Lead Pathways Study – Water

# Sources and Pathways of Contaminants to the Leichhardt River

The University of Queensland Australia

SMI CMLR Centre for Mined Land Rehabilitation

entox national research centre for environmental toxicology

The University of Adelaide

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*Copies of this report may be obtained by contacting Xstrata Mount Isa Mines community information line on 1800 982982.*

# Executive Summary

The Lead Pathways Study — Water Sources and pathways of contaminants to the Leichhardt River investigated:

- the potential sources and pathways of lead and other heavy metals and metalloids in water from the Leichhardt River catchment, particularly at, and below, Mount Isa City and the Mount Isa Mines lease area
- the risk to human, agricultural pastoral, and ecological health from the contributions of lead and other heavy metals and metalloids.

The study had three specific components:

- water quality study
- sediment quality study
- aquatic toxicity assessment in water and sediment.

These components of the study provided data that were then used as inputs to the development of site-specific guidelines for the Leichhardt River catchment.

Nationally, a number of strategies and guidelines regulate water quality outcomes. The major strategies and guidelines, which are the basis for undertaking this study, are:

- National Water Quality Management Strategy
- ANZECC/ARMCANZ Water Quality Guidelines
- Queensland Water Quality Guidelines.

A site-specific risk assessment was also conducted to address human health and ecological concerns in areas where water and sediment contaminants were identified at concentrations above the guideline levels for metals and metalloids.

The study area covered:

- environmental receptors in the Leichhardt River (11 sites both upstream and downstream)
- tributaries from the mine lease (Tailing Dams 5, 7, and 8 and Lena, King Gully, and George Fisher creeks)
- urban discharge (Breakaway Creek).

This study determined the distribution of metal and metalloid concentrations within the study area and their pathways. The study area comprised the Leichhardt River above and below Mount Isa City down to below Lake Moondarra and taking into account all tributaries from the mine lease and city. Upstream sampling extended to Rifle Creek Dam in the upper catchment of the Leichhardt River. The potential risk of these concentrations were assessed for:

- people occasionally drinking the river water
- people using the river water for recreational activities
- using the river water for irrigation and livestock watering
- the ecological health of the river water.

The human health risk assessment was undertaken according to guidelines set by the National Health and Medical Research Council, the Australian Drinking Water Guidelines, and the National Environmental Protection Council.

No site exceeded the ANZECC/ARMCANZ livestock watering guidelines for the metals and metalloids that were measured.

The generic ANZECC/ARMCANZ decision-tree process was used for assessing metal and metalloid toxicants in the water. Water samples were collected from eleven sites on Leichhardt River, five tributaries from the mine lease, three tailings seepage ponds, and two urban tributaries over five sampling periods from November 2002 until June 2010. The samples were analysed for metal and metalloid concentrations in different fractions (total and 0.45 µm filtration fractions) to compare dissolved metal or metalloid concentrations as per the decision tree. The in situ measurement by Diffusive Gradients in Thin Films technique (DGT) was used to determine labile metal concentrations in the water to give the bioavailable metal concentration and alternatively speciation modelling was applied for arsenic because it was not measured by the DGT technique.

Six sets of sediment samples were taken from the Leichhardt River upstream down to the Lake Moondarra. The sampling program included:

- sediment collected in 2007
- sediment collected concurrently with toxicity testing in October 2009
- Leichhardt River Verification Samples (13–14 November 2009) comprising seventy-nine sediment samples collected from the section of the Leichhardt River comprising Alma Crossing to Moondarra Junction, which were collected by Xstrata to confirm current sediment concentrations
- regional/background stream sediment sampling program to give a background data set comprising twenty-nine sediment samples collected by Xstrata from the upstream section of the Leichhardt River (from Mica Creek up to Rifle Creek) with additional three sediment samples from Spring Creek (SPC) Bridge, and First and Second SPC Gullies lying in the upper catchment of George Fisher Creek that flows to Lake Moondarra
- the Annual Stream Sediment Samples (11 November 2009) conducted as part of Xstrata's Mine Plan Commitment.

Sediment samples were analysed for total and 1M hydrochloric acid (HCl) extraction of metals and metalloids. The results were compared against ANZECC/ARMCANZ Interim Sediment Quality Guidelines-Low (ISQG-Low) for sediments. Sediment samples were also prepared as the <2 mm or <250 µm fraction and analysed for both total concentrations of metals and metalloids and bioaccessibility (%BAc). Human health risk was assessed by comparing these levels with the NEPM HIL — Level E for recreational use of dried river sediment.

Aquatic toxicity assessment was undertaken as part of the ANZECC/ARMCANZ decision-tree process for both water and sediment. Three water-sampling programs collected water for aquatic toxicity testing. Three sets of sediment samples were also collected for toxicity assessment.

The overall results of the water quality assessments show that the Leichhardt River water, at the time of testing, was alkaline and the water pH varied from 7.0 to 8.5 over five sampling periods. The electrical conductivity (EC) of samples at upstream sites (Leichhardt River upstream and Mica Creek upstream) and downstream sites (Moondarra Junction, Lake Moondarra and Clear Water Lagoon were within the limits for safe drinking water (<1000 µS/cm), which applies to palatability associated with total dissolved salts. However, the EC of water sampled at the Leichhardt River sites within Mount Isa City were >1000 µS/cm. The EC values of water collected at all sites in the wet season were significantly lower than pre-wet and post-wet season samples indicating a reduction in total dissolved salts with renewed river flow.

Total concentrations of metals and metalloids in water were compared with Australian Drinking Water Guidelines. The results show that six sites from the Leichhardt River (19th Avenue, 23rd Avenue, Davis Crossing, Moondarra Crossing, Moondarra Junction) and four sites at tributaries from the mine lease (King Gully Creek, Lena Creek, Downstream North Tailing Dams 3 and 5) exceeded the guideline values. Two seepage ponds (Tailing Dam 5 and 8) exceeded the Australian Drinking Water Guidelines for arsenic, cadmium, and lead; however, these ponds are not accessible by the general public or livestock.

Total concentrations of metals and metalloids in the water were compared with the ANZECC/ARMCANZ Water Quality Guidelines trigger values for fresh water species at two levels: to protect 90% of all freshwater species and to protect 95% of all freshwater species. The trigger values were also adjusted for site-specific water hardness, as stipulated by the ANZECC/ARMCANZ decision-tree process. The filtered concentrations (0.45 µm fraction) and dissolved species, measured by DGT technique, at sites with a total concentration of a heavy metal or arsenic exceeding the trigger values, were compared with the site-specific trigger values. The results show that concentrations of cadmium in the 0.45 µm fraction, measured by DGT technique, and inorganic species, calculated by the MINTEQ multi-equilibrium program:

- exceeded the trigger values of cadmium for fresh water species at the 95% protection level at:
  - Davis Crossing in the post-wet season in 2009
  - Alma Crossing in the wet season in 2010
- exceeded the site-specific trigger values of copper for fresh water species at 95% protection level at:
  - two upstream sites (Mica Creek and Leichhardt River upstream)
  - three sites within Mount Isa City (Alma Crossing and Isa Crossing)
  - one downstream site (Moondarra Junction)
  - five sites at tributaries from the mine lease (King Gully Creek, Lena Creek, George Fisher Creek, Downstream North Tailing Dams 3 and 5)

  - two seepage ponds (Tailing Dams 5 and 8)
  - one urban discharge site (Breakaway creek)
- exceeded the site-specific trigger values of arsenic at the at 95% protection level at:
  - seepage Tailing Dam 5 exceeded the site-specific trigger values of arsenic
- exceeded the site-specific trigger values of lead for fresh water species at 95% protection level at:
  - Downstream North Tailing Dam 3 and Downstream North Tailing Dam 5.

These results indicate that further investigation needs to be conducted at these sites for biological effects following the ANZECC/ARMCANZ decision-tree process.

During the 2010 wet season, five sites at Leichhardt River (upstream and within Mount Isa City) showed that no site exceeded the Australian Drinking Water Guidelines for arsenic, cadmium, copper, nickel, lead and zinc. However, water samples collected from five sites at tributaries from the mine lease at the same exceeded the Australian Drinking Water Guidelines for arsenic, cadmium, and lead.

The overall results of the sediment quality assessment show there are several sites from the Leichhardt River that exceeded the ISQG-Low for arsenic (2 sites); cadmium (79 sites); copper (78 sites); lead (79 sites); and at a lesser number of sites for zinc (50 sites) for 1M HCl extraction concentrations. These sites will require further assessment of contamination, including a toxicity assessment according to the ANZECC/ARMCANZ decision-tree process for sediment. Comparison of these sediment results with ISQG-High shows exceedance for cadmium (22 sites); copper (10 sites); lead (46 sites); and a lesser number of sites for zinc (18 sites) for 1M hydrochloric acid extraction concentrations. Exceedence of the ISQG-High is indicative of a high probability of biological effects. These sites may collectively require remediation if they show toxicity to aquatic test species following the ANZECC/ARMCANZ decision-tree process for sediment. The five sites at tributaries from the mine lease (King Gully Creek, Lena Creek, George Fisher Creek, Downstream North Tailing Dams 3 and 5) also requires further assessment of the sediment metal and metalloid concentrations according to the ANZECC/ARMCANZ (2000) decision process. Site LR10 (Leichhardt River at exit from Star Gully) is the only site from 79 sites assessed by the Mount Isa Mines Verification Program that exceeded the NEPM HIL—Level E criteria for human health risk for cadmium and lead, when the total concentration was adjusted for bioaccessibility. Therefore, site LR10 requires further evaluation to define the extent of potential human contact with contaminated sediment and to enable a remediation plan to be implemented.

Exposure to lead from direct consumption of Leichhardt River water and sediment is mutually exclusive. The total lead exposure was recalculated by replacing the drinking water intake with the Leichhardt River water. As a conservative approach, it was assumed that Leichhardt River water is the only source of drinking water. The potential total intake of lead was below the tolerable daily intake of 0.25 mg/d for adults as well as TDI of 0.05 mg/d for children, adjusted for 10% bioavailability and normal food lead intake. However, a number of Leichhardt River water samples could pose a risk if soil lead is included in this calculation.

An additional risk from particulate matter in river sediment is that acute toxicity from the consumption of fish contaminated with metals and metalloids is unlikely. The potential risk was assessed by comparing with the allowable daily intake (ADI). In general, the liver of the fish have higher heavy metal and metalloid concentrations compared to the muscle. Frequent or regular consumption of fish from the Leichhardt River that exceed maximum levels (MLs) of heavy metals and metalloids is not recommended.

The aquatic toxicity in Leichhardt River water collected in 2008 was assessed using the acute 48-h *Ceriodaphnia* cf *dubia* survival toxicity test (short-term effects). The 48-h EC50 showed that acute toxicity was observed at Davis Crossing (61.6 % EC50 and 0% survival). This sample was taken after the Leichhardt River Remediation Program, which was completed in 2007. Further sampling in 2009 for acute toxicity reconfirmed that toxicity was observed at Davis Crossing and, to a lesser extent, at the junction of Breakaway Creek and Leichhardt River. The water metal and metalloid concentration results showed that copper concentrations (0.45 µm fraction) at fours sites and cadmium concentration at Davis Crossing exceeded the trigger values for the 95% species protection. Ammonia as a toxicant could also not be ruled out. The results of further toxicity testing and water quality measurements also reconfirmed cadmium concentrations of 3.5 µg/L at Davis Crossing, which exceeds the trigger value of 2 µg/L for 95% species protection.

To fully evaluate the effectiveness of the Leichhardt River Remediation Program, the decision-tree process recommends that five species in water and five in sediment were tested. A comprehensive sampling of Leichhardt River water and sediment was undertaken in October 2009. The aquatic toxicity studies showed various effects at 23rd Avenue (growth inhibition to *Lemna*); Davis Crossing (chronic toxicity to *Ceriodaphnia*); and Moondarra

Crossing (effects with three different species). These findings indicate that, overall, only limited toxicity was observed in the Leichhardt River water for a range of aquatic species covering the five taxa. The water metal concentrations confirmed that the cadmium concentration at Davis Crossing and copper concentration at Alma Crossing and Moondarra Crossing exceeded the trigger value for 95% fresh water species protection.

Rifle Creek Dam, located furthest upstream of the Leichhardt River, was chosen as a background site relative to Leichhardt River downstream from above Mount Isa City to below Lake Moondarra for aquatic toxicity assessment in both water and sediment. The toxicity results showed that no toxicity was observed at Rifle Creek Dam in both water and sediment making it a suitable site for comparing with any effects of metals and metalloids on aquatic biota downstream.

Comparison of aquatic toxicity testing results showed, in general, that upstream background sediments were not toxic to aquatic test species and confirmed that exceedances of ISQG–Low for 1M HCl extract do not always indicate that the sediment will be toxic to aquatic test biota. In particular, Rifle Creek Dam sediment concentration data for 1M HCl extract demonstrated little or nil toxicity, even though there was historical mining in its sub-catchment.

An approach that takes into account both the presence of natural mineralisation and some effects of historical mining is suggested for deriving background water quality data and site-specific guidelines for the Leichhardt River. It is considered appropriate to use all upstream sediment metal and metalloid concentration data for developing site-specific guidelines because aquatic toxicity was not generally demonstrated with the presence of natural mineralisation or historical mining in upstream Leichhardt River sediment.

Specific recommendations for further work are:

- Identify the specific source of toxicity observed in water from the lower part of the Leichhardt River, adjacent to Mount Isa City and the mine lease. The Toxicity Identification Evaluation (TIE) procedure from the United States Environmental Protection Agency (USEPA) could be used to identify constituents causing toxicity.
- Investigate the section of the Leichhardt River and tributaries from the mine lease with sediment metal and metalloid concentrations exceeding ISQGs that may show potential ecological effects and may require remedial attention.
- Investigate the section of the Leichhardt River at the exit from Star Gully where contaminated sediment exceeds HIL Level E and could impact on human health. This area has been identified for possible remedial attention. The link with sediment and elevated levels of cadmium and lead in fish needs to be better understood.
- Consider changing the frequency of water and sediment monitoring programs to enable collection of sufficient data for developing adequate site-specific guidelines undertaken according to the *Queensland Water Quality Guideline* procedure. Make use hardness-corrected data compared with bioavailable fractions and support this data with both acute and chronic aquatic toxicity tests using sensitive species.
- Continue to identify aquatic species that may be suitable for testing whole sediment for effects from metals and metalloids.

# Glossary

| Term | Meaning |
|---|---|
| Acute exposure | Exposure to a chemical for 14 days or less, either as a single or repeated dose. |
| Acute toxicity | Toxicity typically elicited during, or immediately after short-term exposure of a test organism to a toxicant or stimulus severe enough to induce an adverse reaction rapidly, relative to the lifespan of the organism. In aquatic toxicity tests, an effect is generally considered to be acute if it is observed within 95 hours or less for fishes and macroinvertebrates, and in less time for organisms with shorter life spans. |
| Acute toxic units (TU) | The ratio of the copper in the water to the instantaneous water quality criteria for that water. If TU > 1, it indicates a violation of the instantaneous copper water quality criteria (WQC). |
| ANZECC/ARMCANZ guidelines | Guidelines for water and sediment quality prepared by the Australian and New Zealand Environment and Conservation Council. |
| ANZFSC | Australian New Zealand Food Standards Code maximum levels of metals and metalloid contaminants in aquatic foods. |
| Anglesite | Lead sulfate mineral, $PbSO_4$. It occurs as an oxidation product of the primary lead sulfide ore galena. |
| Anodic stripping voltammetry | Measures the electrochemically labile species of metal in solution. |
| AusRivAS | Australian River Assessment Scheme protocols for rapid sampling of macroinvertebrates. |
| Background Concentration | Naturally occurring, ambient concentrations in the local area of a site. |
| Bioaccessibility (BAc in-vitro) | The soluble fraction under physiological conditions, i.e. an indicator of bioavailability to the receptor (e.g. humans). |
| Bioavailability (BA in-vivo) | The fraction of dose that reaches the systemic circulation of a receptor (e.g. humans). It is expressed as the ratio of the systemic dose to the applied dose, i.e. what is able to have an effect on the body compared to the total concentration to which it is exposed. |
| Biotic Ligand Model | Proposed by Di Toro et al. (2000, 2001) and used to calculate the acute toxicity of cationic metals (e.g., Ag, Cd, Cu, Ni, and Zn) to aquatic organisms. |
| $C_{DGT}$ | Concentrations of metals measured by the Diffusive Gradients in Thin Films technique (DGT). |
| $C_E$ | The effectively available concentration of metals from the solution – phase and solid-phase $C_E = C_{DGT}/R_{diff}$. |
| $C_{SOL}$ | Concentrations of metals in pore water. |
| Certified Reference Material | 'Controls' or standards having certified concentrations of constituents such as metals and used to check the quality and traceability of products. |
| Cerussite | Lead carbonate or white lead ore, a mineral consisting of lead carbonate ($PbCO_3$). |
| Clear Water Lagoon | The lagoon was partitioned off from Lake Moondarra in 1968, approximately 10 years after the Leichhardt River was dammed downstream of Mount Isa City. It was built as a protected reservoir to overcome high turbidity inflows entering Lake Moondarra during the wet season (from Mount Isa Water Board). It is the primary component of the reed bed system. |
| Chronic exposure | Repeated exposure to a chemical for a duration of three months or greater. |
| Chronic toxicity | Toxicity resulting from long-term exposure to a toxicant. |

| Term | Meaning |
|---|---|
| Criterion Continuous Concentration (CCC) | As established by the US Environmental Protection Agency, an estimate of the highest concentration of a material in ambient water to which an aquatic community can be exposed indefinitely without resulting in an unacceptable adverse effect (CCC=FAV/ACR). |
| Criterion Maximum Concentration (CMC) | Established by the US Environmental Protection Agency, it is an estimate of the highest concentration of a material in ambient water to which an aquatic community can be exposed briefly without resulting in an unacceptable adverse effect (CMC=FAV/2). |
| Bicarbonate | $HCO_3^-$ |
| D | Diffusion coefficient of metal ions in DGT gel. |
| d | Day |
| DATFIT | Fits XANES spectra to a linear combination of other spectra. |
| Donnan Membrane Technique | Designed to follow the approach of Fitch and Helmke (1989) to determine speciation of metals in soil solution. |
| DOM-SHM model | Stockholm Humic Model for humic substance. |
| Electrical conductivity | Estimates the amount of total dissolved salts or the total amount of dissolved ions in the water. |
| EC50 | Median effects concentration, which is the concentration of a specified chemical in an exposure water that causes a non-lethal adverse effect in 50% of the organisms tested, where the effect could be immobilisation, avoidance, etc. |
| Environmental values | Particular values or uses of the environment that are important for a healthy ecosystem or for public benefit, welfare, safety, or health and that require protection from the effects of contaminants, waste discharges and deposits. Several environmental values may be designated for a specific water body. |
| Eh | Redox potential. |
| Exposure | Contact of a chemical, physical, or biological agent with the outer boundary of an organism (inhalation, ingestion, or dermal contact). |
| Exposure settings | Categories based on several conservative assumptions used to provide a 'tiered' set of soil criteria for different exposure settings:<br>'A' = standard residential with garden/accessible soil<br>'B' = residential with substantial vegetable garden, and poultry<br>'C' = residential with substantial vegetable garden, excluding poultry<br>'D' = residential with minimal opportunities for soil access<br>'E' = parks, recreational open space and playing fields<br>'F' = commercial industrial. |
| EXAFSPAK | An operating system, which is an independent package for analysing X-ray absorption spectroscopic data. |
| FAV | Final Acute Value |
| Filtration | Commonly the mechanical or physical operation used for separating solids from fluids (water) by interposing a medium through which only the fluid can pass through the 0.45 µm membrane. |
| g | Gram |
| GEOCHEM | Geochemical models relying on chemical equilibrium. |
| Galena | The natural mineral form of lead (II) sulfide, PbS. It is the most important lead ore mineral. |

| Term | Meaning |
|---|---|
| Guideline values | Values, such as concentrations in soil, which are derived after appropriate allocation of tolerable intake of possible different media of exposure. |
| h | Hour. |
| Hardness | A measure of the sum of the concentrations of calcium and magnesium ions in water, expressed as mg/L calcium carbonate equivalent. |
| Humic substances | Heterogeneous yellow-black organic materials that include most of the naturally dissolved organic matter in water. They are classified as humin (not soluble at any pH), humic acid (not soluble at pH <2) and fulvic acid (soluble at all pH values). |
| Health Risk Assessment | The process of estimating the potential impact of a chemical, biological, physical, or social agent on a specific human population system under a specific set of conditions and timeframe. |
| IC50 | Median inhibitory concentration, which is the concentration of a specified chemical in an exposure water that causes 50% inhibition (i.e. decrease) of an attribute, where the attribute could be growth, reproduction, etc. |
| ICP-MS | Inductively coupled plasma mass spectrometry. |
| ICP-OES | Inductively coupled plasma optical emission spectrometry. |
| Indicator | Measurement parameter or combination of parameters that can be used to assess the quality of water. |
| Invertebrates | Animals lacking a dorsal column of vertebrae or a notochord. |
| In-vitro test | Tube test. |
| In-vivo test | Whole organism (animal) test. |
| ISQG-High | Australia and New Zealand Environment and Conservation Council Interim Sediment Quality Guidelines-High. Probable-effects concentrations below which biological effects in sediment would possibly occur. Concentrations at or above the ANZECC/ARMCANZ ISQG-High represent a probable-effects range within which effects in sediment would be expected to frequently occur. |
| ISQG-Low | Australia and New Zealand Environment and Conservation Council Interim Sediment Quality Guidelines-Low. Probable effects concentrations below which biological effects in sediment would rarely occur. |
| ISE | Ion-selective electrode method to determine metal and metalloid speciation in solution. |
| LA50 | Median lethal accumulation, which is the concentration of a specified chemical in bound to a biotic ligand that causes 50% mortality. |
| Lead goethite | Lead adsorption on goethite. |
| Level of protection | The acceptable level of change from a defined reference condition. |
| LC50 | Median lethal accumulation, which is the concentration that exposure of a specified chemical in water causes 50% mortality. |
| M | Molar concentration moles per litre. |
| Magneto Plumbite | Black mineral consisting of a ferric oxide of plumbite and manganese, and occurring in acute metallic hexagonal crystals $(Pb,Mn)_2Fe_6O_{11}$. |
| MICC | Mount Isa City Council. |
| MINEQL | Multi-ion models for predicting solution concentrations based on chemical equilibrium. |
| MINTEQA2 | Upgraded program for multi-ion models for predicting solution concentrations based on chemical equilibrium. |
| MIWB | Mount Isa Water Board. |
| mg/kg | Milligrams per kilogram. |
| $mg/m^3$ | Milligrams per cubic metre. |

| Term | Meaning |
|---|---|
| Natural mineralisation | Naturally occurring minerals in a geological setting. |
| NEPM Level A | Standard residential with garden soil/accessible soil. |
| OECD test guidelines | The OECD guidelines for the testing of chemicals for the ecotoxicity test. |
| Organism | Any living animal or plant; anything capable of carrying on life processes. |
| Oxidation | The combination of oxygen with a substance, or the removal of hydrogen from it, or, more generally, any reaction in which an atom loses electrons. |
| Parameter | A measurable or quantifiable characteristic or feature. |
| Percentile | Interval in a graphical distribution that represents a given percentage of the data points. |
| Performance indicators | Indicators used to assess the risk that a particular issue will occur, used in the guidelines to compare against the trigger values. They are generally median (or mean) concentrations in the ambient water, and may be stressor and/or condition indicators. |
| Physiologically based extraction test | An in-vitro test for measuring bioaccessibility. |
| pH | Negative logarithm of molar hydrogen ion concentration used as a measure of acidity or alkalinity. |
| Phytotoxicity | Toxic to plants. |
| Plumbojarosite | A mineral composed of basic lead iron sulfate; it is isostructural with jarosite, $PbFe_6(SO_4)_4(OH)_{12}$. |
| Poisoning | The physiological state produced by absorption of excessive poison or other toxic substance. |
| Quality assurance | The implementation of checks on the success of quality control (e.g. replicate samples, analysis of samples of known concentration). |
| Quality assurance | The implementation of checks on the success of quality control (e.g. replicate samples, analysis of samples of known concentration). |
| Quality control | The implementation of procedures to maximise the integrity of monitoring data (e.g. cleaning procedures, contamination avoidance, sample preservation methods). |
| $R_{diff}$ | is determined by the geometry of the DGT unit, deployment time and sediment tortuosities. |
| Redox | Simultaneous (chemical) reduction and oxidation. Reduction is the transfer of electrons to an atom or molecule, whereas oxidation is the removal of electrons from an atom or molecule. |
| Red lead | Lead tetroxide or triplumbic tetroxide, is a bright red or orange crystalline or amorphous pigment. Chemically, red lead is lead tetroxide, $Pb_3O_4$, or $PbO{\cdot}PbO_2$. |
| Reference condition | An environmental quality or condition that is defined from as many similar systems as possible (including historical data) and used as a benchmark for determining the environmental quality or condition to be achieved and/or maintained in a particular system of equivalent type. |
| Rehabilitation | In the context of mining, 'rehabilitation' is described as returning the disturbed area to a stable and economically productive landform |
| Relative bioavailability | The comparative bioavailability of different forms of a chemical or for different exposure media containing the chemical and is expressed as a fractional relative absorption factor. |

| Term | Meaning |
|---|---|
| Risk | A statistical concept defined as the expected frequency or probability of undesirable effects resulting from a specified exposure to known or potential environmental concentrations of a material, organism or condition. A material is considered safe if the risks associated with its exposure are judged to be acceptable. Estimates of risk may be expressed in absolute or relative terms. Absolute risk is the excess risk due to exposure. Relative risk is the ratio of the risk in the exposed population to the risk in the unexposed population. |
| Salinity | The presence of soluble salts in water or soils. |
| Sediment | The clay, silt, or gravel carried by a flowing river or stream and deposited where the flow slows and results in alluvial deposition below the low water mark or up to the high water mark. Sediment comprises bed load material (>63 µm) that moves just above the bed and suspended material (<63 µm) that moves in suspension under the influence of turbulence. The fine sediment (<63 µm) is most representative for sampling purposes. |
| Soil | The part of the earth's surface consisting of humus and disintegrated rock that is located above the high water mark of an adjacent river or stream. |
| Stressor | A chemical or biological agent, environmental condition, an external stimulus or an event that causes stress to an organism. |
| Sub-chronic exposure | Repeated exposure to a chemical for a one to three month period. |
| $\mu g/m^3$ | Micrograms per cubic metre. |
| Site specific trigger value | A trigger value derived from data collected at a specific location and is only applicable at that specific location. |
| Solution concentration | Concentration of contaminants in the liquid phase. |
| Speciation | Measurement of different chemical forms or species of an element in a solution or solid. |
| Species | Generally regarded as a group of organisms that resemble each other to a greater degree than members of other groups and that form a reproductively isolated group that will not normally breed with members of another group. (Chemical species are differing compounds of an element.) |
| Species richness | The number of species present (generally applied to a sample or community). |
| Standard e.g. water quality standard | An objective that is recognised in environmental control laws enforceable by a level of government. |
| Statistical power | The ability of a statistical test to detect an effect given that the effect actually exists. |
| TDI | Tolerable Daily Intake |
| TIE | Toxicity Identification Evaluation, a procedure of the USEPA. |
| Total Alkalinity | Total alkalinity is the total concentration of bases in water expressed as milligrams per litter (mg/L) of calcium carbonate ($CaCO_3$). These bases are usually bicarbonates ($HCO_3$) and carbonates ($CO_3$), and they act as a buffer system that prevents drastic changes in pH. |
| Toxicant | A chemical capable of producing an adverse response (effect) in a biological system, seriously injuring structure or function or producing death. Examples include pesticides, heavy metals, and biotoxins. |
| Toxin | A poisonous substance produced by living cells or organisms. |
| Toxicity | The inherent potential or capacity of a material to cause adverse effects in a living organism. |

| Term | Meaning |
|---|---|
| Toxicity test | The means by which the toxicity of a chemical or other test material is determined. A toxicity test is used to measure the degree of response produced by exposure to a specific level of stimulus (or concentration of chemical). |
| Time-weighted average | The average occupational exposure for an eight-hour day/exposure period. |
| Uptake | A process by which materials are absorbed and incorporated into a living organism. |
| Visual MINTEQ | A chemical equilibrium model for the calculation of metal speciation, solubility equilibria, and sorption for natural waters. |
| Water quality standard | A legally enforceable water quality guideline. |
| Wellbeing | Note: defined in EP (Air) P (2008). |

# List of Acronyms

| Acronym | Definition |
|---|---|
| ACR | Acute-Chronic Ratios |
| ADI | Acceptable Daily Intake |
| ADWG | Australian Drinking Water Guidelines |
| ANZECC/ARMCANZ | Australia and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand |
| ANZFSC | Australian New Zealand Food Standards Code |
| ASTM | American Society for Testing and Materials |
| ASV | Anodic Stripping Voltammetry |
| BLM | Biotic Ligand Model |
| BOM | Bureau of Meteorology |
| C | Concentration |
| CCC | Criterion Continuous Concentration |
| CEAM | Centre of Exposure Assessment Modeling |
| CMC | Criterion Maximum Concentration |
| DERM | Department of Environment and Resource Management |
| DGT | Diffusive Gradients in Thin Films technique |
| DMT | Donnan Membrane Technique |
| DOC | Dissolved Organic Carbon |
| DTA | Direct Aquatic Toxicity Assessment |
| EC | Electrical Conductivity |
| EIL | Ecological Investigation Level |
| FAV | Final Acute Value |
| FAO | Food and Agricultural Organization of the United Nations |
| FSANZ | Food Standards Code Australia New Zealand |
| FIT | Fish Imbalance Test |
| HCI | Hydrochloric Acid |
| HIL | Health Investigation Level |
| ICP-MS | Inductively Coupled Plasma-Mass Spectrometry |
| ICP-OES | Inductively Coupled Plasma Optical Emission Spectrometry |
| IPCS | International Programme on Chemical Safety |
| ISE | Ion-selective Electrode |
| ISQG | Interim Sediment Quality Guidelines |
| JECFA | Joint Food and Agricultural Organization of the United Nations / World Health Organization Expert Committee on Food Additives |
| ML | Metal Ligand |
| ML | Maximum Level in Food |
| MICC | Mount Isa City Council |
| MIM | Mount Isa Mine |
| MIWB | Mount Isa Water Board |
| MPC | Maximum Permissible Concentration in Food |
| NATA | National Association of Testing Authorities |
| NEPC | National Environmental Protection Council |

| Acronym | Definition |
|---|---|
| NEPM | National Environmental Protection Measure |
| NH&MRC | National Health and Medical Research Council |
| NRM | (Department of) Natural Resources and Mines |
| NWQMS | National Water Quality Monitoring Strategy |
| OECD | Organisation for Economic Co-operation and Development |
| PBET | Physiologically based extraction test |
| QA | Quality Assurance |
| QC | Quality Control |
| QLD EPA | Queensland Environmental Protection Agency |
| SPC | Spring Creek |
| TDI | Tolerable Daily Intake |
| TDS | Total Dissolved Salts |
| TI | Tolerable Intake |
| TIE | Toxicity Identification Method |
| TU | Toxic Units |
| TV | Trigger values for freshwater species |
| USEPA | United States Environmental Protection Agency |
| WHO | World Health Organization |
| WQC | Water Quality Criteria |
| XAS | X-ray absorption spectroscopy |
| XANES | X-ray absorption near edge spectroscopy |
| XRD | X-ray diffraction |

# Contents

# List of Figures

# List of Tables

# List of Appendices

# 1. Introduction

## 1.1 Purpose

The Phase III study is part of the Lead Pathways Project, a research program being conducted by the Centre for Mined Land Rehabilitation at The University of Queensland to investigate sources and pathways of heavy metals (primarily lead) to land, air, and water at Mount Isa (Noller et al., 2009). The University of Queensland was engaged by Xstrata Mount Isa Mines to undertake this work.

The Leichhardt River flows through the Mount Isa region where large copper, silver, lead, and zinc-bearing ore deposits occur (Conaghan et al., 2003; see Section 2.6.2.1). The urban area of Mount Isa with the city's sewage treatment plant and the Mount Isa Mines mineral extraction and processing facilities are located in the upper part of the catchment, as are areas of natural mineralisation and historical mining activities. Therefore, potential sources of contaminants into the surface water are from historical mine sediments, current mining activities, urban activities and natural mineralisation in the catchment.

Phase III investigated potential sources of lead and other metals and metalloids that contribute to the water and sediments in the Leichhardt River, and any sources of concern for community, pastoral, and ecological health. The study also identified if impacts from current discharges, residual historical mining sediments, urban activities, and natural mineralisation were of significance to the Leichhardt River.

The purpose of this study was to:

1. investigate the potential sources and pathways of lead and other heavy metals and metalloids in water from various tributaries leading into the Leichhardt River Catchment, particularly at, and below, Mount Isa City and the mine lease
2. assess the risk to human, pastoral, and ecological health from the contributions of lead and other heavy metals and metalloids using national guidelines and decision tree processes.

The National Water Quality Management Strategy (NWQMS, 2008), the ANZECC/ARMCANZ Water Quality Guidelines (ANZECC/ARMCANZ, 2000) and the Queensland Water Quality Guidelines (QWQG, 2009), all identify management aims for protecting water resources. The strategy and guidelines also specify biological, water, and sediment quality for protecting a range of aquatic ecosystems. Site-specific risk assessments can be conducted to address human health, pastoral, and ecological concerns when water and sediment contaminants are identified at concentrations above the guideline levels. These assessments depend on site-specific conditions (NEPC, 1999) and the sediments must be technically classified as 'soils' for human health risk assessments.

This Phase III study assessed the sources and potential impact of metal and metalloid additions to the Leichhardt River fluvial system on human, pastoral, and ecological health so appropriate management practices can be implemented to protect environmental values. The broad objectives of the study were:

1. to ensure the continued health and wellbeing of residents of the Mount Isa community
2. to ensure continued pastoral activities with no adverse effects on livestock or other activities
3. to ensure the continued health of aquatic ecosystems that live in the water and sediments in the Leichhardt River
4. minimise the impact of existing mine sediments resulting from historical mining practices and any current discharges.

This study aimed to indicate the extent of the distribution of metal and metalloid contamination within the Mount Isa region and the Leichhardt River Basin. (Figure 1) and their pathways, and assess the potential resulting risk to human, pastoral, and ecological health. This was achieved by a site assessment processes that (ANZECC/ARMCANZ, 2000):

- identified environmental values to be protected in a particular water body
- selected sampling sites, pathways, and sampling timelines
- conducted the sampling and analysis program to understand the distribution of heavy metal and metalloid contamination within the study area and their pathways
- assessed heavy metal and metalloid concentrations and water quality of the Leichhardt River and its tributaries using filtration and applying water hardness adjustment
- determined the predicted bioavailability factor of total concentrations in river soil and sediment using bioaccessibility-adjusted concentrations for human health risk

- measured metal and metalloid concentrations in sediment extracted by cold 1M hydrochloric acid (HCl) to assess against the low and high Interim Sediment Quality Guidelines (ISQG)
- determined the speciation of heavy metals for aquatic biota using the Diffusive Gradients in Thin Films technique (DGT) to give a prediction of bioavailability
- conducted aquatic toxicity assessments on water and sediments at selected sites following decision tree processes to evaluate the significance of water and sediment status and assess locations of potential ecological effects
- conducted desktop human-health risk assessments using bioaccessibility as an indicator of bioavailability to understand the site-specific potential toxicity of lead and other metals and metalloids to human health
- conducted desktop risk assessments of pastoral health using comparing water and sediment concentrations in irrigation and livestock drinking water with the ANZECC/ARMCANZ (2000) guidelines.

## 1.2 Background

The Leichhardt River, located in north-west Queensland, flows north into the Gulf of Carpentaria and lies within the northern Australian tropical climatic zone (Figure 1). At Mount Isa, the Leichhardt River is part of a fluvial system, which is subject to seasonal river flow and flooding during the annual wet season. The flow regime of the Leichhardt River is ephemeral (Figure 2).

Almost all rain in the southern Gulf region falls within two or three months of the year, normally January and February (high flow), with smaller falls in December and March (base flow) and contraction of water to isolated pools during the dry season (nil flow) from April to November (Figure 3). The southern Gulf region has a dry tropical savannah climate, with distinct, highly variable wet and dry seasons. The river fluvial material has a dry, exposed surface, which technically becomes soil for most of the year before the January rainfall.

Most water bodies and their aquatic ecosystems in the Leichhardt River are temporary due to a combination of high temperatures and evaporation rates. Cyclones and rain depressions also have a profound influence on total rainfall. This influence was illustrated in January 2009 when rainfall was more than five times the average. Without these extreme weather events, some sections of the river may not receive any water or connecting flows for several years.

