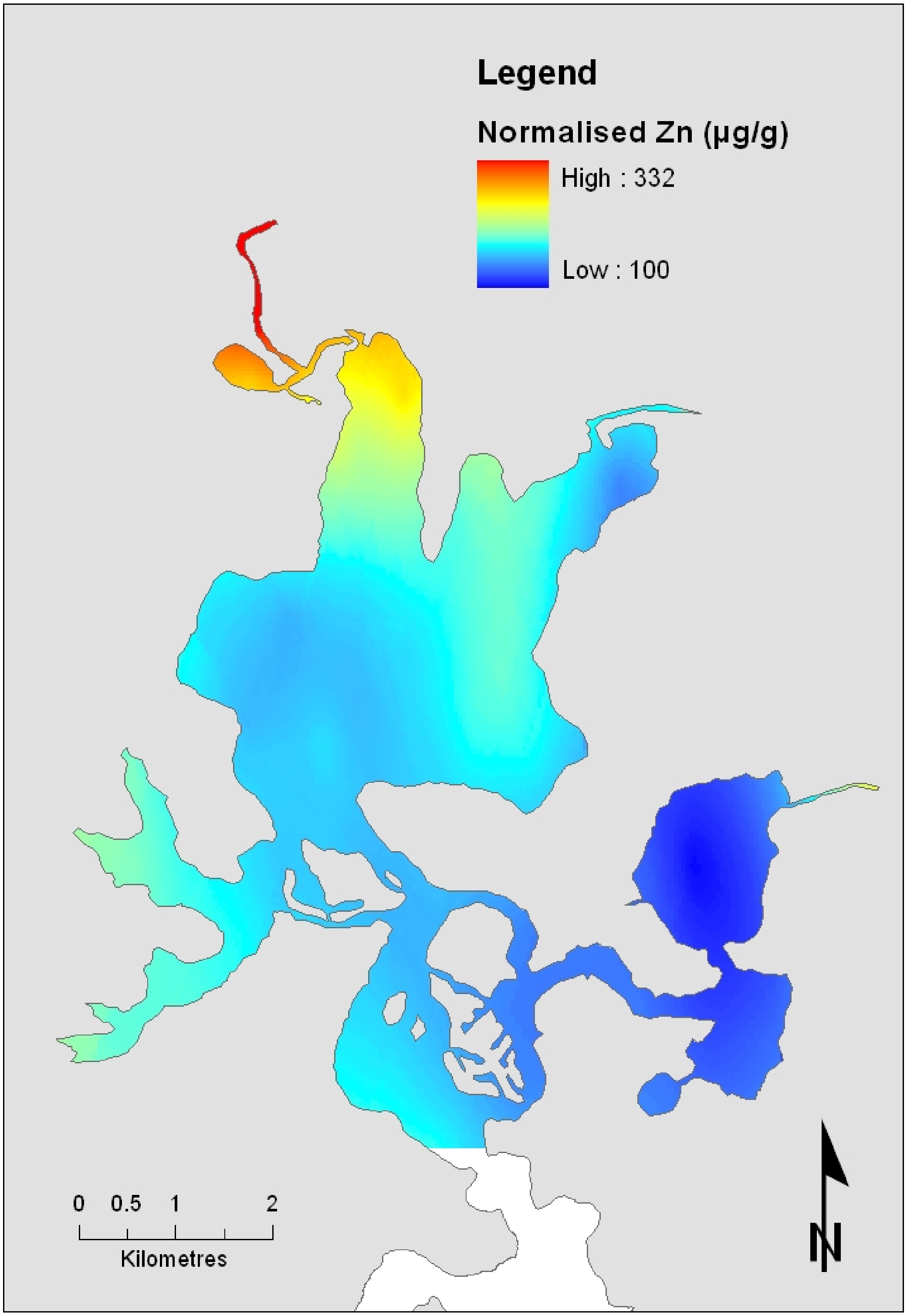


Figure 14. Normalised Zn concentrations for Brisbane Water estuary and the surrounding catchment land use.

Background and Enrichment

Highest metal concentrations at the top of the three cores were recorded in Core C3 adjacent to Narara Creek, followed by C4 opposite Erina Creek. Core C5, located in the Kincumber Creek area in the southern part of the estuary, had the lowest top-core heavy metal concentrations of the three cores collected.

A relatively constant concentration of Cu, Pb and Zn occurred deeper than about 80 cm depth in cores C3 and C4 and at approximately 15cm in core C5 (Figure 9). If sedimentation rates were reasonably consistent throughout Brisbane Water, then contamination started considerably earlier in the north than in Kincumber Creek catchment to the south. However, the important point, as far as management is concerned, is that concentrations continue to increase rapidly to the present day in all of the four sub-catchments of Brisbane Water for these three metals. An exception is Pb in core C4 adjacent to Erina Creek, which has declined in the recent past. Lead is derived mainly from vehicular sources and this decrease in Pb may reflect a reduction in the amount of Pb-based fuel being used, or the introduction of some form of remedial structure. If the decrease was due to a reduction in Pb-based fuel, then a similar decrease would be expected in the other two cores, as well and a remedial device would reduce loading of all three metals not only Pb. More cores should be taken for Pb analysis before any conclusions are made regarding the apparent decrease in Pb concentration in recent times in this area.

The consistently low concentrations at the bottom of all three cores were used to calculate background concentrations for Cu, Pb and Zn for sediments of Brisbane Water (Table 8). Metal concentrations of sediment in the most pristine fluvial and estuarine parts of Brisbane Water and catchment were compared to background estimates obtained from estuarine cores to assess the validity of these determinations. Background levels from adjacent estuaries were also compared to the Brisbane Water background core data to provide support for the estimate of background concentrations. Pre-anthropogenic concentration for Brisbane Water was low for Cu compared to Port Jackson, Lake

Macquarie, Lake Illawarra and Hawkesbury River, but similar for Pb and Zn, except for Lake Illawarra, which has slightly higher Zn background concentrations. Such a variation in background values can be expected from different geological provinces.

Table 8. Background concentrations (μg/g) for analysed heavy metals.

	Cu	Pb	Zn
This work			
Brisbane Water - Min (Estuarine)	19	37	102
Brisbane Water - Min (Fluvial)	14	16	94
Brisbane Water Cores Mean	8	20	55
Port Jackson[1]	12	20	48
Lake Macquarie[2]	6 - 17	5.5 - 17	12 - 68
Lake Illawarra[3]	39	19	87
Hawkesbury River[4]	16	22	62

[1]Birch and Taylor, 1999; [2]Roach, 2005; [3]Gillis and Birch, 2006
[4]Birch et al., 1998

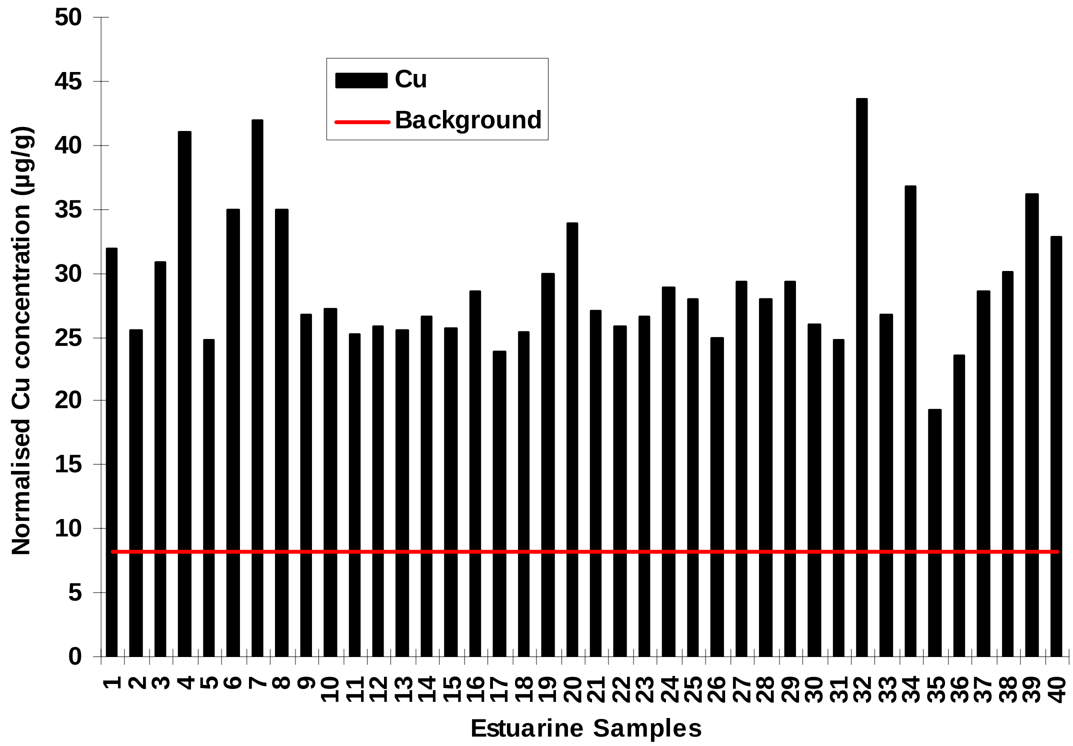
Metal concentrations from the most pristine parts of the catchment (minimum concentration in fluvial samples) and estuary (minimum concentration in estuarine samples) were higher than that obtained from the base of the estuarine cores indicating that sediments from the whole of the Brisbane Water estuary and catchment were elevated (enriched) above pre-anthropogenic concentrations in Cu, Pb and Zn. Figures 15 to 17 illustrate enrichment in estuarine and fluvial samples. Mean enrichment values for Cu, Pb and Zn were 3.5, 2.7 and 2.9 times greater than background for estuarine samples, and 6.3, 4.1 and 5.8 times for fluvial samples (Table 9). Mean enrichment for Pb and Zn (2.7 and 2.9 times, respectively) were similar to Lake Illawarra, but considerably less than that in Port Jackson sediment (30.8 and 18.1, respectively). Copper enrichment in Brisbane Water sediments was slightly higher (3.5 times) than in Lake Illawarra (1.8), but considerably less enriched than in Port Jackson sediments (16.8 times).

