DISPERSAL AND STORAGE OF SEDIMENT-ASSOCIATED ZINC IN THE LEICHHARDT RIVER, MT ISA, QUEENSLAND

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INTRODUCTION

Many river basins throughout the world have been severely contaminated with metals released as a result of mining operations (e.g., Taylor & Kesterton 2002). In such catchments, as much as 90 % of the total metal load is transported and stored in the sediment phase. Once sediment-bound contaminants enter river systems, they are dispersed by fluvial processes, transported downstream and deposited in channels, floodplains, riparian wetlands, lakes and reservoirs. Such sediments can act as significant long-term secondary sources of contaminants if they are remobilised via physical entrainment (e.g., channel and floodplain erosion) or chemical processes (pH or Eh changes). Geomorphological-geochemical investigations of mining-contaminated river systems have focused mainly on temperate rather than arid systems, despite the often extreme climatic regimes in the latter that may have a more dynamic impact on the transport, storage and chemical mobilisation of sediment-associated metals. We seek to address this imbalance in this paper by presenting the results of a study investigating the spatial and temporal distribution of zinc in the Leichhardt River, Mt. Isa, Queensland (Figure 1).

Figure 1: Location map of the Leichhardt River and the general study area of Mt Isa, north-west Queensland.

STUDY AREA

The study area of the Leichhardt River has a catchment area of 1,113 km^2 from the slopes of Selwyn Ranges through to Lake Moondarra, Mt Isa City's principal water supply. The river continues flowing north before debouching into the Gulf of Carpentaria (Figure 1) where it has an approximate catchment area of 33,000 km^2. The Leichhardt River lies in the semi-arid tropical zone of Queensland with a warm-dry season from April to September and a hot-wet season from October to March. Average rainfall is around 453 mm per annum. The Leichhardt River flows adjacent to, and to the east of, Mt Isa where mines exploit large stratiform copper, zinc, lead and silver-bearing ore deposits. Large-scale mining of these deposits began in the 1930s and continues to the present-day. Several small tributary channels that drain the mine area and connect with the main Leichhardt River were also sampled for their zinc sediment concentrations.

METHODS AND MATERIALS

In July 2003, 20 samples of in-channel, fine-grained sediment were collected from the centre point of the river bed over a ca. 47 km stretch of the Leichhardt River, covering some 27 km upstream of the mine to ca. 16 km downstream of the mine area. Samples were collected at approximately 2-3 km intervals where access permitted. Twelve tributary streams were also sampled above, adjacent to and below the mine. Sediment samples were collected to a depth of ca. 5 cm from a ca. 4 m^2 area using a plastic trowel. Prior to sampling at each location, the trowel was passed through local sediments to remove any significant elemental effects associated with the previous sample site. Samples were also collected from six one to two metre cut riverbank sediment sections located upstream of the mining area (OB1 and OB2), within the mining area (OB3 and OB4) and downstream of the mining area (OB5 and OB6) (Figure 2). Sediments were sampled up-section in 10-20 cm intervals.

In the laboratory, the sediments were air-dried and passed through a 2 mm sieve to remove large stones and organic debris. Zinc (Zn) concentrations in channel sediments were analysed by Instrumental Neutron Activation Analysis (INAA) at the Becqueral Laboratory (ANSTO), Lucas Heights, Sydney, and cut riverbank sediments and four replicate in-channel sediments by ICP-AES (Perkin Elmer Optima 3300DV) following an aqua regia digestion (4:1 HNO3:HClO4). For quality control blanks, replicates and standard

In: Roach I.C. ed. 2005. *Regolith 2005 - Ten Years of CRC LEME*. CRC LEME, pp. 309-313.

reference materials were inserted into the sample batch, representing 10, 20 and 10 % of the sample population, respectively. The precision and bias in the analysis were < 7%, and Zn recovery was around 92%.