Immediately downstream from Mount Isa is the man-made reservoir Lake Moondarra, which was constructed on the Leichhardt River in 1959. Lake Moondarra provides the water supply for Mount Isa City and local industry, including Mount Isa Mines (Fountain, 1994). Lake Moondarra is also a popular recreational location for activities such as boating, fishing and swimming. The Lake Moondarra reservoir is operated by Mount Isa Mines on behalf of the Mount Isa Water Board (MIWB, 2010).

The dry Leichhardt River catchment results in little groundcover to prevent erosion; therefore the initial river flow and Lake Moondarra can also both be highly turbid. Clear Water Lagoon is used as a biological filter as part of the program for treating water from Lake Moondarra to meet Australian Drinking Water Guidelines (ADWG, 2004). The water from Lake Moondarra enters the lagoon through reed beds and other aquatic plants that remove suspended solids by filtration, producing clear drinking water even when the Leichhardt River is in flood. This lagoon barrier system has a capacity of about 40 days' water supply and has operated successfully for forty years (Fountain, 1994).

### 1.2.1 Historical contamination

Sediment from the Leichhardt River has been contaminated by historical mining activities (Mount Isa Mines, 2003). Tailings discharges, use of waste rock for construction in and around the riverbed, and reinforcing banks and stormwater discharge channels have all contributed to the current sediment quality of the river. Approximately 40,000 tonnes of tailings were discharged into the river during the 1940s and process waste continued to be discharged into the river during the 1950s and 1960s (Mount Isa Mines, 2003).

Surveys conducted in 1973 to determine the extent of metal dispersion in sediments provided a useful background to the state of the river before any significant remedial projects. Mount Isa Mines undertook a number of sediment removal projects throughout the 1970s, 1980s, and 1990s, removing up to 100,000 tonnes of material from the river (Mount Isa Mines, 2003). The Leichhardt River Management Plan was developed in 1993 as a joint project between the Mount Isa City Council (MICC), the Queensland Government, and Mount Isa Mines to address issues, including historical contamination. The plan committed Mount Isa Mines to remove any further contamination as it became exposed in the riverbed.

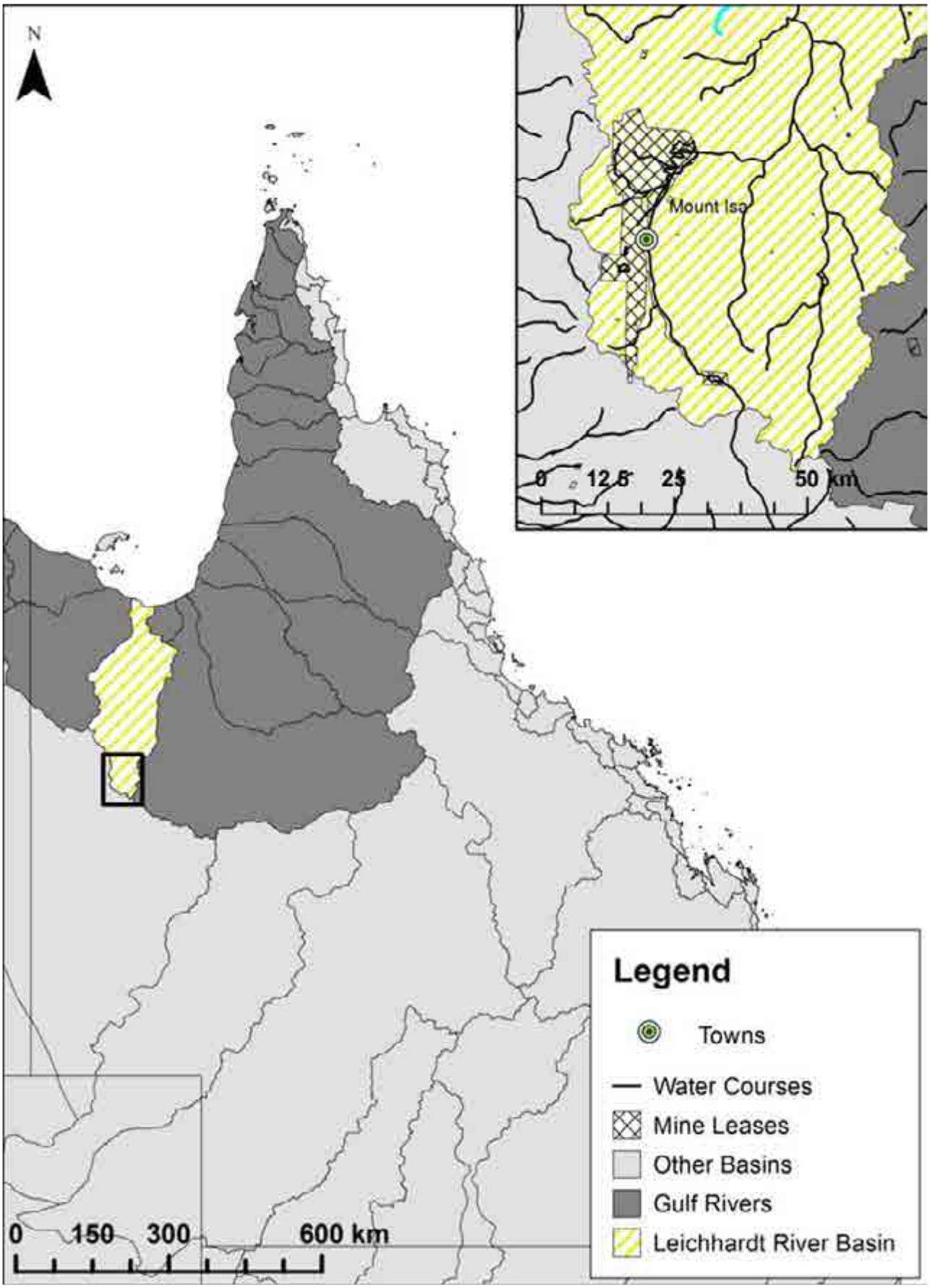



**Figure 1. Regions adopted from the Queensland Water Quality Guidelines. Leichhardt River is in the Gulf River drainage division and Leichhardt River Basin (QWQG, 2009)**

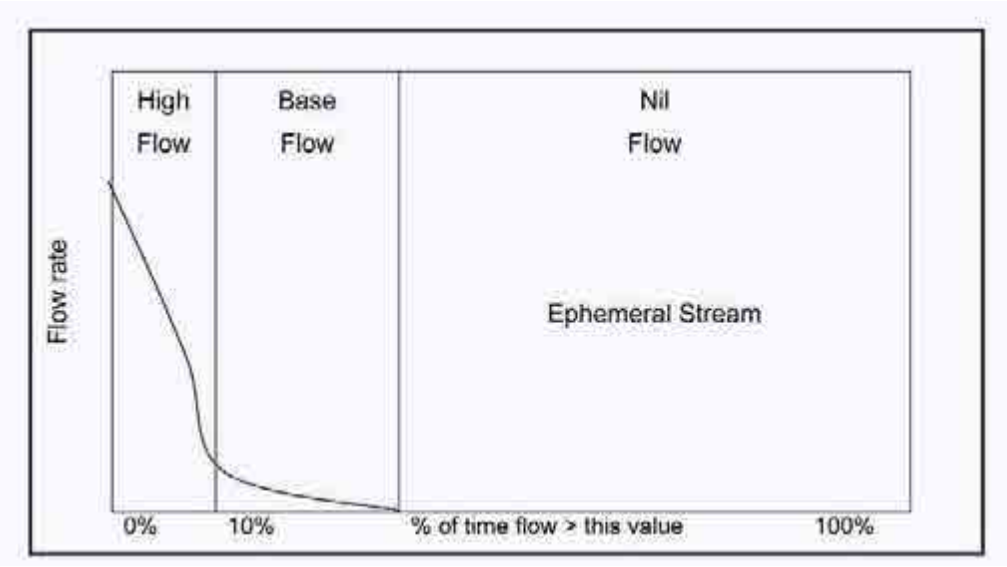



**Figure 2. Generic flow duration curve for an ephemeral stream in Queensland (QWQG, 2009)**

A 2002 survey (Mount Isa Mines, 2003) showed that sediment quality had improved since the previous major survey in 1973, although there was an area of concern between the Grace Street Bridge and the Alma Street crossing. The intensive surface sampling of this area in 2002 showed a number of locations within this stretch of the riverbed were in excess of the then Queensland Environment Protection Agency's thresholds for contaminated land. In 2002, excavations in the riverbed were recommended (Mount Isa Mines, 2003) to better define the extent of contaminated material and to remove it. Phase I of the Lead Pathways Project started in 2007. Phase I assessed the extent and significance of contamination of the Leichhardt River sediments and soils from lead and other heavy metals and metalloids for human and ecological health (Noller et al., 2009).

In June 2008, Mount Isa Mines completed the Leichhardt River Remediation project, removing 120,000 tonnes of historical mine sediment material and disposing of it on the mine lease. A grid sampling of the entire remediation area was undertaken in 2007. Sampling of the remediation area was repeated after the 2008/09 wet season to verify that all exposed historical mine sediment was removed. A follow-up protocol was established to conduct annual post-wet season sampling through to 2011 to ensure river flows and riverbed and bank erosion do not uncover any more historical mine sediments (Mount Isa Mines, 2008).

### 1.2.2 Potential sources of contaminants

Ephemeral discharges supply water to the Lake Moondarra storage reservoir and are affected by a range of upstream activities. These activities include mine site seepage, town seepage, urban stormwater from Mount Isa City, input from the sewerage treatment system, and historic mining contaminants stored within the Leichhardt River and its tributaries (Figure 4).

## 1.3 Basis for managing the Leichhardt River

This study identified and assessed the significance of all potential water exposure pathways of metals and metalloids for members of the population that may have contact with the Leichhardt River. The assessment followed the potential pathways through to human contact endpoints, assessing the hazards and risks of exposure to the metals and metalloids in the various sources of the water environment.

The basis for the human health risk assessment of the water and sediment compared the total concentrations of metals and metalloids against the health-related guideline values (ADWG, 2004). Based on present knowledge, the recommended guideline values do not result in any significant risk to health over a lifetime of consumption. This approach was considered to be the most applicable for this study because the sample sites include recreational open space in the river, Lake Moondarra, and Clear Water Lagoon where occasional direct consumption of water may occur. However, the majority of people living in Mount Isa City consume potable water from the storage at Clear Water Lagoon, which is demonstrated to be safe to human health (ADWG, 2004).

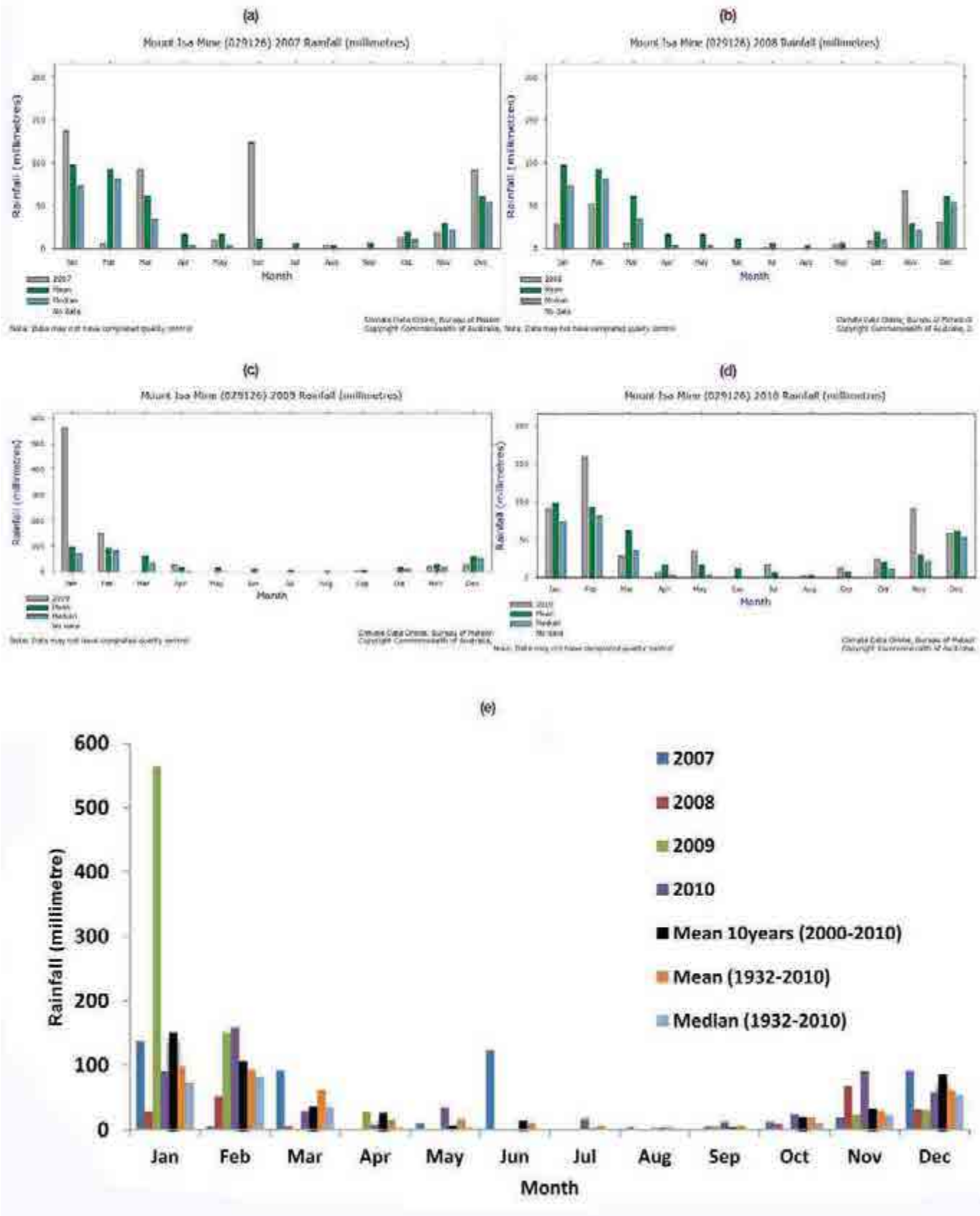



**Figure 3. Mount Isa rainfall (mm) for (a) 2007; (b) 2008; (c) 2009; (d) 2010; and (e) the period 2007–2010 (BOM, 2011)**

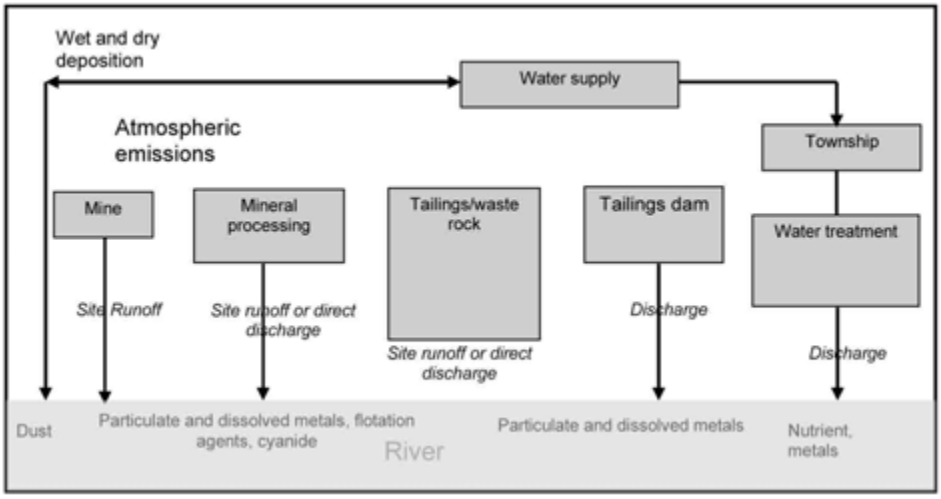



**Figure 4. Typical conceptual model showing inputs of contaminants to a river (Batley et. al., 2003)**

The basis for assessing pastoral risk was to use the guidelines for irrigation and livestock drinking water described by ANZECC/ARMCANZ (2000). The ANZECC/ARMCANZ (2000) guidelines have also developed a risk framework for ecological health. The guidelines for ecological health are based on the water quality of the aquatic ecosystem and the level of protection for the ecosystems. In this study, the total concentrations of metals and metalloids in the water were compared with trigger values at 95% protection levels for 'slightly to moderately disturbed systems', as recommended by ANZECC/ARMCANZ (2000). When these concentrations were exceeded, the generic decision tree process for metal toxicant assessment was followed, including aquatic toxicity assessment. The processes are summarised in Figure 5.

## 1.4 Environmental values, indicators, and water quality guidelines and objectives

### 1.4.1 Environmental values

Environmental values to be protected in a particular water body need to be identified (ANZECC/ARMCANZ, 2000). Environmental values are site-specific and are highly dependent on local factors, including land use and the pre-existing condition of the catchment relative to its position on the pristine-to-highly degraded continuum. In line with the ANZECC/ARMCANZ (2000) guidelines, the environmental values for the study are broadly defined as:

- aquatic ecosystems
- irrigation and livestock drinking water
- recreation and aesthetics
- fishing
- water sports
- drinking water sources
- cultural and spiritual values.

### 1.4.2 Indicators

Physico-chemical and toxicant indicators have traditionally been identified as appropriate indicators for water quality (ANZECC/ARMCANZ, 2000). For this study, the indicators were identified as:

- pH
- electrical conductivity (EC)
- dissolved organic carbon (DOC)
- water hardness
- concentrations of sulfate, metals and metalloids.

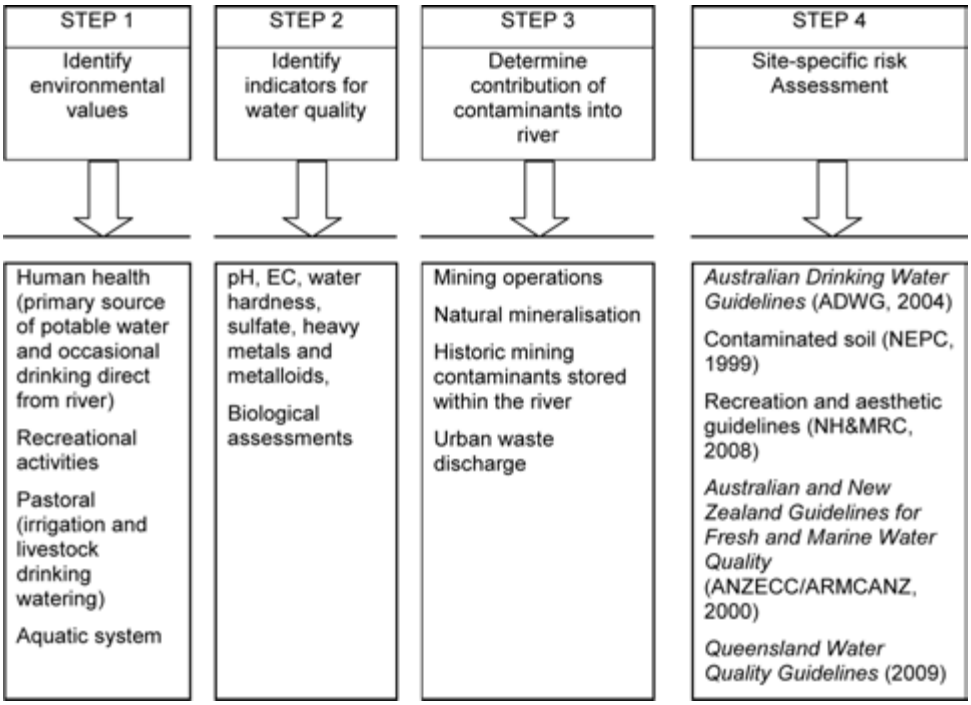



**Figure 5. Process showing relationship of environmental values and site-specific risk assessments for water quality**

Biological indicators are also important because they provide a direct measure of ecosystem health. Protecting aquatic ecosystems from toxic substances can be achieved by adapting water quality guidelines based on aquatic toxicological studies for local conditions. The ANZECC/ARMCANZ (2000) decision-tree processes for water and sediment both identify that toxicity assessment is required when the guidelines are exceeded, after being adjusted for bioavailability or speciation effects.

Biological indicators should complement physical and chemical indicators. ANZECC/ARMCANZ (2000) describes indicators for biological assessment and provides guidance for determining acceptable levels of change to estimate the relative condition of the ecosystem. For some environmental values, it may not be feasible to protect all water resources to the same level, and the community may want to aim for different levels of protection for different resources. The identified levels of protection should be reflected in the management goals and the water quality objectives for a particular resource. ANZECC/ARMCANZ (2000) recognises that three levels of protection are required for aquatic ecosystems, based on ecosystem condition.

The highest level of protection (95% species protected) is for systems with high conservation and ecological values where management is expected to ensure there is no change in biological diversity, relative to a reference condition. For aquatic ecosystems, the ANZECC/ARMCANZ (2000) guidelines have been developed mainly for the second and third levels of protection: slightly to moderately disturbed ecosystems and highly disturbed ecosystems. For highly disturbed ecosystems that cannot feasibly be returned to the second level of protection, the ANZECC/ARMCANZ (2000) guidelines provide advice on deriving alternative guidelines that give lower levels of protection.

Ecotoxicological testing is used to show the effects of toxic substances in water and sediment on single species, multispecies, and community bioassays (ANZECC/ARMCANZ, 2000). Both acute toxicity and chronic toxicity responses may be appropriate and relevant for selecting suitable organisms for toxicity testing. Aquatic assessment needs to be conducted with a range of species that reflect different trophic levels of the aquatic habitat of the test sites, following the ANZECC/ARMCANZ (2000), which recommend using a minimum of five taxa from at least four taxonomic groups. The choice of species for testing needs to take into account the similarity to locally occurring species of aquatic biota within the Leichhardt River ecosystem.

### 1.4.3 Water quality guidelines

A water quality guideline is a recommended numerical concentration limit or statement to support and maintain a designated water use (ANZECC/ARMCANZ 2000). Water quality guidelines include chemical and physical

parameters in water and sediment and biological indicators. Water quality guidelines are used for assessing water quality and to determine water quality objectives that protect and support the environmental values of the water resources, and against which the performance of water quality improvement activities can be measured. Water quality parameters can be divided into those with a direct affect on organisms and animals (e.g. pH, heavy metals and temperature) and those with an indirect affect (e.g. nutrients, turbidity and enrichment with organic matter). The direct or indirect nature of these affects has important implications for management, and how guidelines are derived. Some physical and chemical stressors can also indirectly modify the toxicity of other contaminants. While specific guidelines are not provided for this these stressors, ANZECC/ARMCANZ (2000) provide guidance on how to take them into account.

The ANZECC/ARMCANZ (2000) guidelines divide Queensland divided into several regions (Figure 1). Although some regional and sub-regional guidelines have been developed, there are no regional guidelines for the Gulf region, due to limited local water quality data (QWQG, 2009). In the absence of regional guidelines, the QWQG (2009) advises that the ANZECC/ARMCANZ (2000) default freshwater types and decision process should be used. However, this process is not particularly useful for the Leichhardt River catchment due to the catchment's high salinity and hardness levels, compared with temperate freshwater. The only alternative is to create site-specific guidelines for water quality (QWQG, 2009) and to use the default ANZECC/ARMCANZ (2000) guidelines as a starting point.

The ANZECC/ARMCANZ (2000) guidelines providing some confidence that there will be no significant impact on the environmental values of water bodies if the guidelines are achieved. Exceeding the guidelines indicates there is potential for an impact, but does not provide any certainty that an impact will or has occurred. In areas where protection of aquatic ecosystems is a designated environmental value, ANZECC/ARMCANZ (2000) recommends direct assessment of the biological community to assess determine whether ecosystem integrity is maintained, threatened, or compromised by contaminants.

### 1.4.4 Water quality objectives

Water quality objectives are the specific water quality targets agreed between stakeholders, or set by local jurisdictions, which become the indicators of management performance. Normally, only indicators relevant to the environmental issues or problems facing the resource are selected for deriving water quality objectives. Water quality objectives protect the designated environmental values of resources and are usually based on information from the guidelines.

Developing site-specific water quality guidelines for the Leichhardt River catchment requires science-based water quality criteria (QWQG, 2009), but can be modified by other inputs such as social, cultural, economic, or political constraints. Some of these inputs may be intangible and, therefore, hard to quantify. However, ANZECC/ARMCANZ (2000) considered these intangible inputs to be valid to the management. Modifying guidelines to establish water quality objectives is normally carried out through cost–benefit analyses involving input from stakeholders or local jurisdictions.

An additional consideration for setting water quality objectives for the Leichhardt River catchment was the water quality required to meet management goals and to protect environmental values established further downstream. The water quality required to support local environmental values may not be sufficient to support downstream environmental values, particularly for chemicals that persist in the environment or where downstream ecosystems are more sensitive to contaminants.

The ANZECC/ARMCANZ (2000) management framework for applying guidelines, as shown in Figure 6 was used.

## 1.5 Frameworks for assessment

### 1.5.1 Framework for drinking water guidelines

Water quality guidelines protect water for human consumption. Water for consumption in Mount Isa is treated at the point of storage in Clear Water Lagoon (MIWB, 2010). Drinking water is managed by the scheme outlined in Figure 7 (ADWG, 2004) and meets their guidelines. Although the majority of the population drink potable water, there are occasions when members of the population may consume water directly from the Leichhardt River. For this reason, the Leichhardt River water quality is compared against the ADWG (2004) guidelines, even though the river water is not treated as potable water. In addition, river sediment in a <2 mm fraction or a <250 µm fraction (Ng et al., 2010a,b) was compared against the NEPM Level E Health Risk Investigation Level E for recreational use of land (Noller et al., 2009). This comparison evaluated the health risk from exposure to river soil

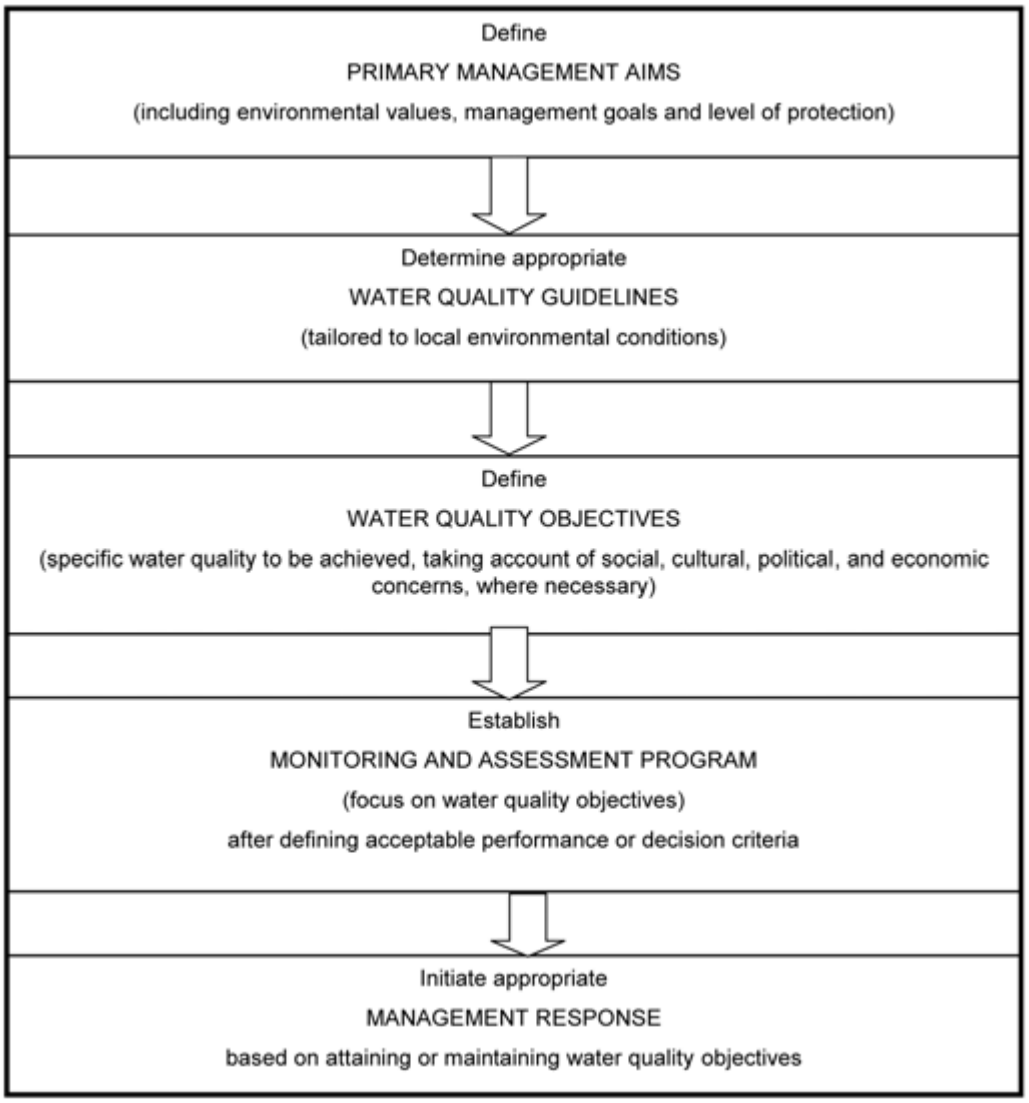



**Figure 6. Management framework for applying water quality guidelines (ANZECC/ARMCANZ, 2000)**

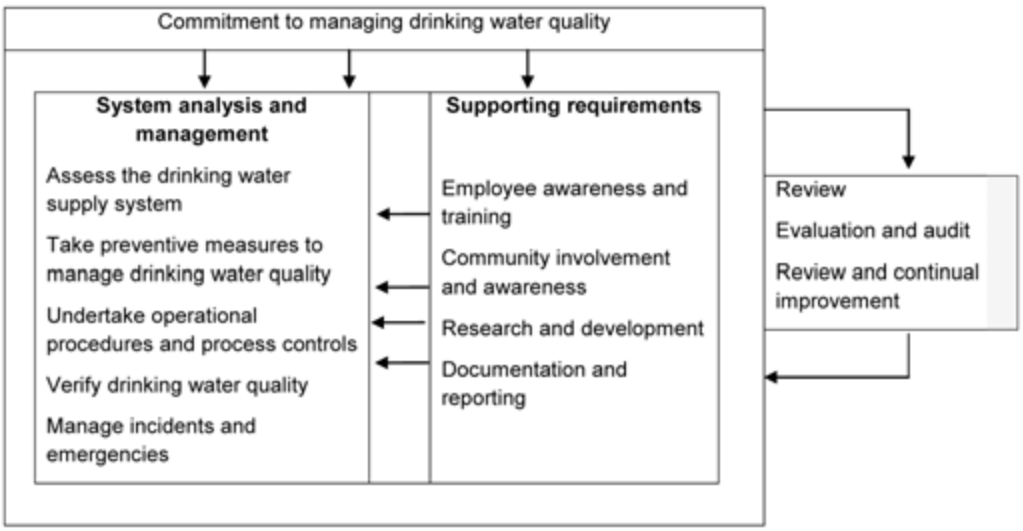



**Figure 7. Framework for drinking water (ADWG, 2004)**

to be evaluated when dispersed in the water column, assessing the dose contribution of lead and other metals and metalloids in the particulate phase (>0.45 µm fraction) of water. During the dry season (Figure 2) riverflow is diminished or ceases altogether and river sediments are exposed. Under these conditions suspended solids levels in water can increase dramatically.

### 1.5.2 Framework for recreational water quality and aesthetics

Water quality guidelines are necessary to protect water bodies for recreational activities, such as swimming and boating, and to preserve their aesthetic appeal. Water quality guidelines are used to determine the suitability of a water resource for recreational purposes. Waters contaminated with chemicals that are either toxic or irritating to the skin or mucous membranes are unsuitable for recreational purposes. Recreational water should have a pH in the range 6.5–8.5 and dissolved oxygen content greater than 80% (ANZECC/ARMCANZ, 2000; NH&MRC 2008). Guidelines for drinking water values are only used as a guide to deriving chemical values applicable to recreational water. The drinking water quality guideline values are based on the daily consumption of 2 L of water. When applying these values to recreational water exposure, consumption of 100–200 mL per day should be considered (NH&MRC, 2008).

Recreational water bodies should be aesthetically acceptable to recreational users (Figure 8). The water should be free from:

- visible materials that may settle to form deposits
- floating debris, oil, scum and other matter
- substances producing objectionable colours, odours, taste, or turbidity
- substances and conditions that produce undesirable aquatic life (ANZECC/ARMCANZ, 2000; NH&MRC, 2008).

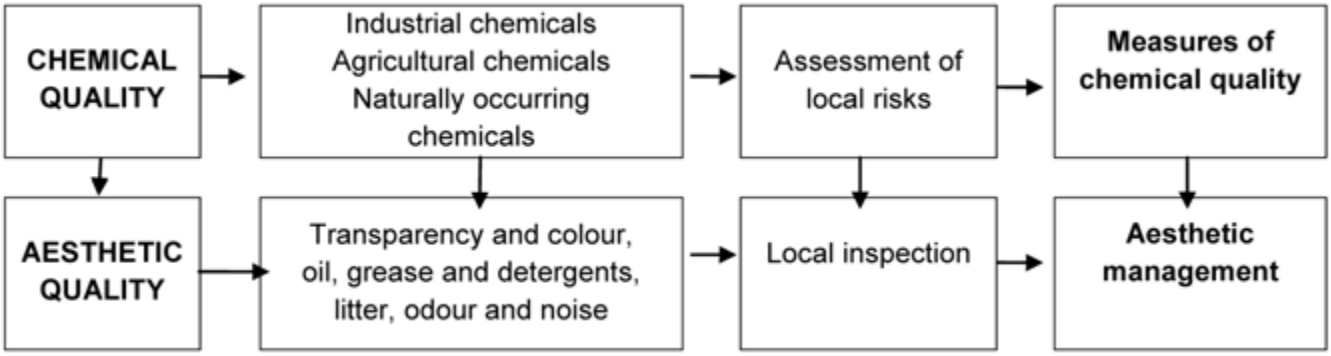



**Figure 8. Adapted from the guidelines for managing risks in recreational water (NH&MRC, 2008)**

### 1.5.3 Framework for irrigation and livestock drinking water

Irrigation and livestock watering are the major agricultural uses of water from the Leichhardt River. Minor amounts of water are used for other production purposes, such as mixing pesticides, fertilisers, veterinary formulations, and livestock dietary supplements. In the Leichhardt River catchment, both the irrigation and livestock industries may also rely on the use of groundwater and surface water resources. Therefore, the ANZECC/ARMCANZ (2010) guidelines for irrigation and livestock drinking water are applicable to both surface and groundwater quality.

The management framework for applying these guidelines includes defining the management aims, determining appropriate trigger values, defining water quality objectives, and establishing a monitoring and assessment program.

### 1.5.4 Framework for protection of aquatic ecosystems

ANZECC/ARMCANZ (2000) water quality guidelines for protecting aquatic ecosystems can be developed by following the generic process shown in Figure 9. There is currently no basis for assigning specific water quality guidelines for the Leichhardt River catchment in the Gulf region of Queensland (QWQG, 2009). Accordingly, it is necessary to follow the process in Figure 9 for deriving site-specific guidelines given by ANZECC/ARMCANZ (2000) and QWQG (2009).