Figures 18 to 20 show the spatial distribution of enrichment in the estuary for Cu, Pb and Zn. Sediment in the northern part of the estuary was the most enriched in the waterway. Maximum enrichment for Cu, Pb and Zn in this area was five times, four times and five times, respectively. Sediment in the Kincumber Creek area was the least enriched for Cu, Pb and Zn in the estuary, however even in this seemingly pristine part of Brisbane Water, metals were enriched by two times. This recent enrichment was clearly evident in the down-core profiles for Cu, Pb and Zn in core C5. These core data suggested that the Kincumber Creek area remained pristine for a considerably longer period compared to the northern part of the estuary.

Table 9. Enrichment in estuarine sediments.

	Cu	Pb	Zn
This work			
Mean enrichment (Estuarine)	3.5	2.7	2.9
Max enrichment (Estuarine)	5.3	4.7	5.6
Mean enrichment (Fluvial)	6.3	4.1	5.8
Max enrichment (Fluvial)	27.3	12.8	17.4
Lake Illawarra[1]			
Mean enrichment (Estuarine)	1.8	2.7	2.4
Max enrichment (Estuarine)	5.4	7.2	8.8
Mean enrichment (Fluvial)	2.3	4.1	3
Max enrichment (Fluvial)	7.5	25.8	10.6
Port Jackson[2]			
Mean enrichment (Estuarine)	16.8	30.8	18.1
Max enrichment (Estuarine)	102.1	599.9	178.1
Mean enrichment (Fluvial)	15.6	17.3	13.6
Max enrichment (Fluvial)	87.8	180.2	158.8

[1]Gillis and Birch, 2006; [2]Birch and Taylor, 1999



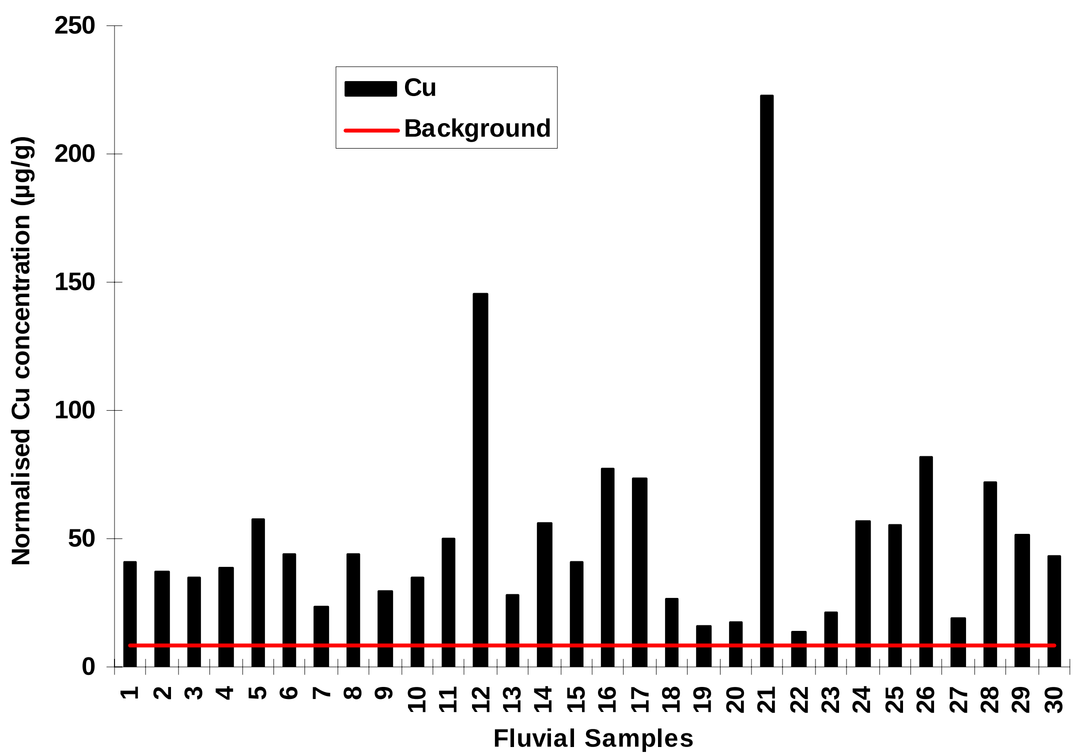
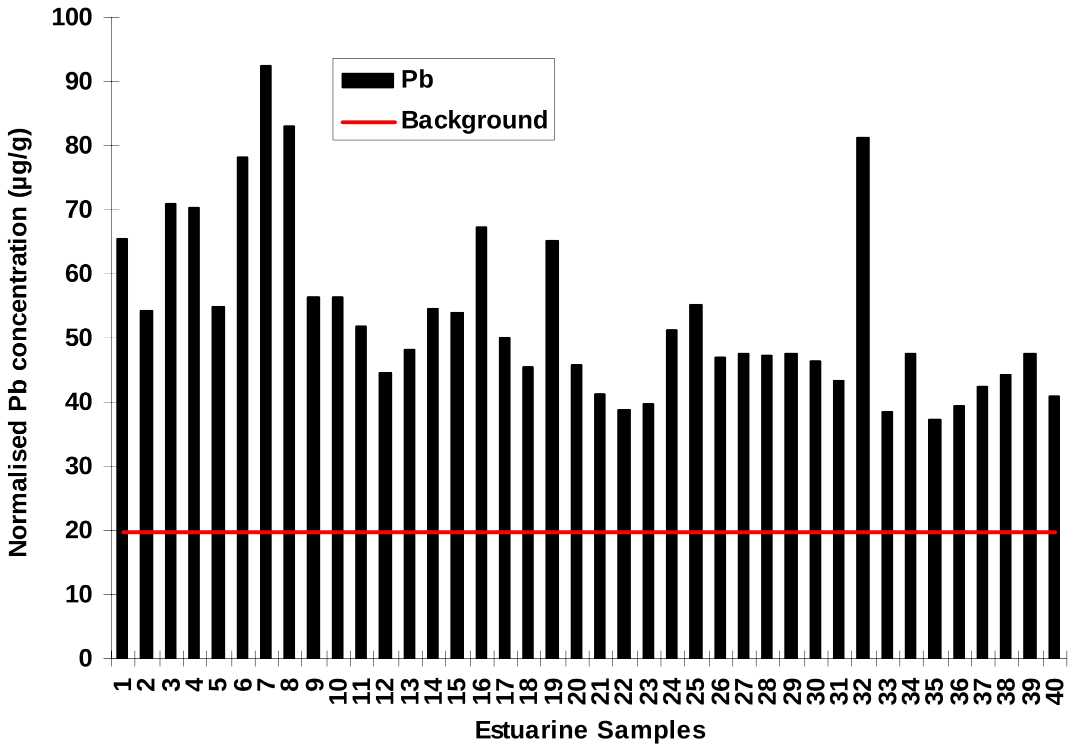


Figure 15. Normalised Cu concentrations in fluvial samples and background level.