RESULTS AND DISCUSSION

Downstream Zn concentrations of in-channel Leichhardt River and tributary sediments

Upstream of the mine area, sediment Zn concentrations of in-channel sediments are below instrumental detection limit (< 100 ppm) and the Interim Sediment Quality Guideline (ISQG) Low Trigger Value of 200 ppm as prescribed by the ANZECC/ARMCANZ (2000) (Figure 2). Sediment Zn concentrations in the channel adjacent to the mine area rise dramatically to over 1,000 ppm, which may be due to the input of fines from at least three tributaries possessing concentrations between 2,480 and 4,300 ppm (Figure 2). Just downstream of the mining area, however, sediment Zn concentrations decline dramatically to < 100 ppm. This is probably due to dilution from tributary fines with relatively lower sediment Zn concentrations, although some of the tributaries still supply sediment with relatively high Zn (658 ppm at c. 31 km downstream; Figure 2). At 36.1 km downstream, Leichhardt in-channel sediment Zn concentrations rise again to 280 ppm, but decline downstream thereafter to background levels. The rise is probably due to contributions from either tributaries draining the mine area, or to chemical or physical remobilisation of previously-deposited contaminated sediment. The subsequent decline in channel Zn concentrations probably arises either from inputs of cleaner material diluting concentrations or because contaminated material has been flushed downstream. This is discussed further below.

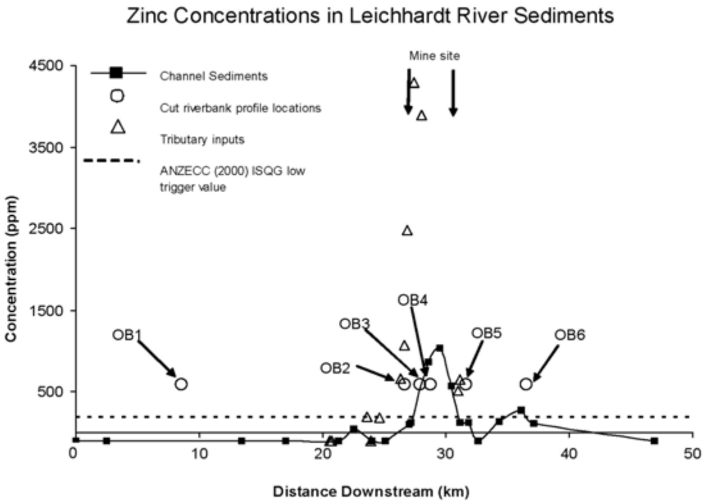

Figure 2: Sediment Zn concentrations down the Leichhardt River system. Samples less than zero (0) were below instrumental detection limits (< 100 ppm). Sediment zinc concentrations from selected tributary streams are also shown (Δ). Note how values increase markedly around the mine area in both trunk and tributary samples. The samples marked OB (O) are shown for their relative position along the Leichhardt River; the y –axis is not relevant for these samples.

Cut riverbank sediment zinc concentrations

The sediment zinc concentrations in cut riverbank samples OB1 and OB2 (Figure 3) are all below the 200 ppm ANZECC/ARMCANZ (2000) guideline described above. Given that these profiles occur upstream of the mine, they probably typical of uncontaminated, background sediment Zn concentrations in cut riverbank sediments. Adjacent to the profile OB2 was a layer of waste containing a well-preserved Victoria Bitter beer can and plastic at around 50 cm below the floodplain surface. This suggests that overbank deposition is probably relatively recent and may be very rapid in parts of the system. Photographic evidence of channel and floodplain areas following a large flood event on January 6th 2004 revealed that substantial quantities of sediment are deposited in the channel and in overbank areas.

The most contaminated cut riverbank profile is OB3. Field examination of the sequence reveals that the section contains a range of materials likely to cause contamination including oxidising mine tailings, slag and general waste materials including broken bricks at the top of the section (Figure 4). All the samples have Zn values above the low trigger ISQG (ANZECC/ARMCANZ 2000) with the maximum value of 3960 ppm occurring at the top of the sample section. This value coincides with deposits slag/tailings material (Figure 4). The profile lies below the local velodrome facility that was constructed in the 1950s (unnamed Mt Isa resident *pers. comm.*) and thus the sequence may be assumed to pre-date this time. It is common local knowledge amongst older long-term Mt Isa residents that during the 1940s mine tailings were released directly into the river system. Indeed, a local author, Johnson (1998, p. 38) notes: "Grey sludge containing lead waste from the mine tailings dump came down the creek, fouling the water. It was so bad the children could no longer swim there. We knew the gully as Lead Creek". Officially, the name of this system is Death Adder Creek, which drains into the Leichhardt River upstream of OB3. Sediment Zn concentrations of modern channel sediment from the Creek returned a value of 2480 ppm while another small tributary that also drains the mine site, known as Star Gully, had a concentration of 3890 ppm. Thus, while it is very likely that the high Zn concentrations have arisen due to the deliberate historic dispersal of mining spoil/tailings directly into the channel bed coupled to the ongoing natural weathering of the ore body, sampling of the modern system suggests that contaminants are either still being inadvertently sourced from the mine site or are being locally reworked from adjoining tributary sediment stores.