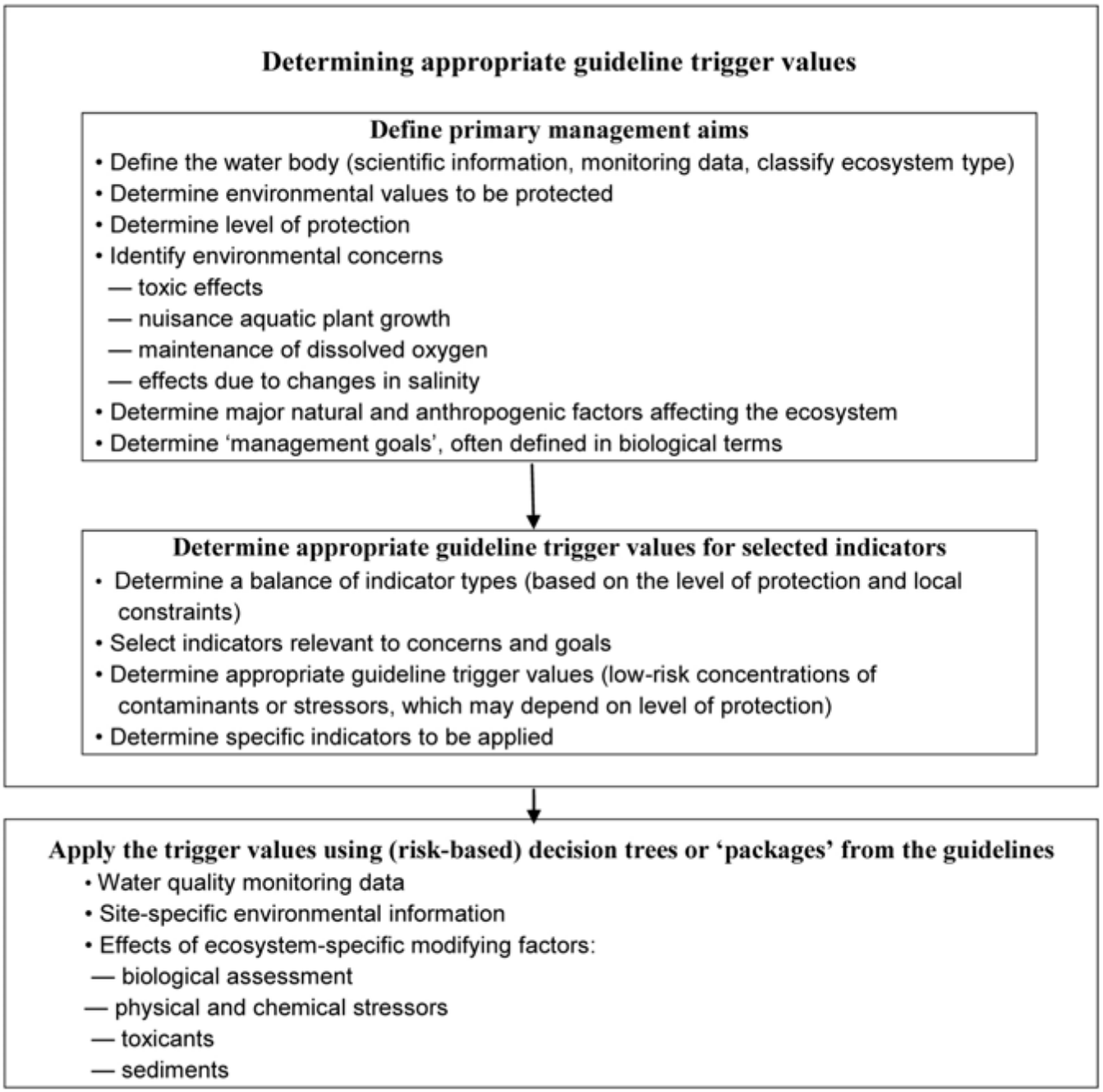
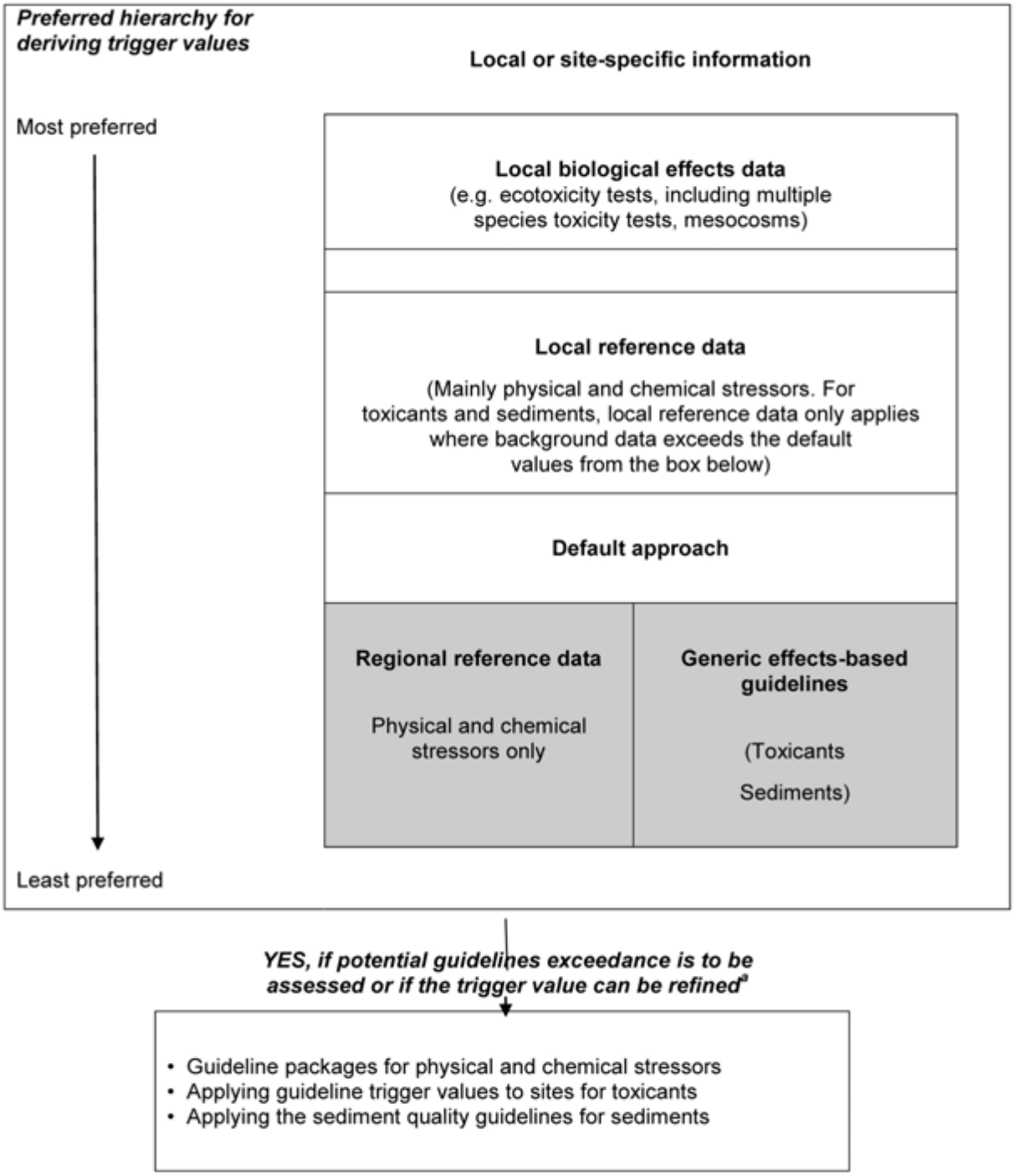



**Figure 9. Flow chart of the steps involved in applying the guidelines for protection of aquatic ecosystems (ANZECC/ARMCANZ, 2000)**

## 1.6 Site-specific risk assessment process

Following the decision process in Figure 9, the next step is to undertake a site-specific risk assessment to identify and assess the significance of all potential contributions of lead and other heavy metals and metalloids that may enter the Leichhardt River and determine the effects on ecological health (Figure 10).




a Local biological effects data and data from local reference site(s) that closely match test site generally not required in the decision trees

**Figure 10. Procedures for deriving and refining trigger values, and assessing test sites, for physical and chemical stressors and toxicants in water and sediment. Dark grey shading indicates most likely point of entry for users requiring trigger values (ANZECC/ARMCANZ, 2000)**

## 1.7 Components of the Phase III study and specific objectives

### 1.7.1 Water quality study

The water quality study aims to identify the major inputs of lead and other metals and metalloids that may be risks to achieving or maintaining designated water qualities. The study area extended from higher in the catchment upstream of the city and Mount Isa Mines to downstream below Lake Moondarra.

The specific objectives of the water quality study component of the Phase III project were to:

- investigate the potential sources and pathways of lead and other heavy metals and metalloids into the Leichhardt River catchment
- determine the contribution of lead and other heavy metals and metalloids in water from all potential sources
- assess the risks of the contaminants to human, irrigation and livestock drinking water and ecological health
- validate the approach of using DGT for assessing the bioavailable metal concentrations that are relevant to the aquatic ecosystem.

### 1.7.2 Sediment quality study

Sediments are a sink for contaminants and influence surface water quality. Sediments can act as a source of contaminants to benthic organisms and can potentially be transferred to the aquatic food chain. Sediments in the Leichhardt River have contaminant loads derived from natural mineralisation and historical mining activities as well as current urban and mining discharges. This study is designed to assess the contaminants in sediments and their sources.

The specific objectives of the sediment study component of Phase III are to:

- determine the nature and extent of lead and other heavy metals and metalloid contaminants in the sediments
- assess the risks of the lead and other heavy metals and metalloid contaminants to human, irrigation and livestock drinking water and ecological health.

### 1.7.3 Water and sediment ecotoxicology study

This study is designed to conduct aquatic toxicity assessments at selected sites (including background and contaminated sites), when trigger values or predictions of bioavailability of lead and other heavy metals and metalloids are exceeded, as described by the ANZECC/ARMCANZ (2000) decision tree processes.

The specific objectives of the water and sediment ecotoxicology study component of Phase III are to:

- determine the nature and extent of toxicity of contaminants in the waters that are relevant to the water quality part of the study
- determine the nature and extent of toxicity of contaminants in the sediments that are relevant to the sediment quality part of the study.

The Phase III study commenced in 2006 and continued until 2011 with most study being undertaken from 2008–2010. The choice and justification of methodologies that were selected are described in the following chapter together with study sites for sampling programs and analytical quality control and assurance procedures.

# 2. Methodology

## 2.1 Selection methods for determining water quality

For the water quality component of the study, the potential sources and pathways of lead and other heavy metals and metalloids into the Leichhardt River catchment were investigated. Water quality measurements associated with the water quality guidelines were taken.

Total elemental concentration data was used to compare against the guidelines for metals and metalloids in drinking water (ADWG, 2004) and in water used for irrigation and livestock (ANZECC/ARMCANZ, 2000). There are no guidelines for metals and metalloids in water used for recreation (NH&MRC, 2008) except that metal and metalloid concentrations should not exceed ten times that of the drinking water criteria.

The assessment of water quality for protecting the aquatic ecosystem required a combination of analytical methods based on following the ANZECC/ARMCANZ (2000) decision-tree process for assessing metal toxicity in water (Figure 11). An initial step in the decision process was to calculate site-specific trigger values for cadmium, copper, chromium, lead, nickel, and zinc by using a correction for hardness, calculated from the calcium plus magnesium concentrations ($CaCO_3$), to the default ANZECC/ARMCANZ guideline value. Aquatic toxicity decreases with increasing water hardness as soluble metal is precipitated. The default trigger value (for a hardness of 30 mg/L $CaCO_3$) can be adjusted for the actual (measured) water hardness values using the simple algorithms given in Appendix 2.

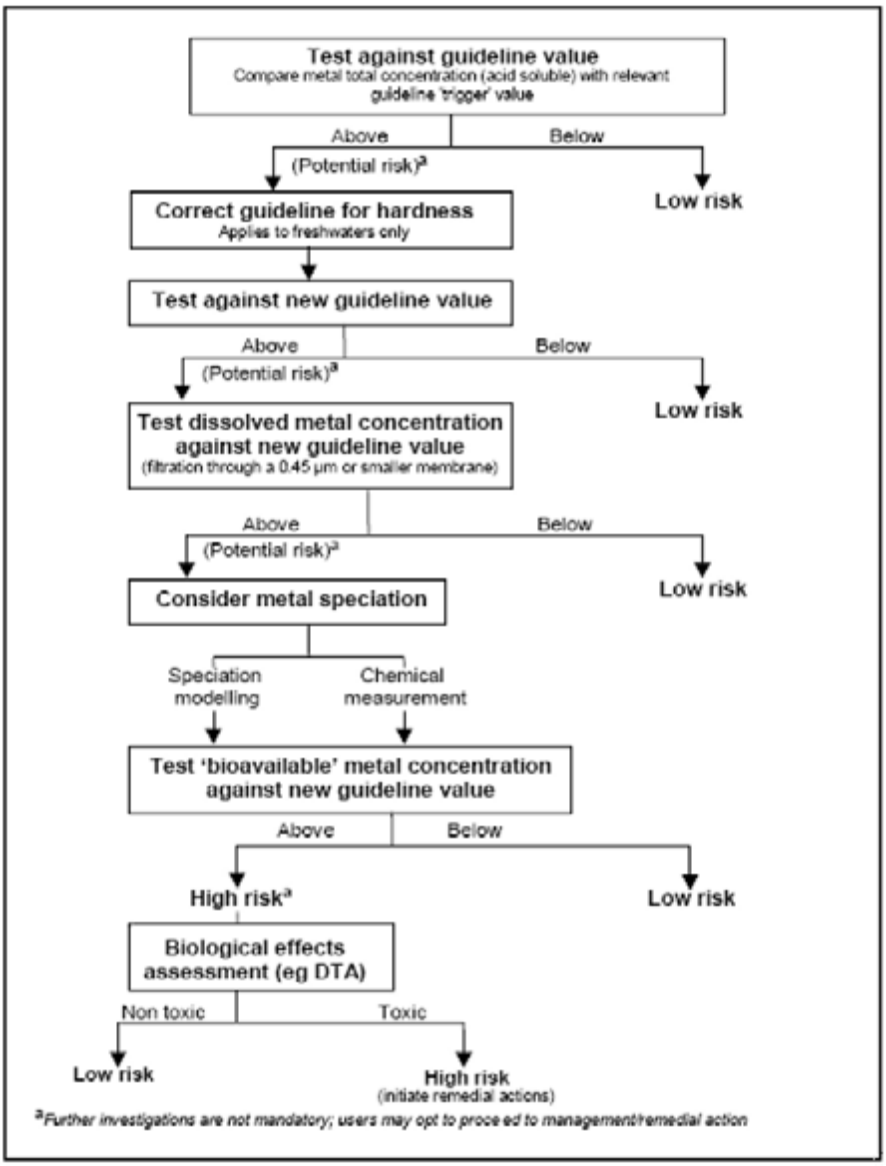



**Figure 11. Generic decision tree for assessing metal toxicant in water (ANZECC/ARMCANZ, 2000)**

The next step in the decision-tree process (Figure 11) used the measurements of metals and metalloids in the filtered (<0.45 µm) fraction (measured by filtration through a 0.45 µm membrane) to determine 'dissolved' concentrations. Following the <0.45 µm filtration step, the bioavailable concentrations of metals and metalloids in waters were predicted by chemical measurement or calculation by speciation modelling. Metals in labile forms were measured using the in situ DGT technique (Section 2.4.1.1) and its measurement is indicated as $C_{DGT}$. Soluble metalloids such as arsenic could not be measured using in situ DGT deployment. Prediction of metal and metalloid speciation in water, particularly for arsenic when the DGT technique could not be used, was determined by the geochemical model program, Visual MINTEQ (USEPA, 1999). The physico-chemical properties of pH, EC, water hardness, and DOC concentrations were input data to the model. Using the in situ DGT deployment enabled a relationship between pH and the chemical forms of the metals and metalloids in the water to be determined. The measured or predicted bioavailable concentration may be used as a further step in the decision process to calculate site-specific trigger values.

Water samples were collected from the Leichhardt River during the pre-wet, wet, and post-wet seasons. Water sampling was also conducted from the three tailings seepage ponds at the bases of Tailing Dams 5, 7, and 8 to determine the total, filtered, and predicted bioavailable metal and metalloid concentrations at potential drainage points to Leichhardt River. However, seepage is, pumped back to the respective dams. An understanding of the concentrations of metals and metalloids in the different fractions of water samples assisted evaluating potential sources of metals and metalloids in the Leichhardt River and its environmental values. During the dry season, levels of suspended solids will increase and cause similar increases to metal and metalloid total concentrations.

## 2.2 Selection methods for determining sediment quality

For sediment quality component of the study, the potential sources and pathways of lead and other heavy metals and metalloids into the Leichhardt River sediment were reviewed. Sediment quality measurements associated with sediment quality guidelines were taken.

Sediment was sampled according to ANZECC/ARMCANZ (2000) to give a <63 µm fraction from each whole collected sediment sample. This gives the most homogenous fraction of the whole sediment sample that is relevant to ecological effects from exposure of biota to metals and metalloids (Noller et al., 2009).

Physical properties of sediment such as grain size and density are important in sedimentation and transport processes. Typically, sediments are characterised as coarse material, clay/silt and sand fractions, on the basis of separations using 2 mm and 63 µm sieves. Particles >2 mm may consist of shells, rocks, wood and other detrital materials, and are usually not a source of bioavailable contaminants. The clay/silt fraction has a high surface area and because of this its surface chemistry is more likely to absorb organic and heavy metal and metalloid contaminants. Particles <63 µm are more commonly found in the gut of sediment-ingesting biota. A significant metal fraction may be present in detrital, mineralized form (i.e. the >2 mm fraction), but this is generally considered of little ecological importance as it is usually unavailable for bioaccumulation (ANZECC/ARMCANZ, 2000).

The decision tree for undertaking sediment quality assessment given in Figure 12 was followed (ANZECC/ARMCANZ 2000) with a focus on identifying the issues and protection measures necessary to manage them. The ANZECC/ARMCANZ (2000) Interim Sediment Quality Guidelines (ISQGs) are trigger values that, if exceeded, prompt further action as defined by the decision tree (Figure 12). The two kinds of trigger levels that are indicated are:

1. ISQG-High, which is defined as the median of effects data from a large sediment toxicity database and represents a concentration above which there is a high probability of biological effects and below which effects are possible.
2. ISQG-Low, which is derived from the lower 10th percentile of toxicity data from a US effects database and represents a concentration below which there is a low probability of effects.

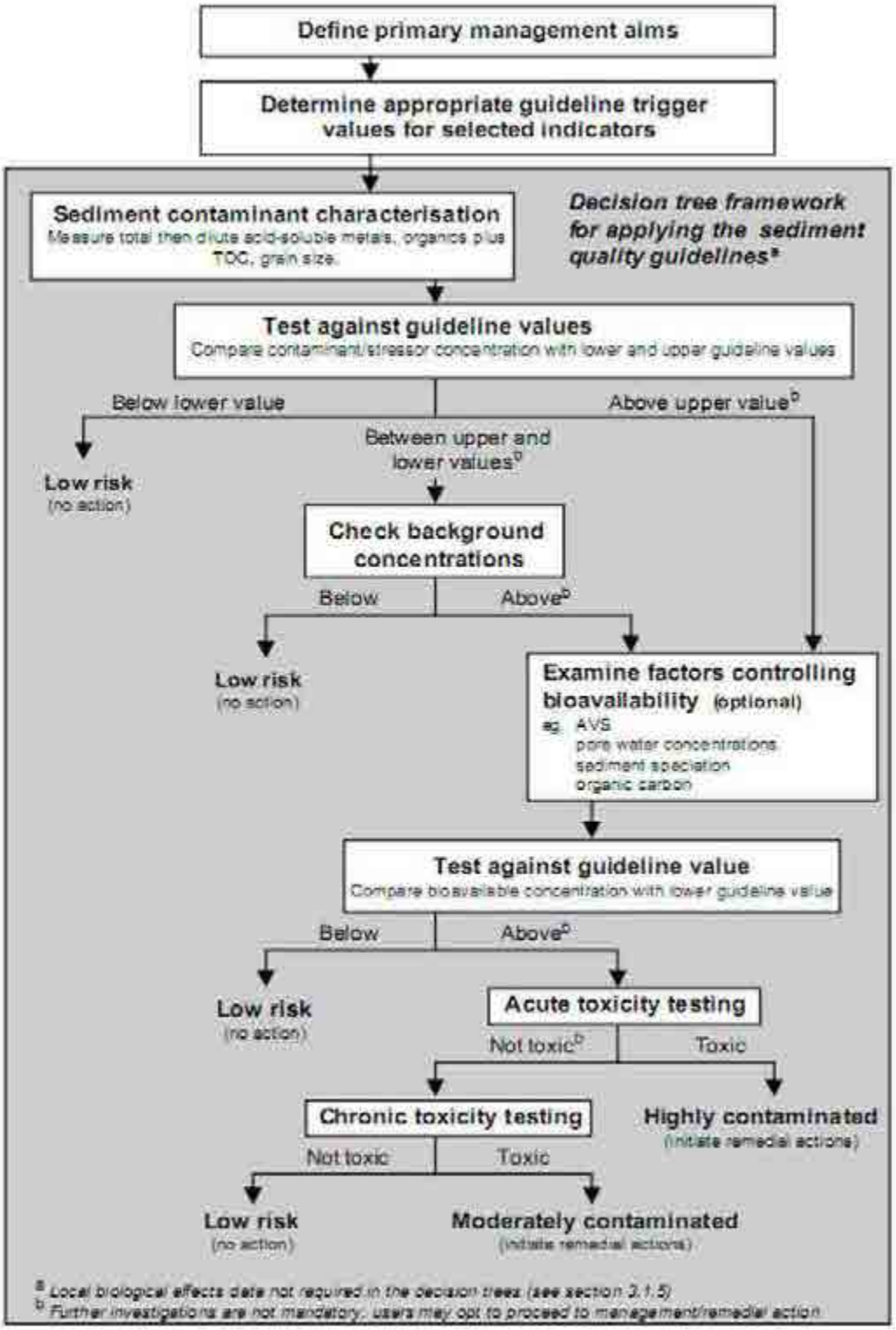



**Figure 12. Decision tree for the assessment of contaminated sediment (ANZECC/ARMCANZ, 2000)**

As a first step, the total metal and metalloid concentrations were compared with the ISQG-High and ISQG-Low trigger values (Table 1). If the low trigger value was exceeded and the concentration was greater than background levels, then management or remedial action or further investigation was required. Further investigation considers the contaminant that is bioavailable in the <63 µm fraction or can be transformed and mobilised into a bioavailable form, allowing comparison of contaminant concentrations adjusted for bioavailability with the ISQG-Low trigger value (Figure 12). In the case of metals and metalloids, the bioavailable concentration was estimated by extraction with cold HCl (ANZECC/ARMCANZ, 2000). This was considered to be a more meaningful measure than the total contaminant concentration, particularly for the Leichhardt River where natural mineralisation in sediment is commonly found (Noller et al., 2009). When the ISQG-Low trigger value was exceeded by the concentration after it was adjusted for predicted bioavailability (by extraction with 1M HCl), acute and chronic toxicity testing was undertaken (Figure 12). Toxicity testing enabled the response of the test organism to the bioavailable fraction in sediment to be assessed and was considered to be the most reliable measure of potential effect of metals and metalloids (Noller et al. 2009).

**Table 1. ANZECC/ARMCANZ ISQG-Low and ISQG-High trigger values for sediments**

| Metal or Metalloid | Sediment ISQG-Low (mg/kg) | Sediment ISQG-High (mg/kg) |
|---|---|---|
| Antimony (Sb) | 2 | 25 |
| Arsenic (As) | 20 | 70 |
| Cadmium (Cd) | 1.5 | 10 |
| Cobalt (Co) | NA | NA |
| Copper (Cu) | 65 | 270 |
| Lead (Pb) | 50 | 220 |
| Manganese (Mn) | NA | NA |
| Nickel (Ni) | 21 | 52 |
| Zinc (Zn) | 200 | 410 |

## 2.3 Selection of methods for assessing aquatic toxicity of water and sediment

The water and sediment ecotoxicology component of the study, the nature and extent of toxicity of contaminants in the waters relevant to the water quality part of the study were determined. The nature and extent of toxicity of contaminants in the sediments relevant to the sediment quality part of the study were also determined.

To protect aquatic ecosystems, the ANZECC/ARMCANZ (2000) guidelines identify the need to protect species that have special significance in the aquatic ecosystem. The guidelines recommend that a suite of organisms is used for aquatic testing. The ANZECC/ARMCANZ (2000) decision trees for assessing contaminated water (Figure 11) and sediment (Figure 12) both indicate that biological effects assessment and acute and chronic toxicity testing may be required when guideline values for metals and metalloids are exceeded. The following sections describe the toxicity testing approaches that were selected for water and sediment. In the first instance, toxicity testing of both water and sediment was undertaken to determine how toxic the media was. When the decision tree water or sediment quality process indicated that effects to aquatic biota are likely, toxicity testing can confirm this. The ecotoxicity data can also be used for subsequent site-specific development of guidelines by showing the sensitivity of different species to both acute and chronic responses of metal constituents in both water and sediment.

### 2.3.1 Toxicity testing of water

The Queensland Environmental Protection Agency (now Queensland Department of Environment and Resource Management (DERM)) has published a guide for direct toxicity assessment of wastewater discharges (QLD EPA, 2009), which is consistent with the ANZECC/ARMCANZ (2000) guidelines. The EPA outlines the following features (QLD EPA, 2009):

1. effluent series dilution
2. normalising for salinity (not important for freshwaters)
3. collection and use of effluent and bulk natural water
4. appropriate species end points
5. acute effects

6. sub-lethal effects
7. chronic effects
8. exposure times
9. appropriate test species.

Selecting suitable test aquatic organisms for toxicity testing is governed by the available species and the fully validated test methods, accepted by DERM, that conform to US Environmental Protection Agency (USEPA, 1994), Organisation of Economic Cooperation and Development (OECD, 2004), and American Society for Testing and Materials (ASTM, 1994) guidelines. For aquatic toxicity testing, it is usually accepted that sensitive end-point species that occupy key steps in the trophic chain are identified (USEPA, 1998). Apart from the need to protect species that have special significance in the aquatic ecosystem, ANZECC/ARMCANZ (2000) criteria recommend that a suite of at least five organisms from at least four taxonomic groups be used with, as a minimum, an invertebrate, a fish, and an alga.

Ecotox Services Australasia (NATA accredited) undertook both the acute and chronic testing using well-validated standardised test methods. The species that were selected for aquatic toxicity testing of water were:

- acute toxicity testing — 48-h EC50 test using the freshwater Cladoceran (*Ceriodaphnia* cf *dubia*) (Bailey et al., 2000; ESA, 2008; USEPA, 2002a)
- 72-h growth inhibition test using the green alga (*Selenastrum capricornutum*) representing two levels of food chain (chronic testing) (ESA, 2010a; USEPA, 2002b)
- 7-d growth inhibition of the freshwater aquatic duckweed *Lemna disperma* (ESA, 2010b; OECD, 2006)
- Fish Imbalance Test (FIT) — modified 96-h acute assay using *Melanotaenia splendida* to observe if fish are stressed or have loss of balance (ESA, 2009; USEPA, 2002a)
- chronic toxicity testing — one test species 7-d reproductive impairment test using the freshwater Cladoceran (*Ceriodaphnia* cf *dubia*) as test species to show longer-term effects on the organism (Bailey et al., 2000; ESA, 2008; USEPA, 2002b).

Water samples for toxicity testing were collected in clean 4 L glass bottles supplied by Ecotox Services Australasia, with chain-of-custody forms and returned within 48 h of collection in eskies containing chilled ice bricks.

### 2.3.2 Toxicity testing of sediment

The Handbook for Sediment Quality Assessment (Simpson et al., 2005) covers a number of aspects of relevance to sediment toxicity testing in tropical locations in Australia. However, the main focus of this reference is marine and estuarine sediments, with a minor section on freshwater sediments. A review of the status of toxicity testing assessment for marine ecosystems by Adams and Stauber (2008) is equally relevant to tropical freshwater category. In this Phase III study, test species were selected based on their availability from Ecotox Services Australasia and their compatibility assessing the aquatic ecosystem of Leichhardt River, particularly the ephemeral sediment habitat.

Before Phase I of the study (Noller et al., 2009), Ecowise (2005, 2006) undertook an extensive aquatic ecosystem monitoring program was undertaken to monitor freshwater fish and macroinvertebrates at six sites in a 60 km section of the Leichhardt River above and below the mine. Ecowise (2005, 2006) followed the Queensland Department of Natural Resources and Mines AusRivAS (Australian River Assessment Scheme) protocols for rapid sampling of macroinvertebrates (NRM, 2001). The results were assessed against reference sites using the Qld AusRivAS model (NRM, 2001). This protocol is based on the ANZECC/ARMCANZ (2000) recommendation to use aquatic macroinvertebrates as the key biological indicator group for assessing the health of Australian rivers and streams.

A total of 51 different macroinvertebrate taxa were collected during the 2005 program (Ecowise 2005, 2006). Of all the macroinvertebrates collected, Insecta were the dominant (38 taxa), followed by Gastropoda (5 taxa) and Crustacea (4 taxa).

There are limitations to using the AusRivAS model with ephemeral streams. Therefore, Ecowise was unable to provide an ecological assessment for the Leichhardt River sites. Advice from NRM highlighted the limited reference data collected from the Mount Isa region and Leichhardt River to develop the models.

Univariate data analysis undertaken by Ecowise (2005, 2006) showed the sites were in moderate to poor ecological condition, with average taxa richness. The seven taxa collected at all sites during both sampling events

were a mixture of moderately sensitive and pollution tolerant taxa. Acarina are considered to be moderately sensitive to poor water quality, while species such as Corixidae and Pleidae are air breathers and are not as susceptible to poor water quality.

During the September sampling event, the two control sites had dried out and the taxa richness was higher at the impact (mine site) and recovery (downstream) sites. This result may be due to the surviving macroinvertebrates finding refuge in deeper waterholes during the dry season where the interaction of predation and competition can markedly alter community composition.

Despite the macroinvertebrate identifications undertaken by Ecowise (2005, 2006), identification of suitable end or test species for aquatic toxicity testing of sediment, for this Phase III study was not clear. The features needed for assessing the aquatic ecosystem of the Leichhardt River, and particularly the dry sediment habitat, are:

- a macroinvertebrate species that burrows and is compatible with high pH (8.0) and reasonable levels of salinity and EC arising from the presence of sulfate and chloride
- a species of macroinvertebrate that exists and emerges in water in contact with sediment and can be a food source to higher species e.g. fish.

In ephemeral waters, many aquatic macroinvertebrates have developed strategies to survive the dry periods when surface water disappears. Many organisms burrow down into the saturated sediments where interstitial water is permanently available. This aspect was considered to be important in selecting a suitable test aquatic organism for toxicity testing of the Leichhardt River sediments. There is no validated aquatic toxicity test protocol for the macroinvertebrate species that exist in tropical northern Australia, including the Leichhardt River catchment. However, *Chironomid* sp. are potentially a suitable tropical species for a test protocol (Smith et al., 1999) and are a suitable test species for tropical conditions as they are a source of food for fish.

Due to a lack of fully validated test methods for tropical aquatic sediment macroinvertebrates that conform to USEPA (1994), ASTM (1994) and OECD (2004) guidelines for sediment toxicity at the time of undertaking the study, an alternative approach was required. Ecotox Services Australasia undertook acute aquatic toxicity testing using three species, based on tests for sediments suggested by ANZECC/ARMCANZ (2000):

- 10-d whole sediment survival toxicity test using the estuarine amphipod *Corophium spp.*, and Test Protocol ESA SOP 109, based on USEPA (1996). *Corophium spp.* is a burrowing organism that is compatible with the high pH found in the Leichhardt River (pH 8.0). It has been fully validated as a test species for both fresh and marine waters, is used internationally, and is sensitive to heavy metals (Surtikanti and Hyne, 2000; USEPA, 1996)
- 48-h acute (survival) toxicity test using the freshwater cladoceran *Ceriodaphnia* cf *dubia* and Test Protocol ESA SOP 101 (Bailey et al., 2000; ESA, 2008), based on USEPA (2002a) and 72-h IC50% concentration of cells for the green alga *Selenastrum capricornutum* (ESA, 2010a) based on USEPA (2002b). These species emerge in water and can be a food source to higher species, including fish. Tests were conducted by Ecotox Services Australasia on elutriate prepared from the dry sediment and according to the US EPA procedure (USEPA, 1991). According to this procedure, sediment is mixed with dilution water at a ratio of 1:4, stirred and allowed to settle for two hours before preparing a dilution series and seeding it with test organisms.
- The reference to the use of dry sediment in these two methods needs to be understood as being moist riverbed sediment collected in situ and kept chilled at 4 °C before dispatch for ecotoxicity measurement. Metal and metalloid concentrations were measured in elutriates from the 2007 sediment tests, but not in the 2009–2010 tests.

The available test species appeared to be good model organisms for sediment toxicity assessment (Noller et al., 2009). However, it has become apparent that *Corophium spp.* as a test species was affected by sharp features of sediment material found in Leichhardt River and caused injury. This meant that there was no burrowing test species available for measuring toxicity of tropical sediments during the remaining period of the study. Therefore, as an alternative, the number of species used to assess toxicity of the water elutriate of sediment was increased.

The chironomid (Diptera) is a well-recognised species suitable for assessing sediment toxicity (Burton, 1991). A sediment toxicity test has been developed to evaluate contaminated Australian freshwater sediments (Smith et al., 1999). A study with chironomid species has also been undertaken to test metal bioavailability from tropical acid sulfate sediments (Peck et al., 2002) and response to tropical acid streams (Cranston et al., 1997). These studies show promise for future applications to bridge the gap of the number of species required to meet the ANZECC/ARMCANZ (2000) guidelines for assessing sediment toxicity (Figure 12).

Chironomids are a potentially suitable burrowing test species for measuring toxicity of the Leichhardt River and is widely accepted internationally as a suitable test organism. Chironomid species have been identified in the Leichhardt River (Ecowise 2005, 2006) and are proposed as suitable test species for future testing of sediment toxicity. Some preliminary evaluation of availability of chironomid species was undertaken in the Leichhardt River in July 2010. A preliminary examination was undertaken of the presence of chironomid species in Leichhardt River sediments and were found at all five sites examined.

### 2.3.3 Bioaccumulation of metals and metalloids in aquatic biota

In August 2010, Xstrata Mount Isa Mines Limited commissioned a study of bioaccumulation of heavy metals and metalloids in fish and aquatic macroinvertebrates in the Leichhardt River in and around Mount Isa (FRC Environmental, 2010). Physico-chemical water quality data and the concentration of 14 metals and metalloids in water, sediment, and biota (fish, crayfish, prawns, crabs, mussels, and algae) were sampled from 12 survey sites in late August and early September 2010 (Appendix 9). Algae, macroinvertebrates (including insects, crustaceans, and molluscs) and fish are key components of aquatic ecosystems and represent a range of trophic levels. They absorb and release metals, passing them through the aquatic food web. Therefore, they are indicators of waterway health and the bioavailability of heavy metals. The results of this project have been incorporated into this Phase III study and contributed to the understanding of heavy metals in Mount Isa waterways.

The study area incorporates the Leichhardt River catchment upstream of Lake Moondarra, and extends downstream approximately 100 km to Lake Julius (Appendix 9). The catchment area included the Mount Isa Mines operations, Mount Isa City, large areas of cattle grazing, and the upstream water supply dam (Rifle Creek Dam) in the headwaters of the catchment. Lake Moondarra, 30 km downstream of Mount Isa, also provides potable water to Mount Isa, with water pumped from the lake into Clear Water Lagoon (immediately adjacent to the lake) for treatment and supply (Section 1.2).

Selected aquatic invertebrates (freshwater crayfish, prawns, crabs, and mussels), fish, algae, sediment and water quality were assessed during the dry season of 2010. Twelve sites were surveyed, including two background sites and 10 test sites (Appendix 9). Results from earlier surveys conducted in 2005 and 1978–1992 were also compared with the 2010 survey (FRC Environmental, 2010).

## 2.4 Bioavailability of metals and metalloids in water

Although the ANZECC/ARMCANZ (2000) water quality guidelines are based on unfiltered and 0.45 µm filtered metal and metalloid concentrations, determining bioavailable fractions of metals in water is recognised as an important way to predict the effects of metals and metalloids on biota. Research has demonstrated that not all dissolved metals in water appear to contribute to acute toxicity (Christiansen et al., 2011). In addition, there are mitigating factors from both environmental and intracellular effects that can result in a decrease in the effective of toxicity of metals and metalloids to aquatic biota. For example, several water quality variables including water hardness, alkalinity, and pH are known to influence the toxicity of metals and metalloids to aquatic biota and these variables are considered to be correction factors in the generic decision tree for assessing metal toxicity (ANZECC/ARMCANZ, 2000). In natural waters, metals and metalloids exist in a variety forms, mostly as cations that are complex by inorganic and organic ligands (Florence, 1982) with a small proportion of free metal ions. It has been reported that the toxicity of metals (e.g. cadmium, copper, iron, and manganese) is proportional to their free ionic activity ($Mz^+$) rather than to the total concentration (Campbell, 1995). The bioavailability of cadmium, copper, and zinc was reduced in the presence of organic chelators (Zamuda et al., 1985). In addition, soluble metal forms that can be disassociated from organic and inorganic ligand-bound metals have been reported as contributing to the toxicity or show uptake by biota (Meyer et al., 2007).

Chemical speciation is key to understanding the reactivity, mobility, bioavailability, and toxicity of metals and metalloids in the aquatic ecosystem (Hamilton-Taylor et al., 2011). Bioavailability is a concept that has been variously defined; however, it is commonly assumed to mean the ability to be taken up by, and cross, a biological membrane (Batley et al., 2004). Meyer (2002) defined the bioavailable fraction as the amount of metal or metalloid in water that is accumulated and correlated well with the observed toxicity in aquatic biota.