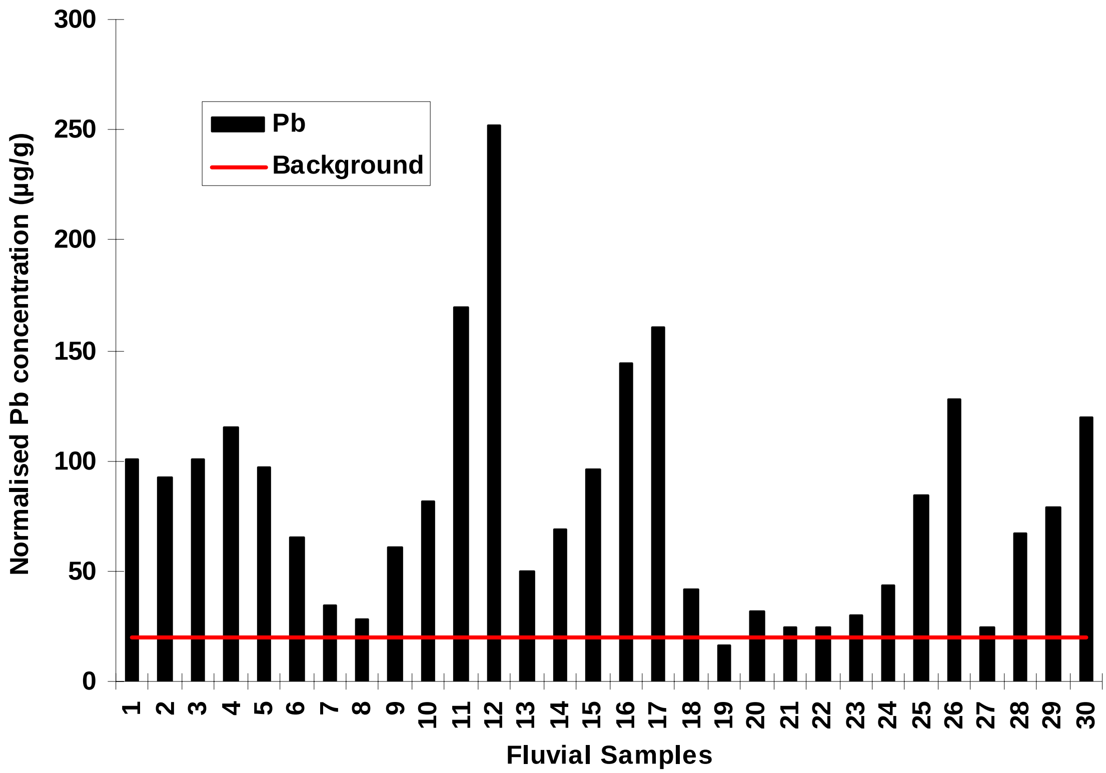
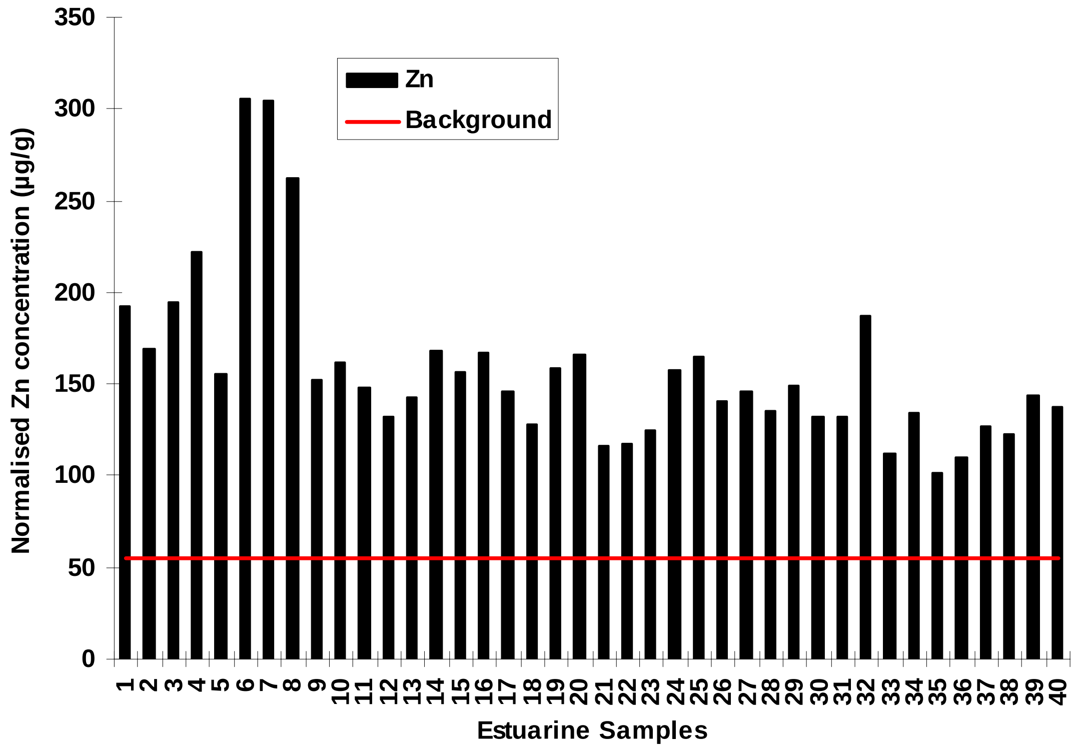


Figure 16. Normalised Pb concentrations in fluvial samples and background level.



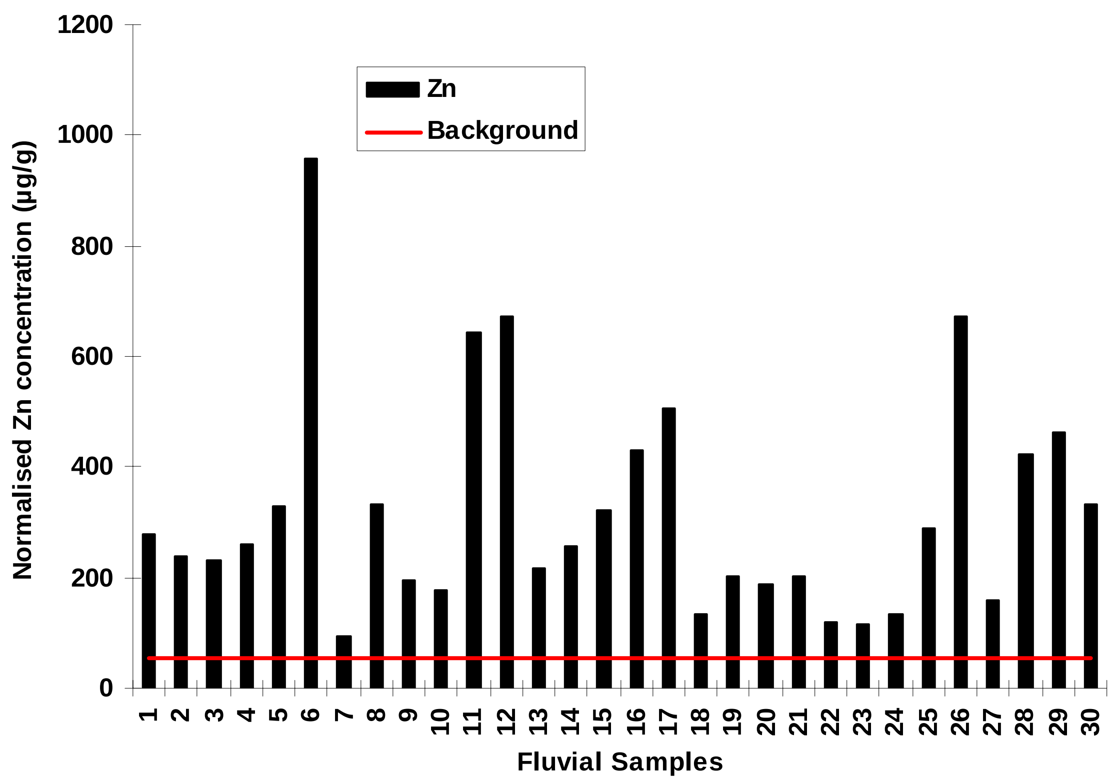


Figure 17. Normalised Zn concentrations in fluvial samples and background level.

