IDENTIFYING AND MANAGING CONTAMINANTS IN DRINKING WATER SYSTEMS: THE LEICHHARDT RIVER CATCHMENT, MOUNT ISA, QUEENSLAND: UNESCO-IHP Symposium, Paris, 12-14 September 2007

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ABSTRACT
This article examines the storage, transfer and cycling of metals within water, soil and sediment systems in and around Mount Isa Queensland, Australia. The impacts and risks arising from agricultural activities, Mount Isa mine ore extraction, sewage treatment releases, urban runoff on the downstream Leichhardt River and associated drinking water supplies are considered. The ephemeral Leichhardt River bisects the City and the Mine and drains downstream to Lake Moondarra where the City's water is captured and stored. During the dry season the channel is characterised by numerous pools that act as storage zones for sediment and water-soluble metals as well as urban and agriculturally derived and pathogens. Our results show that sediment and water quality within the Leichhardt River adjacent to and downstream of the mine frequently exceed Australian government sediment guidelines with average values of Cu-1550; Pb-510 and Zn-470 ppm found adjacent to the footprint of the mine. Dry season analysis of water-soluble Cu, Pb and Zn concentrations within pools showed that Australian government low trigger guidelines are exceeded in 100; 56 and 100 % of cases, respectively. The pathogen content of water stored in remnant pools also exceeded acceptable guidelines with maximum faecal coliform densities of 220 CFU/100mL and *Enterococcus* values of 900 orgs/100mL. The impacts on biota were also examined by assessing the metal content of the flesh of seven fish (three species) and three crayfish from Lake Moondarra for their Cd-Cu-Hg-Pb-Se-Zn concentration. Flesh metal values were generally low but mean Zn concentrations exceeded the guideline value for each of the species. In the three crayfish samples, the mean Cu concentration exceeded the guideline value marginally. The effectiveness of the City's natural reed-bed potable water processing facility for removing metals held with the water body (soluble and particulate) was also assessed. The results show that the treated water generally meets Australian drinking water guidelines. Overall it is clear that sediment and water quality in the area upstream of the potable water storage zone is seriously impaired. The combined effects of industrial, agricultural and urban activities present a considerable risk to the consistency and reliability of water quality, especially during highly turbid wet season flows that are shown to transfer highly elevated water-soluble metal concentrations.

Key words: contaminants, metals, pathogens, sediment, water, river

1. INTRODUCTION

1.1 Drinking water supply catchments and contaminants

In order to achieve maximum protection of water quality in a catchment a thorough understanding of the nature of the river system and any associated environmental hazards is required in order to achieve this objective effectively (NHRMC, 2004). Sudden or extreme changes in water quality, flow or environmental conditions (e.g. extreme rainfall or flooding) should arouse suspicion that drinking water may become contaminated (NHRMC, 2004). Australia's variable climatic conditions, which are characterised by floods and droughts, present extremely challenging conditions under which water authorities are obliged to provide consistent water quality. This problem is well exemplified in the Leichhardt River-Lake Moondarra water supply catchment that is located in the monsoonal region of northwest Queensland. A range of upstream industrial activities affects ephemeral flows down the Leichhardt River that supply water to Lake Moondarra storage reservoir. These include urban stormwaters that drain Mount Isa city, inputs from the sewerage treatment system and current and historic mining contaminants stored within the Leichhardt River and its tributaries.

Although a number of studies have examined the dynamics of river systems with respect to the transfer of contaminants from source to sink (e.g. Macklin, 1996; Miller, 1997; Hudson-Edwards et al., 1999, 2001), relatively few by comparison have examined arid rivers (Graf et al., 1991; Taylor and Kesterton, 2002; Taylor 2007). The extreme temperatures and sporadic rainfall regimes of the latter may result in significantly different contaminant cycling patterns, which need to be understood if the risk of metals, nutrients and pathogens to water and ecosystems are to be modelled effectively. Indeed, recent studies on arid areas affected by mining in Australia (e.g. Broken Hill: Coggin et al., 1979; Gulson et al., 1994, 1996; Lyle et al., 2001; Low et al., 2005) suggest that the impacts of human activity with respect to deliveries of contaminants may be significant.