### 2.4.1 Techniques to determine bioavailability of metal and metalloids in water

Various analytical techniques have been used to determine metal and metalloid speciation in water, including:

- anodic stripping voltammetry (ASV) (Figura and McDuffie, 1980)
- ion-exchange resins, chromatographic methods (Tills and Alloway, 1983)

- ion-selective electrodes (ISE) (Bakker and Pretsch, 2002)
- competitive chelation (Workman and Lindsay, 1990)
- filtration and ultrafiltration (Buffle et al., 1992).

Most of these methods have limitations from either chemical interference or poor limits of detection and disturbance of solution equilibria (Batley, 1989). Losses of metals may occur through the adsorption onto surfaces of filter in the filtration technique (Batley et al., 2004).

Potentiometric techniques used for determining trace metals free ions were mainly restricted to measuring $Cu^{2+}$ using the ISE (Koryta, 1990). Recently, the ISE technique has been developed and improved in detection limits for $Pb^{2+}$ and $Cd^{2+}$ (Puntener et al., 2004) and $Cu^{2+}$ and $Ag^{+}$ (Bakker and Pretsch, 2002). Voltammetric techniques such as ASV are not species-specific (Mota and Correia dos Santos, 1995) as they measure the electrochemically-labile species of metal in solution. Labile copper determined by ASV was correlated with bioavailable copper (Tubbing et al., 1994 and Lage et al., 1996). However, limitations of the ASV technique include that it is 'non-robust', has adsorptive interferences, has possible artefacts of dissolved oxygen removal, and is unsuitability for in situ application (Batley et al., 2004). Dialysis or filtration techniques work on the principle of only allowing certain species to cross a semi-permeable membrane (Buffle et al., 1992; Cox et al., 1984). Separation can be on the basis of either ion size or charge (Minnich and McBride, 1987). The Donnan Membrane Technique (DMT) is designed to follow the approach of Fitch and Helmke (1989) to determine speciation of metals in soil solution. It involves a continuous flow system in which the donor-side and the acceptor-side of the DMT cell are continuously flushed with solution across the membrane. The free ions in the acceptor-side solution are then determined using ICP (Temminghoff et al., 2000).

Several geochemical models have been used to determine metal and metalloid speciation in solution. Geochemical models rely on chemical equilibrium programs such as GEOCHEM (Parker et al., 1995), MINEQL+ (William and Drew, 1992), MINTEQA (Allison and Brown, 1995) or WinHumic where metal speciation is calculated using known solution composition and making significant assumptions about the interaction of metal with DOC. The WHAM/Model VI (Tipping, 1994) and ECOSAT/NICA-Donnan (Bennedetii et al., 1995) are equilibrium-based models, calibrated using published data on metals and proton binding to fulvic and humic acid. The BLM (Biotic Ligand Model) was developed to incorporate metal speciation and the protective effects of competing cations into predictions of metal bioavailability and toxicity to selected aquatic organisms (Paul et al., 2007). The BLM model has been incorporated in the Environmental Risk Assessment Procedures (USEPA, 2007a) to give freshwater quality criteria of copper.

The following section discusses the rationale of techniques selected for this study including DGT, the geochemical speciation model Visual MINTEQ, and the BLM model that takes metal and natural ligand interactions into account in the prediction.

### 2.4.2 Diffusive Gradients in Thin Films technique

A different approach using DGT was first introduced by Zhang and Davison (1995) to give in situ measurement of soluble trace metal forms in natural water. The DGT technique is based on Fick's First Law of Diffusion. An ion exchange resin layer is separated from the bulk solution by an ion-permeable hydrogel membrane of thickness $\Delta g$ (Figure 13). Metal ions that diffuse through the gel membrane are rapidly bound by the resin gel. If the gradient concentration remains constant during the deployment time (t), the flux of ions diffusing through the gel layer (F) is given by Equation (1) and the concentration of ions in bulk solution (C) can be calculated using Equation (2) (Zhang and Davison, 1995)

$$F = DC/\Delta g \qquad (1)$$

$$C = M\,\Delta g\,/(DtA) \qquad (2)$$

where D is the diffusion coefficient of a given metal ion, A is the area of gel membrane exposed to the bulk solution, and M is the mass of metal accumulated in the resin layer. M is determined from the elution of resin gel by inductively coupled plasma mass spectrometry (ICP-MS).

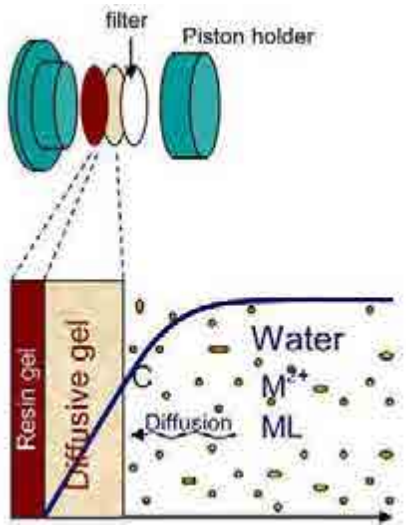



**Figure 13. Schematic representation of diffusive gradient in thin films principle in water (Zhang and Davison, 1995)**

Since 2000, the DGT technique has been used to assess the bioavailable fractions of metals and metalloids, including arsenic cadmium, copper, nickel, lead, and zinc in natural waters. The study by Divis et al. (2007) reported that the concentrations of cadmium, chromium, lead, and zinc measured by DGT were proportionally related to the biological uptake of metals by an aquatic moss *Fontinalis antipyretica* in natural water. The DGT technique was shown to be a surrogate for bioaccumulation of cadmium, copper, lead, and zinc by mussels (Webb and Keough, 2002). The accumulation of copper by the gills of rainbow trout was compared with DGT-measured copper (Luider et al., 2004). Tusseau-Vuillemin et al. (2004) suggested that copper toxicity to *Daphnia magna* could be predicted by the DGT measurement. Aluminium measured by the DGT technique was found to predict the gill uptake of aluminium more accurately than conventional measurements of aluminium. As evidenced by strong linear correlations with the fish physiological response, aluminium increased blood glucose levels and decreased plasma chloride (Røyset et al., 2005). Warnken et al. (2007) suggested that better prediction by the DGT technique was attributed to the measurement being in situ.

In addition, DGTs can be placed directly into sediment and used to give in-situ measurement of metal concentrations in the pore water (Camusso and Gasparella, 2006; Happer et al., 1998). The results from a study on assessing heavy metal pollution and ecotoxicological status of rivers using the DGT technique by Roig et al. (2011) showed a good correlation was found between toxicity values of extracts (from sediments and DGTs) and heavy elements levels in sediments. The results supported the suitability of using combined spot sampling and the DGT technique for assessing the chemical and ecotoxicological status of aqueous environments.

### 2.4.3 Geochemical speciation model – Visual MINTEQ

Speciation modelling provides a means to consider metal and metalloid speciation in the 0.45 µm filtered fraction of the water sample (ANZECC/ARMCANZ, 2000). The soluble and potentially bioavailable forms of metals and metalloids in waters were predicted by calculation using the equilibrium speciation program Visual MINTEQA2 ver 2.61 (update August 2009) to confirm DGT measured concentrations and when the DGT technique was not available (USEPA, 1999). The basic measured chemical properties of the water sample were used. Visual MINTEQ is a Windows-based program of MINTEQ2 version 4, which was released by the Centre of Exposure Assessment Modeling (CEAM) USEPA in 1999. The model incorporates the NICA-Donnan model for predicting the equilibrium-speciation of metal ions and the fraction associated with humic and fulvic substances. The model has been used in previous studies to calculate metals species in water (Wu et al., 2011; Unsworth et al. 2006; Romero and Jonson, 2005); the calculated metal species concentrations were compared with those measured using the DGT technique.

### 2.4.4 Biotic Ligand Model

The toxicity and bioavailability of metals have been recognized as being dependent on water chemistry. The formation of inorganic and organic complexes and sorption on particle surfaces can reduce metal toxicity. Therefore, metal toxicity can be highly variable and depend on ambient water chemistry (Batley et al., 2003). The relationship between metal speciation and toxicity has been used to predict the range of effects on selected species of aquatic biota for site-specific water quality assessment (Batley et al., 2003). The BLM is a mechanistic approach that greatly improves the ability to predict toxicity for certain metals and generate site-specific water quality criteria (ANZECC/ARMCANZ, 2000). The model was developed to incorporate metal speciation and the protective effects of competing cations into predictions of metal bioavailability and toxicity (Di Toro et al., 2001). The BLM is based on the premise that toxicity is primarily related to the amount of metal bound to a biochemical receptor on an organism (e.g. gill membrane in a fish). Many water quality characteristics, including pH, alkalinity, DOC, and hardness, can affect the bioavailability, and thus the toxicity, of a metal such as copper.

The BLM was developed using published information on metal toxicity and biotic ligand accumulation as a function of water chemistry. The Biotic Ligand for copper (Acute copper-BLM) is the most advanced model. Playle et al. (1993) identified that the site of acute toxicity for fathead minnow was the sodium ion uptake channels in the gill membrane. The absorption of copper on gill surfaces in the BLM has been calibrated to measurements of copper accumulation on the gill surfaces over a wide range of water quality conditions (Playle et al., 1992). MacRae et al. (1999) established a dose response relationship to determine the biotic ligand LC50 in rainbow trout. In the BLM, metal toxicity is defined as the amount of metal necessary to result in accumulation at the biotic ligand equal to the biotic ligand LC50. While others models were capable of predicting metal bioaccumulation on the gill in short-term exposures (Playle et al., 1993), the BLM was the first to include aquatic toxicity prediction.

The BLM was used to calculate the chemical speciation of a dissolved metal including complexation with inorganic and organic ligands, and the biotic ligand. The biotic ligand represents a discrete receptor or site of action on an organism where accumulation of metal leads to acute toxicity. The BLM can therefore be used to predict the amount of metal accumulation at this site for a variety of chemical conditions and metal concentrations i.e. the inorganic, organic, and biotic speciation of metals in aquatic settings.

The conceptual framework of BLM defines accumulation of metal at the biotic ligand at, or above, a critical threshold concentration, which leads to acute toxicity. This critical accumulation on the biotic ligand is also termed the LA50, the lethal accumulation of metal on the biotic ligand that results 50% mortality in a toxicological exposure. The LA50 is expressed in units of mol/g wet weight of the biotic ligand. The BLM includes inorganic and organic metal speciation and competitive complexation with the biotic ligand. The amount of dissolved metal required to reach this threshold will vary, depending on the water chemistry. Therefore, the BLM can also be used to predict the concentration of metal that would result in acute toxicity within a given aquatic system. The ability of the BLM to account for site-specific variations in the bioavailability and toxicity of copper has also lead the USEPA to develop a BLM-based approach for calculating the water quality criteria for copper (USEPA, 2007a).

## 2.5 Study sites, sampling program, and analytical test methods for water

### 2.5.1 Study sites for water sampling

A total of 10 sites were chosen for the Leichhardt River sampling (Figure 14):

- three sites upstream — Mica Creek, Leichhardt River upstream, and Rifle Creek Dam (not including DGT sampling)
- four sites within Mount Isa City — 23rd Avenue crossing, east of 19th Avenue crossing, Isa Bridge, and Moondarra Crossing east
- one site at the Moondarra Junction, two sites at the Lake Moondarra and Clear Water Lagoon.

### 2.5.2 Water sampling

Both surface water and water table samples in the riverbed were collected at Moondarra Junction. Three seepage ponds including Tailing Dams 5, 7, and 8 were also included (Figure 14). Samples were collected over the period May 2008 to February 2009 with three sampling times: pre-wet season (November 2008); wet season (January and February 2009); and post-wet season (May 2009). DGT units were deployed in situ at each site and water samples were collected concurrently for the filtration and physico-chemical measurements.

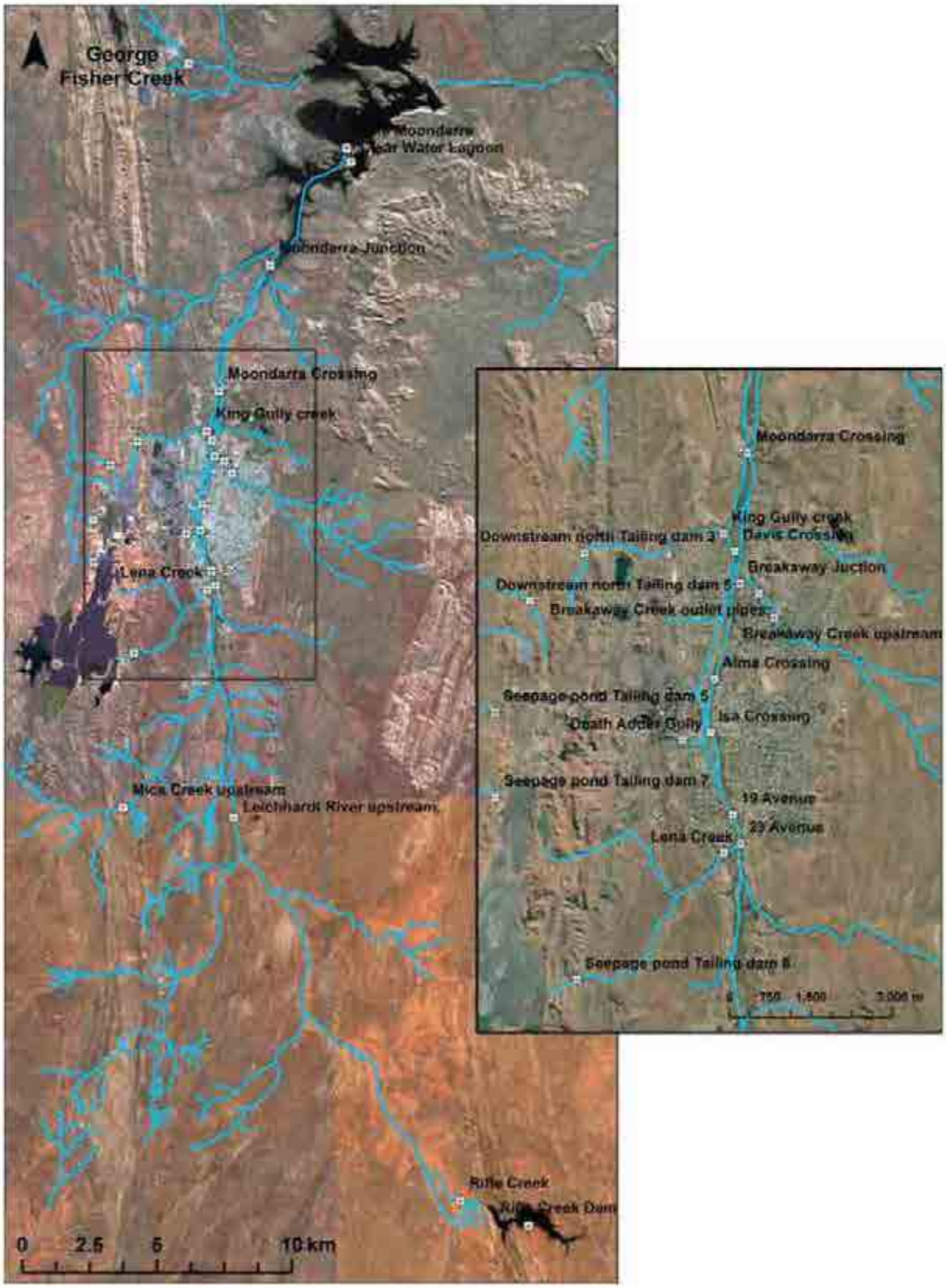



**Figure 14. Study sites for water sampling**

### 2.5.3 Water filtration

An awareness of contamination sources was particularly relevant for all steps in the sampling procedure (e.g. personal hygiene, sweating, and non-smoking). The syringes and filters were rinsed twice with sample water. The first part of the filtered samples was discarded to reduce the chance of contamination from the impurities in the filters and syringe itself. Sample bottles were also rinsed using filtered water.

Water samples were filtered into 75 mL bottles using 0.45 µm disposable filters (Minisart Sartorius) onsite. Approximately 100 mL of water samples were filtered into 150 mL bottles using 0.45 µm filter (polyethersulfone Minisart Sartorius No. 16533) onsite. Unfiltered and filtered samples were preserved with ultra pure nitric acid (to pH <2) before undertaking metals and major cations analysis using ICP-MS. Blanks were also prepared to assess contamination from sampling or filtration processes. All water samples were stored at 4°C until analysed. Another 100 mL of 0.45 µm filtered samples were stored at 4 °C for major anion determinations (sulfate, chloride, nitrate, and total alkalinity for bicarbonate/carbonate). These samples were chilled immediately and kept frozen within 24 h until analyses were undertaken by the Environment Water Section (FSS) of Queensland Health's Scientific Services Laboratories.

### 2.5.4 Measurement physico-chemical properties of water

The pH and EC of water was determined onsite using calibrated field meters. The concentrations of metals and metalloids and major cations in filtered and unfiltered water samples were determined using ICP-MS at the National Research Centre for Environmental Toxicology. The total water hardness was calculated using filtered calcium and magnesium concentration data. The hardness values of water samples were used to adjust the trigger value for aquatic toxicity in fresh water as described by ANZECC/ARMCANZ (2000). Monitoring data for ammonia in water and pH from selected sites was also examined to compare with the ANZECC/ARMCANZ (2000) guideline for ammonia in freshwater.

### 2.5.5 DGT in situ measurement in water

Three to five DGT units (supplied by DGT Research Ltd) and one temperature data logger were deployed in the water column at each site for seven days. Water samples were collected at each site concurrently for metal and water quality analysis and aquatic toxicity testing.

The concentrations of metals in the river water were estimated from the capacity of the gel and the calculated deployment time. In this study, DGT units were deployed in surface river and creek water for seven days and in tailing seepage for five days. The DGT units were tied in PVC cages with holes (Figure 15). Polyester fly mesh was used to cover the ends of the cages to prevent fish damaging the DGT gels. A temperature data logger (HOBO Ware Lite) was deployed at each site to record the water temperature over the period of sampling. The temperature logging interval was set at 30 minutes.

The DGT units were intended for a single use. When they were recovered, the DGT units were rinsed with Milli-Q water and placed into clean ziplock plastic bags and kept cool at 4°C until sample recovery was undertaken at the laboratory. The caps of the DGT units were removed and the resin gel retrieved with plastic tweezers and placed in the acid-washed 1.5 mL vial, adding 1 mL of 1M 'Suprapur' nitric acid solution. Samples of the DGT eluate were analysed by ICP-MS (Appendix 3) to give the concentration of metals in the solution.

The measurement and calculation of metal concentrations by DGT deployment followed the methods described by Zhang et al. (1998) and presented in Section 2.4.1.1. The concentrations of metals in the water (referred to as $C_{DGT}$) were calculated from the eluted concentration using the procedure of Zhang and Davidson (1995) and Zhang et al. (2001).

**Figure 15. DGT in situ deployment**

### 2.5.6 DGT in situ deployment in sediment and effective concentration calculation

Three DGT units (supplied by DGT Research Ltd) and one temperature data logger were deployed in the sediment in the river. The DGT units and temperature data logger (Hobo Ware Lite) were immersed in sediment (at an approximate depth of 2 cm depth) for approximately two days. Sediment samples at each site were collected concurrently for pore water extraction and other analysis including aquatic toxicity, sediment moisture content, sediment quality, and heavy metal concentrations. There were two sites with no water, so sediment samples were collected. The sediment samples were rewetted to the moisture content at 100% according to Hooda et al. (1999) and allowed to equilibrate for 24 h before deployment of the DGT. The DGT window was smeared with moist sediment. Three replicates were carried out for each site. The blank DGTs were carried out by retrieving DGT that were not in contact with soil and analysing them in same way as deployed DGT.

The measurement and calculation of metal concentrations by DGT deployment followed the methods described by Zhang et al. (1998) and was presented in Sections 2.4.1.1 and 2.5.5.

The total dissolved metal (referred to as $C_{SOL}$) of pore water in sediment was extracted by centrifuge from the same sediment samples used to determine $C_{DGT}$ by DGT units. The sediment samples were centrifuged at 1,509 g for five min using an Eppendorf Centrifuge 5818. The centrifuged water was filtered through a 0.45 µm filter and the concentrations of metals were analysed by ICP-MS (Appendix 3). The pore water ($C_{SOL}$) concentrations of metals and metalloids, however, are not directly comparable to the elutriate concentrations (Section 2.3.2).

The concentrations of metals in sediment obtained using DGT (referred to as $C_{DGT}$) was calculated from the eluted concentration using the procedure of Zhang et al. (2004). Temperature data over the deployment time were retrieved from the data logger and average temperature was used to select the diffusion coefficients of metal ions in the DGT gel. These diffusion coefficients were used to calculate the concentration of metals determined by the DGT technique using Equation (2).

To further interpret the DGT measurements in sediment, the $C_{DGT}$ (concentration directly measured by the DGT technique) is converted to an effective concentration ($C_E$) using Equation (3). The $C_E$ represents the hypothetical elemental concentration that is effectively available from the solution-phase and solid-phase.

$$C_E = C_{DGT}/R_{diff} \quad (3)$$

Where, $R_{diff}$ is the ratio of the mean interfacial concentration due to resupply by diffusion ($C_{diff}$) only to the initial or bulk concentration ($C_{SOL}$). $R_{diff}$ is determined by the geometry of the device, deployment time, and sediment tortuosities (Zhang et al., 2001) and calculated using the 2D DIFS (DGT induced fluxes in sediment and soils) model by Harper et al. (1998).

The principles for calculating $C_E$ were described by Zhang et al. (2004). The following parameters were used in the 2D DIFS model to calculate $R_{diff}$ and $C_E$ for five sediment sites (refer to Table 63):

- $P_c$ (particle concentration) = m (soil g) / V ($cm^3$) was 0.9 ± 0.2 $gcm^{-3}$ based on actual values of weight and volume of five sediments wet sediment samples collected concurrently with the DGT unit in situ deployment. Wet samples were weighed and then dried in the oven at 100 °C.
- $D_d$ are the diffusive coefficients of the labile metal species in the diffusion layer (DGT Research Ltd, Lancaster, UK)
- $D_o$ (diffusive coefficients of water) where $D_o=D_d/0.85$ (gel contains 85% water)
- $D_s$ (sediment layer coefficients - $cm^2\ s^{-1}$) where $D_s=D_o/(1-\ln ø_s^2)$
- $ø_s$ (sediment porosity) $=d_p/(P_c+d_p)$ calculated by the DIFS model.

Fixed parameters were used according to Zhang et al. (2004): a large value for $T_c$ (sediment time respond) of $10^{10}$ and a small value for $K_d$ (distribution ratio of sorbed to dissolved concentration at equilibrium) of $10^{-10}$, Δg for standard gel is 0.94 and $d_p$ (density of soil particle) is 2.65 $gcm^{-3}$.

### 2.5.7 Speciation modelling with Visual MINTEQ

Section 2.4.1.3 indicated that speciation modelling with Visual MINTEQ was used when the DGT technique was not available to predict the various metal and metalloid species concentrations in surface water. The input components and parameters (Table 2) used for the speciation calculation in Visual MINTEQ followed the earlier MINTEQ user's manual. Gustafsson (2010) and Wu et al. (2011) used Visual MINTEQ to calculate the metal-humic complexes for cadmium, copper and lead that were present at the lower dissolved organic carbon concentrations.

**Table 2. Summary of input variables for visual MINTEQ speciation modelling.**

| Input variable | Description/ unit/ set up parameters | References |
|---|---|---|
| pH, temperature | Fixed at measured value | |
| Alkalinity | Measured value (mg $CaCO_3$/L) | |
| Dissolved metal concentrations | Concentrations of metals in 0.45 $\mu$m filtered fraction | |
| Major cations | Calcium, magnesium, potassium, sodium | |
| Major anions | Sulfate, chloride, nitrate | |
| Dissolved organic carbon (DOC) | DOM-SHM model (Default values set up of 10% humic acid and 90% fulvic acid) | Martin-Mousset et al., (1997) |

## 2.6 Sampling program, study sites, and analytical test methods for sediment

### 2.6.1 Sediment sampling program

Six sediment sampling programs were conducted in the Leichhardt River from November 2007 to November 2009. A description of the sampling programs is presented in Table 3 and site locations are shown in Figure 16. In 2007, the sediment-sampling program was conducted as part of the Phase I study (Noller et al., 2009). Six sediment samples were collected (L). In October 2009, sediment samples at five sites were assessed for aquatic toxicity (AT) and five samples analysed for metal and metalloids (DGT-S) (Table 3).

Samples of about 1 kg were collected as a composite of five individual sub-samples, using a stainless steel scoop. The samples were contained in polyethylene zip lock bags and forwarded to the Centre for Mined Land Rehabilitation Laboratory. Soil and sediment samples were prepared according to the NEPC (1999), Standards Australia (2005), and ANZECC/ARMCANZ (2000) recommended procedures. Sediments and soils were dried at 60$^0$C. The whole dried soils were initially sieved to separate the <2 mm size material. In 2010 the < 250 µm sized material was used for analysis of bioaccessibility if the sediment posed a human health risk assessment (Noller et al., 2009) (refer to Section 2.7). Ng et al. (2010a,b) stated that the < 250 µm size material is appropriate for bioaccessibility measurement. A portion of the whole dried sediment was then sieved and the <63 µm fraction was retained for analysis.

The dried and sieved sediment samples were digested with aqua regia according to the USEPA (method 200.2) procedure, and the concentrations of metals and metalloids in digested solution was determined by the ALS Laboratory, using ICP-MS and appropriate certified reference materials. Sediment samples (<63 µm fraction) were also extracted with cold 1M HCl according to the ANZECC/ARMCANZ (2000) procedure for sediments. These samples were analysed for metals and metalloids at the ALS Laboratory by ICP-OES to enable comparisons with the ANZECC/ARMCANZ (2000) ISQG-Low trigger values (Table 1).

#### 2.6.1.1 Leichhardt River verification sediment sampling program

In November 2009, Xstrata conducted the Leichhardt River Verification Program along a length of the Leichhardt River, after the Leichhardt River Remediation Program. Seventy-nine sediment samples were collected from Alma Crossing to Moondarra Junction (LR) (Table 3).

**Table 3. Details of the legend on the sampling map**

| Groups | Site descriptions |
|---|---|
| **Water** | |
| DGT-T | In situ DGT deployment in water and water sampling and aquatic toxicity test in October 2009. Site details are presented in Appendix 5, Table A21. |
| DGT-W | In situ DGT deployment in water and water sampling in five seasons (November 2008–June 2010). Site details are presented in Appendix 5, Table A7. |
| T-W | Aquatic toxicity test for water samples collected at Rifle Creek and Rifle Creek Dam. Site details are presented in Appendix 5, Table A21. |
| **Sediment** | |
| L | Sediment samples collected for Phase I study (2007). Site details are presented in Appendix 6, Table A11. |
| DGT-S | In situ DGT deployment in sediment. Site details are presented in Appendix 6, Table A33. |
| T-S | Sediment samples collected concurrently with a toxicity test by CMLR and Xstrata (15–16 October 2009) and Rifle Creek and Rifle Creek Dam. Site details are presented in Appendix 6, Table A21. |
| LR | Leichhardt River verification samples taken along a length of the Leichhardt River (13–14 November 2009). Site details are presented in Appendix 6, Table A12. |
| RB | Regional and background stream sediment sampling program by Xstrata (11 November 2009). Site details are presented in Appendix 6, Table A16. |
| SS | Annual stream sediment samples conducted as part of the Mine Plan Commitments (by Xstrata 11 November 2009). Site details are presented in Appendix 6, Table A16. |

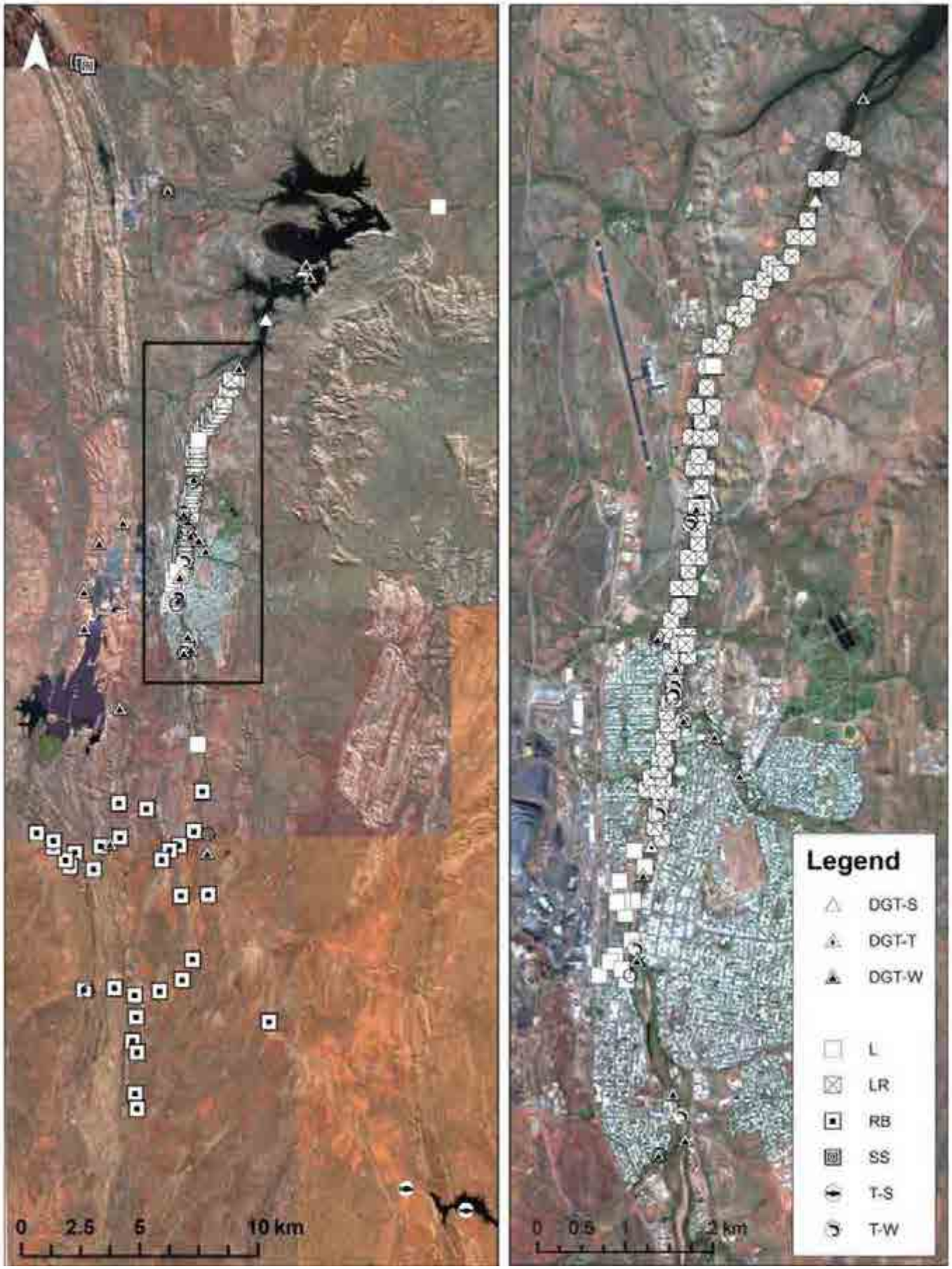



**Figure 16. Water and sediment sampling sites of the study. Details of the legend is presented in Table 3**

#### 2.6.1.2 Regional and background sampling program

The effects-based sediment guidelines currently recommended by ANZECC/ARMCANZ (2000) are primarily based on a single, large biological-effects dataset originating from North American sediment data. With the operations of Xstrata Mount Isa Mines occurring within a unique, semi-arid and naturally mineralised environment, it is unlikely that the current guidelines will be applicable and suitable as an important tool in sediment quality management (QWQG, 2009). Indeed, the ANZECC/ARMCANZ (2000) guidelines themselves suggest that the relevance of the adopted guidelines to Australia is yet to be determined and that the values are to be considered as only interim until verified by new, local data. The purpose of the regional background sediment sampling, undertaken by Xstrata Mount Isa Mines, was to obtain sufficient local data to make a preliminary assessment of sediment background quality for metals and metalloids (Xstrata, 2009). In November 2009, Xstrata conducted the Leichhardt River regional/background sediment sampling program and 29 sediment samples named RB1 to RB 29 were collected.

### 2.6.2 Study sites for sediment sampling

#### 2.6.2.1 Geological character of reference locations for Mount Isa operations

The major geological units that upper catchments underlie the area (Figure 17) in which Xstrata Mount Isa Mines conducts its operational activities including, but not limited to, concentrating and smelting, are the Eastern Creek Volcanics and Myally Subgroup (Conaghan et al., 2003).

In the lower part of the catchments, minerals processing occurs over the Urquhart Shale and the Native Bee Siltstone. As catchment geology and land-use contribute to sediment chemical composition, catchments that contain similar geology to that within the Mount Isa operational area and which have been subjected to minimal disturbance (as far as practicable) have been selected in order to characterise sediment composition within a natural, mineralised environment. The Mica Creek (Figure 18) and Sybella Creek (Figure 19) catchments were selected for sampling. The upper reaches of the Mica and Sybella Creek catchments consist of the Queen Elizabeth Granite and the Eastern Creek Volcanics. The lower reaches of the Mica and Sybella Creek catchments consist of the Myally Subgroup, Breakaway Shale and Native Bee and other siltstones (Figure 20). Unfortunately, due to the Crystallena Fault, extension of the Urquhart Shale into areas of minimal disturbance is not observed. However, the Mica and Sybella Creek catchments remain valid catchments for comparison due to their otherwise similar geological character and the presence of numerous explorative prospects within these areas.

#### 2.6.2.2 Geological character of reference locations for George Fisher and the Handlebar Hill Open Cut

The major geological units that underlie the George Fisher and Handlebar Hill Open Cut operations in the upper catchment areas are the Myally Subgroup and the Eastern Creek Volcanics. The lower areas of the catchments in which George Fisher and Handlebar Hill Open Cut are situated consist of the Breakaway Shale, Urquhart Shale and Moondarra and other siltstones.

In order to detemine background sediment (no-effect) composition from areas that have been subject to minimal disturbance (aside from grazing), and which have similar geological character to those units described above, it was proposed to utilise sediment quality information obtained from Spring Creek as part of the annual stream sediment sampling as conducted per mining plan commitments.

#### 2.6.2.3 Background (no-effect) sample locations

Sediment samples were collected from major creek systems on and surrounding the Mining Lease. A map providing a regional context is presented in Figure 17. The detailed sampling locations are within Mica Creek Catchment (Figure 18); Mid-Leichhardt River (Figure 19), near Leichhardt River and Sybella Creek Junction (Figure 20); within Sybella Creek and upper Sybella catchment (Figure 21) and within Sybella Creek and upper Leichhardt River (Figure 22). Three additional samples were taken at Spring Creek (SPC) Bridge, First SPC Gully, and Second SPC Gully as part of the annual stream sediment program (Figure 17).