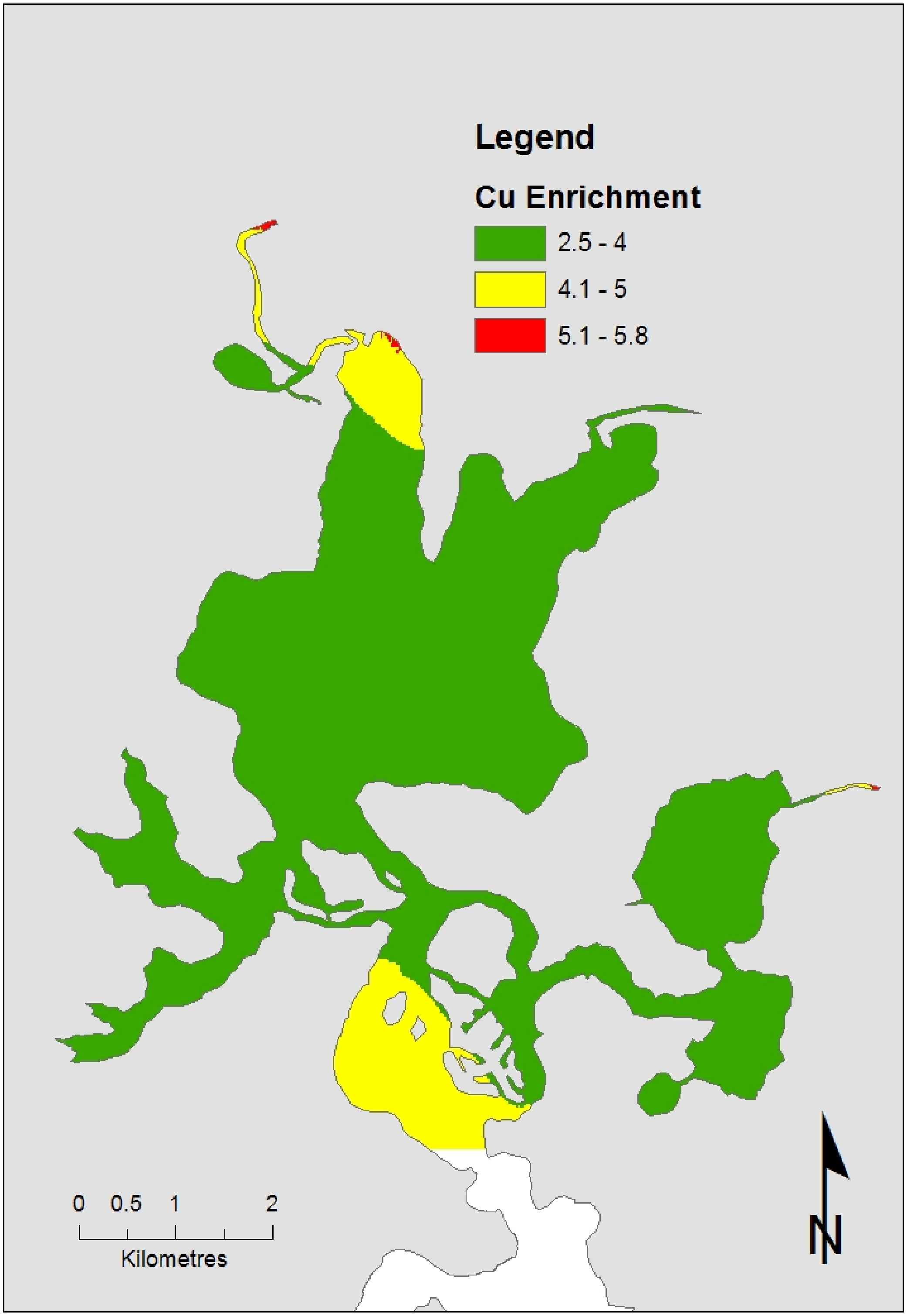


Figure 18. Cu enrichment levels for Brisbane Water estuary.

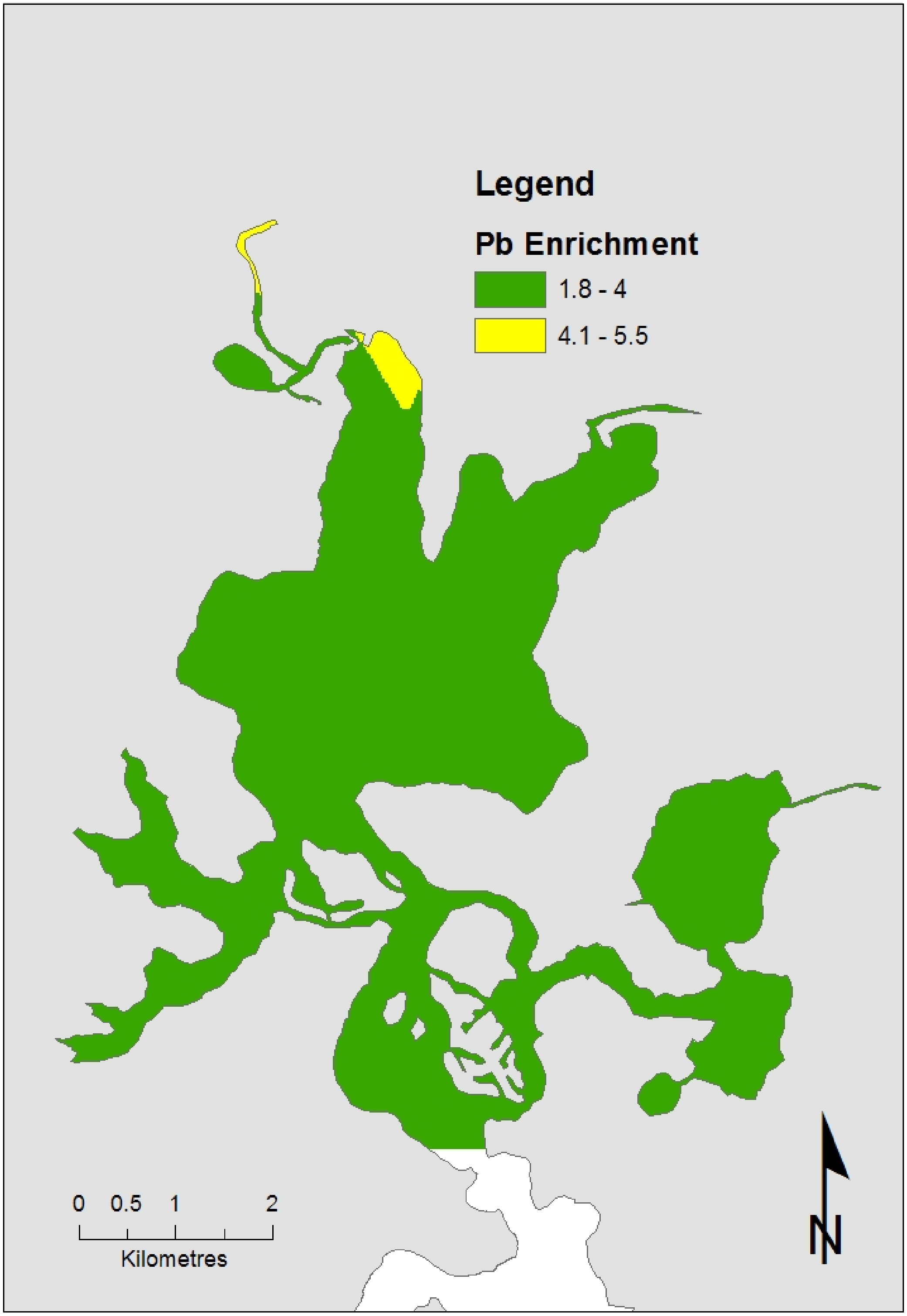


Figure 19. Pb enrichment levels for Brisbane Water estuary.