This paper summarises research carried out over the past six years on the spatial and temporal variations of sediment associated and soluble metals and pathogens within the aquatic system of the Leichhardt River catchment. With the exception of Lake Moondarra and the reed bed technology used to treat drinking water (Finlayson, 1980, 1984; Farrell, 1989; Griffiths and Farrell, 1991; Wrigley et al., 1991; Kuypers et al., 2006) very little research, until recently, had been undertaken to explore sediment and water quality through the wider catchment (Taylor et al., 2003; Taylor and Hudson-Edwards, 2005; Mackay et al., 2007; Taylor and Hudson-Edwards, 2007). This area is particularly unusual because of the spatial arrangement of the city of Mount Isa (through which the Leichhardt River passes) and its industrial activities and sources and capture site of its water supply.

1.2 Study area

The study area described in this paper is the Leichhardt River, north-west Queensland (Figure 1). The area examined covers a 50 km stretch of river extending from the Selwyn Ranges to Mount Isa's drinking water supply reservoir, Lake Moondarra (catchment area 1,113 km^2). The Leichhardt River lies in the semi-arid tropical zone of Queensland that has a warm-dry season between April and September and a hot-wet season from October to March. Annual rainfall is highly sporadic and localised, ranging from 480 mm to 1,250 mm (Taylor and Hudson-Edwards, 2005), with large inter-annual variations resulting from fluctuations in monsoonal intensity. Consequently, the Leichhardt River displays ephemeral characteristics, flowing only during and shortly after rainfall with the riverbed remaining dry minus a series of disconnected permanent and temporary pools. Riparian vegetation comprises a sparse coverage of spinifex grass and eucalypt trees, which in part is due to the climate but is also a result of extensive cattle grazing in the area.

In the late 1950s the upper Leichhardt River was dammed to create Lake Moondarra (20^{o} 34' S, 139^{o} 35' E) to capture runoff from the Selwyn Ranges to provide water to Mount Isa City (population 20, 695: ABS, 2006) and Xstrata Mount Isa Mines (XMIM). Since 1982, water drawn from Lake Moondarra for potable water has been diverted through an engineered red bed system, known as Clear Water Lagoon, to treat it (CWL, Kuypers et al., 2006). Following transfer through the system, the treated water generally reaches the Australian Drinking Water Guidelines (NHMRC, 2004; Kuypers et al., 2006). The water is then chlorinated before being pumped to the Mount Isa Terminal Reservoir for distribution.

The reliance on a dynamic natural system such as CWL for potable water presents an associated relatively high risk, especially during times of highly turbid runoff that is affected by metals and pathogens. Nineteen kilometres upstream of Lake Moondarra are the urban area of Mount Isa, Mount Isa Waste Water Treatment Plant (MIWWTP) and XMIM (Figure 1). Current mining operations occur underground, but in previous decades open cut surface mining operated that, coupled with relaxed environmental regulation, resulted in mine waste being regularly flushed into the Leichhardt River (Johnson, 1998). Contamination of the Leichhardt River and Lake Moondarra by pathogenic micro-organisms is also of concern. Inadequate functioning of the MIWWTP, the associated sewerage system and associated effluent reuse irrigation scheme, particularly during times of heavy rain, present a risk to recreational water users and the downstream water supply system (Finlayson, 1980, Mackay et al., 2007). As a consequence of these environmental pressures, it is essential to understand the potential point and diffuse sources of contaminants so that these can be managed properly to ensure runoff into Lake Moondarra is of the highest possible quality.