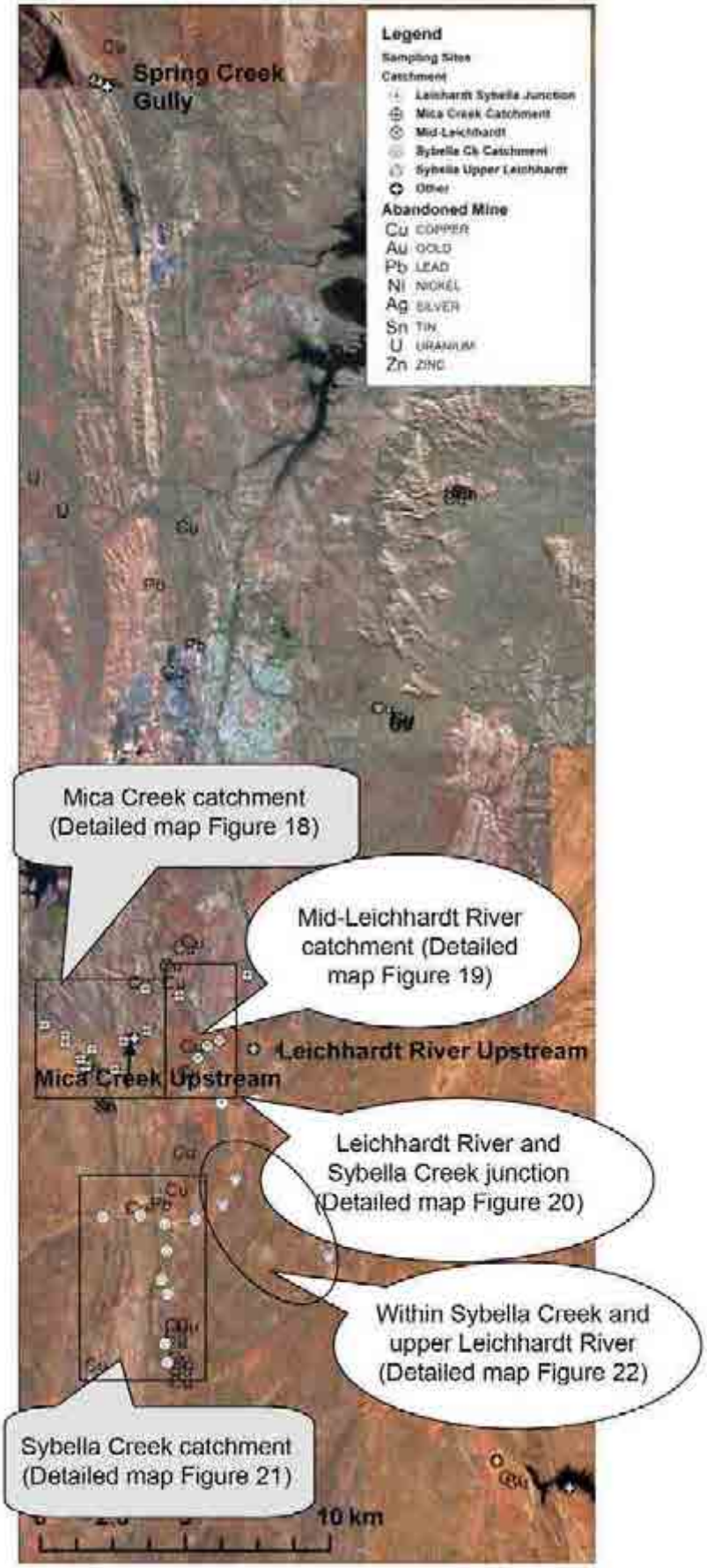



**Figure 17. Sediment sampling locations for regional and background samples, Spring Creek Gully as the annual stream sediment program and Rifle Creek and Rifle Creek Dam sites**

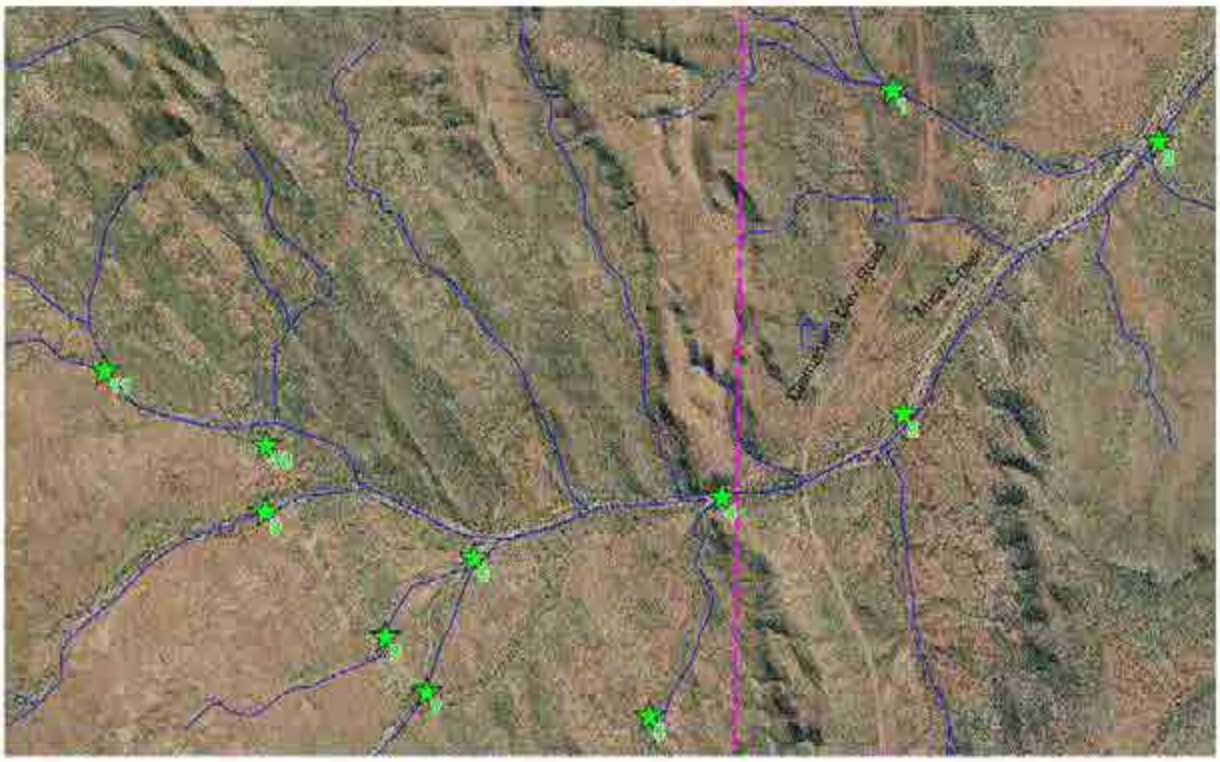



**Figure 18. Sampling locations of regional and background samples within the Mica Creek catchment (RB1-11).**


**Figure 19. Sampling locations of regional and background samples along the mid-Leichhardt River catchment (RB12-16)**


**Figure 20. Sampling locations of regional and background samples near Leichhardt River and Sybella Creek Junction (RB17-18)**

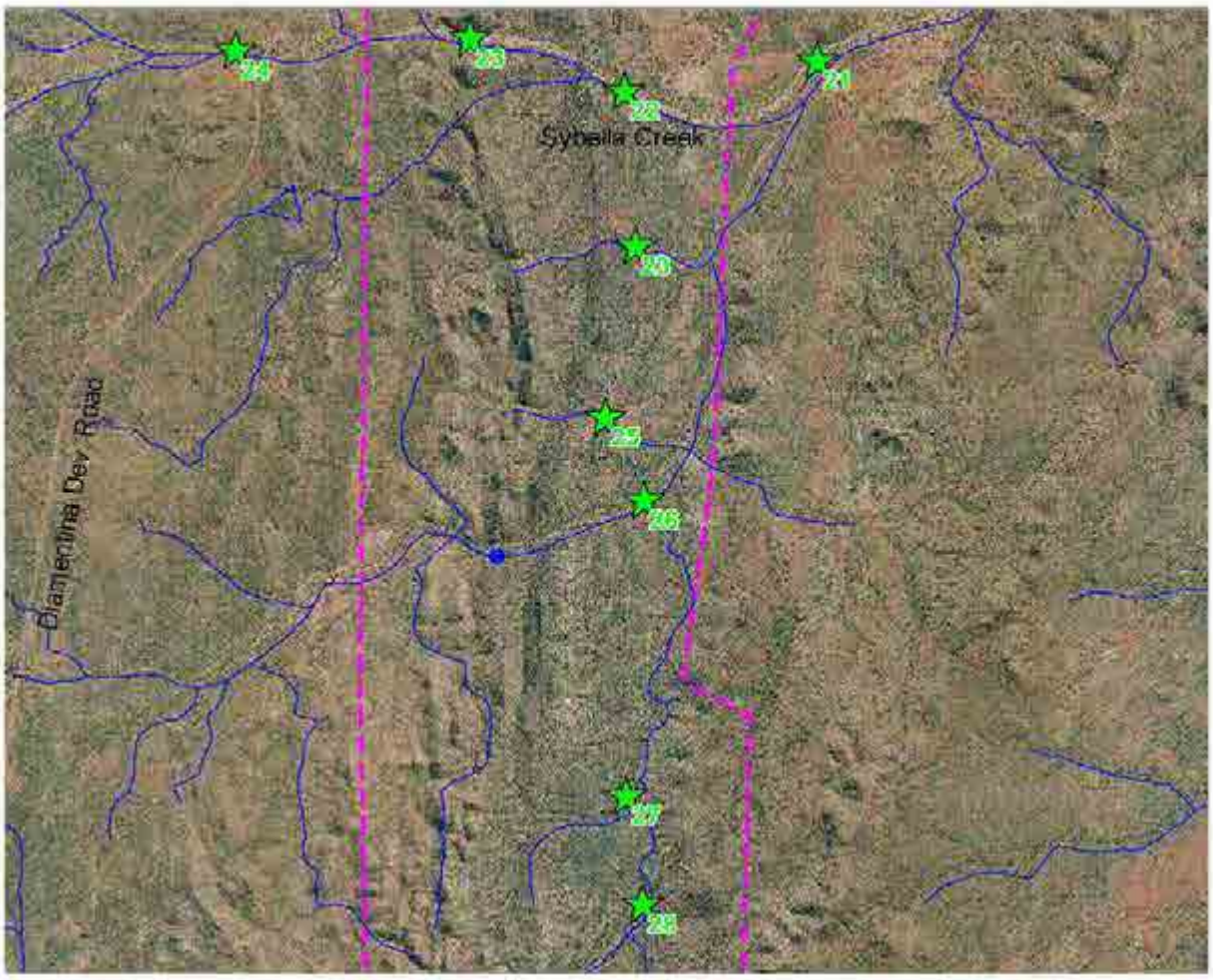



**Figure 21. Sampling locations within Sybella Creek and upper Sybella catchment (RB21-28)**


**Figure 22. Sampling locations within Sybella Creek and Upper Leichhardt River**

## 2.6.3 Analytical testing methods for sediment

### 2.6.3.1 X-ray absorption spectroscopy measurement of lead in sediment samples

Fifteen representative sediment samples collected from upstream to downstream of the Leichhardt River were selected for X-ray absorption spectroscopy (XAS) measurement of lead compound and mineral forms using the synchrotron-induced X-ray absorption near edge spectroscopy (XANES) technique (see Phase II report for further details). The estimated range of lead concentration in these samples was 50–25,000 mg/kg, which included some contaminated sediments from the Phase I report (Noller et al. 1999), which were removed from Leichhardt River in 2008. All samples were analysed for lead concentration using ICP-MS before the XANES analysis. Samples were ground to less than 20 µm and placed in cell holders and covered with X-ray transparent tape (Nitto) for XANES analysis. The scans were recorded for a number of river sediments and lead model compounds. Different model compounds were prepared either directly, or diluted in an X-ray transparent substance, boron nitride. All samples were scanned at room temperature.

Lead L3-edge XANES spectra were collected at the Australian National Beamline Facility (BL-20B) Photon Factory, Tsukuba, Japan, over the energy range 13,000–13,150 eV (ring conditions: 2.5 GeV, 300-400 mA). BL–20B was equipped with a channel-cut Silicon (111) monochromator, which was detuned 50% to reject harmonics. The monochromator step size was reduced to 0.25 eV per step in the XANES region (13,000–13 085 eV) to collect high-resolution spectra. XANES data for samples and model compounds were collected at ambient temperature and pressure in fluorescence, with the simultaneous collection of a lead metal reference foil for energy calibration. The first peak of the first derivative of the spectrum of elemental lead was assumed to be 13,035 eV.

Data analysis was undertaken using the EXAFSPAK suite of programs (George and Pickering, 2000). XANES spectra of model compounds and samples were background subtracted and normalised to edge jump, normalised to the absorbance value of the spline at 13,050 eV. Identification of lead chemical forms (Brown, 1999; Ohmsen, 2001) in the collected samples was achieved using statistical analysis of the lead L3-edge XANES spectra using the linear combination fitting technique. The fitting of linear combination of model spectra to the XANES sample spectra to calculate the percentage composition of lead compounds in each sample was undertaken using the program DATFIT (George and Pickering, 2000).

## 2.7 Health and ecological risk assessment of Leichhardt River sediment and water

The whole dried soils sieved to <2 mm size material and following 2010 to < 250 µm were analysed for total concentrations of metals and metalloids following acid digestion (NEPM Level E) and also for bioaccessibility (%BAc) using PBET (Ruby et al. 1996) for human health risk assessment as described in Noller et al. (2009). Following 2010 the whole dried soils were sieved to <250 µm, based on the recommendation for revision of the NEPM that this size fraction be used for human health risk assessment purposes (Ng et al., 2010 a, b). The results for total concentration were then bioaccessibility adjusted for comparison with NEPM Level E health investigation level for assessing soil contamination (Table 4).

**Table 4. NEPM Soil Investigation Levels (HIL = Health Investigation Level and EIL = Ecological Investigation levels)**

| Metal or Metalloid | Soil HIL (Level A) | Soil HIL (Level D) | Soil HIL (Level E) | Soil HIL (Level F) | Soil EIL (Int Urban) |
|---|---|---|---|---|---|
| Antimony (Sb) | NA | NA | NA | NA | – |
| Arsenic (As) | 100 | 400 | 200 | 500 | 20 |
| Cadmium (Cd) | 20 | 80 | 40 | 100 | 3 |
| Cobalt (Co) | 100 | 400 | 200 | 500 | – |
| Copper (Cu) | 1,000 | 4,000 | 2,000 | 5,000 | 100 |
| Lead (Pb) | 300 | 1200 | 600 | 1,500 | 600 |
| Manganese (Mn) | 1,500 | 6,000 | 3,000 | 7,500 | 500 |
| Nickel (Ni) | 600 | 2,400 | 600 | 3,000 | 60 |
| Zinc (Zn) | 7,000 | 28,000 | 14,000 | 35,000 | 200 |

Level A — Standard residential with garden/accessible soil
Level D — Residential with minimal soil access
Level E — Parks, recreational open space and playing fields including secondary schools
Level F — Commercial/Industrial

### 2.7.1 Health risk assessment of metal and metalloid uptake in aquatic biota from Leichhardt River

The study of bioaccumulation of heavy metals and metalloids in fish and aquatic macroinvertebrates in the Leichhardt River in and around Mount Isa was commissioned by Xstrata Mount Isa Mines Limited in August 2010 (Section 2.3.3: FRC Environmental, 2010). The report by FRC Environmental (2010) also included a health risk assessment of metal and metalloid bioaccumulation in fish and aquatic macroinvertebrates to identify if there were exceedances of the Australian New Zealand Food Standards Code (FSANZ, 2010), which gives the maximum levels of specified metal and metalloid contaminants in foods, including aquatic foods (Table 5). In addition, a health risk assessment was undertaken of particular metal and metalloid bioaccumulation levels in fish and aquatic macroinvertebrates where observed levels are considered to be of significance. The location of sampling sites and data for the health risk assessment on metals in aquatic biota from FRC Environmental (2010) is summarised in Appendix 9.

**Table 5. Australian New Zealand Food Standards Code maximum levels of metals and metalloid contaminants in aquatic foods (FSANZ 2010)**

| Metal or metalloid | Maximum level (mg/kg) |
|---|---|
| Aluminium | N/A |
| Arsenic (inorganic) | |
| Crustacea | 2 |
| Fish | 2 |
| Molluscs | 1 |
| Barium | N/A |
| Cadmium | |
| Molluscs (excluding dredge or bluff oysters and queen scallops) | 2 |
| Copper | N/A |
| Iron | N/A |
| Lead | |
| Fish | 0.5 |
| Molluscs | 2 |
| Manganese | N/A |
| Mercury | |
| Crustacea | Mean level of 0.5* |
| Fish and fish products, excluding gemfish, billfish, southern bluefin tuna, barramundi, ling, orange roughy, rays, and all species of shark | Mean level of 0.5* |
| Gemfish, billfish, southern bluefin tuna, barramundi, ling, orange roughy, rays, and all species of shark | Mean level of 1* |
| Fish for which insufficient samples are available to analyse in accordance with clause (6) of Standard 1.4.1 | 1 |
| Molluscs | Mean level of 0.5 |
| Selenium | N/A |
| Silver | N/A |
| Vanadium | N/A |
| Uranium | N/A |
| Zinc (Zn) | N/A |

* A reference to a mean level is to the mean level of mercury in a minimum of 5 prescribed sample units as described in clause (6) of the FSANZ (2010), Standard 1.4.1. NA = not applicable.

## 2.8 Quality assurance and quality control in metals analysis

The appropriate quality assurance (QA) and quality control (QC) were applied in the metals analysis procedure on the ICP-MS. Triplicate spiked samples were included in the analysis and the recovery of these known addition were determined. Triplicate certified references samples (TM-28.3 and LGC6019) were included in each batch of samples. Triplicate blanks samples were also included to determined the background contaminant levels. Three blank DGT units were included in each batch of DGT deployment. Various certified reference materials were used in conjunction with sediment analyses together with internal standards and repeated samples. Details are given in Appendix 4.

# 3. Results

## 3.1 Study on metals and metalloids in waters

### 3.1.1 Water chemistry

Table 6 summarises the water conditions of all sites during the sampling periods. The upstream sites were generally dry during the pre-wet season with flowing water after the start of the wet season and pooled water in the post-wet season period, until it was completely evaporated. Sites within Mount Isa City had flowing water during the short period of the wet season and pooled water, which sometimes lasted all year. Lake Moondarra, Clear Water Lagoon, and water storage and seepage ponds always retain water, although Lake Moondarra nearly depleted towards the end of 2008. All results for the study on metals and metalloids in water are given in Appendix 5.

**Table 6. Summary of water conditions at the sampling sites**

| Time | Season | Upstream sites | Sites within Mount Isa City | Downstream sites | Sites at creeks/ waterways | Seepage ponds |
|---|---|---|---|---|---|---|
| **Five sampling periods** | | | | | | |
| 29/10/2008 to 7/11/2008 | Pre-wet 2008 | Dry | Pooled water | Flowing water | Dry | Contain water |
| 9/01/2009 to 17/02/2009 | Wet season 2008–09 | Flowing water | Flowing water | Flowing water | Flowing water | Contain water |
| 12/05/2009 to 20/05/2009 | Post-wet 2009 | Pooled water | Flowing water | Flowing water | Pooled water | Contain water |
| 13/01/2008 to 20/01/2008 | Wet season 2010 | Pooled water | Flowing/ pooled water | Flowing water | Flowing/ pooled water | Contain water |
| 21/05/2010 to 01/06/2010 | Post-wet 2010 | Pooled water | Flowing water | Flowing water | Pooled water/ dried | Contain water |
| **Aquatic toxicity and first flush collection** | | | | | | |
| 15/10/2009 to 20/10/2009 | Aquatic toxicity & DGT study | Pooled water | Pooled water | Flowing water | Flowing/ pooled water | Contain water |
| 3/01/2010 | First flush collection | Pooled water | Flowing/ pooled water | Flowing water | Flowing/ pooled water | Contain water |

The water quality data (pH, EC, and water hardness) for water collected over the five sampling periods is presented for Leichhardt River, urban discharge, and tributaries from the mine lease (Table 7) and tailing seepage ponds (Table 8). The pH of water measured at all Leichhardt River sites was alkaline (range 7.0–8.5). The pH of water decreased slightly (0.5 unit) over the sampling period at the 19th Avenue site. However, the pH of water at Alma Crossing increased by 1.0 unit from the wet season to the post-wet season. At other sites, the change in water pH was not significant over the sampling period from pre-wet to post-wet seasons.

The EC gives an estimate of the amount of dissolved salt in the water. The EC of samples at upstream sites (Leichhardt River upstream and Mica Creek upstream) and downstream sites (Moondarra Junction, Lake Moondarra, and Clean Water Lagoon) were low and within the range for drinking water (<1000 µS/cm) (ADWG, 2004). The EC of water sampled at the sites within Mount Isa City (19th Avenue, Isa Crossing, Davis Crossing, Moondarra Crossing, and Moondarra Junction) sampled in the pre-wet and post-wet seasons exceeded the drinking water guideline for EC (ADWG, 2004). The EC values of water at all sites collected in the wet season were significantly lower than those of pre-wet and post-wet season.

The water hardness of water samples collected over five sampling periods is presented in Table 7. The hardness at Leichhardt River sites within Mount Isa City was higher than for sites from upstream and downstream. The hardness of water at the points of urban discharge, the tributaries from the mine lease, and seepage ponds (Table 7) to Leichhardt River was high and variable from season to season.

**Table 7. Summary ranges of pH, EC, and hardness of water over the sampling periods in the Leichhardt River, urban discharge, and tributaries from the mine lease (November 2008–June 2010)**

| Sites | pH | | EC (µS/cm) | | Hardness (mg/L as $CaCO_3$) | |
|---|---|---|---|---|---|---|
| | Range | Median | Range | Median | Range | Median |
| Leichhardt River upstream | 7.3–7.9 | 7.4 | 114–420 | 200 | 32–128 | 84 |
| Mica Creek upstream | 7.5–8.1 | 7.5 | 230–530 | 277 | 21–94 | 58 |
| 19th Avenue | 7.1–8.5 | 8.1 | 690–11,040 | 3,920 | 263–842 | 545 |
| 23rd Avenue | 7.6–8.6 | 8.0 | 192–1,037 | 434 | 123–281 | 161 |
| Isa Crossing | 7.3–8.3 | 8.2 | 189–3,530 | 1,505 | 187–485 | 221 |
| Alma Crossing | 7.3–9.3 | 7.9 | 203–958 | 711 | 51–230 | 149 |
| Davis Crossing | 8.0–8.6 | 8.1 | 2,830–5,900 | 4,336 | 392–873 | 660 |
| Moondarra Crossing | 7.7–8.2 | 8.0 | 350–6,900 | 1,224 | 265–1,096 | 526 |
| Moondarra Junction | 7.7–9.3 | 8.0 | 364–6,900 | 455 | 61–294 | 90 |
| Lake Moondarra | 7.3–8.4 | 8.1 | 253–499 | 303 | 43–122 | 78 |
| Clear Water Lagoon | 7.3–8.4 | 8.0 | 160–322 | 245 | 43–71 | 64 |
| **Urban discharge** | | | | | | |
| Breakaway Creek upstream | 7.5–8.6 | 8.2 | 2,610–7,480 | 4,165 | 501–622 | 580 |
| Breakaway Creek outlet pipes | 7.3–8.2 | 8.0 | 1,697–7,110 | 1,724 | 282–785 | 623 |
| Breakaway Junction | 7.4–8.6 | 8.4 | 1,983–6,220 | 4,990 | 257–524 | 375 |
| **Tributaries from the mine lease** | | | | | | |
| George Fisher Creek | 7.8–9.1 | 8.5 | 153–703 | 334 | 54–264 | 144 |
| King Gully Creek | 7.4–8.2 | 7.8 | 346–1,860 | 1,103 | 94–436 | 265 |
| Lena Creek | 7.6–7.7 | 7.6 | 161 | 161 | 65 | 65 |
| Downstream north Tailing Dam 3 | 8.0 | 8.0 | 345 | 345 | 1,635 | 1,635 |
| Downstream north Tailing Dam 5 | 7.7–8.0 | 7.9 | 451–14,750 | 10,950 | 132–8,468 | 4,300 |

| Sites | pH | EC (µS/cm) | Hardness (mg/L as $CaCO_3$) |
|---|---|---|---|
| Drinking water guideline (ADWG, 2004) | 6.5–8.5 | 746 | N/A |
| Livestock drinking watering guideline (ANZECC/ ARMCANZ, 2000) | N/A | 7,462 | N/A |
| TV for 95% species protection (ANZECC/ ARMCANZ, 2000) | N/A | N/A | N/A |

Degrees of hardness can be described as follows (ANZECC/ARMCANZ, 2000):

- <60 mg/L $CaCO_3$: soft but possibly corrosive
- 60–200 mg/L $CaCO_3$: good quality
- 200–500 mg/L $CaCO_3$: increasing scaling problems
- >500 mg/L $CaCO_3$: severe scaling.

**Table 8. Summary ranges of pH, EC, and hardness of water over the sampling periods in the tailing seepage ponds (November 2008–June 2010)**

| Sites | pH | | EC (µS/cm) | | Hardness (mg/L as $CaCO_3$) | |
|---|---|---|---|---|---|---|
| | Range | Median | Range | Median | Range | Median |
| Seepage pond at Tailing Dam 5 | 7.2–8.4 | 8.3 | 4,260–11,620 | 9,840 | 1,790–5,040 | 3,630 |
| Seepage pond at Tailing Dam 7 | 7.1–8.1 | 7.8 | 6,900–13,300 | 11,700 | 3,310– 6,780 | 6,440 |
| Seepage pond at Tailing Dam 8 | 7.1– 10.4 | 7.8 | 4,120–8,210 | 7,778 | 935–3,180 | 2,450 |

Note: Seepage is controlled.

Table 9 shows the concentrations of major anions and DOC in water samples collected over five sampling periods vary over time. Four sites in the Leichhardt River within Mount Isa City, including 19th Avenue, 23rd Avenue, Davis Crossing, and Moondarra Crossing, had chloride concentrations that exceeded the trigger values for drinking water (ADWG, 2004). The results also show that three sites exceeded the drinking water guidelines for chloride at Breakaway Creek, namely the tributaries downstream north of Tailing Dam 3 and three from the seepage ponds at Tailing Dam 5, Tailing Dam 7, and Tailing Dam 8.

There was a wide range of sulfate concentrations for samples from the Leichhardt River (Table 9). A number of sites exceeded the drinking water guideline for sulfate (ADWG 2004): three sites from the Leichhardt River (19th Avenue, Davis Crossing, and Moondarra Crossing); three sites at the urban discharge (Breakaway Creek); two sites at the tributaries from the mine lease (King Gully Creek and downstream north TD5); and three seepage ponds. None of the sites exceeded the drinking water guideline for nitrate. There is no drinking water guideline for DOC and bicarbonate.

**Table 9. Summary ranges of DOC and major anions in water over the sampling periods (November 2008–June 2010)**

| Sites | DOC | Chloride | Sulfate | Nitrate | Alkalinity mg/L as Bicarbonate |
|---|---|---|---|---|---|
| | (mg/L) | | | | |
| **Leichhardt River** | | | | | |
| Leichhardt River upstream | 3–7 | 10–45 | 10–33 | 0.5–0.9 | 81–140 |
| Mica Creek upstream | 6–10 | 24–40 | 16–30 | 0.5–0.7 | 81–107 |
| 19th Avenue | 3–20 | 102–**1,200** | 72–670 | 0.5–2.5 | 96–440 |
| 23rd Avenue | 4–26 | 10–116 | 15–31 | <0.5 | 57–215 |
| Isa Crossing | 5–22 | 74–308 | 60–254 | 0.5–1.0 | 91–240 |
| Alma Crossing | 5–7 | 55–113 | 95–106 | 0.5–2.6 | 77–174 |
| Davis Crossing | 6–8 | **520–1,220** | 370–**810** | 0.5–9.5 | 273–446 |
| Moondarra Crossing | 4–23 | **604–880** | 436–**520** | 0.5–2.5 | 263–351 |
| Moondarra Junction | 5–8 | 41–51 | 30–37 | 0.5–0.8 | 73–82 |
| Lake Moondarra | 5–9 | 24–34 | 26–30 | 0.5–1.1 | 60–76 |
| Clear Water lagoon | 4–7 | 26–32 | 26–27 | <0.5 | 65–70 |
| **Urban discharge** | | | | | |
| Breakaway Creek upstream | 4–5 | **510–1,630** | **499–962** | 0.5–8.5 | 362–545 |
| Breakaway Creek outlet pipes | 6–11 | 261–**1,560** | 216–**932** | 0.5–2.4 | 228–521 |
| Breakaway Junction | 4–10 | 346–**1,280** | 224–**810** | 0.5–16.0 | 214–463 |
| **Tributaries from the mine lease** | | | | | |
| George Fisher Creek | 5–10 | 6–26 | 16–130 | 0.5–2.7 | 18–41 |
| King Gully creek | 6–8 | 40–180 | 84–**560** | 5.6–18.0 | 42–103 |
| Lena Creek | 5–9 | 13 | 48 | 3.6 | 11 |
| Downstream north Tailing Dam 3 | 7–17 | 52 | 130 | 4.1 | 10 |
| Downstream north Tailing Dam 5 | 17 | 290–**380** | **2,000–9,000** | 23.0–30.0 | 83–356 |
| **Tailing seepage ponds (controlled)** | | | | | |
| Seepage pond at Tailing Dam 5 | 5–18 | **780–828** | **4,900–5,220** | 0.5–20.0 | 382–455 |
| Seepage pond at Tailing Dam 7 | 5–12 | **565–868** | **8,300–7,700** | <0.5 | 259–355 |
| Seepage pond at Tailing Dam 8 | 4–29 | **470–968** | **1,500–3,610** | <0.5 | 45–296 |
| Drinking water guidelines (ADWG, 2004) | – | 300 | 500 | 50.0 | – |
| Livestock watering guideline (ANZECC/ ARMCANZ, 2000) | | – | 1,000 | 400.0 | – |
| TV for 95% species protection (ANZECC/ ARMCANZ, 2000) | | – | – | 700.0 | – |

Note: Bold figures exceed trigger values

### 3.1.2 Nutrients

A limited examination of nutrients (Section 2.5.4) was undertaken to identify if ammonia, in particular, was likely to be a significant toxicant in waste water from the sewage treatment plant that is discharged via Breakaway Creek to the Leichhardt River.

Table 10 gives nutrient concentration data for five sites from Leichhardt River and also compares the ammonia as N concentration for ambient pH with the TV 95% trigger values for 95 % protection for fresh water species (Table 8.3.7 ANZECC/ARMCANZ, 2000). The TV 95% trigger values for 95 % protection for fresh water species is not exceeded for these samples.

**Table 10. Summary of water quality of samples collected 27–28 July 2010**

| Sites | pH | Ammonia as N (µg/L) | TV 95% Amonia-N* (µg/L) | Ammonia as N mg/L | Nitrite as N mg/L | Nitrate as N mg/L | Nitrite + Nitrate as N mg/L | Total Nitrogen as N mg/L |
|---|---|---|---|---|---|---|---|---|
| 23rd Avenue Crossing | 8.1 | 52 | 780 | 0.052 | 0.003 | <0.002 | <0.002 | 0.3 |
| Alma Crossing | 9.3 | 32 | 180 | 0.032 | <0.002 | <0.002 | <0.002 | 0.38 |
| Davis Crossing | 7.8 | <5 | 1180 | <0.005 | 0.127 | 1.97 | 2.1 | 2.49 |
| Moondarra Crossing | 8.4 | 228 | 480 | 0.228 | 0.103 | 0.535 | 0.638 | 1.56 |
| Rifle Creek Dam | 8.6 | 47 | 340 | 0.047 | <0.002 | <0.002 | <0.002 | 0.65 |

*TV 95% trigger values for total ammonia-N at different pH for 95 % protection for fresh water species (Table 8.3.7 ANZECC/ARMCANZ, 2000)

### 3.1.3 Metal and metalloid concentrations in waters

The results for arsenic, cadmium, copper, lead, nickel, and zinc concentrations in water sampled at Leichhardt River, urban discharge, the tributaries the from mine lease, and seepage ponds over five sampling period are presented in Table 11 to Table 22. Metal and metalloid concentrations in the water were determined in three fractions:

1. unfiltered water sample (referred to as total)
2. filtered water sample through 0.45 µm filter
3. the free and labile metal ion concentrations in solution (referred to as $C_{DGT}$), which were sampled by using the DGT technique as described in Section 2.5.5.

The soluble complexed metals may have included labile forms. If the complexed metals were labile, they were measured by the DGT technique. The particulate concentration was the difference between total and the 0.45 µm fractions. In this study, arsenic was not measured by the DGT technique. There is a general decline in metal and metalloid concentrations over time, which may be attributed to the higher flow conditions following the dry period in 2009.

#### 3.1.3.1 Arsenic in waters

Table 11 shows a wide range of arsenic concentrations in two fractions and over the five sampling periods in Leichhardt River. The concentrations of arsenic in Leichhardt River water in the pre-wet season in 2008 were greater than for the other four seasons, due to an abnormally long dry period.

The arsenic concentrations in water sampled at Breakaway Creek, where urban wastewater was discharged to the Leichhardt River (Table 12), show significantly higher levels at Breakaway Creek outlet pipes, compared with sites upstream of Breakaway Creek and at the junction with the Leichhardt River.

Arsenic concentrations in water sampled at the tributaries from the mine lease varied from site to site (Table 11). The highest concentrations of arsenic were found in the creek downstream north of Tailing Dam 3 and in Lena Creek during the wet season in 2010. Arsenic concentrations in the seepage pond at Tailing Dam 5 were higher than those of Tailing Dams 7 and 8.

The total arsenic fraction of all water samples was slightly higher than the 0.45 µm fraction (Table 11). This indicates that the primary forms of arsenic in water sampled at all sites in the <0.45 µm fraction were free or soluble complexes.

#### 3.1.3.2 Cadmium in waters

The results of cadmium concentrations in the water sampled at sites from the Leichhardt River over five sampling periods are presented in Table 13 and show that cadmium concentrations in water at most of the sites were low, being 1 µg/L to less than 0.01 µg/L or below the detection limit, except for the sites at Alma Crossing, Davis Crossing, Moondarra Junction, and Clear Water Lagoon. The cadmium concentrations in water sampled at Davis Crossing were significantly higher than those at others sites over the five sampling periods with a range for total concentrations from 0.7–4.7 µg/L and a corresponding pH range of 8.0–8.6. The dissolved anion concentrations, particularly chloride and sulfate, at Davis Crossing (Table 14) were high and explained why the filtered and soluble cadmium concentrations were 20–70% of the total. In contrast, the maximum cadmium concentration at Clear Water Lagoon sampled, at the start of the wet season in 2009, was 4.2 µg/L as a total, at a pH of 7.3. However, <3% was soluble, indicating that most cadmium was present as particulate matter. At the start of the wet season in 2009, Clear Water Lagoon was almost empty and the water was excessively turbid. Therefore, the high concentration of particulate cadmium was probably present in detritus from the reed bed purification system (Fountain, 1994). The water itself was 0.01 µg/L cadmium and was well below the ADWG (2004) guideline. Monitoring data from the MIWB (2010) confirmed that the cadmium in the potable water in January 2009 was at the detection limit and below the ADWG (2004) guideline.

The concentrations of cadmium in water sampled at Breakaway Creek were low (<0.1 µg/L) (Table 14). However, the concentrations of cadmium in water collected at the tributaries from the mine lease were high in the wet season in 2010 and varied from site to site. The highest total concentrations of cadmium in water were found at the creek downstream north of Tailing Dam 3 (16.4 µg/L); downstream of Tailing Dam 5 (9.9 µg/L); Lena Creek (3.23 µg/L); King Gully Creek (3.5 µg/L); and George Fisher Creek (2.3 µg/L) in the wet season in 2010. The total concentrations of cadmium in seepage at the three seepage ponds at Tailing Dam 5, Tailing Dam 7, and Tailing Dam 8 were all < 1 µg/L, except for seepage at Tailing Dam 7 for the wet season in 2009 (1.2 µg/L).

The total cadmium concentrations of all water samples were significantly higher than the 0.45 µm and $C_{DGT}$ fractions. The results indicate that cadmium was primarily in the particulate fraction. Cadmium in the 0.45 µm fractions was greater than the $C_{DGT}$ concentrations in most of the samples. These results indicate both free and soluble complexed cadmium forms in solution. The proportion of labile to total cadmium in the water was low.

#### 3.1.3.3 Copper in waters

There was a wide range of copper concentrations in the three fractions of water over the five sampling periods in the Leichhardt River (Table 15). The total concentrations of copper in Leichhardt River water varied from 0.5–14.0 µg/L. The highest total concentration of copper (37 µg/L) was found at Moondarra Junction in the pre-wet season in 2008. However, the $C_{DGT}$ copper concentrations at all sites in the Leichhardt River were very low. This can be explained by the high hardness and pH of the water in the Leichhardt River (Table 7). The total concentrations of copper in water sampled at Breakaway Creek ranged from 3–14 µg/ (Table 16). Water at the tributaries from the mine lease had some elevated copper levels, especially the sample collected at the creek downstream of Tailing Dam 3 (817 µg/L) in the wet season in 2010. Total concentrations of copper in seepage were found to be highest at the seepage pond at Tailing Dam 5 for the wet season in 2009 (54.3 µg/L). The total copper concentrations of all water samples were significantly higher than in the 0.45 µm and $C_{DGT}$ fractions. The indicated that copper was primarily in the particulate fraction and was a function of the high pH of the water (Table 7).

#### 3.1.3.4 Lead in waters

The lead concentrations in Leichhardt River water sampled at the pre-wet season in 2008 were higher than for the other four sampling periods (Table 17). The highest total lead concentrations were found at Moondarra Junction (158 µg/L); 23rd Avenue (39 µg/L); and Moondarra Crossing (17.7 µg/L). However, the concentrations of lead in the 0.45 µm filtered and $C_{DGT}$ fractions were significantly lower than the total lead concentrations because of the high pH of the water (Table 7).

The concentrations of lead in water sampled at Breakaway Creek was low and ranged from 0.5–5.0 µg/L (Table 18). Water at the tributaries from the mine lease were found to have high lead concentrations, especially in the sample collected at the George Fisher Creek (444 µg/L) and downstream of Tailing Dam 3 (417 µg/L) in the wet season in 2010. The total concentrations of lead in water at the seepage ponds at Tailing Dams 5, 7, and 8 varied from 1–21 µg/L. The lead concentrations in the 0.45 µm and $C_{DGT}$ fractions were significantly lower than total lead concentrations indicating that lead was primarily in the particulate fraction at all sites.