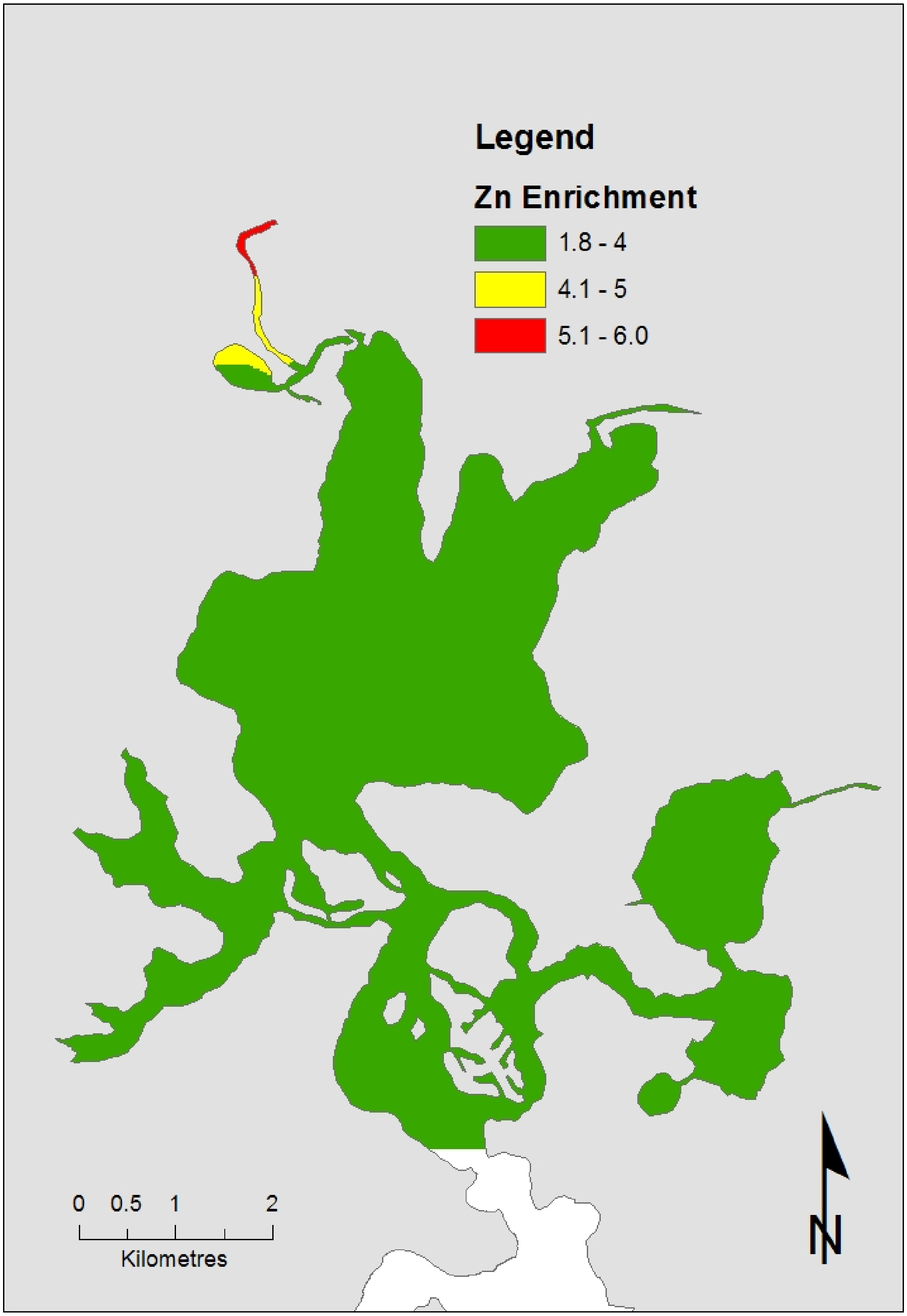


Figure 20. Zn enrichment levels for Brisbane Water estuary.

Sediment Quality

Only six estuarine samples exceed ISQG L concentrations and all were located in the northernmost part of the estuary. Eight fluvial sediment samples exceeded ISQG L and all but two were located on the Narara Creek. No estuarine or fluvial sediment samples exceeded ISQG H. Metal concentrations at these levels suggested that the risk of adverse effects on biota due to metallic contamination was very minor.

Bioavailability

A large proportion (~40%) of Cu, Pb and Zn was probably available to sediment-dwelling biota, whereas about 20% of Co and Ni and only approximately 10-20% of Cr were bioavailable. HCl and EDTA removed about the same proportion of these metals, except for Cu, which was more readily extractable by EDTA (76%) than HCl (44%). Although bioavailability was high for some metals (Cu, Pb and Zn), overall metal concentrations in Brisbane Water sediment was low and thus minor metals are probably available to benthic animals.

Conclusions

The distribution of heavy metals Cu, Pb and Zn in estuarine sediment decreased rapidly southwards from a maximum adjacent Narara Creek. A similar, but less marked trend was observed off Erina Creek in the north east of the waterway. Consistently high concentrations of these metals in fluvial samples taken from the Narara Creek catchment and high loadings calculated for this river, suggested that the Narara Creek and catchment plays an important role in contamination of the northern part of Brisbane Water estuary. Metal concentrations were elevated above pre-anthropogenic levels over the entire estuary. Maximum enrichment of Cu, Pb and Zn was 4-5 times background in the north and 2 times in the south and eastern parts of the waterway. Only six estuarine sediment samples exceeded ISQG L values for Cu, Pb and Zn and no fluvial or estuarine samples exceeded ISQG H. The risk to benthic fauna due to metallic contamination is therefore probably low. Although almost 50% of Cu, Pb and Zn were available to sediment-dwelling animals, overall concentrations of these metals were low and thus the total metals that are bioavailable is probably minor.

Recommendations

Recommendations for further investigation as a result of the current research are:

Primary sources of contamination, especially in the Narara Creek catchment, should be identified. Detailed modelling of the catchment will provide insight as to probable sources, and this should be followed by on-the-ground measurement of discharges under base and high-precipitation conditions.

An audit should be made of industries in the Narara Creek catchment for possible contaminant discharges. High priority industries should be monitored for compliance using programmable water quality assessment technology. Targeted, on-going education should be implemented and changes assessed using water quality analysis to determine success of various strategies.

Because organic contaminants frequently co-occur with heavy metals, especially in stormwater-dominated systems, selected sampling and analyses should be undertaken of a small number of sediments in the northern part of the estuary for organochlorine compounds (OCs), polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs).

A small, detailed study should be undertaken of sediment in the most contaminated, northern part of Brisbane Water to fully evaluate toxicity, including bioavailability, speciation and partitioning studies.

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APPENDICES

Appendix 1 – Heavy metal extraction results – Total fraction

Estuarine Samples (Blue = above ISQG Low)