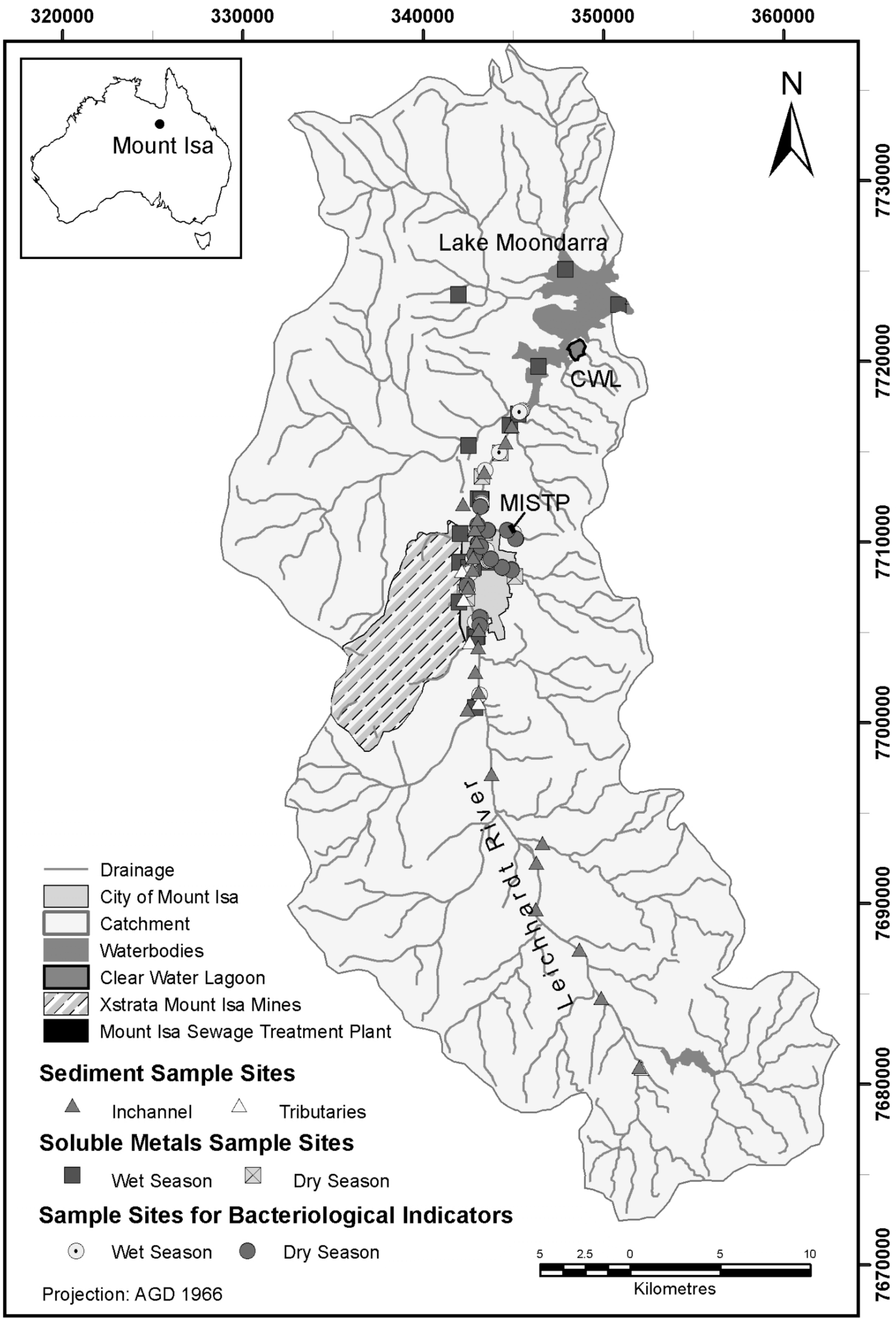

Figure 1. Catchment and location map of Mount Isa and the various sample sites and types.

2. METHODS

2.1 Sediment sampling

Sediment sampling of the Leichhardt Riverbed was conducted in two separate field campaigns in July 2003 and September 2005. Sediment samples were collected from contemporary deposits stored in the channel using a mixture of stratified and judgmental sampling based upon the probability of contamination associated with catchment specific land-use. On average one sample was taken every two kilometres over a 50 km length of channel with the sampling frequency increasing in areas adjacent to the footprint of XMIM and Mount Isa city. In addition, three background samples and seven sediment tributary samples draining the mine side of the Leichhardt River (Figure 1) were collected. In the laboratory, sediments were air-dried and passed through a 2 mm sieve and the retained fraction digested in aqua regia (4:1 HNO_3:$HClO_4$) and then analysed by IC-AES (Perkin Elmer Optima 3300DV).