### 3.1.3.5 Nickel in waters

The nickel concentrations in Leichhardt River water sampled in the pre-wet season in 2008 were higher than for the other four sampling periods (Table 19). The total nickel concentrations in water at the Leichhardt River sites varied from 0.1–7.0 µg/L.

The concentrations of nickel in the water sampled at Breakaway Creek were low and ranged from 0.5–6.0 µg/L (Table 20). Water at the tributaries from the mine lease had low nickel concentration. However, the total concentration of nickel in the water at the seepage ponds at Tailing Dams 5, 7, and 8 in the pre-wet season in 2008 were significantly higher for other sampling periods. The total nickel concentrations were slightly higher than in the 0.45 µm and $C_{DGT}$ fractions. The results indicate that nickel was present primarily in soluble forms in water at all sites.

### 3.1.3.6 Zinc in waters

The total zinc concentrations in Leichhardt River water sampled at the pre-wet season in 2008 were higher than for the other four sampling periods (Table 21). The total zinc concentrations in water at sites in the Leichhardt River varied from 1–67 µg/L.

The concentrations of zinc in the water sampled at Breakaway Creek were of low concentration in the range of 7–15 µg/L (Table 22). Water in the tributaries from the mine lease was found to be high in zinc at the George Fisher Creek site (407 µg/L). The total concentrations of zinc in the waters at the seepage ponds at Tailing Dams 5, 7, and 8 varied from 7–20 µg/L. The zinc concentrations in the 0.45 µm and $C_{DGT}$ fractions were slightly lower than the total zinc concentrations.

**Table 11. Concentrations of arsenic (µg/L) in surface water sampled at Leichhardt River over five sampling periods (November 2008–June 2010)**

| Sites | Fraction | Arsenic (µg/L) | | | | |
|---|---|---|---|---|---|---|
| | | Pre-wet season 2008 | Wet season 2009 | Post-wet season 2009 | Wet season 2010 | Post-wet season 2010 |
| Leichhardt River upstream | Total | – | 0.6 | 0.9 | 1.3 | – |
| | 0.45 µm | – | 0.6 | 0.9 | 1.0 | – |
| Mica Creek upstream | Total | – | 0.9 | 2.5 | 4.9 | – |
| | 0.45 µm | – | 0.9 | 2.5 | 3.4 | – |
| 23rd Ave Crossing | Total | 17.1 | – | 1.2 | 0.8 | 0.9 |
| | 0.45 µm | 13.6 | – | 1.0 | 0.8 | 0.5 |
| 19th Ave Crossing | Total | 9.4 | 0.9 | 1.6 | 1.3 | 0.9 |
| | 0.45 µm | 8.5 | 0.9 | 1.4 | 1.2 | 0.7 |
| Isa Bridge Crossing | Total | 5.2 | 0.9 | 1.5 | 2.3 | 1.5 |
| | 0.45 µm | 6.4 | 0.9 | 1.6 | 2.0 | 0.6 |
| Alma St Crossing | Total | – | 1.5 | 1.3 | 1.5 | 1.4 |
| | 0.45 µm | – | 1.4 | 1.0 | 1.2 | 1.2 |
| Davis Crossing | Total | 7.0 | – | 2.9 | 3.1 | 3.4 |
| | 0.45 µm | 6.8 | – | 2.7 | 2.9 | 1.6 |
| Moondarra Crossing | Total | 21.4 | 1.7 | 2.6 | 5.0 | 2.1 |
| | 0.45 µm | 18.5 | 1.7 | 2.5 | 4.6 | 1.1 |
| Moondarra Junction | Total | 8.0 | 2.4 | 1.5 | 5.0 | 1.3 |
| | 0.45 µm | 5.0 | 2.4 | 1.2 | 4.0 | 1.2 |
| Lake Moondarra | Total | 3.4 | 2.7 | 1.4 | 2.3 | 0.8 |
| | 0.45 µm | 3.3 | 2.6 | 1.2 | 2.1 | 0.6 |
| Clear Water Lagoon | Total | 1.9 | 3.2 | 1.3 | 1.7 | 0.8 |
| | 0.45 µm | 1.9 | 1.1 | 1.1 | 1.6 | 0.6 |

Note: '–' data is not available

**Table 12. Concentrations of arsenic (μg/L) in surface water sampled at Leichhardt River over five sampling periods (November 2008–June 2010)**

| Sites | Fraction | Arsenic (μg/L) | | | | |
|---|---|---|---|---|---|---|
| | | Pre-wet season 2008 | Wet season 2009 | Post-wet season 2009 | Wet season 2010 | Post-wet season 2010 |
| **Urban discharge** | | | | | | |
| Breakaway Creek upstream | Total | – | – | 2.6 | 3.7 | 1.3 |
| | 0.45 μm | – | – | 2.6 | 3.5 | 1.3 |
| Breakaway Creek outlet pipes | Total | – | – | 3.1 | 4.2 | 7.3 |
| | 0.45 μm | – | – | 3.1 | 4.2 | 7.3 |
| Breakaway Junction | Total | – | – | 3.3 | 6.3 | 3.8 |
| | 0.45 μm | – | – | 3.1 | 6.6 | 3.3 |
| **Tributaries from the mine lease** | | | | | | |
| George Fisher Creek | Total | – | – | – | 4.1 | 1.4 |
| | 0.45 μm | – | – | – | 1.3 | 1.0 |
| King Gully Creek | Total | – | – | – | 8.2 | 6.5 |
| | 0.45μm | – | – | – | 4.6 | 4.7 |
| Lena Creek | Total | – | – | – | 12.4 | - |
| | 0.45 μm | – | – | – | 5.3 | - |
| Downstream north Tailing Dam 3 | Total | – | – | – | 26.4 | - |
| | 0.45 μm | – | – | – | 12.6 | - |
| Downstream north Tailing Dam 5 | Total | – | – | – | 11.8 | 2.3 |
| | 0.45 μm | – | – | – | 6.6 | 1.0 |
| **Tailing seepage ponds** | | | | | | |
| Seepage pond at Tailing Dam 5 | Total | 26.4 | 36.0 | 43.8 | 46.6 | 4.9 |
| | 0.45 μm | 25.1 | 35.8 | 42.2 | 44.1 | 3.8 |
| Seepage pond at Tailing Dam 7 | Total | 10.2 | 5.4 | 4.7 | 9.3 | 2.2 |
| | 0.45 μm | 8.1 | 4.3 | 3.4 | 7.5 | 1.7 |
| Seepage pond at Tailing Dam 8 | Total | 2.4 | 2.5 | 1.7 | 7.1 | 6.4 |
| | 0.45 μm | 2.3 | 2.3 | 1.5 | 6.0 | 4.7 |

Note: '–' data is not available

**Table 13. Concentrations of cadmium (μg/L) in surface water sampled in the Leichhardt River over five sampling periods (November 2008–June 2010)**

| Sites | Fraction | Cadmium (μg/L) | | | | |
|---|---|---|---|---|---|---|
| | | Pre-wet season 2008 | Wet season 2009 | Post-wet season 2009 | Wet season 2010 | Post-wet 2010 |
| Leichhardt River upstream | Total | – | <0.01 | 0.03 | – | – |
| | 0.45 μm | – | <0.01 | 0.02 | – | – |
| | $C_{DGT}$ | – | 0.02 | <0.01 | – | – |
| Mica Creek upstream | Total | – | 0.03 | 0.05 | – | – |
| | 0.45 μm | – | 0.03 | 0.06 | – | – |
| | $C_{DGT}$ | – | 0.04 ± 0.0 | <0.01 | – | – |
| 23rd Avenue | Total | <0.01 | - | 0.04 | <0.01 | 0.12 |
| | 0.45 μm | <0.01 | - | 0.03 | <0.01 | 0.06 |
| | $C_{DGT}$ | <0.01 | - | <0.01 | <0.01 | 0.02 |
| 19th Avenue | Total | <0.01 | 0.01 | 0.04 | <0.01 | 0.15 |
| | 0.45 μm | <0.01 | <0.01 | 0.04 | <0.01 | 0.12 |
| | $C_{DGT}$ | <0.01 | 0.07± 0.09 | 0.01 | – | 0.03 |
| Isa Street Crossing | Total | <0.01 | 0.05 | 0.29 | 0.06 | 0.71 |
| | 0.45 μm | <0.01 | 0.04 | 0.16 | <0.01 | 0.19 |
| | $C_{DGT}$ | <0.01 | 0.11 ± 0.01 | 0.13 | <0.01 | 0.15 ± 0.02 |
| Alma Crossing | Total | – | 0.7 | 0.16 | 2.98 | 0.29 |
| | 0.45 μm | – | 0.6 | 0.03 | 2.74 | 0.22 |
| | $C_{DGT}$ | – | – | 0.14 ± 0.09 | 1.22 ± 0.07 | 0.05 |
| Davis Crossing | Total | 3.75 | – | 4.73 | 0.70 | 2.65 |
| | 0.45 μm | 1.22 | – | 3.91 | 0.53 | 0.61 |
| | $C_{DGT}$ | 0.15 ± 0.11 | – | 2.71 ± 0.29 | 0.34 ± 0.16 | 0.08 |
| Moondarra Crossing | Total | 0.206 | 1.85 | 0.23 | <0.01 | 0.18 |
| | 0.45 μm | <0.01 | 1.48 | 0.19 | <0.01 | 0.10 |
| | $C_{DGT}$ | <0.01 | 0.71 ± 0.14 | 0.07 | 0.04 | 0.03 |
| Moondarra Junction | Total | 9.15 | 0.12 | 0.1 | 1.31 | 0.16 |
| | 0.45 μm | 0.46 | 0.08 | 0.05 | <0.01 | 0.12 |
| | $C_{DGT}$ | <0.01 | 0.07 ± 0.01 | 0.01 | <0.01 | 0.02 |
| Lake Moondarra | Total | <0.01 | 1.29 | 0.05 | 0.11 | 0.08 |
| | 0.45 μm | <0.01 | 0.24 | 0.02 | 0.11 | 0.07 |
| | $C_{DGT}$ | <0.01 | 0.07 ± 0.01 | <0.01 | <0.01 | 0.02 |
| Clear Water Lagoon | Total | <0.01 | 4.18 | 0.03 | 0.10 | 0.08 |
| | 0.45 μm | <0.01 | 0.17 | 0.02 | 0.12 | 0.08 |
| | $C_{DGT}$ | <0.01 | 0.02 ± 0.01 | <0.01 | <0.01 | 0.02 ± 0.01 |

Note: '–' data is not available

**Table 14. Concentrations of cadmium (μg/L) in water sampled in creeks (urban discharge, tributaries from the mine lease, and seepage ponds) over five sampling periods (November 2008–June 2010)**

| Sites | Fraction | Cadmium (μg/L) | | | | |
|---|---|---|---|---|---|---|
| | | Pre-wet season 2008 | Wet season 2009 | Post-wet season 2009 | Wet season 2010 | Post-wet season 2010 |
| **Urban discharge** | | | | | | |
| Breakaway Creek upstream | Total | – | – | 0.06 | <0.01 | 0.06 |
| | 0.45 μm | – | – | 0.06 | <0.01 | 0.06 |
| | $C_{DGT}$ | – | – | 0.03 ± 0.01 | <0.01 | 0.03 ± 0.01 |
| Breakaway Creek outlet pipes | Total | – | – | 0.05 | <0.01 | 0.05 |
| | 0.45 μm | – | – | 0.05 | <0.01 | 0.05 |
| | $C_{DGT}$ | – | – | 0.01 | <0.01 | 0.01 |
| Breakaway Junction | Total | – | – | 0.12 | 0.08 | 0.12 |
| | 0.45 μm | – | – | 0.09 | 0.06 | 0.09 |
| | $C_{DGT}$ | – | – | 0.02 | 0.01 | 0.02 |
| **Tributaries from the mine lease** | | | | | | |
| George Fisher Creek | Total | – | – | – | 2.3 | 0.2 |
| | 0.45 μm | – | – | – | 1.3 | 0.2 |
| | $C_{DGT}$ | – | – | – | 0.5 ± 0.05 | 0.05 ± 0.01 |
| King Gully Creek | Total | – | – | – | 3.5 | 5.8 |
| | 0.45 μm | – | – | – | 1.2 | 5.9 |
| | $C_{DGT}$ | – | – | – | 0.37 ± 0.04 | 3.1 ± 0.1 |
| Lena Creek | Total | – | – | – | 3.2 | – |
| | 0.45 μm | – | – | – | 2.7 | – |
| | $C_{DGT}$ | – | – | – | 0.98 ± 0.09 | – |
| Downstream north Tailing Dam 3 | Total | – | – | – | 16.4 | – |
| | 0.45 μm | – | – | – | 16.3 | – |
| | $C_{DGT}$ | – | – | – | 3.05 ± 0.02 | – |
| Downstream north Tailing Dam 5 | Total | – | – | – | 9.9 | 0.8 |
| | 0.45 μm | – | – | – | 8.7 | 0.7 |
| | $C_{DGT}$ | – | – | – | 5.5 ± 0.5 | 0.3 ± 0.01 |
| **Tailing seepage ponds** | | | | | | |
| Seepage pond at Tailing Dam 5 | Total | 0.29 | 0.72 | 0.14 | 0.07 | 0.3 |
| | 0.45 μm | 0.18 | 0.64 | 0.12 | 0.02 | 0.3 |
| | $C_{DGT}$ | 0.11 ± 0.01 | 0.53 ± 0.03 | 0.05 | 0.15 | 0.09 ± 0.01 |
| Seepage pond at Tailing Dam 7 | Total | 0.20 | 1.24 | 0.77 | 0.03 | 0.4 |
| | 0.45 μm | 0.11 | 0.56 | 0.50 | 0.03 | 0.4 |
| | $C_{DGT}$ | 0.06 ± 0.01 | 0.22 ± 0.08 | 0.45 ± 0.01 | 0.09 | 0.1 |
| Seepage pond at Tailing Dam 8 | Total | 0.09 | 0.022 | 0.12 | 0.64 | 0.2 |
| | 0.45 μm | 0.02 | 0.017 | 0.05 | 0.61 | 0.1 |
| | $C_{DGT}$ | 0.01 ± 0.003 | 0.03 | 0.01 | 0.32 ± 0.02 | 0.04 |

Note: '–' data is not available

**Table 15. Concentrations of copper (μg/L) in surface water sampled in the Leichhardt River over five sampling periods (November 2008–June 2010)**

| Sites | Fraction | Copper (μg/L) | | | | |
|---|---|---|---|---|---|---|
| | | Pre-wet season 2008 | Wet season 2009 | Post-wet season 2009 | Wet season 2010 | Post-wet 2010 |
| Leichhardt River upstream | Total | – | 6.2 | 2 | 4.8 | – |
| | 0.45 μm | – | 4.9 | 1.4 | 3.2 | – |
| | $C_{DGT}$ | – | 1.1 ± 0.1 | 0.2 ± 0.03 | 1.1 ± 0.5 | – |
| Mica Creek upstream | Total | – | 15.9 | 5.6 | 5.6 | – |
| | 0.45 μm | – | 11.2 | 4.4 | 3.6 | – |
| | $C_{DGT}$ | – | 3.1 ± 0.6 | 0.5 ± 0.1 | 0.7 ± 0.2 | – |
| 23rd Avenue | Total | 17 | – | 3 | 5.5 | 3.0 |
| | 0.45 μm | 6 | – | 2 | 5.8 | 1.1 |
| | $C_{DGT}$ | 1.5 ± 0.3 | – | 0.4 ± 0.1 | 1.8 ± 0.6 | 0.4 ± 0.1 |
| 19th Avenue | Total | 8.3 | 5.6 | 4.8 | 6.6 | 3.4 |
| | 0.45 μm | 6.9 | 3.3 | 2.6 | 4.7 | 1.2 |
| | $C_{DGT}$ | 1.3 ± 0.2 | 0.9 ± 0.2 | 0.5 ± 0.2 | 0.9 ± 0.2 | 0.3 ± 0.1 |
| Isa Street Crossing | Total | 5.9 | 14.0 | 7.0 | 11.7 | 9.9 |
| | 0.45 μm | 3.9 | 13.3 | 5.4 | 5.4 | 3.3 |
| | $C_{DGT}$ | 0.9 ± 0.1 | 0.9 ± 0.04 | 0.8 ± 0.03 | 0.9 ± 0.1 | 1.7 ± 0.2 |
| Alma Crossing | Total | – | 23.1 | 6.0 | 17.2 | 5.2 |
| | 0.45 μm | – | 18.5 | 2.1 | 8.4 | 4.7 |
| | $C_{DGT}$ | – | – | 0.9 ± 0.04 | 1.7 ± 0.1 | 1.0 ± 0.1 |
| Davis Crossing | Total | 4.9 | – | 4.2 | 12.1 | 5.7 |
| | 0.45 μm | 3.3 | – | 3.0 | 3.8 | 3.7 |
| | $C_{DGT}$ | 0.2 ± 0.1 | – | 0.7 ± 0.1 | 1.4 ± 0.5 | 1.1 ± 0.1 |
| Moondarra Crossing | Total | 13.6 | 11.1 | 5.7 | 8.8 | 3.0 |
| | 0.45 μm | 3.8 | 12.5 | 3.6 | 6.2 | 1.7 |
| | $C_{DGT}$ | 0.1± 0.01 | 1.4 ± 0.1 | 0.8 ± 0.01 | 1.5 ± 0.02 | 0.6 ± 0.02 |
| Moondarra Junction | Total | 37 | 8.8 | 5.4 | 6.2 | 6.6 |
| | 0.45 μm | 2.1 | 6.6 | 3.6 | 7.2 | 5.2 |
| | $C_{DGT}$ | 0.2 ± 0.1 | 1.6 ± 0.1 | 0.9 ± 0.02 | 1.2 ± 0.1 | 0.9 ± 0.2 |
| Lake Moondarra | Total | 4.9 | 30.7 | 5.6 | 4.5 | 1.1 |
| | 0.45 μm | 2.8 | 11.7 | 3.3 | 3.7 | 0.8 |
| | $C_{DGT}$ | 0.7 ± 0.3 | 3.6 ± 0.4 | 0.8 ± 0.04 | 0.6 ± 0.02 | 0.4 ± 0.03 |
| Clear Water Lagoon | Total | 1.5 | 19.5 | 3.9 | 1.8 | 1.7 |
| | 0.45 μm | 1.3 | 1.8 | 1.7 | 1.7 | 1.4 |
| | $C_{DGT}$ | 1.1 ± 0.8 | 0.5 ± 0.1 | 0.2 ± 0.01 | 0.2 | 0.3 ± 0.1 |

Note: '–' data is not available

**Table 16. Concentrations of copper (μg/L) in water sampled at the creeks (urban discharge, tributaries from the mine lease, and seepage ponds) over five sampling periods (November 2008–June 2010)**

| Sites | Fraction | Copper (μg/L) | | | | |
|---|---|---|---|---|---|---|
| | | Pre-wet season 2008 | Wet season 2009 | Post-wet season 2009 | Wet season 2010 | Post-wet season 2010 |
| **Urban discharge** | | | | | | |
| Breakaway Creek upstream | Total | – | – | 7.5 | 5.5 | 10.8 |
| | 0.45 μm | – | – | 2.9 | 4.1 | 7.6 |
| | $C_{DGT}$ | – | – | 0.6 ± 0.1 | 0.5 ± 0.2 | 1.0 ± 0.1 |
| Breakaway Creek outlet pipes | Total | – | – | 7.4 | 10.0 | 3.7 |
| | 0.45 μm | – | – | 2.5 | 8.3 | 2.9 |
| | $C_{DGT}$ | – | – | 0.6 ± 0.1 | 1.6 ± 0.4 | 1.8 ± 0.4 |
| Breakaway Junction | Total | – | – | 8.3 | 13.7 | 8.4 |
| | 0.45 μm | – | – | 2.9 | 11.2 | 6.3 |
| | $C_{DGT}$ | – | – | 0.6 ± 0.1 | 1.7 ± 0.1 | 1.7 ± 0.5 |
| **Tributaries from the mine lease** | | | | | | |
| George Fisher Creek | Total | – | – | – | 42.7 | 9.8 |
| | 0.45 μm | – | – | – | 11.5 | 5.3 |
| | $C_{DGT}$ | – | – | – | 2.7 ± 0.2 | 1.6 ± 0.6 |
| King Gully Creek | Total | – | – | – | 318 | 154 |
| | 0.45 μm | – | – | – | 102 | 96 |
| | $C_{DGT}$ | – | – | – | 15 ± 1 | 27 ± 1 |
| Lena Creek | Total | – | – | – | 310 | – |
| | 0.45 μm | – | – | – | 134 | – |
| | $C_{DGT}$ | – | – | – | 28 ± 2 | – |
| Downstream north Tailing Dam 3 | Total | – | – | – | 817 | – |
| | 0.45 μm | – | – | – | 355 | – |
| | $C_{DGT}$ | – | – | – | 132 ± 2 | – |
| Downstream north Tailing Dam 5 | Total | – | – | – | 305 | 23.9 |
| | 0.45 μm | – | – | – | – | 14.4 |
| | $C_{DGT}$ | – | – | – | 65 ± 5 | 2.6 ± 0.4 |
| **Tailing seepage ponds** | | | | | | |
| Seepage pond at Tailing Dam 5 | Total | 30.8 | 54.3 | 24.0 | 28.5 | 27.9 |
| | 0.45 μm | 23.0 | 33.8 | 17.2 | 24.2 | 6.4 |
| | $C_{DGT}$ | 5.7 ± 0.4 | 16.8 ± 6.7 | 3.4 ± 0.1 | 5.6 ± 0.2 | 1.9 ± 0.6 |
| Seepage pond at Tailing Dam 7 | Total | 13.1 | 12.7 | 15.3 | 9.9 | 7.7 |
| | 0.45 μm | 6.8 | 7.3 | 12.0 | 7.6 | 5.0 |
| | $C_{DGT}$ | 0.7 ± 0.1 | 2.8 ± 0.4 | 3.1 ± 0.2 | 1.3 ± 0.1 | 1.2 ± 0.3 |
| Seepage pond at Tailing Dam 8 | Total | 7.2 | 6.9 | 6.5 | 8.4 | 11.9 |
| | 0.45 μm | 3.4 | 3.0 | 6.5 | 6.8 | 4.5 |
| | $C_{DGT}$ | 0.04 | 1.1 ± 0.8 | 0.33 | 1.3 ± 0.1 | 1.2 ± 0.1 |

Note: '–' data is not available

**Table 17. Concentrations of lead (μg/L) in surface water sampled at the Leichhardt River over five sampling periods (November 2008–June 2010)**

| Sites | Fraction | Lead (μg/L) | | | | |
|---|---|---|---|---|---|---|
| | | Pre-wet season 2008 | Wet season 2009 | Post-wet season 2009 | Wet season 2010 | Post-wet 2010 |
| Leichhardt River upstream | Total | – | 1.0 | <0.3 | 1.6 | – |
| | 0.45 μm | – | 0.5 | <0.3 | 0.1 | – |
| | $C_{DGT}$ | – | 0.4 | <0.03 | <0.03 | – |
| Mica Creek upstream | Total | – | 1.3 | 1.2 | 3.2 | – |
| | 0.45 μm | – | 0.5 | 0.3 | 2.1 | – |
| | $C_{DGT}$ | – | 0.4 | <0.03 | 0.07 ± 0.02 | – |
| 23rd Avenue | Total | 39 | – | 0.5 | 0.9 | 1.3 |
| | 0.45 μm | 6 | – | 0.3 | 0.3 | 0.5 |
| | $C_{DGT}$ | <0.04 | – | <0.03 | – | 0.04 |
| 19th Avenue | Total | 0.4 | 0.2 | 0.2 | 1.5 | 1.6 |
| | 0.45 μm | <0.4 | 0.1 | <0.3 | 0.4 | 0.7 |
| | $C_{DGT}$ | 0.1 4 ± 0.06 | 0.03 ± 0.02 | <0.03 | – | 0.05 ± 0.01 |
| Isa Street Crossing | Total | 5.7 | 0.8 | 1.2 | 4.7 | 2.8 |
| | 0.45 μm | 0.2 | 0.3 | 0.5 | 0.4 | 0.6 |
| | $C_{DGT}$ | 0.04 ± 0.02 | 0.03 ± 0.02 | <0.03 | <0.03 | 0.06 ± 0.01 |
| Alma Crossing | Total | – | 6.6 | 2.0 | 4.1 | 1.0 |
| | 0.45 μm | – | 1.8 | <0.3 | 0.7 | 0.4 |
| | $C_{DGT}$ | – | – | <0.03 | <0.03 | 0.06 ± 0.04 |
| Davis Crossing | Total | 3.9 | – | 1.4 | 10.5 | 1.8 |
| | 0.45 μm | 0.6 | – | <0.3 | 0.1 | 1.3 |
| | $C_{DGT}$ | <0.04 | – | <0.03 | 2.6 ± 0.5 | 0.04 |
| Moondarra Crossing | Total | 17.7 | 2.2 | 5.6 | 3.9 | 0.4 |
| | 0.45 μm | 2.8 | 0.4 | 0.5 | 0.04 | 0.8 |
| | $C_{DGT}$ | 0.3 ± 0.2 | 0.04 ± 0.01 | <0.03 | 0.03 ± 0.03 | 0.05 ± 0.03 |
| Moondarra Junction | Total | 158 | 2.4 | 4.7 | 2.2 | 3.5 |
| | 0.45 μm | 2.4 | 0.5 | <0.3 | 0.8 | 0.6 |
| | $C_{DGT}$ | 0.11 ± 0.03 | 0.04 ± 0.01 | <0.03 | 0.03 ± 0.01 | 0.03 |
| Lake Moondarra | Total | 6.8 | 4.6 | 2.5 | 3.3 | 0.6 |
| | 0.45 μm | <0.4 | 1.9 | <0.3 | 1.5 | 0.7 |
| | $C_{DGT}$ | 0.09 | 0.1 ± 0.04 | <0.03 | 0.3 ± 0.01 | 0.03 |
| Clear Water Lagoon | Total | <0.4 | 3.9 | 1.4 | 1 | 0.77 |
| | 0.45 μm | <0.4 | 0.1 | <0.3 | 1.5* | – |
| | $C_{DGT}$ | <0.04 | 0.01 ± 0.0 | <0.03 | 0.4 ± 0.02 | <0.03 |

Notes:
'–' data is not available.
* may have been contaminated during filtration

**Table 18. Concentrations of lead (μg/L) in water sampled at the creeks (urban discharge, tributaries from the mine lease, and seepage ponds) over five sampling periods (November 2008–June 2010)**

| Sites | Fraction | Lead (μg/L) | | | | |
|---|---|---|---|---|---|---|
| | | Pre-wet season 2008 | Wet season 2009 | Post-wet season 2009 | Wet season 2010 | Post-wet season 2010 |
| **Urban discharge** | | | | | | |
| Breakaway Creek upstream | Total | – | – | 0.6 | 3.2 | 0.7 |
| | 0.45 μm | – | – | <0.3 | 0.3 | 1.3 |
| | $C_{DGT}$ | – | – | <0.03 | 0.04 | 0.07 ± 0.01 |
| Breakaway Creek outlet pipes | Total | – | – | 0.7 | 5.1 | 0.5 |
| | 0.45 μm | – | – | <0.3 | 3.4 | 0.4 |
| | $C_{DGT}$ | – | – | <0.03 | 0.08 ± 0.04 | 0.12± 0.05 |
| Breakaway Junction | Total | – | – | 1.9 | 3.4 | 2.0 |
| | 0.45 μm | – | – | <0.3 | 1.4 | 0.6 |
| | $C_{DGT}$ | – | – | <0.03 | 0.07 ± 0.02 | 0.1 |
| **Tributaries from the mine lease** | | | | | | |
| George Fisher Creek | Total | – | – | – | 444 | 0.7 |
| | 0.45 μm | – | – | – | 21 | – |
| | $C_{DGT}$ | – | – | – | 3.8 ± 0.3 | 0.2 ± 0.1 |
| King Gully Creek | Total | – | – | – | 191 | 129 |
| | 0.45 μm | – | – | – | 8 | 52.4 |
| | $C_{DGT}$ | – | – | – | 0.4 ± 0.04 | 13 ± 1.6 |
| Lena Creek | Total | – | – | – | 108 | – |
| | 0.45 μm | – | – | – | 13 | – |
| | $C_{DGT}$ | – | – | – | 0.7 ± 0.03 | – |
| Downstream north Tailing Dam 3 | Total | – | – | – | 417 | – |
| | 0.45 μm | – | – | – | 138 | – |
| | $C_{DGT}$ | – | – | – | 24 ± 2 | – |
| Downstream north Tailing Dam 5 | Total | – | – | – | 159 | 26.8 |
| | 0.45 μm | – | – | – | 180 | 1.3 |
| | $C_{DGT}$ | – | – | – | 18.3 ± 1.2 | 0.2 ± 0.1 |
| **Tailing seepage ponds** | | | | | | |
| Seepage pond at Tailing Dam 5 | Total | 21.0 | 11.1 | 5.2 | 9.4 | 15.0 |
| | 0.45 μm | 6.4 | 1.4 | 1.6 | 3.5 | 1.6 |
| | $C_{DGT}$ | 1.24 ± 0.12 | 0.59 ± 0.35 | 0.23 | 1.75 ± 0.11 | 0.2 ± 0.12 |
| Seepage pond at Tailing Dam 7 | Total | 9.17 | 6.65 | 5.25 | 5.34 | 2.84 |
| | 0.45 μm | 1.56 | 0.61 | 0.07 | 0.57 | 0.81 |
| | $C_{DGT}$ | 0.17 ± 0.02 | 0.08 ± 0.01 | <0.03 | 1.24 ± 0.06 | 0.06 ± 0.01 |
| Seepage pond at Tailing Dam 8 | Total | 1.22 | 0.59 | 2.80 | 33.03 | 1.05 |
| | 0.45 μm | <0.4 | 0.11 | 0.85 | 14.08 | 0.27 |
| | $C_{DGT}$ | <0.04 | 0.04 ± 0.02 | <0.03 | 3.98 ± 0.22 | 0.25 ± 0.05 |

Note: '–' data is not available

**Table 19. Concentrations of nickel (μg/L) on surface water sampled in the Leichhardt River over five sampling periods (November 2008–June 2010)**

| Sites | Fraction | Nickel (μg/L) | | | | |
|---|---|---|---|---|---|---|
| | | Pre-wet season 2008 | Wet season 2009 | Post-wet season 2009 | Wet season 2010 | Post-wet 2010 |
| Leichhardt River upstream | Total | – | 2.4 | 2.1 | 0.8 | – |
| | 0.45 μm | – | 2.3 | 2.2 | 0.9 | – |
| | $C_{DGT}$ | – | 0.6 ± 0.1 | 0.3 ± 0.03 | 0.5 ± 0.2 | – |
| Mica Creek upstream | Total | – | 2.1 | 2.6 | 8.3 | – |
| | 0.45 μm | – | 2.1 | 2.2 | 1.8 | – |
| | $C_{DGT}$ | – | 0.9 ± 0.3 | 0.6 ± 0.1 | 0.4 ± 0.1 | – |
| 23rd Avenue | Total | 5.5 | – | 2.2 | 0.5 | 0.93 |
| | 0.45 μm | 5 | – | 2.1 | 0.6 | 0.46 |
| | $C_{DGT}$ | 0.7 ± 0.1 | – | 0.5 ± 0.02 | 0.4 ± 0.3 | 0.16 ± 0.01 |
| 19th Avenue | Total | 10.2 | 2.3 | 2.1 | 1.6 | 0.80 |
| | 0.45 μm | 8.6 | 2.2 | 2.1 | 1.9 | 0.60 |
| | $C_{DGT}$ | 0.4 ± 0.01 | 1.0 ± 0.8 | 0.4 ± 0.03 | 0.19 ± 0.03 | 0.19 ± 0.03 |
| Isa Street Crossing | Total | 6.2 | 2.3 | 2.7 | 1.9 | 1.21 |
| | 0.45 μm | 7.5 | 2.3 | 3.2 | 1.4 | 0.73 |
| | $C_{DGT}$ | 1.1 ± 0.1 | 0.6 ± 0.1 | 0.9 ± 0.1 | 0.3 ± 0.01 | 0.36 ± 0.02 |
| Alma Crossing | Total | – | 2.2 | 2.6 | 2.0 | 0.79 |
| | 0.45 μm | – | 1.9 | 13.2 | 1.9 | 0.77 |
| | $C_{DGT}$ | – | – | 0.6 | 0.5 ± 0.1 | 0.16 ± 0.03 |
| Davis Crossing | Total | 6.5 | – | 2.9 | 1.8 | 1.36 |
| | 0.45 μm | 6.3 | – | 7.3 | 1.8 | 1.01 |
| | $C_{DGT}$ | 0.2 ± 0.01 | – | 0.6 ± 0.03 | 0.4 ± 0.04 | 0.28 ± 0.01 |
| Moondarra Crossing | Total | 12.2 | 2.5 | 3 | 2.3 | 1.35 |
| | 0.45 μm | 11.3 | 2.6 | 3 | 2.71 | 0.83 |
| | $C_{DGT}$ | 0.3 ± 0.1 | 0.6 ± 0.1 | 0.6 ± 0.04 | 0.37 ± 0.14 | 0.13 ± 0.01 |
| Moondarra Junction | Total | 5.2 | 2.1 | 2.3 | 1.57 | 0.76 |
| | 0.45 μm | 4.4 | 2.1 | 2.1 | 0.91 | 4.87 |
| | $C_{DGT}$ | 0.2 ± 0.01 | 1.3 ± 1.1 | 0.4 ± 0.01 | 0.29 ± 0.09 | 0.14 ± 0.02 |
| Lake Moondarra | Total | 2.2 | 3.2 | 2.2 | 1.42 | 0.38 |
| | 0.45 μm | 2 | 2.9 | 2.1 | 1.34 | 0.29 |
| | $C_{DGT}$ | 0.3 ± 0.01 | 0.6 ± 0.1 | 0.5 ± 0.1 | 0.27 ± 0.02 | 0.12 ± 0.01 |
| Clear Water Lagoon | Total | 0.8 | 4.4 | 2.9 | 1.35 | 0.43 |
| | 0.45 μm | 0.7 | 2.1 | 1.9 | 1.32 | 0.39 |
| | $C_{DGT}$ | 0.1 ± 0.01 | 0.4 ± 0.1 | 0.4 ± 0.1 | 0.18 ± 0.02 | 0.1 ± 0.01 |

Note: '–' data is not available

**Table 20. Concentrations of nickel (μg/L) in water sampled at the creeks (urban discharge, tributaries from the mine lease, and seepage ponds) over five sampling periods (November 2008–June 2010)**

| Sites | Fraction | Nickel (μg/L) | | | | |
|---|---|---|---|---|---|---|
| | | Pre-wet season 2008 | Wet season 2009 | Post-wet season 2009 | Wet season 2010 | Post-wet season 2010 |
| **Urban discharge** | | | | | | |
| Breakaway Creek upstream | Total | – | – | 2.8 | – | – |
| | 0.45 μm | – | – | – | – | – |
| | $C_{DGT}$ | – | – | 0.61 ± 0.07 | – | – |
| Breakaway Creek outlet pipes | Total | – | – | 2.6 | – | – |
| | 0.45 μm | – | – | 2.4 | – | – |
| | $C_{DGT}$ | – | – | 0.75 ± 0.09 | – | – |
| Breakaway Junction | Total | – | – | 3.1 | – | – |
| | 0.45 μm | – | – | 2.6 | – | – |
| | $C_{DGT}$ | – | – | 0.58 ± 0.06 | – | – |
| **Tributaries from the mine lease** | | | | | | |
| George Fisher Creek | Total | – | – | – | 5.0 | 0.8 |
| | 0.45 μm | – | – | – | 4.9 | 1.3 |
| | $C_{DGT}$ | – | – | – | 0.38 ± 0.07 | 0.24 ± 0.06 |
| King Gully Creek | Total | – | – | – | 4.1 | 1.5 |
| | 0.45 μm | – | – | – | 2.4 | 1.2 |
| | $C_{DGT}$ | – | – | – | 0.53 ± 0.14 | 0.64 ± 0.03 |
| Lena Creek | Total | – | – | – | 3.3 | – |
| | 0.45 μm | – | – | – | 2.2 | – |
| | $C_{DGT}$ | – | – | – | 0.57 ± 0.07 | – |
| Downstream north Tailing Dam 3 | Total | – | – | – | 4.9 | – |
| | 0.45 μm | – | – | – | 11.9 | – |
| | $C_{DGT}$ | – | – | – | 0.77 ± 0.01 | – |
| Downstream north Tailing Dam 5 | Total | – | – | – | 7.6 | 2.3 |
| | 0.45 μm | – | – | – | 4.3 | 2.4 |
| | $C_{DGT}$ | – | – | – | 0.67 ± 0.09 | 0.93 ± 0.04 |
| **Tailing seepage ponds** | | | | | | |
| Seepage pond at Tailing Dam 5 | Total | 33 | 2.6 | 2.6 | 4.4 | 0.9 |
| | 0.45 μm | 32 | 2.6 | 2.5 | 4.8 | 0.7 |
| | $C_{DGT}$ | 0.4 ± 0.03 | 0.72 ± 0.07 | 1.17 ± 0.28 | 0.51 ± 0.07 | 0.18 ± 0.01 |
| Seepage pond at Tailing Dam 7 | Total | 23 | 10.2 | 7.5 | 5.3 | 2.7 |
| | 0.45 μm | 21 | 9.8 | 5.6 | 5.5 | 2.7 |
| | $C_{DGT}$ | 0.5 ± 0.01 | 2.7 ± 1.4 | 5.4 ± 0.1 | 1.0 ± 0.2 | 1 ± 0.01 |
| Seepage pond at Tailing Dam 8 | Total | 24 | 6.2 | 10.4 | 10.6 | 1.6 |
| | 0.45 μm | 24 | 6.0 | 7.1 | 8.8 | 0.8 |
| | $C_{DGT}$ | 1.7 ± 0.1 | 2.2 ± 0.2 | 3.6 ± 0.1 | 2.2 ± 0.1 | 1.0 ± 0.1 |