SampleID	Al	Ca	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
BW01	8296.55	1108.30	0.38	1.76	10.21	9.29	10990.80	39.94	3.87	23.59	65.32
BW02	10638.27	1866.04	0.56	1.96	12.98	11.50	14556.92	73.61	4.71	26.62	78.85
BW03	24961.25	3551.59	1.20	4.41	31.94	30.66	34139.09	160.99	12.13	68.95	189.35
BW04	1862.25	472.86	0.03	0.46	2.74	1.20	3171.57	22.20	0.84	4.61	8.04
BW05	32830.41	10938.40	1.34	7.13	39.83	24.72	37497.94	315.79	15.97	54.32	153.32
BW06	4847.95	901.71	0.24	0.98	6.07	6.35	6936.55	26.12	2.82	15.04	61.46
BW07	29466.50	3407.85	1.65	5.59	38.11	41.44	43042.06	150.56	17.64	91.60	300.38
BW08	14141.94	1717.51	0.67	2.58	18.50	17.04	19287.76	96.86	8.10	38.21	115.77
BW09	28190.29	4386.91	1.44	6.54	39.32	27.83	36864.61	206.71	14.31	56.68	150.22
BW10	30300.45	2985.41	1.03	5.45	40.00	27.64	36717.29	220.46	16.44	56.18	158.68
BW11	15166.50	40677.62	0.54	4.94	21.98	12.29	20460.44	296.18	8.34	27.37	76.31
BW12	11369.02	43947.23	0.33	3.47	15.87	8.55	13524.16	229.04	6.66	17.25	50.33
BW13	20627.10	11982.11	0.88	5.43	29.19	15.88	25596.68	241.21	11.39	30.57	90.58
BW14	15074.44	4356.48	0.74	4.16	26.31	10.61	22247.41	280.81	7.76	25.28	69.68
BW15	31648.78	3062.53	1.51	6.15	39.53	25.66	36726.28	296.06	14.60	53.52	152.18
BW16	24039.66	2228.04	0.94	4.44	27.90	23.13	31047.51	98.22	10.96	54.08	133.49
BW17	26880.58	9075.66	1.15	7.54	37.89	23.59	34470.93	464.03	15.56	49.07	142.19
BW18	7939.40	31604.19	0.39	2.45	12.75	7.42	11526.97	134.54	4.70	15.02	41.23
BW19	24163.60	7213.43	1.27	7.09	37.86	29.50	32663.06	301.75	15.31	61.21	147.04
BW20	4622.66	11923.97	0.28	1.56	7.45	11.93	9924.30	94.50	3.13	13.75	41.42
BW21	5115.78	6508.96	0.26	1.45	8.37	5.52	7597.56	41.03	3.48	8.91	23.52
BW22	6674.59	13641.30	0.34	2.51	12.95	4.41	12660.29	115.09	3.94	10.72	43.12
BW23	3825.44	2123.28	0.15	1.14	6.05	4.31	5147.24	32.49	2.47	7.70	19.71
BW24	31361.14	10026.36	0.24	6.13	32.97	0.95	32577.57	238.33	11.95	39.53	123.02
BW25	35801.70	6937.58	0.28	7.29	39.04	28.02	41762.50	295.98	13.88	49.35	150.43
BW26	29743.70	12713.50	0.21	7.03	34.67	23.41	39756.50	672.24	13.29	45.44	134.00
BW27	33365.55	6531.97	0.07	7.25	36.96	28.06	39830.18	340.15	13.80	46.63	141.58
BW28	2502.58	5383.54	0.01	0.67	4.22	1.69	4879.85	36.03	1.02	4.11	10.29
BW29	30393.39	37080.97	0.06	6.62	32.73	23.03	34871.52	222.07	13.33	36.61	117.35
BW30	23975.00	28763.73	0.14	5.72	28.54	17.52	33522.27	209.45	10.67	33.47	97.92
BW31	29136.10	25407.10	0.08	6.79	32.11	22.26	37503.60	403.27	12.46	40.47	120.43
BW32	8794.56	7384.68	0.20	1.74	11.77	10.46	13282.08	34.96	4.04	23.23	53.05
BW33	3117.11	1548.49	0.04	0.76	5.09	2.23	3617.29	24.11	1.82	4.46	13.19
BW34	2308.62	2705.28	0.02	0.51	3.24	2.59	2430.10	18.83	1.22	3.26	9.22
BW35	24385.19	2792.25	0.74	6.06	37.13	17.08	32559.30	361.98	12.95	33.25	88.68
BW36	22983.43	3210.29	0.60	5.86	36.27	19.32	32096.93	253.62	13.30	34.05	90.68
BW37	1780.50	9277.20	0.02	0.60	3.14	1.33	3391.10	23.03	0.97	2.80	7.83
BW38	3942.41	6270.60	0.07	1.01	5.69	3.23	5296.69	36.57	2.12	5.82	14.46
BW39	1335.41	19971.39	0.00	0.62	3.03	0.84	2942.26	34.08	0.93	2.87	6.38
BW40	1820.64	21200.83	0.05	0.57	3.03	1.02	2404.32	28.03	1.06	2.88	6.01
Mean	16735.8	10672.2	0.5	3.9	21.8	14.6	21738.0	179.3	8.3	30.5	87.4
SD	11779.29	11527.1	0.5	2.5	14.2	10.83	14205.6	149	5.58	21.95	64.66
Min	1335.41	472.86	0.00	0.46	2.74	0.84	2404.32	18.83	0.84	2.80	6.01

Max	35801.70	43947.23	1.65	7.54	40.00	41.44	43042.06	672.24	17.64	91.60	300.38

Fluvial Samples (Blue = above ISQG Low, Red = above ISQG High)

SampleID	Al	Ca	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
BWR01	10913.09	1215.89	0.61	2.09	13.66	14.85	15804.01	43.45	6.35	37.01	102.59
BWR02	9521.66	1054.12	0.54	1.76	11.02	13.21	14728.45	25.86	5.08	30.98	79.81
BWR03	3450.56	449.98	0.21	0.69	3.69	4	5765.85	13.38	1.99	14.07	27.29
BWR04	2459.49	528.43	0.11	0.91	2.76	2.93	3745.95	16.11	2.27	7.96	19.76
BWR05	9934.63	2982.08	BDL	4.68	23.24	24.76	22967.8	165.49	13.51	46.68	143.11
BWR06	14135.68	7011.29	BDL	8.17	33.13	40.75	29381.62	449.11	23.23	55.15	792.23
BWR07	6630.63	1140.94	BDL	1.47	11.81	12.65	16517.81	39.02	4.87	13.42	38.73
BWR08	11995.13	19092.06	BDL	17.86	16.51	31.21	23345.11	300.97	31.71	14.54	167.25
BWR09	4361.61	1342.78	BDL	1.78	6.36	11.46	10710.57	108.74	2.75	13.52	39.92
BWR10	6740.24	3723.52	BDL	5.27	11.8	20.19	17629.06	135.28	8.37	51.67	151.16
BWR11	5046.69	3829.82	BDL	14.59	9.29	16.41	35818.08	233.61	9.09	50.4	216.62
BWR12	9254.67	9028.32	BDL	10.94	36.01	33.72	25042.5	427.66	24.52	64.02	237.79
BWR13	5205.8	2156.29	BDL	7.2	9.63	13.44	23852.96	698.17	7.84	20.06	119.03
BWR14	9378.97	9857.62	BDL	9.41	38.06	25.23	32213.43	272.23	27.61	33.56	138.95
BWR15	9540.88	3765.03	BDL	4.82	19.32	21.04	18815.75	113.98	12.83	48.77	181.2
BWR16	7380.66	5576.96	BDL	6.75	16.66	26.07	23727.16	297.95	18.56	48.31	139.66
BWR17	9429.33	6579.44	BDL	8.37	24.49	33.52	35647.78	247.14	21.04	88.12	276.77
BWR18	4792.54	3036.94	BDL	3.05	10.92	13.39	11484.03	109.65	5.77	19.29	73.31
BWR19	4845.9	3339.5	BDL	5.27	12.78	10.2	11362.54	172.04	11.11	4.93	56.07
BWR20	20794.68	2021.76	BDL	21.49	20.93	16.77	30652.54	783.47	10.54	32.01	185.65
BWR21	4809.56	1049.66	BDL	3.66	6.89	76.32	11360.51	79.07	4.96	9.63	76.63
BWR22	8644.11	4155.26	BDL	9.27	20.93	12.88	18064.66	672.6	19.35	7.7	68.42
BWR23	13608.41	2605.13	BDL	3.33	20.38	16.38	25806.21	182.11	7.34	24.47	93.16
BWR24	14575.44	11397.96	BDL	17.91	23.93	30.66	31034.69	353.5	46.28	9.79	68.88
BWR25	4733.03	3387.56	BDL	3.98	16.65	17.05	13534.97	103.94	10.94	34.06	100.37
BWR26	10531.93	5355.91	BDL	6.09	11.41	31.38	17796.58	194.53	12.1	30.86	174.47
BWR27	15543.69	6746.02	BDL	10.58	39.57	51.17	27013.19	610.21	25.09	80.47	440.4
BWR28	8055.57	8743.5	BDL	5.94	20.49	41.44	36361.21	454.91	12.46	46.03	301.4
BWR29	7101.81	4180.41	BDL	9.36	20.61	60.6	19656.33	407.49	18.19	28.12	191.61
BWR30	3701.66	4711.84	BDL	1.62	8.92	11.44	15980.24	67.12	4.65	23.76	75.69
Mean	8570.6	4668.87	0.37	6.94	17.39	24.5	20860.72	259.29	13.68	32.98	159.27
SD	4209.13	3967.73	0.24	5.37	9.73	16.61	8859.24	217.34	10.2	21.5	150.83
min	2459.49	449.98	0.11	0.69	2.76	2.93	3745.95	13.38	1.99	4.93	19.76
max	20794.68	19092.06	0.61	21.49	39.57	76.32	36361.21	783.47	46.28	88.12	792.23