2.2 Water sampling

Water sampling of the Leichhardt River, Lake Moondarra, CLW and associated tributaries was conducted in three separate campaigns during the wet seasons of January 2006 and January- February 2007 and the dry season, September 2007. Dry season water samples were collected from remnant pools within reaches of the Leichhardt River adjacent to, and downstream of Mount Isa city. Wet season sampling during January 2006 was conducted by collecting grab samples during the rising stage of the first flush flood at various intervals along the Leichhardt River for metals. The January 2007 sampling program extended the previous season's sampling by using sixteen staged samplers in addition to 'grab samples' within the Leichhardt River (approximately every 4 km) and within tributaries draining XMIM and Mount Isa city. The aim of the sampling program was to characterise the spatial and temporal variations in soluble and total metal concentrations, as well as the presence of faecal coliform and *Entrococcus* densities during the rising stages of the first flush flood.

Water samples for soluble metal analysis were filtered to 0.45 μm, acidified with nitric acid to pH < 2 and stored in HDPE bottles at 4^oC until delivery to the National Measurement Institute (NMI), Pymble, Sydney. Samples collected for total metal concentrations were handled in the same manner but were not filtered. Soluble metal and major cation concentrations were analysed by ICP-MS (Perkin Elmer Elan 6100 DRC) and ICP-AES (Varian Pro- AX). Ion chromatography and acid base titration was used to determine Cl, SO_4 and HCO_3, respectively. Conductivity, pH, dissolved oxygen, and water depth were also recorded at each site using a handheld YSI- meter.

Brown glass detergent washed sample bottles were used for the collection of bacterial water quality indicators, with a small air space left at the top of the bottle to ensure the survival of anaerobic bacteria. Sample bottles were connected to an extendable sampler and submerged to a depth of 30 cm in the centre of each pool. Samples were stored immediately on ice in insulated containers (1-4^oC) prior to transportation to Simmonds and Bristow Pty Ltd, Brisbane, a NATA accredited laboratory for analysis of *Enterococcus* and faecal coliforms.

2.4 Fish

Seven fish (three barramundi, three sleepy cod and one sooty grunter) were captured from Lake Moondarra in October 2006. The fish were all mature samples with the Barramundi < 82 cm in length, Sleepy Cod > 42 cm and the Sooty Grunter 34 cm. Fish were stored on ice until dissection and were then frozen immediately. Samples of muscle from behind the gills, liver and heads were collected from each fish, and these were digested in aqua regia (4:1 HNO_3:$HClO_4$) and analysed by ICP-AES (Perkin Elmer Optima 3300DV).

2.5 QA/QC

Blanks, replicates and standard certified reference materials (~25% of the sample batch) were used for quality control and data assurance purposes. Precision was evaluated using duplicate and, in some cases, multiple analyses of random samples. Precisions were within 10 % for Cu, Pb and Zn. Analysis of certified reference materials also were also within 10 % of reported values. Full details of laboratory procedures for sediment and water analyses are given in Kuypers et al. (2006), Mackay et al. (2007) and Taylor and Hudson-Edwards (2007). Fish analysis was carried out by CSIRO, Lucas Heights, Sydney. Spike recoveries were 3% for Hg and 4% for Se. The recovery of reference fish material (DORM-2) was 16 % for Se and better for Cu, Cd, Hg, Pb and Zn.

2.6 Environment Guideline Values

The analytical results were assessed relative to background concentrations and ANZECC/ARMCANZ (ANZECC, 2000) criteria. Sediment data were compared to the two categories: the Interim Sediment Quality Guideline (ISQG) Low Trigger and High Trigger values (ANZECC, 2000). Values greater than the ISQG High Trigger value are taken to indicate that sediments are considered to pose a threat to aquatic systems and that regulatory authorities should consider examining the factors controlling metal bioaccessibility (ANZECC, 2000). Water data were compared to ANZECC Water Quality Guidelines (2000). Since there were no specific or local guidelines for the evaluation of water quality in Queensland's ephemeral rivers (EPA, 2006) the data were compared to the ANZECC (2000) guidelines. Water data were compared to two categories: the 99 % and 80 % protection level trigger values for freshwater ecosystem survival, and herein are referred to as the high and low trigger values, respectively.