Cut riverbank profiles OB4, OB5 and OB6 all have lower levels of contamination. While all the profiles have concentrations well above the ISQG low trigger values (ANZECC/ARMCANZ 2000), the pattern of the peak values differs between the sites with OB4s occurring toward the top of the section adjacent to the floodplain surface and OB5 and OB6 toward base of their profiles. The general pattern of declining Zn concentrations up the profile in OB5 and OB6 suggests that on the whole, cleaner sediments are now being transferred and deposited within Leichhardt River floodplains, burying older mining-contaminated sediment. The peaks in Zn concentrations at depth probably reflect early mining and tailings discharge practices and subsequent improvement in limiting discharges have meant subsequent sediment accumulation is much less contaminated than deeper, older material.

One of the main issues with respect to river systems affected by metal mining is the storage and dispersal of contaminants in floodplain and in-channel sediment sinks because they can pose an ongoing and long-term risk (Miller 1997). The spatial distributions of contaminants in river and floodplain systems are notoriously complex because system morphology, associated sediment dynamics and discharge patterns vary over time and space. The dispersal of metal mining waste into catchment systems can affect the ecological functioning of channel and floodplain systems (Miller *et al.* 2004). In addition, and of perhaps greater concern to the population at large, are the effects of elevated sediment- and soil-metal concentrations on food quality and safety, crop production and environmental health. Metals move through the food chain via uptake and bioaccumulation and bio-magnification in plants, animals and ultimately humans. With respect to the Leichhardt system specifically, the high sediment Zn metal values (and other, yet to be published, elevated sediment metal values) may pose a significant risk to the proper ecologically functioning of the adjacent urban and agricultural environments as well as the City's principal water source, Lake Moondarra.

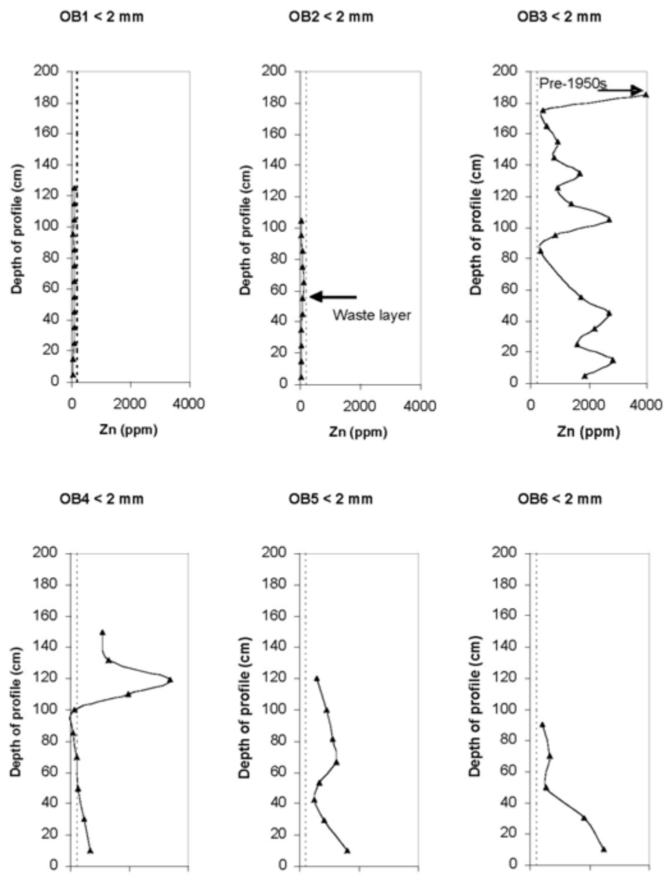

Figure 3: Sediment Zn concentrations in six cut riverbank profiles along the Leichhardt River. OB1 and OB2 occur above area of river affected by Mt Isa mine, OB3 and OB4 are adjacent to the mine area and OB5 and OB6 occur downstream of mine site. The profiles are measured from the base to the top of the floodplain – thus the highest point on each profile is the floodplain surface. The dashed line denotes the zinc Interim Sediment Quality Guideline Low Trigger Value of 200 pm (ANZECC/ARMCANZ 2000).