BDL = Below Detection Limit

Core Samples

SampleID	Al	Ca	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn	Depth cm
BWC3-1	23806.11	5382.84	0.71	4.45	31.68	28.07	28058.34	104.11	12.07	69.89	160.56	-5
BWC3-2	22194.19	1749.29	0.59	3.90	28.22	18.85	25136.14	80.32	9.63	60.45	111.73	-15
BWC3-3	11341.23	854.20	0.20	2.15	13.68	7.20	15633.86	41.32	4.56	20.89	42.70	-30
BWC3-4	10578.05	1789.78	0.24	2.28	13.12	4.68	15888.12	44.30	4.63	15.05	27.67	-50
BWC3-5	6659.32	2841.74	0.12	1.35	9.17	1.41	9888.31	34.47	3.33	4.89	13.90	-80
BWC3-6	6238.21	3505.38	0.12	1.39	9.08	1.39	11149.97	28.65	2.97	5.28	11.18	-100
BWC3-7	5603.95	1766.55	0.08	1.13	7.80	1.10	8757.95	22.43	2.45	4.38	11.92	-110
BWC3-8	10998.99	1166.86	0.20	2.26	15.43	2.33	17305.14	44.89	4.82	8.23	20.09	-120
BWC3-9	6509.29	1354.66	0.06	1.28	9.45	1.35	10104.05	26.00	2.81	5.76	11.64	-130
BWC4-1	15267.09	19337.76	0.43	3.14	20.01	16.45	23449.98	72.65	7.55	33.00	84.86	-3
BWC4-2	23892.00	2162.77	0.74	4.62	29.70	20.33	30352.87	82.49	10.72	53.71	106.26	-15
BWC4-3	23713.81	2613.80	0.77	5.13	31.07	18.46	29721.07	110.76	11.12	42.38	100.55	-30
BWC4-4	11432.52	4676.18	0.30	2.47	14.51	6.55	17883.88	52.79	5.30	12.31	31.13	-50
BWC4-5	21209.27	7052.86	0.41	5.23	28.72	7.23	29704.43	124.36	10.65	14.55	47.90	-80
BWC4-6	21797.30	5310.52	0.49	5.31	29.45	7.06	30994.25	129.00	10.74	15.91	42.37	-100
BWC4-7	22575.80	5147.51	0.43	5.67	31.15	7.51	29712.33	138.89	11.36	16.62	43.95	-110
BWC4-8	23136.49	2400.23	0.44	5.57	33.22	6.68	29842.35	135.20	11.35	15.77	44.70	-118
BWC5-1	11388.21	4101.36	0.29	2.92	16.38	5.61	15668.94	67.09	6.33	10.12	30.19	-4
BWC5-2	15806.96	22310.12	0.56	4.45	22.95	6.75	24521.28	117.23	10.92	11.78	37.06	-15
BWC5-3	13789.34	22451.94	0.28	3.33	20.38	4.38	19585.95	97.65	7.97	8.82	27.45	-30
BWC5-4	16927.02	33460.75	0.59	4.39	25.77	5.08	24167.22	128.10	10.43	9.93	32.43	-50
BWC5-5	15712.52	1875.88	0.43	4.00	25.95	4.44	23866.18	112.36	9.76	10.66	33.05	-80
BWC5-6	12223.04	4824.10	0.25	2.80	19.17	3.05	18960.53	73.90	6.38	7.67	22.19	-100
BWC5-7	10310.95	8468.57	0.23	2.40	17.06	2.70	16755.41	56.84	5.65	7.45	21.35	-110
BWC5-8	5592.53	6089.92	0.08	1.48	10.02	1.32	10664.43	33.25	3.18	4.58	12.77	-120
BWC5-9	7299.75	10652.86	0.10	1.65	12.18	1.61	12216.25	37.33	3.81	5.63	15.13	-130
BWC5-10	5597.31	8561.08	0.13	1.25	9.29	1.17	9727.92	30.20	2.87	3.99	11.02	-140

Appendix 2 – Heavy metal extraction results – Fine fraction

Estuarine Samples

SampleID	Al	Ca	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
BW01	27677.62	2023.88	1.31	4.44	31.39	31.98	34127.43	105.10	12.07	65.45	192.19
BW02	24461.71	2034.58	1.35	4.02	28.98	25.59	33399.52	135.99	10.79	54.36	169.59
BW03	26263.71	2603.33	1.27	4.59	33.39	30.84	36958.57	168.62	12.77	70.99	195.06
BW04	42610.76	3320.67	1.48	8.61	53.04	41.04	44794.00	511.76	21.65	70.30	222.45
BW05	33188.10	10473.90	1.37	7.21	40.29	24.74	38390.00	319.43	16.18	54.70	155.15
BW06	28500.95	2634.10	1.45	4.92	33.97	34.94	39833.71	118.61	14.71	78.10	305.63
BW07	29992.00	3360.90	1.68	5.67	38.68	41.89	43791.90	153.31	17.90	92.51	304.05
BW08	32625.81	2966.33	1.52	5.83	42.16	35.00	43041.81	207.76	18.43	83.09	262.19
BW09	28705.62	3422.62	1.50	6.62	39.91	26.70	38024.67	199.42	14.54	56.45	152.18
BW10	31166.29	2699.70	1.04	5.51	41.00	27.23	38052.86	217.31	16.94	56.34	161.39
BW11	31439.52	11584.76	0.96	7.75	41.30	25.28	36068.19	438.62	16.36	51.79	148.42
BW12	31836.67	24401.62	0.97	8.17	41.55	25.88	34844.86	518.38	18.70	44.48	132.03
BW13	32902.00	10411.52	1.36	8.18	44.10	25.53	37554.29	361.63	17.92	48.29	143.00
BW14	34815.43	4403.52	1.62	8.47	47.80	26.55	41993.43	583.36	17.95	54.57	168.21
BW15	32440.86	2580.40	1.60	6.23	40.43	25.64	38286.48	299.07	14.89	54.02	156.11
BW16	30146.67	2629.77	1.25	5.39	34.94	28.61	40382.95	122.87	13.62	67.35	166.65
BW17	27035.52	6740.50	1.21	7.68	38.55	23.81	36303.43	482.56	15.90	50.12	146.27
BW18	23750.67	11444.67	1.35	6.52	34.20	25.45	32874.67	353.80	14.51	45.47	127.45
BW19	25301.62	6589.75	1.48	7.44	40.07	29.93	37522.76	318.84	16.27	65.10	158.10
BW20	21233.14	17942.48	1.10	6.81	32.74	33.95	33285.52	341.82	14.63	45.64	166.19
BW21	24193.62	13070.10	1.41	7.08	38.76	26.99	36052.76	185.95	16.72	41.27	116.20
BW22	26076.76	6362.43	1.16	7.63	39.81	25.81	35849.24	391.09	16.04	38.69	117.85
BW23	23718.95	5631.88	1.34	6.45	35.38	26.62	31384.95	177.95	14.92	39.57	125.13
BW24	38647.86	4296.48	0.26	7.81	42.95	28.83	42485.38	327.72	15.97	51.17	157.59
BW25	40184.33	3871.01	0.28	8.22	42.96	27.97	46419.22	303.24	15.93	55.13	164.61
BW26	35717.17	9214.67	0.11	7.76	38.58	24.91	39097.55	626.83	15.00	47.09	140.18
BW27	35632.67	4701.03	0.33	7.72	40.66	29.35	36870.67	341.53	15.29	47.70	146.11
BW28	35685.33	9382.60	0.39	7.44	40.79	27.93	41603.89	393.39	15.53	47.30	135.54
BW29	39094.50	16869.90	0.14	8.43	43.82	29.40	46437.45	330.95	17.10	47.52	149.39
BW30	35806.39	17904.54	0.43	7.98	39.11	25.98	38836.39	270.96	15.50	46.32	132.33
BW31	35390.79	16537.34	0.24	7.56	37.59	24.80	37963.24	491.42	15.20	43.41	132.11
BW32	27676.14	2627.03	0.83	5.30	38.97	43.56	37821.45	113.89	13.66	81.18	186.81
BW33	26769.74	4574.31	0.43	6.67	40.79	26.78	32912.81	196.86	15.95	38.60	112.36
BW34	30698.13	5157.88	0.55	8.07	46.20	36.71	38581.61	253.29	18.03	47.68	134.20
BW35	28976.25	2370.66	0.61	6.97	43.00	19.23	39039.70	427.47	15.85	37.41	101.94
BW36	29792.56	2515.31	0.53	6.87	43.97	23.52	39582.70	301.82	16.45	39.46	109.64
BW37	30910.57	4890.80	0.79	8.11	48.22	28.55	35279.20	390.09	18.61	42.54	127.33
BW38	31413.11	13278.09	0.73	8.04	45.49	30.07	37964.32	284.73	18.75	44.11	122.58
BW39	34549.88	26664.49	0.38	9.46	45.37	36.16	37165.83	336.73	20.24	47.68	144.03
BW40	34209.52	29397.35	0.63	8.73	45.38	32.81	35805.86	252.98	18.97	40.87	137.14
Mean	31031.0	8339.7	1.0	7.1	40.4	29.2	38167.1	308.9	16.2	53.3	158.1
SD	4926.739	7169.24	0.5	1.3	4.88	5.273	3599.335	133.3	2.15	13.5	45.8
min	21233.14	2023.88	0.11	4.02	28.98	19.23	31384.95	105.10	10.79	37.41	101.94
max	42610.76	29397.35	1.68	9.46	53.04	43.56	46437.45	626.83	21.65	92.51	305.63