For the assessment of health risks associated with pathogens in recreational waters, the ANZECC (2000) guidelines favour the use of faecal coliform bacteria and *Enterococci* as 'indicator' micro-organisms. The Guidelines for Recreational Water Quality and Aesthetics (ANZECC, 2000) stipulate that where people come into primary contact with a water body (e.g. swimming, diving, accidental contact) the median bacterial content should not exceed 150 faecal coliform organisms/100 mL (based upon a minimum of five samples taken at regular intervals not exceeding one month, with four out of five samples must contain less than 600 organisms/100 mL). For *Enterococci* organisms the accepted density of organisms is a median value of 35/100 mL. These guidelines are applicable to the Leichhardt River and associated waterbodies because people regularly use both the dry season pools and river during wet season flows for recreational purposes.

Given that fishermen often consume fish from Lake Moondarra, we compared our fish muscle metal concentrations to Australian Food Standards Authority guidelines using the GELs (FSANZ, 2001) and Standard 1.4.1 Contaminants and Toxicants (FSANZ, 2007). These guidelines provide advice on acceptable metals within a range of food sources for retail purposes. However, since the fish in Lake Moondarra are not sold as commercial produce, the values used here may only be taken as indicative to what is deemed acceptable for human consumption.

3. RESULTS

The data sets have been categorised into sediment-associated metals, dry and wet season soluble metals, pathogens and fish muscle metals. The results for all investigated contaminants are presented in summary data tables for discussion and comparative purposes. To ascertain the relative impacts of the mine on the environment, a series of samples were also collected from outside the urban area of Mount Isa city and more than 100 m away from main roads. The results from the background samples show that only Cu concentrations are elevated with respect to the ANZECC (2000) ISQG low trigger value (Table 1).

Table 1. Summary values of background metal concentrations around Mount Isa.

3.1 Sediment Metals

n= 3 (results based on < 2 mm grain size fraction)	Cu (ppm)	Pb (ppm)	Zn (ppm)
	159 ± 16	36 ± 18	86 ± 24
ANZECC 2000 ISQG low and high trigger values	65-270	50-220	200-410

Channel sediment associated metal concentrations are presented in Table 2. The results indicate that Cu (35 %), Pb (35 %) and Zn (30 %) of the channel sediments exceed the ISQG low trigger value. The proportion of samples exceeding the ISQG high trigger value was much lower, with Pb and Zn being the highest at 9 % each. The spatial distribution of all the sediment-associated metals in the Leichhardt River reveals that the primary contaminant problem is geographically associated with the footprint of the mine (27.5 to 33.8 km, Figure 3). For example, upstream of the mine average channel Cu, Pb and Zn values are 15, 6 and 26 ppm, whereas directly opposite the mine they rise significantly to 1500, 510 and 470 ppm, respectively. Downstream of the mine's footprint sediment metal values are reduced but on average remain above or close to the ANZECC (2000) low trigger values: Cu-90; Pb- 85; Zn-200 ppm.

Table 2. Summary results for sediment and water quality sampling of the Leichhardt River and selected tributaries.* NHMRC (2004) Australian Drinking Water Guideline.

	No. of samples	Minimum	Maximum	Mean ± StDev	ANZECC 2000 Guideline	% of samples exceeding low trigger	% of samples exceeding high trigger value
Channel Sediment (ppm)							
Pb	23	<1	1900	159 ± 412	50-220	35%	9%
Cu	23	4	8500	423 ± 1760	65-270	35%	4%
Zn	23	8	1050	187 ± 286	200-410	30%	9%
Tributary Sediment (ppm)							
Pb	7	7	8100	1649 ± 2921	50-220	71%	71%
Cu	7	12	3800	1340 ± 1494	65-270	71%	71%
Zn	7	19	11500	2603 ± 4283	200-410	57%	57%
Dry season pools (µg/L)							
Pb	9	<1	12	5.8 ± 5.3	1.0-9.4	56%	22%
Cu	9	1.7	12	5.9 ± 3.8	1.0-2.5	100%	89%
Zn	9	3.6	140	22.3 ± 22.3	2.4-31.0	100%	11%
Wet season flows (µg/L)							
Pb	27	<1	16	4.9 ± 4.2	1.0-9.4	70%	11%
Cu	27	1.8	27	11.2 ± 6.6	1.0-2.5	100%	96%
Zn	27	1.7	470	96.8 ± 129.8	2.4-31.0	96%	41%
Wet season tributary flows (µg/L)							
Pb	11	<1	61	17.5 ± 22.4	1.0-9.4	91%	27%
Cu	11	6.9	780	99.6 ± 22.7	1.0-2.5	100%	100%
Zn	11	15.0	1500	210 ± 430	2.4-31.0	100%	73%
Clear Water Lagoon							
Unfiltered Cu (µg/L)	42	0.0	81	26 ± 33	2000*	0%	0%
Sediment Pb (ppm)	4	11	52	33 ± 24	50-220	25%	0%
Sediment Cu (ppm)	4	18.0	64	43 ± 24	65-270	0%	0%