Note: '–' data is not available

**Table 21. Concentrations of zinc in surface water sampled in the Leichhardt River over five sampling periods (November 2008–June 2010)**

| Sites | Fraction | Zinc (µg/L) | | | | |
|---|---|---|---|---|---|---|
| | | Pre-wet season 2008 | Wet season 2009 | Post-wet season 2009 | Wet season 2010 | Post-wet 2010 |
| Leichhardt River upstream | Total | – | 4.9 | 5.5 | 6.5 | – |
| | 0.45 µm | – | 4.3 | 5.1 | 4.2 | – |
| | $C_{DGT}$ | – | 1.1 ± 0.2 | 0.5 ± 0.1 | 0.9 ± 0.4 | – |
| Mica Creek upstream | Total | – | 5.9 | 8.2 | 11.5 | – |
| | 0.45 µm | – | 3.4 | 5 | 8.1 | – |
| | $C_{DGT}$ | – | 3.7 ± 1.4 | 0.7 ± 0.02 | 0.8 ± 0.2 | – |
| 23rd Avenue | Total | 15.8 | – | 7.9 | 5.2 | 9.3 |
| | 0.45 µm | 6.2 | – | 7.1 | 4.2 | 3.7 |
| | $C_{DGT}$ | 0.9 ± 0.2 | – | 0.4 ± 0.1 | 0.6 ± 0.1 | 0.4 ± 0.1 |
| 19th Avenue | Total | 13.5 | 4.5 | 10.8 | 7.6 | 8.5 |
| | 0.45 µm | 14.6 | 5.5 | 9.8 | 7.0 | 9.1 |
| | $C_{DGT}$ | 0.6 ± 0.4 | 0.8 ± 0.5 | 0.5 ± 0.1 | 0.1 | 0.6 ± 0.1 |
| Isa Street Crossing | Total | 9 | 17.6 | 67.8 | 27.3 | 89.6 |
| | 0.45 µm | 5.4 | 13.4 | 42.5 | 13.9 | 26.3 |
| | $C_{DGT}$ | 1.2 ± 0.2 | 15.6 ± 1.8 | 41.1 ± 3.7 | 14.3 ± 1.3 | 27.9 ± 2.9 |
| Alma Crossing | Total | – | 166.8 | 15.2 | 307 | 18.7 |
| | 0.45 µm | – | 147.9 | 6.3 | 282 | 15.8 |
| | $C_{DGT}$ | – | – | 15.9 ± 8.6 | 101.2 ± 4.9 | 0.77 ± 0.08 |
| Davis Crossing | Total | 11.3 | – | 20.3 | 10.4 | 29.5 |
| | 0.45 µm | 8.1 | – | 15.3 | 8.4 | 5.7 |
| | $C_{DGT}$ | 0.5 ± 0.2 | – | 7.9 ± 1.1 | 6.0 ± 1.4 | 1.1 ± 0.1 |
| Moondarra Crossing | Total | 22.6 | 22.9 | 15.7 | 16.1 | 17.3 |
| | 0.45 µm | 7.5 | 16.5 | 11.7 | 13.6 | 8.8 |
| | $C_{DGT}$ | 0.3 ± 0.1 | 6.7 ± 0.7 | 1.3 ± 0.1 | 0.8 ± 0.1 | 0.7 ± 0.4 |
| Moondarra Junction | Total | 35 | 7.5 | 8.3 | 13.5 | 8.5 |
| | 0.45 µm | 3.5 | 5.2 | 6.9 | 4.2 | 12.4 |
| | $C_{DGT}$ | 0.5 ± 0.2 | 1.3 ± 0.6 | 0.8 ± 0.1 | 0.7 ± 0.06 | 0.3 ± 0.07 |
| Lake Moondarra | Total | 3.8 | 25.9 | 6.3 | 6.5 | 4.0 |
| | 0.45 µm | 2 | 8.7 | 3.6 | 5.8 | 2.5 |
| | $C_{DGT}$ | 0.4 ± 0.1 | 3.9 ± 0.5 | 0.9 ± 0.1 | 1.1 ± 0.1 | 0.4 ± 0.2 |
| Clear Water Lagoon | Total | 2.3 | 47.8 | 6.1 | 9.5 | 3.4 |
| | 0.45 µm | 2.5 | 3.9 | 5 | 6.6 | 2.8 |
| | $C_{DGT}$ | 0.2 ± 0.1 | 1.1 ± 0.8 | 0.5 ± 0.1 | 1.1 ± 0.1 | 0.9 ± 0.7 |

Note: '–' data is not available

**Table 22. Concentrations of zinc in water sampled at the creeks (urban discharge, tributaries from the mine lease and tailing seepage ponds) over five sampling periods (November 2008–June 2010)**

| Sites | Fraction | Zinc (µg/L) | | | | |
|---|---|---|---|---|---|---|
| | | Pre-wet season 2008 | Wet season 2009 | Post-wet season 2009 | Wet season 2010 | Post-wet season 2010 |
| **Urban discharge** | | | | | | |
| Breakaway Creek upstream | Total | – | – | 7.0 | 9.0 | 13.7 |
| | 0.45 µm | – | – | 6.3 | 6.5 | 10.3 |
| | $C_{DGT}$ | – | – | 3.2 ± 1.1 | 3.8 ± 0.2 | 1.3 ± 0.2 |
| Breakaway Creek outlet pipes | Total | – | – | 8.1 | 11.9 | 7.1 |
| | 0.45 µm | – | – | 7.0 | 8.6 | 6.5 |
| | $C_{DGT}$ | – | – | 1.0 ± 0.2 | 0.9 ± 0.2 | 2.1 ± 0.9 |
| Breakaway Junction | Total | – | – | 10.1 | 14.7 | 11.5 |
| | 0.45 µm | – | – | 7.9 | 13.8 | 8.3 |
| | $C_{DGT}$ | – | – | 0.8 ± 0.2 | 1.4 ± 0.2 | 3.9 ± 1.8 |
| **Tributaries from the mine lease** | | | | | | |
| George Fisher Creek | Total | – | – | – | 407 | 11 |
| | 0.45 µm | – | – | – | 87 | 6 |
| | $C_{DGT}$ | – | – | – | 39 ± 4 | 2.1 ± 0.7 |
| King Gully Creek | Total | – | – | – | 207 | 154 |
| | 0.45 µm | – | – | – | 40 | 123 |
| | $C_{DGT}$ | – | – | – | 16 ± 2 | 60.8 ± 2.6 |
| Lena Creek | Total | – | – | – | 214 | – |
| | 0.45 µm | – | – | – | 165 | – |
| | $C_{DGT}$ | – | – | – | 64 ± 6 | – |
| Downstream north Tailing Dam 3 | Total | – | – | – | 458 | – |
| | 0.45 µm | – | – | – | 260 | – |
| | $C_{DGT}$ | – | – | – | 141 ± 0.6 | – |
| Downstream north Tailing Dam 5 | Total | – | – | – | 273 | 22.8 |
| | 0.45 µm | – | – | – | 270 | 16.2 |
| | $C_{DGT}$ | – | – | – | 96 ± 8 | 18 ± 0.7 |
| **Tailing seepage ponds** | | | | | | |
| Seepage pond at Tailing Dam 5 | Total | 19.0 | 16.3 | 6.7 | 9.6 | 11 |
| | 0.45 µm | 15.0 | 9.2 | 4.3 | 6.8 | 4.5 |
| | $C_{DGT}$ | 3.3 ± 1.6 | 17.9 ± 5.5 | 2.8 ± 0.4 | 3.4 ± 0.2 | 4.7 ± 0.2 |
| Seepage pond at Tailing Dam 7 | Total | 15.0 | 164.7 | 76.9 | 21 | 12.1 |
| | 0.45 µm | 14.0 | 126.3 | 50.9 | 18 | 10.3 |
| | $C_{DGT}$ | 1.7 ± 0.3 | 42.6 ± 16.4 | 87.7 ± 1.7 | 6.1 ± 0.2 | 7.5 ± 0.2 |
| Seepage pond at Tailing Dam 8 | Total | 13.0 | 65 | 8.6 | 177 | 22 |
| | 0.45 µm | 9.0 | 4.5 | 4.9 | 170 | 6 |
| | $C_{DGT}$ | 0.4 ± 0.2 | 3.3 ± 2.6 | 1.0 ± 0.2 | 67.2 ± 4.2 | 11 ± 2.3 |

Note: '–' data is not available

### 3.1.4 Comparison of water concentration with drinking water guidelines

The total concentrations of metals and metalloids in water were compared against the Australian Drinking Water Guidelines (ADWG, 2004). Table 23 presents a summary of sites exceeding the guideline values of ADWG (2004) for arsenic, cadmium, and lead. The results show that nickel and zinc total concentrations in water samples from all sites in the Leichhardt River over five sampling periods did not exceed the drinking water guidelines. However, there were number of sites where the total water concentrations of arsenic (19th Avenue, 23rd Avenue, Davis Crossing, Moondarra Crossing, and Moondarra Junction); cadmium (Alma Crossing, Davis Crossing, and Moondarra Junction); and lead (23rd Avenue, Davis Crossing, Moondarra Crossing, and Moondarra Junction) exceeded the drinking water guideline values ADWG (2004). Such high levels of metals and arsenic were associated with very dry periods when only isolated pools of water were present and were very unlikely to have been consumed.

Table 24 presents a summary of sites at the tributaries from the mine lease that exceeded the drinking water guideline values (ADWG, 2004) for arsenic, cadmium, and lead. These results indicate that the drinking water guidelines were exceeded in the tributaries from the mine lease during the wet season of 2010.

**Table 23. Summary of sites at Leichhardt River exceeding Australian drinking water guidelines over five sampling periods for arsenic, cadmium, and lead (November 2008–June 2010)**

| Metal or metalloid | Sites exceeding drinking water guidelines | Sampling time exceeding water guideline | Total metal or metalloid concentrations (µg/L) | pH | Australian drinking water guideline (µg/L) |
|---|---|---|---|---|---|
| Arsenic | 19th Avenue | Pre-wet 2008 | 9.4 | 8.5 | 7 |
| | 23rd Avenue | Pre-wet 2008 | 17.1 | 7.9 | |
| | Davis Crossing | Pre-wet 2008 | 7.0 | – | |
| | Moondarra Crossing | Pre-wet 2008 | 21.4 | 8 | |
| | Moondarra Junction | Pre-wet 2008 | 8.0 | 7.9 | |
| Cadmium | Alma Crossing | Wet 2010 | 3.0 | 7.4 | 2 |
| | Davis Crossing | Pre-wet 2008 | 3.8 | - | |
| | | Post-wet 2009 | 4.7 | - | |
| | | Post-wet 2010 | 2.7 | 8.6 | |
| | Moondarra Junction | Pre-wet 2008 | 9.2 | 8 | |
| | Clear Water Lagoon | Wet 2009 | 4.2 | 7.3 | |
| Lead | 23rd Avenue | Pre-wet 2008 | 39 | 7.9 | 10 |
| | Davis Crossing | Wet 2010 | 10 | 8 | |
| | Moondarra Crossing | Pre-wet 2008 | 18 | 8 | |
| | Moondarra Junction | Pre-wet 2008 | 158 | 7.9 | |

Note: '–' data is not available

**Table 24. Summary of sites at the tributaries from the mine lease and seepage ponds exceeding Australian drinking water guidelines for arsenic, cadmium, and lead over five sampling periods (November 2008–June 2010)**

| Metal or metalloid | Sites exceeding drinking water guidelines | Sampling time exceeding water guideline | Total metal or metalloid concentrations (µg/L) | Australian drinking water guideline (µg/L) |
|---|---|---|---|---|
| Arsenic | King Gully Creek | Wet 2010 | 8.2 | 7 |
| | Lena Creek | Wet 2010 | 12.4 | |
| | Downstream north Tailing Dam 3 | Wet 2010 | 26.4 | |
| | Downstream north Tailing Dam 5 | Wet 2010 | 11.8 | |
| | Seepage pond at Tailing Dam 5 (highest) | All seasons except post-wet 2010 | 46.6 | |
| | Breakaway Creek outlet pipes | Post-wet 2010 | 7.3 | |
| | Seepage pond at Tailing Dam 8 | Wet 2010 | 7.1 | |
| Cadmium | George Fisher Creek | Wet 2010 | 2.3 | 2 |
| | King Gully Creek | Wet 2010 and post-wet 2010 | 5.8 | |
| | Lena Creek | Wet 2010 | 3.2 | |
| | Downstream north Tailing Dam 3 | Wet 2010 | 16.4 | |
| | Downstream north Tailing Dam 5 | Wet 2010 | 9.9 | |
| Lead | George Fisher Creek | Wet 2010 | 444 | 10 |
| | King Gully Creek | Wet 2010 and post-wet 2010 | 191 | |
| | Lena Creek | Wet 2010 | 108 | |
| | Downstream north Tailing Dam 3 | Wet 2010 | 417 | |
| | Downstream north Tailing Dam 5 | Wet 2010 and post-wet 2010 | 158 | |
| | Seepage pond at Tailing Dam 5 | Pre-wet 2008, wet 2009 and post-wet 2010 | 21 | |
| | Seepage pond at Tailing Dam 8 | Wet 2010 | 33 | |

### 3.1.5 Comparison of water concentrations in the Leichhardt River with water guidelines

#### 3.1.5.1 Comparison of water concentrations with recreational water quality and aesthetics guidelines

Water-based recreational activities are related to estuarine and freshwater rivers and lakes. According to ANZECC/ARMCANZ (2000), the parameters for water used for recreation purposes (recreational water) are microbiological, visual clarity and colour, pH, temperature, toxic chemicals, and surface film. In this study, only pH is used to compare with the recreational water guideline (NH&MRC, 2008). The results show that pH of water at all recreation water sites within the study area is within the range 5.0–9.0 (Table 7). According to the NH&MRC (2008), the trigger values for recreation water quality assessments are 10 times that of the drinking water quality guideline values. These trigger values for recreation water are for consumption of 100–200 mL per day. At Moondarra Junction during the pre-wet season in 2008, concentration of lead was 158 µg/L and exceeded the

drinking water guideline (ADWG, 2004). Such a high level of lead was associated with a very dry period when only isolated pools of water were present at the Leichhardt River sites and the river could not be used for swimming or other recreational activities.

#### 3.1.5.2 Comparison of water concentrations with irrigation and livestock water guidelines

The total concentrations of arsenic (Table 11 and Table 12); cadmium (Table 13 and Table 14); copper (Table 15 and Table 16); lead (Table 17 and Table 18); nickel (Table 19 and Table 20); and zinc (Table 21 and Table 22) in water samples collected over five sampling periods showed no exceedances, except for sulfate concentration, at any sites when compared against the irrigation and livestock watering guidelines (ANZECC/ARMCANZ, 2000).

#### 3.1.5.3 Comparison of water concentrations with water guidelines for 95% and 90% species protection

According to ANZECC/ARMCANZ (2000), the default trigger values have been derived using advanced statistical analyses of database information on chronic aquatic toxicity. The trigger values aim to protect the designated percentages of aquatic life. The default levels of species protection depend on the water system. The water system in the Leichhardt River in Mount Isa is considered to be moderately disturbed; therefore, the guideline trigger values that protect 95% of species were applied to these sites.

The total concentrations of metals and metalloids (Table 11 to Table 22) in water were compared against the trigger values for fresh water species at the 95% level of protection, as the first step in the decision-tree process to assess metal toxicants (ANZECC/ARMCANZ, 2000). The trigger values for each element were adjusted to the site-specific water hardness condition described in Section 2.1. Four sites including Alma Crossing, Davis Crossing, Moondarra Crossing, and Clear Water Lagoon had total metal concentrations that exceeded cadmium trigger values for 95% freshwater species protection (Table 25). Nine sites, including upstream and downstream samples from the Leichhardt River, exceeded the copper trigger value for 95% freshwater species protection (Table 26). The total concentrations of lead in the water at two sites, Alma Crossing and Moondarra Junction, exceeded the lead trigger value for 95% freshwater species protection (Table 27). No sites exceeded the 95% protection trigger values for arsenic, nickel, and zinc.

The downstream sites including Alma Crossing, Davis Crossing, Moondarra Crossing, and Moondarra Junction are highly disturbed; therefore, the guideline trigger values that protect 90% of species were applied to these sites (Table 25). The results indicate that two sites, Moondarra Crossing and Moondarra Junction complied with the cadmium trigger value for 90% species protection and three sites, 19th Avenue, Isa Crossing, and Clear Water Lagoon, complied with the copper trigger value for 90% species protection. This implies the condition is classified as ‘highly disturbed’ (ANZECC/ARMCANZ, 2000).

The filterable (0.45 µm) metal concentrations of sites that exceeded the trigger values in the first step (total concentrations) were compared against the trigger values. The results (Table 25) show that one site (Alma Crossing) had a filterable (0.45 µm) cadmium concentration that exceeded the trigger values at both 95% and 90% species protection (Table 25). A more relevant comparison was made for this site using the concentration of cadmium determined by the DGT technique ($C_{DGT}$). The cadmium concentration measured by the DGT technqiue at Alma Crossing complied with the cadmium trigger value 95% species protection. Seven sites (Table 26) had filterable (0.45 µm) copper concentrations that exceeded the trigger values for both 95% and 90% freshwater species protection. The copper concentrations measured by the DGT technqiue at these seven sites were compared against the trigger values guideline of copper for both 95% and 90% species protection concentrations. The results show that one site (Mica Creek) had a copper concentration, measured by the DGT technique, which exceeded the trigger values.

None of the sites had a filterable (0.45 µm) filterable lead concentration that exceeded the 95% species protection trigger value.

**Table 25. Summary of sites at Leichhardt River exceeding trigger values for cadmium for 95% and 90% freshwater species protection (ANZECC/ARMCANZ, 2000) over five sampling periods**

| Sites exceeding water guidelines | Sampling time exceeding water guidelines | Cadmium (µg/L) | | | Hardness $CaCO_3$ (mg/L) | TV for 95% species protection* (µg/L) | TV for 90% species protection* (µg/L) |
|---|---|---|---|---|---|---|---|
| | | Total | 0.45 µm | $C_{DGT}$ | | | |
| Alma Crossing | Wet 2010 | 3 | 2.7 | 1.2 ± 0.1 | 230 | 1.1 | 2.3 |
| Davis Crossing | Pre-wet 2008 | 3.8 | 1.2 | 0.2 ± 0.11 | 801 | 2 | 4.0 |
| | Post-wet 2009 | 4.7 | 3.9 | 2.7 ± 0.3 | 519 | 2 | 4.0 |
| | Post-wet 2010 | 2.7 | 0.6 | 0.08 | 392 | 2 | 4.0 |
| Moondarra Crossing | Wet 2009 | 1.9 | 1.5 | 0.7 ± 0.1 | 265 | 1.1 | 2.3 |
| Moondarra Junction | Pre-wet 2008 | 9.2 | 0.5 | <0.01 | 294 | 1.1 | 2.3 |
| | Wet 2010 | 1.3 | <0.01 | <0.01 | 94 | 0.5 | 1.1 |
| Clear Water Lagoon | Wet 2009 | 4.2 | 0.2 | 0.02 ± 0.01 | 64 | 0.5 | 1.1 |

* ANZECC/ARMCANZ (2000) trigger values (TV) for cadmium for 95% and 90% of freshwater species protection. The TV values have been adjusted to the site-specific conditions of water hardness.

**Table 26. Summary of sites at Leichhardt River exceeding trigger values for copper for 95% and 90% freshwater species protection (ANZECC/ARMCANZ, 2000) over five sampling periods**

| Sites exceeding water guidelines | Sampling time exceeding water guidelines | Copper (µg/L) | | | Hardness $CaCO_3$ (mg/L) | TV for 95% species protection* (µg/L) | TV for 90% species protection* (µg/L) |
|---|---|---|---|---|---|---|---|
| | | Total | 0.45 µm | $C_{DGT}$ | | | |
| Leichhardt River upstream | Wet 2009 | 6.2 | 4.9 | 1.1 ± 0.1 | 32 | 1.4 | 1.8 |
| Mica Creek upstream | Wet 2009 | 15.9 | 11.2 | 3.1 ± 0.6 | 21 | 1.4 | 1.8 |
| 23rd Avenue | Pre-wet 2008 | 17 | 6 | 1.5 ± 0.3 | 281 | 7.3 | 9.4 |
| 19th Avenue | Pre-wet 2008 | 8.3 | 6.9 | 1.3 ± 0.2 | 263 | 7.3 | 9.4 |
| | Wet 2009 | 5.6 | 3.3 | 0.9 ± 0.2 | 160 | 5.5 | 7.0 |
| Isa Crossing | Wet 2009 | 14 | 13.3 | 0.9 ± 0.04 | 51 | 1.4 | 1.8 |
| | Post-wet 2009 | 7 | 5.4 | 0.8 ± 0.03 | 339 | 12.6 | 16.2 |
| | Wet 2010 | 11.7 | 5.4 | 0.9 ± 0.1 | 187 | 7.3 | 9.4 |
| | Post-wet 2010 | 9.9 | 3.3 | 1.7 ± 0.2 | 194 | 7.3 | 9.4 |
| Alma Crossing | Wet 2009 | 23.1 | 18.5 | - | 51 | 1.4 | 1.8 |
| | Post-wet 2009 | 6 | 2.1 | 0.9 ± 0.04 | 90 | 3.5 | 4.5 |
| | Wet 2010 | 17.2 | 8.4 | 1.7 ± 0.2 | 230 | 7.3 | 9.4 |
| Moondarra Crossing | Pre-wet 2008 | 13.6 | 3.8 | 0.1 ± 0.01 | 1096 | 12.6 | 16.2 |
| | Wet 2009 | 11.1 | 12.5 | 1.4 ± 0.1 | 265 | 7.3 | 9.4 |

| Sites exceeding water guidelines | Sampling time exceeding water guidelines | Copper (µg/L) | | | Hardness $CaCO_3$ (mg/L) | TV for 95% species protection* (µg/L) | TV for 90% species protection* (µg/L) |
|---|---|---|---|---|---|---|---|
| | | Total | 0.45 µm | $C_{DGT}$ | | | |
| Moondarra Junction | Pre-wet 2008 | 37 | 2.1 | 0.2 ± 0.1 | 294 | 7.3 | 9.4 |
| | Wet 2009 | 8.8 | 6.6 | 1.6 ± 0.1 | 94 | 3.5 | 4.5 |
| | Post-wet 2009 | 5.4 | 3.6 | 0.9 ± 0.02 | 61 | 3.5 | 4.5 |
| | Wet 2010 | 6.2 | 7.2 | 1.2 ± 0.1 | 94 | 3.5 | 4.5 |
| | Post-wet 2010 | 6.6 | 5.2 | 0.9 ± 0.2 | 86 | 3.5 | 4.5 |
| Clear Water Lagoon | Pre-wet 2008 | 1.5 | 1.3 | 1.1 ± 0.8 | 55 | 1.4 | 1.8 |
| | Wet 2009 | 19.5 | 1.8 | 0.5 ± 0.1 | 64 | 3.5 | 4.5 |
| | | 3.9 | 1.7 | 0.2 ± 0.01 | 71 | 3.5 | 4.5 |

* ANZECC/ARMCANZ (2000) trigger values (TV) for copper giving protection of fresh water species at 95% level. The TV have been adjusted to the site-specific conditions of water hardness.

**Table 27. Summary of sites at Leichhardt River exceeding trigger values for lead 95% and 90% freshwater species protection (ANZECC/ARMCANZ, 2000) over two sampling periods**

| Sites exceeding water guidelines | Sampling time exceeding water guidelines | Lead (µg/L) | | | Hardness $CaCO_3$ (mg/L) | TV for 95% species protection* (µg/L) | TV for 90% species protection* (µg/L) |
|---|---|---|---|---|---|---|---|
| | | Total | 0.45 µm | $C_{DGT}$ | | | |
| Alma Crossing | Wet 2009 | 6.6 | 1.8 | – | 51 | 3.4 | 5.6 |
| Moondarra Junction | Pre-wet 2008 | 158 | 2.4 | 0.1 ± 0.03 | 294 | 40 | 66 |

Notes:
* ANZECC/ARMCANZ (2000) trigger values (TV) for lead at 95% and 90% freshwater species protection. The TV have been adjusted to the site-specific conditions of water hardness.
'-' data are not available.

### 3.1.6 Sites from urban discharge, tributaries from the mine lease, and seepage ponds exceeding water guidelines for fresh water species protection

Total concentrations of arsenic in water collected from the creeks downstream north of Tailing Dam 3 (wet season 2010) and the seepage pond at Tailing Dam 5 (four seasons from pre-wet season 2008 through to the wet season 2010) exceeded the arsenic trigger value for the 95% level of freshwater species protection (Table 28). The filterable (0.45 µm) arsenic concentration of Tailing Dam 5 (four seasons from the pre-wet season 2008 to the wet season 2010) exceeded the arsenic trigger value for 95% freshwater species protection. No site of urban discharge exceeded the trigger values for arsenic.

**Table 28. Summary of sites at the tributaries from the mine lease and seepage ponds exceeding trigger values for arsenic for 95% species protection (ANZECC/ARMCANZ, 2000) over five sampling periods**

| Sites exceeding water guidelines | Sampling time exceeding water guidelines | Arsenic (µg/L) | | Hardness $CaCO_3$ (mg/L) | TV at 95% species protection (µg/L) |
|---|---|---|---|---|---|
| | | Total | 0.45 µm | | |
| Downstream north Tailing Dam 3 | Wet 2010 | 26.4 | 12.6 | 1,640 | 24 |
| Seepage pond at Tailing Dam 5 | Pre-wet 2008 | 26.4 | 25.1 | – | |
| | Wet 2009 | 36 | 35.8 | 1,790 | |
| | Post-wet 2009 | 43.8 | 42.2 | 2,710 | |
| | | 46.6 | 44.1 | 5,400 | |

Note: '–' data are not available.

Table 29 presents a summary of the sites of urban discharge, tributaries from the mine lease, and seepage ponds that had total concentrations that exceeded copper trigger values of 95% levels of freshwater species protection. The results show the total concentration of copper exceeded the trigger values for 95% levels of freshwater species protection at one site of urban discharge; five sites at the tributaries from the mine lease; and two seepage ponds at Tailing Dam 5 and Tailing Dam 7. The filterable (0.45µm) concentration of copper at the seepage pond at Tailing Dam 7, however, complied the trigger values. The copper concentrations determined by DGT were compared with the trigger values and the results show the copper concentration determined by DGT ($C_{DGT}$) exceeded the trigger values for 95% species protection at five sites: George Fisher Creek, King Gully Creek, Lena Creek, downstream of Tailing Dams 3 and 5 (Table 29).

**Table 29. Summary of sites of urban discharge, tributaries from the mine lease, and seepage ponds exceeding trigger values for copper for 95% freshwater species protection (ANZECC/ ARMCANZ, 2000) over five sampling periods**

| Sites exceeding water guidelines | Sampling time exceeding water guidelines | Copper (µg/L) | | | Hardness $CaCO_3$ (mg/L) | TV at 95% protection* (µg/L) |
|---|---|---|---|---|---|---|
| | | Total | 0.45 µm | $C_{DGT}$ | | |
| **Urban discharge** | | | | | | |
| Breakaway Creek Junction | Wet 2010 | 13.7 | 11.2 | 1.7 ± 0.1 | 257 | 7.28 |
| **Tributaries from the mine lease** | | | | | | |
| George Fisher Creek | Wet 2010 | 42.7 | 11.5 | 2.7 ± 0.2 | 144 | 5.5 |
| | Post-wet 2010 | 9.8 | 5.3 | 1.6 ± 0.6 | 54 | 1.4 |
| King Gully Creek | Wet 2010 | 318 | 102 | 15 ± 0.8 | 94 | 5.5 |
| | Post-wet 2010 | 154 | 96 | 27 ± 1.3 | 436 | 12.6 |
| Lena Creek | Wet 2010 | 310 | 134 | 27.5 ± 2 | 65 | 3.5 |
| Downstream north Tailing Dam 3 | Wet 2010 | 817 | 355 | 132 ± 2 | 1640 | 12.6 |
| Downstream north Tailing Dam 5 | Wet 2010 | 305 | 564 | 65 ± 5 | 132 | 5.5 |
| | Post-wet 2010 | 23.9 | 14.4 | 2.55 ± 0.41 | 8470 | 12.6 |

| Sites exceeding water guidelines | Sampling time exceeding water guidelines | Copper (μg/L) | | | Hardness $CaCO_3$ (mg/L) | TV at 95% protection* (μg/L) |
|---|---|---|---|---|---|---|
| | | Total | 0.45 μm | $C_{DGT}$ | | |
| **Seepage ponds** | | | | | | |
| Seepage pond at Tailing Dam 5 | Pre-wet 2008 | 30.8 | 23 | 5.7 ± 0.4 | 6,170 | 12.6 |
| | Wet 2009 | 54.3 | 33.8 | 16.8 ± 6.7 | 1,790 | 12.6 |
| | Post-wet 2009 | 24 | 17.2 | 3.4 ± 0.1 | 2,710 | 12.6 |
| | Wet 2010 | 28.5 | 24.2 | 5.6 ± 0.2 | 5,400 | 12.6 |
| | Post-wet 2010 | 27.9 | 6.4 | 1.9 ± 0.6 | 4,540 | 12.6 |
| Seepage pond at Tailing Dam 7 | Pre-wet 2008 | 13.1 | 6.8 | 0.7 ± 0.1 | 6,170 | 12.6 |
| | Wet 2009 | 12.7 | 7.3 | 2.8 ± 0.4 | 6,780 | 12.6 |
| | Post-wet 2009 | 15.3 | 12 | 3.1 ± 0.2 | 3,310 | 12.6 |

* ANZECC/ARMCANZ (2000) trigger values (TV) for copper for 95% species protection.The TV have been adjusted to the site-specific conditions of water hardness.

Table 30 shows that five sites from the tributaries from the mine lease (George Fisher Creek, King Gully Creek, Lena Creek, Downstream Tailing Dams 3 and 5) had total concentrations of lead that exceeded the trigger values for 95% freshwater species protection. Two sites (downstream of Tailing Dams 3 and 5) had filterable (0.45 μm) concentrations of lead exceed the trigger values for 95% freshwater species protection. The concentration of lead determined by the DGT technique at these five sites complied with the trigger values for lead 95% freshwater species protection (Table 30).

**Table 30. Summary of sites at tributaries from mine lease exceeding trigger values for lead for 95% freshwater species protection (ANZECC/ARMCANZ, 2000) over two sampling periods**

| Sites exceeding water guidelines | Sampling time exceeding water guidelines | Lead (μg/L) | | | Hardness $CaCO_3$ (mg/L) | TV at 95% protection* (μg/L) |
|---|---|---|---|---|---|---|
| | | Total | 0.45 μm | $C_{DGT}$ | | |
| George Fisher Creek | Wet 2010 | 434 | 21 | 3.8 ± 0.3 | 144 | 26 |
| King Gully Creek | Wet 2010 | 191 | 8 | 0.4 ± 0.04 | 94 | 14 |
| | Post-wet 2010 | 129 | 52 | 12.5 ± 1.6 | 436 | 91 |
| Lena Creek | Wet 2010 | 108 | 13 | 0.7 ± 0.03 | 65 | 14 |
| Downstream north Tailing Dam 3 | Wet 2010 | 417 | 138 | 24 ± 1.8 | 1,640 | 91 |
| Downstream north Tailing Dam 5 | Wet 2010 | 159 | 180 | 18.3 ± 1.2 | 132 | 26 |

* ANZECC/ARMCANZ (2000) trigger values (TV) for lead giving protection of fresh water species at 95% level. The TV have been adjusted to the site-specific condition of water hardness.

### 3.1.7 Overall summary of water quality

The results of the water quality assessment show that the Leichhardt River water was alkaline and water pH varied from 7.0–8.5 over five sampling periods. The EC of samples at upstream sites (Leichhardt River upstream and Mica Creek upstream) and downstream sites (Moondarra Junction, Lake Moondarra, and Clean Water Lagoon) were low and within the limits of drinking water guidelines (<1000 μS/cm) (ADWG, 2004). However, the EC of water sampled at Leichhardt River sites within Mount Isa City exceeded the drinking water guidelines (ADWG, 2004). The EC values of water at all sites collected in the wet season were significantly lower than those collected during the pre-wet season and the post-wet season.

The total concentrations of metals and metalloids in water were compared with drinking water guidelines (AWDG, 2004) and the results show that six sites from the Leichhardt River, four sites at tributaries from the mine lease, and two seepage ponds exceeded the drinking water guideline for arsenic, cadmium, and lead. A summary of sites exceeding drinking water guidelines is presented in Table 23 and Table 24. The irrigation and livestock watering guidelines for the measured metals and metalloids were not exceeded (ANZECC/ARMCANZ, 2000).

#### 3.1.7.1 Overall results for total metal and metalloid concentrations compared against guidelines for the 95% level for freshwater species protection (first step on the decision tree)

Total metal and metalloid concentrations of water were compared with water hardness adjusted trigger values for 95% level of freshwater species protection (ANZECC/ARMCANZ, 2000). The results show that five sites in the Leichhardt River exceeded the trigger value for cadmium (Table 25); nine sites exceeded the trigger value for copper (Table 26); and two sites exceeded the trigger value for lead (Table 27). No site in Leichhardt River exceeded the trigger value for arsenic, but two sites in the tributaries from the mine lease exceeded the trigger value for arsenic (Table 28). Table 29 showed that the trigger value for 95% species protection for copper was exceeded at one site from urban discharge (Breakaway Creek Junction); five sites in tributaries from the mine lease; and two seepage ponds at Tailing Dam 5 and Tailing Dam 7.

Table 31 and Figure 23 summarise the locations of sites exceeding drinking water guidelines for arsenic, cadmium, and lead and Table 32 and Figure 24 summarise the locations of sites exceeding the 95% species protection trigger values for arsenic, cadmium, copper, and lead.