The Leichhardt River data show that sediment-associated heavy metals are not uniformly distributed either vertically through cut riverbank exposures or longitudinally throughout the channel system downstream of the mine. In other systems, river sediment metal concentrations tend to decrease downstream from contaminant point sources in a systematic way that can be approximated using negative linear, exponential or power functions (Wolfenden & Lewin 1977). Deviations from these models are due to local environmental controls such as floodplain storage or inputs of contaminants from diffuse or other point sources (Axtmann & Luoma 1991). While the Leichhardt system does display a general downstream decrease in sediment Zn concentrations from the Mt Isa mine site, there are anomalies within this distribution. Sampling of tributary systems draining the mine site would appear to explain some these anomalies (Figure 2), while a secondary peak in sediment Zn at 36 km is probably related to the storage of contaminated particles in channel and floodplain deposits (e.g., Macklin *et al.* 1992) or possibly due to the chemical oxidation and precipitation of Zn in slackwater sediments that have experienced evaporation (cf. Hudson-Edwards *et al.* 2005). It is of concern that elevated levels of Zn and other metallic elements remain within the fluvial environment that drains toward Mt Isa City's principal drinking water supply. The source of these contaminant inputs appears to be traceable to two primary sources: historic sediments stored in cut riverbank exposures; and, contemporary channel sediment systems draining the Mt Isa mine area.

Figure 4: Photograph of cut riverbank OB3. The dark coloured, upper most layer is rich in slag deposits and has the highest corresponding sediment Zn with a value of 3960 ppm (Figure 3). Mid way down the section the sequence appears to have undergone oxidation with the precipitation of a probable calcium sulphate deposit on the outer surface.

The release of metals into an ephemeral system presents a unique problem because sediments and metal-rich waters exposed to high evaporation rates such as those experienced in the Leichhardt system (potential evapo-transpiration is > 1500 mm per annum, Bureau of Meteorology 2005) can cause the precipitation of metals and various associated minerals including Fe oxides, hydroxides and oxyhydroxsulphates (cf. Hudson-Edwards *et al.* 2005). Consequently, metals that accumulate in pools and slackwater deposits are not only subject to oxidation and liberation as a result of evaporation but are also prone to physical mobilisation during wet season floods. Once mobilised they may be transferred downstream to grazing lands, stored in Lake Moondarra or ephemeral pools that support aquatic biota and providing drinking holes for native and agricultural animals during the long dry season. Thus, not only is there direct risk to bulk water supply and its quality but also habitat and gazing lands utilised by biota may potentially be negatively impacted by the release of heavy metals. Understanding the nutrient, contaminant and sediment fluxes are especially important for the Leichhardt River because it is integral to north-west Queensland's largest urban population as well as numerous agricultural production activities that require a reliable, high quality water supply. The very recent passing of the Queensland Wild Rivers Act (September 28th 2005) is an acceptance that systems such as the Leichhardt River are likely to contain rare, unusual and fragile bio-physical systems that require not only legal protection but further baseline research (Hogan & Vallance 2005).

CONCLUSION AND RECOMMENDATIONS

Analysis of river deposits from the Leichhardt River and several small tributaries reveals mining has, and apparently continues, to supply Zn-contaminated sediment to the Leichhardt River system. Sediment with Zn concentrations in excess of the Low Trigger value of 200 ppm (ANZECC/ARMCANZ 2000) remain stored within the bed of the main channel system, in cut riverbank sections and are also being delivered by tributary systems draining the mine area. Upstream of the mine area the Leichhardt River has sediment-Zn concentrations below instrument detection levels (100 ppm), while downstream of the mine site it appears that dilution with clean sediment is reducing Zn concentrations, in many cases, to below the Low Trigger value. However, contaminated sediment stored and buried within river and floodplain alluvium may continue to supply Zn (if eroded and remobilised) to the system for some time to come. The high magnitude floods associated seasonal monsoonal rains coupled to the high evaporation conditions in the dry season are likely to be significant controls on the transport, dispersal and mobilisation of metals in the system. Further research is necessary to determine linkages between discharge events and climatic and land-use factors and the response of ecosystems to seasonal fluctuations in ground and surface water and sediment quality. Specifically, such research needs to focus on the bioavailability of these elements and how they may affect water and sediment quality.

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Acknowledgements: MPT would like to thank Macquarie University for supporting this research through a 'New Staff Grant' and for Erika Heiden's help and companionship in the field. KH-E acknowledges support from the Royal Geographical Society through an RGS-IBG Small Research Grant and from Birkbeck, University of London, through a Faculty of Science research grant.