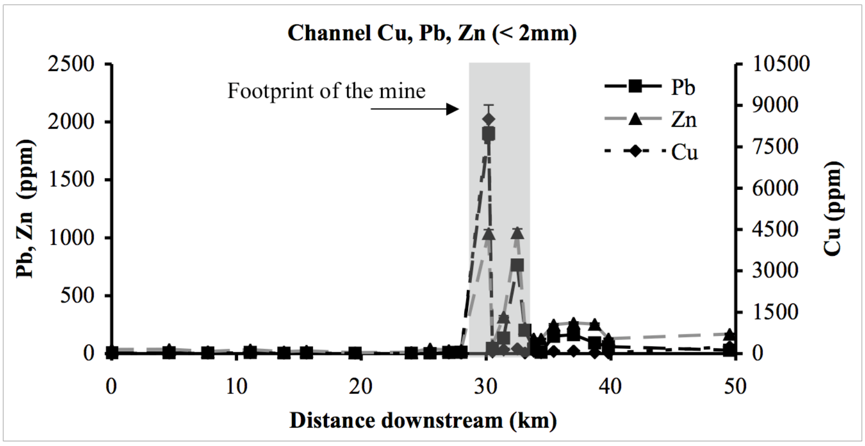

Figure 3. Sediment-associated Cu, Pb and Zn concentrations metals stored within channel sediments. The footprint of the mine on our survey occurs between ~ 27.5 km and 33.8 km, and is coincident with an increase in channel metal values. Errors bars show standard deviation (±) in ppm.

3.2 Soluble Metals

Soluble metal concentrations for wet and dry season sampling are presented in Table 2. The results indicate that Cu (100 %), Pb (56 %) and Zn (100 %) of the dry season pools exceed the ANZECC (2000) low trigger value for freshwater ecosystem protection. The only pools present were located adjacent to and downstream of the mine and urban areas; the remainder of the river bed upstream was totally dry. The proportion of pools in excess of the ANZECC (2000) high trigger value was much lower for Pb and Zn at 22 % and 11 % respectively, while Cu was at 89 %.

Wet season samples indicate a similar number of samples exceeding the low trigger value: Cu-100 %; Pb-70 %; and Zn-96 %. A higher proportion of samples exceeded the high trigger values for Cu (96 %) and Zn (41 %), while the number of samples declined for Pb (11 %). The results from both seasons sampling reveal a similar spatial association with the footprint of the mine and urban areas as the sediment associated metal concentrations. For example, the dry season pool with the highest overall concentrations of Cu (12 µg/L), Pb (9.6 µg/L) and Zn (17 µg/L) was located just downstream of the mine. Similarly, the areas with the highest soluble metal concentrations during the wet season first flush flood were located within two tributaries draining XMIM mining lease, Death Adder Creek (61 Pb µg/L, 780 Cu µg/L and 1500 Zn µg/L) and Spear Creek (37 Pb µg/L, 89 Cu µg/L and 160 Zn µg/L). The highest channel concentrations occurred within the same location as the dry season samples.