Fluvial Samples

SampleID	Al	Ca	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
BWR01	29847.05	3122.46	1.54	5.62	37.43	40.63	43644.95	114.92	17.44	100.45	279.02
BWR02	27661.62	2895.22	1.72	4.95	32.75	37.01	44289.71	74.46	14.74	92.41	238.47
BWR03	27391.33	2907.79	2.19	4.63	30.65	34.91	48586.48	104.82	14.7	100.86	231.06
BWR04	26708.29	3044.05	2.08	5.35	31.68	38.57	47321.33	99.42	16.29	114.97	261.8
BWR05	17068.68	5025.19	BDL	7.9	44.26	57.35	34885.84	258.67	25.93	97.41	329.79
BWR06	16290.15	7495.82	BDL	9.13	38.75	43.96	33055.34	457.01	25.43	65.54	956.77
BWR07	14698.7	2321.09	BDL	3.86	25.75	23.46	30137.93	82.98	10.65	34.1	94.18
BWR08	16781.51	14951.37	BDL	22.91	28.02	43.73	21950.1	337.08	28.98	28.5	333.51
BWR09	15714.06	2637.85	BDL	6.25	24.51	29.59	37449.95	345.59	9.97	60.9	196.57
BWR10	13084.9	3197	BDL	7.69	22.66	34.78	20426.4	187.2	11.89	81.63	176.83
BWR11	15997.9	4271.4	BDL	47.12	25.67	49.72	65389.34	1145.35	25.67	169.7	642.13
BWR12	17733.57	6590.18	BDL	8.6	46.71	145.69	26425.5	465.84	27.93	252.13	671.19
BWR13	12061.68	3026.8	BDL	12.57	21.88	28.32	28252.87	1052.61	12.84	49.87	215.84
BWR14	15219.95	9461.23	BDL	9.85	41.35	56.42	22952.98	372.91	31.8	69	257.73
BWR15	15696.45	3650.17	BDL	5.01	25.43	40.65	19025.6	117.41	13.36	96.34	321.19
BWR16	17686.83	5949.54	BDL	8.53	38.2	77.07	29701.96	615.18	20.44	143.92	430.48
BWR17	17667.11	8330.43	BDL	12.56	45.57	73.47	25866.1	368.93	37.4	160.18	504.68
BWR18	15317.62	2294.56	BDL	5.69	25.54	26.71	19202.02	177.26	11.64	41.84	134.81
BWR19	9065.01	1385.23	BDL	4.33	14.05	15.62	13834.89	226.77	6.79	16.49	203.48
BWR20	16973.91	2918.89	BDL	22.38	21.8	17.47	31305.79	813.35	10.98	31.72	189.65
BWR21	11650.42	2604.96	BDL	7.31	19.97	222.96	21257.24	135.33	12.41	24.28	202.29
BWR22	12623.54	1885.69	BDL	6.99	18.29	13.77	22712.19	1084.19	8.19	24.32	120.94
BWR23	18145.48	2568.58	BDL	4.19	25.57	21.09	31631.16	228.05	8.74	30.13	114.68
BWR24	19641.06	4459.97	BDL	11.81	33.26	56.87	26948.21	211.52	35.42	43.41	134.65
BWR25	17303.03	6828.9	BDL	9.35	41.32	55.5	24940.55	237.06	25.66	84.05	288.48
BWR26	14621.9	6160.51	BDL	9	36.17	81.85	31969.4	221.53	27.84	127.73	670.56
BWR27	6404.09	3814.78	BDL	4.65	15.7	18.8	15531.87	246.62	13.64	24.47	160.02
BWR28	13731.24	8502.25	BDL	8.1	27.93	71.84	30003.98	563.78	16.58	66.78	423.82
BWR29	14329.63	4570.99	BDL	12.48	33.47	51.88	24283.44	560.92	21.58	79.12	462.33
BWR30	17496.3	11472.25	BDL	8.22	38.31	43.05	48139.47	284.57	17.57	119.69	331.58
mean	16820.43	4944.84	1.88	9.9	30.42	51.76	30704.09	373.04	18.75	81.06	319.28
sd	5227.46	3133.78	0.3	8.4	8.97	41.72	11512.1	301.388	8.51	53.27	201.3526
min	6404.09	1385.23	1.54	3.86	14.05	13.77	13834.89	74.46	6.79	16.49	94.18
max	29847.05	14951.37	2.19	47.12	46.71	222.96	65389.34	1145.35	37.4	252.13	956.77

BDL = Beyond Detection Limit

Core Samples

SampleID	Al	Ca	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn	Depth cm
BWC3-1	30675.61	2501.86	0.71	5.73	40.71	37.17	39782.81	127.47	14.80	88.05	210.56	-5
BWC3-2	29643.85	2043.55	0.75	5.14	37.43	24.93	37555.35	102.46	12.96	78.03	150.25	-15
BWC3-3	28710.68	1645.89	0.66	5.20	35.39	20.33	38820.04	107.95	11.66	54.97	121.06	-30
BWC3-4	28622.21	2600.17	0.61	5.80	35.97	15.96	39316.97	124.68	12.43	42.50	92.62	-50
BWC3-5	31039.59	3596.89	0.93	6.84	44.76	8.60	49444.53	187.16	15.94	22.14	59.83	-80
BWC3-6	32487.13	2746.10	0.62	7.42	47.54	8.72	46193.95	149.24	16.38	25.48	60.42	-100
BWC3-7	30321.04	2126.06	0.79	7.37	44.55	8.55	45975.49	139.66	15.62	22.50	58.09	-110
BWC3-8	31277.09	2863.65	0.64	7.71	46.58	8.71	46895.53	146.09	16.75	23.53	61.02	-120
BWC3-9	36729.57	3611.08	0.63	8.40	51.25	9.27	43558.13	150.11	17.74	24.62	67.48	-130
BWC4-1	28229.21	3692.54	0.54	5.37	36.27	26.75	39099.30	124.97	13.61	51.91	141.32	-3
BWC4-2	28872.76	1722.97	0.70	5.26	36.35	24.68	38359.69	98.68	13.22	64.40	128.89	-15
BWC4-3	29068.50	2258.56	0.54	5.54	36.55	21.74	39331.10	129.85	12.96	47.61	118.48	-30
BWC4-4	28282.73	2326.08	0.71	6.22	35.04	17.67	39993.43	138.00	12.15	31.99	78.64	-50
BWC4-5	26708.20	2916.78	0.66	6.64	35.76	9.76	40610.83	155.07	12.70	18.27	52.91	-80
BWC4-6	25560.71	2762.96	0.55	6.03	35.56	8.61	38665.77	150.28	13.25	17.69	48.45	-100
BWC4-7	25832.60	2567.55	0.51	6.19	34.34	8.44	35793.35	149.75	12.19	16.58	47.66	-110
BWC4-8	28205.03	1978.87	0.54	6.20	37.74	8.12	38419.35	150.07	13.00	17.52	50.05	-118
BWC5-1	27991.14	3175.99	0.65	6.53	38.91	15.03	33774.14	162.45	14.86	25.86	76.42	-4
BWC5-2	25169.79	7409.11	0.83	7.11	38.06	10.49	38309.75	189.12	17.28	17.97	56.73	-15
BWC5-3	26136.78	7981.76	0.68	6.25	38.36	8.85	35890.28	185.40	15.75	16.87	55.23	-30
BWC5-4	26782.18	5453.59	0.77	6.89	42.14	8.18	35575.98	198.51	17.05	17.62	54.26	-50
BWC5-5	25085.92	1406.87	0.77	6.78	39.20	7.67	34920.77	180.45	14.81	17.04	50.23	-80
BWC5-6	26044.94	3822.49	0.48	6.06	40.41	7.26	36657.79	165.91	14.97	16.98	51.14	-100
BWC5-7	26239.48	4273.03	0.50	6.09	41.37	7.14	37337.12	141.70	14.11	17.56	49.40	-110
BWC5-8	27191.01	4782.77	0.61	6.60	46.76	7.15	40735.66	150.86	15.59	19.13	56.98	-120
BWC5-9	24882.66	3579.13	0.53	6.40	45.23	7.17	37748.51	146.43	14.53	18.63	54.94	-130
BWC5-10	27027.80	5008.78	0.65	6.58	47.38	7.22	40641.19	154.54	15.23	18.63	56.41	-140