3.3 Microbial water quality

Bacterial indicator densities are presented in Table 3. The results from the dry season sampling identified five of the 14 pools sampled to be unsafe for primary contact as a result of faecal contamination. The highest faecal coliform (220 cfu/100mL) and *Enterococcus* (900 orgs/100mL) densities during the dry season were recorded in a tributary pool fed by a broken pipe at the northwest corner of the city (Figure 1). Intermittent releases from the Mount Isa Wastewater Reclamation Plant storage tank, runoff from the irrigated horse paddocks, inputs from the industrial estates, urban yards and leaking pipes were coincident with elevated pathogen levels in dry season pools. Wet season sampling revealed 15 of the 24 sites including the river's most popular swimming spot (adjacent to Lake Moondarra Caravan park) contained a median faecal coliform value in excess of 600 cfu/100 mL. In addition, wet season trunk channel and tributary sampling revealed the median faecal coliform density also exceeded recreational guidelines by 15 and 8 times, respectively (Table 3). One hundred % of the samples taken in the trunk channel and 98 % of samples collected from urban tributaries exceeded the guideline for acceptable *Enterococcus* density (35 orgs/100 mL). Collectively, the results reveal that there was a very high risk of infection for individuals coming into primary contact with these waters during the wet season sampling period of January to February 2007.

Table 3. Summary results for the density of bacterial indicators within the Leichhardt River.

	No. of samples	Minimum	Maximum	Median	ANZECC Guidelines (2000)*	% of samples exceeding Guidelines
Dry season pools (cfu/100 mL)						
Faecal coliforms	14	1	220	72	150 cfu/100 mL	29%
Enterococcus	14	2	900	11	35 ent/100mL	38%
Wet season flows (cfu/100 mL)						
Faecal coliforms	17	100	12500	2200	150 cfu/100 mL	70%
Enterococcus	17	150	14500	1100	35 ent/100mL	100%
Wet season tributary flows (cfu/100 mL)						
Faecal coliforms	86	2	119000	1200	150 cfu/100 mL	89%
Enterococcus	86	5	95000	2100	35 ent/100mL	98%

*Guidelines for Recreational Water Quality and Aesthetics (ANZECC, 2000)

3.4 *Metal Concentrations in Fish Samples*

The fish flesh metal concentrations were all relatively low, with the exception Zn in fish flesh samples and Cu in crayfish, whose mean assays values exceeded the GELs (FSANZ 2001) and Standard 1.4.1 Contaminant and Toxicants (FSANZ 2007) guideline values (Table 4). While the sample size was relatively small, the data are broadly consistent within and between the sample types. The results indicate that there has been only a limited impact from contaminated sediments and catchment runoff on biota in the receiving water body of Lake Moondarra. Since the FSANZ (2001, 2007) guidelines relate to acceptable standards for retail sales of food, including fish, these may be considered as being indicative as to what is acceptable and safe for the purposes of human consumption.

Units (μg/g Wet)	No of Samples	Minimum	Maximum	Mean ± St Dev	Guideline values
Barramundi					
Cd	3	<1	<1		nv
Cu	3	<1	<1		0.5
Hg	3	0.1	0.13	0.11 ± 0.02	1
Pb	3	<1	<1		0.5
Se	3	0.13	0.26	0.19 ± 0.07	0.5
Zn	3	5.1	10.9	7.29 ± 3.15	5
Sleepy Cod					
Cd	3	<1	<1		nv
Cu	3	<1	<1		0.5
Hg	3	0.05	0.11	0.08 ± 0.03	0.5
Pb	3	<1	<1		0.5
Se	3	0.1	0.2	0.14 ± 0.05	0.5
Zn	3	4.47	22.57	10.91 ± 10.11	5
Sooty Grunter					
Cd	1			<1	nv
Cu	1			<1	0.5
Hg	1			0.06	0.5
Pb	1			<1	0.5
Se	1			0.27	0.5
Zn	1			8.2	5
Redclaw Crayfish					
Cd	3	<1	<1		nv
Cu	3	7.1	15.9	10.37 ± 4.82	10
Hg	3	0.01	0.02	0.01 ± 0.01	0.5
Pb	3	<1	<1		0.5*
Se	3	0.12	0.16	0.15 ± 0.02	0.5
Zn	3	15.95	18.75	16.93 ± 1.58	25

Table 4. Summary results for metal concentrations in fish and crayfish flesh. Guideline values are based on Australia and New Zealand Food Standards Authority: GELs (FSANZ 2001) and Standard 1.4.1 Contaminants and Toxicants (FSANZ 2007). Since these guidelines are for food sold as retail they can therefore only be used as a guide for acceptable metal values within the fish and crayfish samples. nv – no recommended guideline value. * - value of 0.5 is for fish as specific guidelines for crustacea are not available.

3.5. *Clear Water Lagoon*

A water quality monitoring program has been conducted on Lake Moondarra and CWL by Mount Isa Water Board since 1995. Results from near the out-take pump of CWL reveal that faecal coliform densities are consistently <2 cfu/100mL after the water has passed through the reed bed filtration system. Unpublished archival data supplied by Mount Isa Water showed water soluble Zn and Pb concentrations to be consistently below detectable limits within Lake Moondarra and CWL and consequently were not investigated in this study. A marked improvement in soluble Cu occurs from the intake (81 μg/L) to the out-take distribution pump station (9 μg/L), which is within Australian Drinking Water guidelines (NHMRC, 2004; Kuypers et al., 2006). Sediment associated Cu (mean 43 ppm) and Pb (mean 33 ppm) within CWL were well within ANZECC guidelines (2000) and have been shown to be trapped on aquatic macrophytes or retained within the settling pond (Kuypers et al., 2006).

4. DISCUSSION AND CONCLUSIONS

The patterns of storage, transfer and mobility of contaminants identified within this study not only provide valuable baseline data on contaminant fluxes in ephemeral systems but the results are also of direct relevance to local and regional water supply management strategies and provisions. The data suggest that the Mount Isa city, XMIM and MISTTP sites are contributing to the input or redistribution of historic contaminants within the Leichhardt River system. While no absolute definitive link can been identified between the high soluble and sediment-associated metal values and current mining activities, there is a strong spatial relationship with respect to both the mine, known historic mine waste input areas and mineralised bedrock outcrops within the Leichhardt River (Mathias and Clark, 1975; Johnson, 1998). Nonetheless, the source and cause of elevated pathogens and metals in the area is irrelevant given their known impact on human health and ecology.

It is well accepted by eco-toxicologists and medical practitioners that exposure to sub-lethal toxic levels of Pb has harmful affects on human health, particularly on children (Lanphear et al., 2005). The impacts of elevated blood Pb levels are known to be persistent and deleterious, causing negative effects on brain function, lowered intelligence, behavioural problems and diminished school performance. Bioaccessibility testing is required for more conclusive risk assessment but soluble and sediment associated metal concentrations within the river bed were in notable excess of guidelines. Numerous people (especially children) were observed to swim in the most contaminated sections of the Leichhardt River during times of flooding and flow. Indigenous community groups, livestock and native fauna have also been observed to use the dry season pools for recreation and drinking water. These children are increasing their exposure risk to contaminants and the affected children and their families may face serious, long term health and development issues that could affect their future quality of life (cf. Lanphear et al., 2005).

In terms of the local area, our results highlight the need to educate Aboriginal and local residents of the area who use the river beds, pools and Lake Moondaara for recreation, water and food (fish) of the possible risks arising from metal and pathogen contamination. Improvements need to be made to infrastructure to reduce mine run-off and release from the sewage system and fix breaks in pipes. Suppliers of drinking water need to remain vigilant and develop alternative and reliable strategies for clean supplies, especially during periods of highly turbid flow. On a more international level, further research needs to be conducted on arid systems like the Leichhardt on the biogeochemical cycling, bioaccessibility and bioavailability of metals and pathogens, and the role of various geomorphic units to capture and transform these contaminants.

6. ACKNOWLEDGMENTS

The authors acknowledge funding from Macquarie University, The Royal Geographic Society, the Birkbeck Faculty of Science and the NERC (UK) ICP-AES facility. We thank Rhys Hart, Erika

Heiden and Jeremy Pendergast for field assistance, Barry Morales and Sarah Houghton for sediment geochemical analysis and Simon Apte and Leigh Hales (CSIRO Land and Water) for fish analysis. We also acknowledge Mount Isa Water for providing additional logistical and financial support for sampling carried out in 2006-2007.

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