**Table 31. Sites exceeding Australian drinking water guidelines**

| Map no. | Sites exceeding ADWG (2004) | Metal or metalloid |
|---|---|---|
| **Leichhardt River** | | |
| 1 | 23rd Avenue | Arsenic/lead |
| 2 | 19th Avenue | Arsenic |
| 3 | Davis Road Crossing | Arsenic/cadmium/lead |
| 4 | Moondarra Crossing | Arsenic/lead |
| 5 | Moondarra Junction | Arsenic/cadmium/lead |
| 6 | Clear Water Lagoon | Cadmium |
| **Tributaries from the mine lease** | | |
| 7 | King Gully Creek | Arsenic/cadmium/lead |
| 8 | Lena Creek | Arsenic/cadmium/lead |
| 9 | Downstream Tailing Dam 3 | Arsenic/cadmium/lead |
| 10 | Downstream Tailing Dam 5 | Arsenic/cadmium/lead |
| **Seepage ponds** | | |
| 11 | Seepage pond at Tailing Dam 5 | Arsenic/lead |
| 12 | Seepage pond at Tailing Dam 7 | Lead |
| 13 | Seepage pond at Tailing Dam 8 | Arsenic/lead |


**Figure 23. Summary of sites exceeding Australian drinking water guidelines for arsenic, cadmium, and lead (refer to Table 31 for site names)**

**Table 32. Sites where total concentrations exceeded trigger values for 95% freshwater species protection (ANZECC/ARMCANZ, 2000)**

| Map no. | Sites exceeding TV for 95% freshwater species protection | Metal or metalloid |
|---|---|---|
| **Leichhardt River** | | |
| 1 | Leichhardt River upstream | Copper |
| 2 | Mica Creek upstream | Copper |
| 3 | 23rd Avenue | Copper |
| 4 | 19th Avenue | Copper |
| 5 | Isa Crossing | Copper |
| 6 | Alma Crossing | Cadmium/copper/ lead |
| 7 | Davis Road crossing | Cadmium |
| 8 | Moondarra Crossing | Cadmium/copper |
| 9 | Moondarra Junction | Cadmium/copper/ lead |
| 10 | Clear Water Lagoon | Cadmium/copper |
| **Urban discharge** | | |
| 11 | Breakaway Creek Junction | Copper |
| **Tributaries from the mine lease** | | |
| 12 | George Fisher Creek | Cadmium/copper/ lead |
| 13 | King Gully Creek | Cadmium/copper/ |
| 14 | Lena Creek | Cadmium/copper/ lead |
| 15 | Downstream Tailing Dam 3 | Arsenic/cadmium/copper/lead |
| 16 | Downstream Tailing Dam 5 | Cadmium/ copper/lead |
| **Seepage ponds** | | |
| 17 | Seepage pond at Tailing Dam 5 | Arsenic/copper/ lead |
| 18 | Seepage pond at Tailing Dam 7 | Copper |
| 19 | Seepage pond at Tailing Dam 8 | Lead |


**Figure 24. Summary of sites exceeding trigger values for arsenic, cadmium, and lead for 95% freshwater species protection (refer to Table 32 for site names). TV has been adjusted to the site-specific conditions of water hardness**

### 3.1.7.2 Overall results on relevant comparison of metal and metalloid concentration compared against guidelines for the 95% level for freshwater species protection (next steps on decision tree for metals)

The metals and metalloids with filterable (0.45 µm) concentrations, including soluble species, were measured by the DGT technique at sites where total concentrations exceeded the hardness-adjusted trigger values for the 95% levels for freshwater species protection. This comparison aligns with the decision tree process for water (Figure 11). The data for physico-chemical properties and metal and metalloid concentrations of sites with filterable and DGT concentrations that exceeded the hardness-adjusted trigger values, were then used in the visual MINTEQ program (Section 2.5.7). The visual MINTEQ program calculated the free metal or metalloid concentrations as inorganic and organic species, predicted to be in solution. The summary results are presented for cadmium (Table 33); copper (Table 34); and lead (Table 35).

The calculated inorganic species concentrations (including free ions in solution) from Table 33 to Table 35 were compared against the hardness-adjusted trigger values for the 95% level for freshwater species protection. The results of this comparison (Table 36 and Table 37) show:

- one site exceeded the trigger values for arsenic (seepage pond for Tailing Dam 5)
- seven sites exceeded the trigger values for cadmium (Alma Crossing, Davis Crossing, downstream north of Tailing Dam 3, downstream north of Tailing Dam 5, George Fisher Creek, King Gully Creek, and Lena Creek)
- eight sites exceeded the trigger values for copper (Leichhardt River upstream, Mica Creek, Isa Crossing, downstream north of Tailing Dam 3, downstream north of Tailing Dam 5, George Fisher Creek, King Gully Creek and Lena Creek).

These findings indicate that biological effects assessments, such as direct toxicity assessments (Figure 11), needed to be undertaken at these sites.

According to the Queensland Water Quality Guidelines (QWQG 2009), toxicant trigger values in water at the 90% level for freshwater species protection can be applied to highly disturbed systems. Further interpretation of the results at downstream sites, which were considered to be highly disturbed, including Davis Crossing and Alma Crossing was undertaken. The results were compared with the trigger values for metals for 95% freshwater species protection (Table 32). The results show that both sites complied with the trigger values for cadmium for 90% freshwater species protection.

**Table 33. Cadmium concentrations in water samples measured in filtered fractions and calculated by visual MINTEQ from sites that exceeded the trigger values for 95% freshwater species protection and complied with 90% freshwater species protection**

| Sites | Species | Measured results in filtered fraction and DGT technique | | Visual MINTEQ calculation | | | Hardness as $CaCO_3$ (mg/L) | TV* for 95% species protection (µg/L) | TV* for 90% species protection (µg/L) |
|---|---|---|---|---|---|---|---|---|---|
| | | 0.45 µm | $C_{DGT}$ | $Cd^{2+}$ | Inorganic species | Organic species | | | |
| **Post-wet season 2009** | | | | | | | | | |
| Davis Crossing | % 0.45 µm fraction | 100 | 69 | 25.6 | 84.6 | 15.4 | 519 | 2 | 4 |
| | Cd (µg/L) | **3.9** | **2.7 ± 0.3** | 1.0 | **3.3** | 0.6 | | | |
| **Wet season 2010** | | | | | | | | | |
| Alma Crossing | % 0.45 µm fraction | 100 | 44 | 63 | 78 | 22 | 230 | 1.14 | 2.3 |
| | Cd (µg/L) | **2.7** | **1.2 ± 0.1** | **1.7** | **2.1** | 0.6 | | | |

* ANZECC/ARMCANZ (2000) trigger values (TV) for 95% and 90% freshwater species protection. The TV has been adjusted for site-specific conditions of water hardness.

**Table 34. Copper concentrations in water samples measured in filtered fractions and calculated by visual MINTEQ from sites that exceeded the trigger values for the 95% level of freshwater species protection**

| Sites | Species | Measured results in filtered fractions and DGT technique | | Visual MINTEQ calculation | | | Hardness as $CaCO_3$ (mg/L) | TV* 95% species protection (µg/L) |
|---|---|---|---|---|---|---|---|---|
| | | 0.45 µm | $C_{DGT}$ | $Cu^{2+}$ | Inorganic species | Organic species | | |
| **Wet season 2009** | | | | | | | | |
| Mica Creek | % 0.45 µm fraction | 100 | 24.8 | 4.9 | 64 | 36 | 21 | 1.4 |
| | Cu (µg/L) | **11.2** | **3.1 ± 0.6** | 0.6 | **7** | 4 | | |
| Leichhardt River Upstream | % 0.45 µm fraction | 100 | 22 | 4.8 | 50 | 50 | 32 | 1.4 |
| | Cu (µg/L) | **4.9** | 1.1 ± 0.1 | 0.2 | **2** | 2 | | |
| Isa Crossing | % 0.45 µm fraction | 100 | 6.8 | 1.1 | 52 | 48 | 187 | 1.4 |
| | Cu (µg/L) | **13.3** | 0.9 ± 0.04 | 0.1 | **7** | 6 | | |
| Moondarra Junction | % 0.45 µm fraction | 100 | 24 | 0 | 7 | 93 | 94 | 3.5 |
| | Cu (µg/L) | **6.6** | 1.6 ± 0.1 | 0.01 | 0.45 | 6.13 | | |
| **Wet season 2010** | | | | | | | | |
| Alma Crossing | % 0.45 µm fraction | 100 | 20 | 0.4 | 2.5 | 97.5 | 230 | 1.4 |
| | Cu (µg/L) | **8** | **2 ± 0.1** | 0.03 | **0.2** | 8.2 | | |
| Breakaway Creek Junction | % 0.45 µm fraction | 100 | 15 | 0.4 | 9.9 | 90 | 257 | 7.3 |
| | Cu (µg/L) | **11** | 2 ± 0.1 | 0.05 | 1.1 | 10 | | |
| Lena Creek | % 0.45 µm fraction | 100 | 20.5 | 10.1 | 41 | 59 | 65 | 3.5 |
| | Cu (µg/L) | **134** | **28 ± 2** | **14** | **55** | 80 | | |
| King Gully Creek | % 0.45 µm fraction | 100 | 14.7 | 1.9 | 55 | 45 | 94 | 5.5 |
| | Cu (µg/L) | **102** | **15 ± 0.8** | 2.1 | **56** | 46 | | |
| George Fisher Creek | % 0.45 µm fraction | 100 | 26.1 | 1 | 7 | 93 | 144 | 5.5 |
| | Cu (µg/L) | **11.5** | **3 ± 0.2** | 0.1 | 1 | 11 | | |
| Downstream north of Tailing Dam 3 | % 0.45 µm fraction | 100 | 37 | 13 | 73 | 27 | 1635 | 12.6 |
| | Cu (µg/L) | **355** | **132 ± 2** | 17 | **100** | 38 | | |

| Sites | Species | Measured results in filtered fractions and DGT technique | | Visual MINTEQ calculation | | | Hardness as $CaCO_3$ (mg/L) | TV* 95% species protection (µg/L) |
|---|---|---|---|---|---|---|---|---|
| | | 0.45 µm | $C_{DGT}$ | $Cu^{2+}$ | Inorganic species | Organic species | | |
| Downstream north of Tailing Dam 5 | % 0.45 µm fraction | 100 | 12 | 4 | 48 | 52 | 132 | 5.5 |
| | Cu (µg/L) | **564** | **65 ± 5** | **7** | **86** | 94 | | |
| Seepage pond of Tailing Dam 5 | % 0.45 µm fraction | 100 | 10.0 | 5 | 59 | 41 | 5404 | 12.6 |
| | Cu (µg/L) | **24** | **5.6 ± 0.2** | 1 | **14** | 10 | | |

TV*: ANZECC/ARMCANZ (2000) trigger values (TV) for copper for 95% freshwater species protection. The TV has been adjusted for site-specific conditions for water hardness.

**Table 35. Lead concentrations in water samples measured in filtered fractions and calculated by visual MINTEQ from sites that exceeded the trigger values for 95% species protection**

| Sites | Species | Measured results in filtered fractions and DGT technique | | Visual MINTEQ calculation | | | Hardness as $CaCO_3$ (mg/L) | TV* 95% species protection (µg/L) |
|---|---|---|---|---|---|---|---|---|
| | | 0.45 µm | $C_{DGT}$ | $Pb^{2+}$ | Inorganic species | Organic species | | |
| **Wet season 2010** | | | | | | | | |
| Downstream north Tailing Dam 3 | % 0.45 µm fraction | 100 | 17 | 16 | 64 | 36 | 1635 | 91 |
| | Pb (µg/L) | **138** | 24 ± 1.8 | 22 | 89 | 49 | | |
| Downstream north Tailing Dam 5 | % 0.45 µm fraction | 100 | 10 | 0.5 | 5.1 | 94.9 | 132 | 26 |
| | Pb (µg/L) | **180** | 18.3 ± 1.2 | 0.9 | 9.2 | 170 | | |

TV*: ANZECC/ARMCANZ (2000) trigger values (TV) for lead for 95% freshwater species protection. The TV has been adjusted for site-specific conditions of water hardness.

**Table 36. Comparison of arsenic and cadmium concentrations measured in 0.45 μm fractions and by the DGT technique and calculated by visual MINTEQ at sites exceeding trigger values for 95% species protection**

| Metal or metalloid | 0.45 μm fraction | DGT technique | Visual MINTEQ calculation |
|---|---|---|---|
| Arsenic | Seepage pond at Tailing Dam 5 (4 exceedances) | N/A | Seepage pond at Tailing Dam 5 (3 exceedances) |
| Cadmium | Alma Crossing (1 exceedance) | Alma Crossing (1 exceedance) | Alma Crossing (1 exceedance) |
| | Davis Crossing (1 exceedance) | Davis Crossing (1 exceedance) | Davis Crossing (1 exceedance) |
| | Downstream north Tailing Dam 3 (1 exceedance) | Downstream north Tailing Dam 3 (1 exceedance) | Downstream north Tailing Dam 3 (1 exceedance) |
| | Downstream north Tailing Dam 5 (1 exceedance) | Downstream north Tailing Dam 5 (1 exceedance) | Downstream north Tailing Dam 5 (1 exceedance) |
| | George Fisher Creek (1 exceedance) | George Fisher Creek (1 exceedance) | George Fisher Creek (1 exceedance) |
| | King Gully Creek (2 exceedances) | King Gully Creek (1 exceedance) | King Gully Creek (1 exceedance) |
| | Lena Creek (1 exceedance) | Lena Creek (1 exceedance) | Lena Creek (1 exceedance) |

**Table 37. Comparison of copper and lead concentrations measured in 0.45 μm fractions, evaluated using the DGT technique and calculated by visual MINTEQ at sites exceeding trigger values for 95% species protection**

| Metal or metalloid | 0.45 μm fraction | DGT technique | Visual MINTEQ calculation |
|---|---|---|---|
| Copper | Leichhardt River upstream (1 exceedance) | Nil | Leichhardt River upstream (1 exceedance) |
| | Mica Creek upstream (1 exceedance) | Mica Creek upstream (1 exceedance) | Mica Creek upstream (1 exceedance) |
| | Isa Crossing (1 exceedance) | Nil | Isa Crossing (1 exceedance) |
| | Alma Crossing (3 exceedances) | Alma Crossing (2 exceedances | Nil |
| | Moondarra Junction (4 exceedances) | Nil | Nil |
| | Breakaway Creek (1 exceedance) | Nil | Nil |
| | George Fisher Creek (2 exceedances) | George Fisher Creek (1 exceedance) | Nil |
| | King Gully Creek (2 exceedances) | King Gully Creek (2 exceedances) | King Gully Creek (2 exceedances) |
| | Lena Creek (1 exceedance) | Lena Creek (1 exceedance) | Lena Creek (1 exceedance) |
| | Downstream north Tailing Dam 3 (1 exceedance) | Downstream north Tailing Dam 3 (1 exceedance) | Downstream north Tailing Dam 3 (1 exceedance) |
| | Downstream north Tailing Dam 5 (1 exceedance) | Downstream north Tailing Dam 5 (1 exceedance) | Downstream north Tailing Dam 5 (1 exceedance) |
| | Seepage pond Tailing Dam 5 (4 exceedances) | Seepage pond Tailing Dam 5 (1 exceedance) | Seepage pond Tailing Dam 5 (1 exceedance) |

| Metal or metalloid | 0.45 μm fraction | DGT technique | Visual MINTEQ calculation |
|---|---|---|---|
| Lead | Downstream north Tailing Dam 3 (1 exceedance) | Nil | Nil |
| | Downstream north Tailing Dam 5 (1 exceedance) | Nil | Nil |

### 3.1.8 Water chemistry and metal and metalloid concentrations in water at the first flush collection in the wet season of 2010

During the wet season of 2010, five sites at Leichhardt River (upstream and within Mount Isa City) and five sites at tributaries from the mine lease were selected to collect water samples for measuring water quality after the first rain event of the wet season. The results for metals and metalloid concentrations at these Leichhardt River sites are presented in Table 38. The results for arsenic, cadmium, copper, nickel, lead, and zinc did not exceed the drinking water guidelines (ADWG, 2004). However, arsenic, cadmium, and lead concentrations collected at most of the tributaries from the mine lease did exceed the drinking water guidelines (ADWG, 2004) (Table 39).

**Table 38. Metal and metalloid concentrations of water sampled in the Leichhardt River after the first flush event of the wet season in 2010 (3 January 2010)**

| Sites | Fraction | Arsenic | Cadmium | Copper | Nickel | Lead | Zinc |
|---|---|---|---|---|---|---|---|
| | | (μg/L) | | | | | |
| Leichhardt River upstream | Total | 0.5 | <0.1 | 6.3 | 0.9 | 1.5 | 8.5 |
| | 0.45 μm | 0.4 | <0.1 | 4.5 | 1 | 0.2 | 4.6 |
| Mica Creek upstream | Total | 1.2 | <0.1 | 19.1 | 1.7 | 2.3 | 7.4 |
| | 0.45 μm | 1.1 | <0.1 | 14.7 | 6.2 | 0.9 | 3.2 |
| 23rd Avenue | Total | 0.6 | <0.1 | 10.2 | 1 | 2.8 | 18.9 |
| | 0.45 μm | 0.6 | <0.1 | 6.7 | 0.4 | 0.3 | 5.7 |
| Alma Crossing | Total | 0.7 | <0.1 | 11.8 | 0.9 | 3 | 18.4 |
| | 0.45 μm | 0.6 | <0.1 | 8.4 | 0.5 | 0.4 | 8.7 |
| Moondarra Junction | Total | 1.7 | <0.1 | 15.7 | 0.7 | 7.7 | 10.4 |
| | | 1.6 | <0.1 | 10.6 | 0.5 | 1.1 | 9 |
| Australian Drinking Water Guideline (ADWG, 2004) | | 7 | 2 | 1,000 | 20 | 10 | 3,000 |
| Number of sites exceeding ADWG (2004) | | Nil | Nil | Nil | Nil | Nil | Nil |

**Table 39. Metal and metalloid concentrations in water sampled at tributaries from mine lease sites at first flush collection in the wet season of 2010 (3 January 2010)**

| Sites | Fraction | Arsenic | Cadmium | Copper | Nickel | Lead | Zinc |
|---|---|---|---|---|---|---|---|
| | | (μg/L) | | | | | |
| Lena Creek | Total | **12.4** | **3.2** | 310 | 3.3 | **108** | 214 |
| | 0.45 μm | 5.3 | **2.7** | 134 | 2.2 | **13** | 165 |
| | $C_{DGT}$ | - | 1 ± 0.1 | 28 ± 2 | 0.6 ± 0.1 | 0.7 ± 0.03 | 64 ± 6 |
| King Gully Creek | Total | **8.2** | 3.5 | 318 | 4.1 | **191** | 207 |
| | 0.45 μm | 4.6 | 1.2 | 102 | 2.4 | 7.5 | 40 |
| | $C_{DGT}$ | - | 0.4 ± 0.04 | 15 ± 0.8 | 0.5 ± 0.1 | 0.4 ± 0.04 | 16 ± 2 |
| George Fisher Creek | Total | 4.1 | **2.3** | 43 | 5 | **444** | 407 |
| | 0.45 μm | 1.3 | 1.3 | 12 | 5 | **21** | 87 |
| | $C_{DGT}$ | - | 0.5 ± 0.1 | 2.7 ± 0.2 | 0.4 ± 0.1 | 3.75 ± 0.32 | 39 ± 4 |

| Sites | Fraction | Arsenic | Cadmium | Copper | Nickel | Lead | Zinc |
|---|---|---|---|---|---|---|---|
| | | (µg/L) | | | | | |
| Downstream north of Tailing Dam 3 | Total | **26.4** | **16.4** | 817 | 5 | **417** | 458 |
| | 0.45 µm | 12.6 | 16.3 | 355 | 12 | **138** | 260 |
| | $C_{DGT}$ | - | 3.1 ± 0.02 | 132 ± 2 | 0.8 ± 0.01 | **24.3 ± 1.8** | 141 ± 0.6 |
| Downstream north of Tailing Dam 5 | Total | **11.8** | **9.9** | 305 | 8 | **159** | 273 |
| | 0.45 µm | 6.6 | 8.7 | 564 | 4 | **180** | 270 |
| | $C_{DGT}$ | - | 5.5 ± 0.5 | 65 ± 5 | 0.7 ± 0.1 | **18 ± 1.2** | 96 ± 8 |
| Australian Drinking Water Guideline (ADWG, 2004) | | 7 | 2 | 2,000 | 20 | 10 | 3,000 |
| Number of sites exceeding ADWG (2004) | | 4 | 5 | Nil | Nil | 5 | Nil |

Note: Bold values indicate site exceed guideline values.

## 3.2 Sediment studies on metal and metalloids

Six sets of sediment samples were collected at Leichhardt River from 2007 to 2009 (Table 3). The <63 µm fractions of sediments were prepared and analysed for total and cold 1M HCl extraction of metal and metalloids, as described in Section 2.6. The total concentrations of metals and metalloids were initially compared against the ANZECC/ARMCANZ ISQG-Low for sediments (Table 1). When the total concentrations of metals and metalloids exceeded the ISQG-High and ISQG-Low, the 1M HCl extract concentrations, which give an estimate of bioavailability (Figure 12), were compared against the ISQG-Low. If the ISQG-Low was still exceeded, the ANZECC/ARMCANZ decision tree process for assessing contaminated sediment (Figure 12) requires an assessment of toxicity. All results for the six sets of sediment samples are given in Appendix 6.

### 3.2.1 Sediment samples from the Leichhardt River collected in 2007

Table 40 summarises the sites that exceeded ISQG-Low and ISQG-High for 1M HCl extracts of metal and metalloids concentrations in sediments collected in 2007 (Noller et al., 2009).

**Table 40. Summary of sites exceeding ISQG-Low for metal and metalloid concentrations in 1M HCl extraction of sediment samples collected in 2007**

| Metal or metalloid | Number of sites exceed ISQG | | ISQG-Low (mg/kg) | ISQG-High (mg/kg) | Sites exceed ISQG-Low | Sites with highest concentrations (mg/kg) |
|---|---|---|---|---|---|---|
| | ISQG-Low | ISQG-High | | | | |
| Arsenic | 1 | 1 | 20 | 70 | L9 | 174 (L9) |
| Cadmium | 3 | 1 | 1.5 | 10 | L9,L12,L15 | 111 (L12) |
| Copper | 4 | 1 | 65 | 270 | L7,L9,L12,L15 | 6400 (L12) |
| Lead | 4 | 3 | 50 | 220 | L7,L9,L12,L15 | 20,000 (L12) |
| Zinc | 3 | 1 | 200 | 410 | L9,L12,L15 | 4,290 (L12) |
| Nickel | 1 | 0 | 21 | 52 | L7 | 22.2 (l7) |

### 3.2.2 Sediment samples following the Leichhardt River Remediation Program

Ten sites (Figure 14) were selected for sediment quality evaluation and concurrent aquatic toxicity testing following the 2008 Leichhardt River Remediation Program. Samples were collected between 15 and 16 October 2009. The metal and metalloid concentrations of the total digestion and 1M HCl extraction of these sediments are in Table 41. The sediment concentrations were compared against ISQG-Low and ISQG-High (Table 1). The summary of sites exceeding ISQG-Low and ISQG-High (Table 42) showed that nine sites exceeded ISQG-Low and one site exceeded ISQG-High for cadmium.

The highest cadmium concentration was 59 mg/kg at Davis Crossing. Ten sites exceeded ISQG-Low for copper with the highest copper concentration of 272 mg/kg at the upper Lake Moondarra site ‘between the junction and the pump station’. Ten sites exceeded ISQG-Low for lead and seven sites exceeded ISQG-High with the highest

**Table 41. Results for the total concentration and 1M HCl extraction of metals and metalloids in sediment samples collected 15–16 October 2009**

| Sites | Antimony | | Arsenic | | Cadmium | | Cobalt | | Copper | | Nickel | | Lead | | Zinc | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Total | 1MHCl | Total | 1MHCl | Total | 1MHCl | Total | 1MHCl | Total | 1MHCl | Total | 1MHCl | Total | 1MHCl | Total | 1MHCl |
| | (mg/kg) | | (mg/kg) | | (mg/kg) | | (mg/kg) | | (mg/kg) | | (mg/kg) | | (mg/kg) | | (mg/kg) | |
| 23rd Avenue | N/A | <1.0 | 5 | 3 | N/A | 0.5 | N/A | 8.2 | N/A | 194 | N/A | 1.9 | N/A | 50.8 | N/A | 42 |
| Isa Crossing | <5 | <1.0 | 10 | 4.3 | 4 | 4.7 | 16 | 8.7 | 390 | 218 | 19 | 3.6 | 89 | 82.1 | 947 | 932 |
| Alma Crossing | N/A | <1.0 | N/A | 4.2 | N/A | 7 | N/A | 8.5 | N/A | 190 | N/A | 2.7 | N/A | 144 | N/A | 274 |
| Davis Crossing | <5 | <1.0 | 16 | 7.4 | 58 | 59.1 | 21 | 12 | 264 | 148 | 19 | 2.9 | 281 | 225 | 699 | 578 |
| Moondarra Crossing | <11 | <1.0 | 19 | 4.7 | 8 | 6.9 | 18 | 9.2 | 252 | 155 | 23 | 3.2 | 348 | 282 | 500 | 294 |
| Before Junction | <5 | <1.0 | 11 | 2.9 | 6 | 5.7 | 17 | 8.8 | 212 | 138 | 20 | 2.5 | 276 | 253 | 440 | 310 |
| Between junction & pump station | <5 | <1.0 | 24 | 5.9 | 4 | 3.1 | 22 | 7.7 | 502 | 272 | 27 | 2.4 | 328 | 280 | 376 | 173 |
| Lower channel above junction | <5 | <1.0 | 17 | 4.1 | 5 | 5 | 17 | 8.2 | 253 | 156 | 20 | 2.3 | 375 | 343 | 442 | 316 |
| Lake Moondarra | <5 | <1.0 | 22 | 5.1 | 4 | 3.7 | 21 | 8.4 | 459 | 253 | 25 | 2.7 | 308 | 259 | 411 | 204 |
| Clear Water Lagoon | 20 | <1.0 | 34 | 4.2 | 5 | 4.9 | 19 | 8.6 | 349 | 222 | 23 | 4.4 | 389 | 339 | 550 | 327 |

*Total and 1MHCl concentrations were analysed on <63µm fraction

concentration of 343 mg/kg at the ‘lower channel above junction’. Eight sites exceeded ISQG-Low for zinc and two sites exceeded ISQG-High for zinc. The highest zinc concentration in sediment 932 mg/kg was found at Isa Crossing. No site exceeded the ISQG-Low for nickel (Table 42).

**Table 42. Summary of sites exceeding ISQG-Low for 1MHCl extraction**

| Elements | Number of sites exceed | | ISQG-Low (mg/kg) | ISQG-High (mg/kg) | Sites exceeding ISQG-Low | Sites with highest concentration (mg/kg) |
|---|---|---|---|---|---|---|
| | ISQG-Low | ISQG-High | | | | |
| Arsenic | 0 | 0 | 20 | 70 | Nil | Nil |
| Cadmium | 9 | 1 | 1.5 | 10 | • Isa Crossing<br>• Alma Crossing<br>• Davis Crossing<br>• Moondarra Crossing<br>• Before junction<br>• Between junction & pump station<br>• Lower channel & above junction<br>• Lake Moondarra<br>• Clear Water Lagoon | 59 (Davis Crossing) |
| Copper | 10 | 1 | 65 | 270 | • 23rd Avenue<br>• Isa Crossing<br>• Alma Crossing<br>• Davis Crossing<br>• Moondarra Crossing<br>• Before junction<br>• Between junction & pump station<br>• Lower channel & above junction<br>• Lake Moondarra | 272 (Between junction & pump station) |
| Lead | 10 | 7 | 50 | 220 | • 23rd Avenue<br>• Isa Crossing<br>• Alma Crossing<br>• Davis Crossing<br>• Moondarra Crossing<br>• Before junction<br>• Between junction & pump station<br>• Lower channel & above junction<br>• Lake Moondarra<br>• Clear Water Lagoon | 343 (Lower channel & above junction) |

| Elements | Number of sites exceed | | ISQG-Low (mg/kg) | ISQG-High (mg/kg) | Sites exceeding ISQG-Low | Sites with highest concentration (mg/kg) |
|---|---|---|---|---|---|---|
| | ISQG-Low | ISQG-High | | | | |
| Zinc | 8 | 2 | 200 | 410 | • Isa Crossing<br>• Alma Crossing<br>• Davis Crossing<br>• Moondarra Crossing<br>• Before junction<br>• Lower channel & above junction<br>• Lake Moondarra<br>• Clear Water Lagoon | 932 (Isa Crossing) |
| Nickel | 0 | 0 | 21 | 52 | Nil | Nil |

### 3.2.3 Sediment from Leichhardt River Verification Program

During 13–14 November 2009, 79 sediment samples were collected from the section of the Leichhardt River comprising Alma Crossing to Moondarra Junction. These samples were collected by Xstrata for the Leichhardt River Verification Program. Each sample site is referred to as LR (Table 3). The samples were analysed for total digest and 1M HCl extraction metals and metalloids in <63 µm fractions (Section 2.6). The results are presented in Figure 25 to Figure 30. The total concentration and 1M HCl concentrations are compared with the ISQG-Low and ISQG-High of each metal and metalloid. Table 43 summarises:

- the number of sites that have total concentrations of metal and metalloids exceeding the ISQG-Low and ISQG-High for arsenic, cadmium, copper, lead, zinc, and nickel
- the number of sites that exceeded ISQG-Low and ISQG-High for 1M HCl extraction.

The metal and metalloid concentrations for 1M HCl extraction were compared against the ISQG-Low. The results show:

- two sites (LR10 and LR10DUP) (Figure 31) exceeded ISQG-Low for arsenic
- 79 sites exceeded ISQG-Low for cadmium, with the highest readings at LR68
- 78 sites exceeded ISQG-Low for copper with the highest readings at LR10
- 79 sites exceeded ISQG-Low for lead with the highest reading at LR9
- 50 sites exceeded ISQG-Low for zinc with the highest reading at LR10 (Table 43).

The ANZECC/ARMCANZ decision-tree process for assessing contaminated sediment (Figure 12) indicates that sites exceeding ISQG-Low for 1M HCl extraction are considered to be contaminated and require a toxicity assessment.

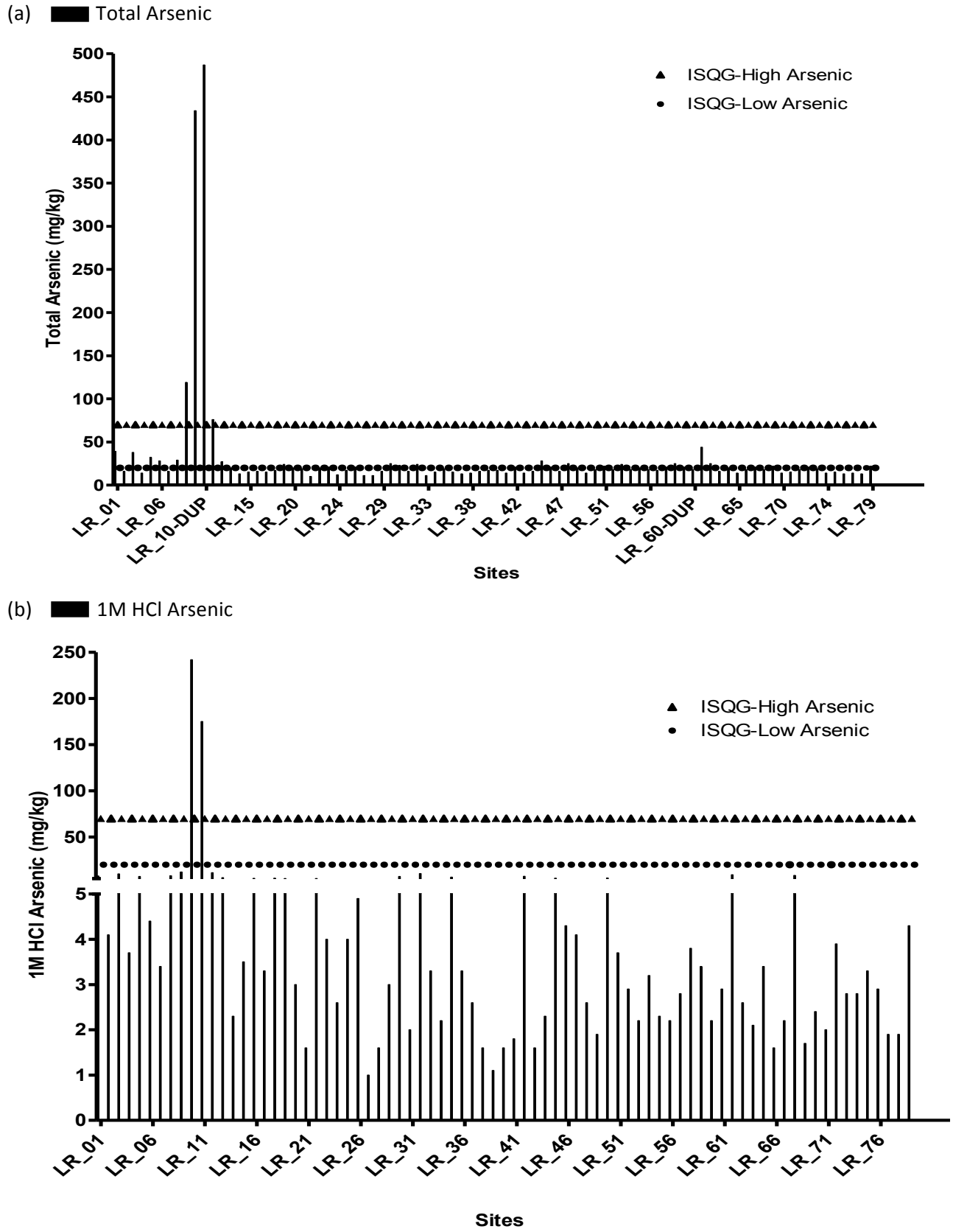



**Figure 25. Total concentration (a) and 1M HCl extraction concentration (b) of arsenic compared with ISQG-Low and ISQG-High for arsenic in sediment samples collected for the Leichhardt River Verification Program by Xstrata (13–14 November 2009)**

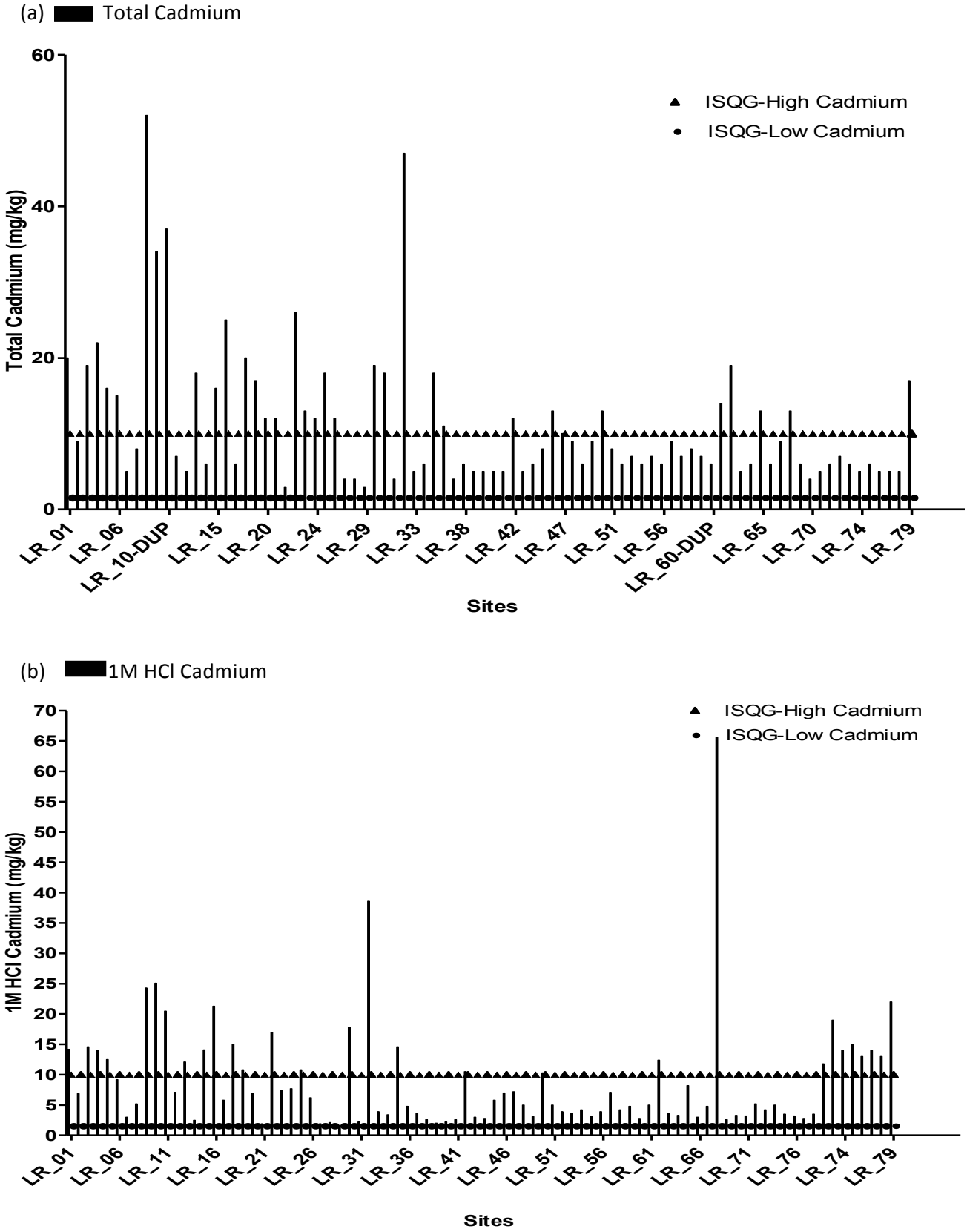



**Figure 26. Total concentration (a) and 1M HCl extraction concentration (b) of cadmium compared with ISQG-Low and ISQG-High for cadmium in sediment samples collected for the Leichhardt River Verification Program by Xstrata (13–14 November 2009)**

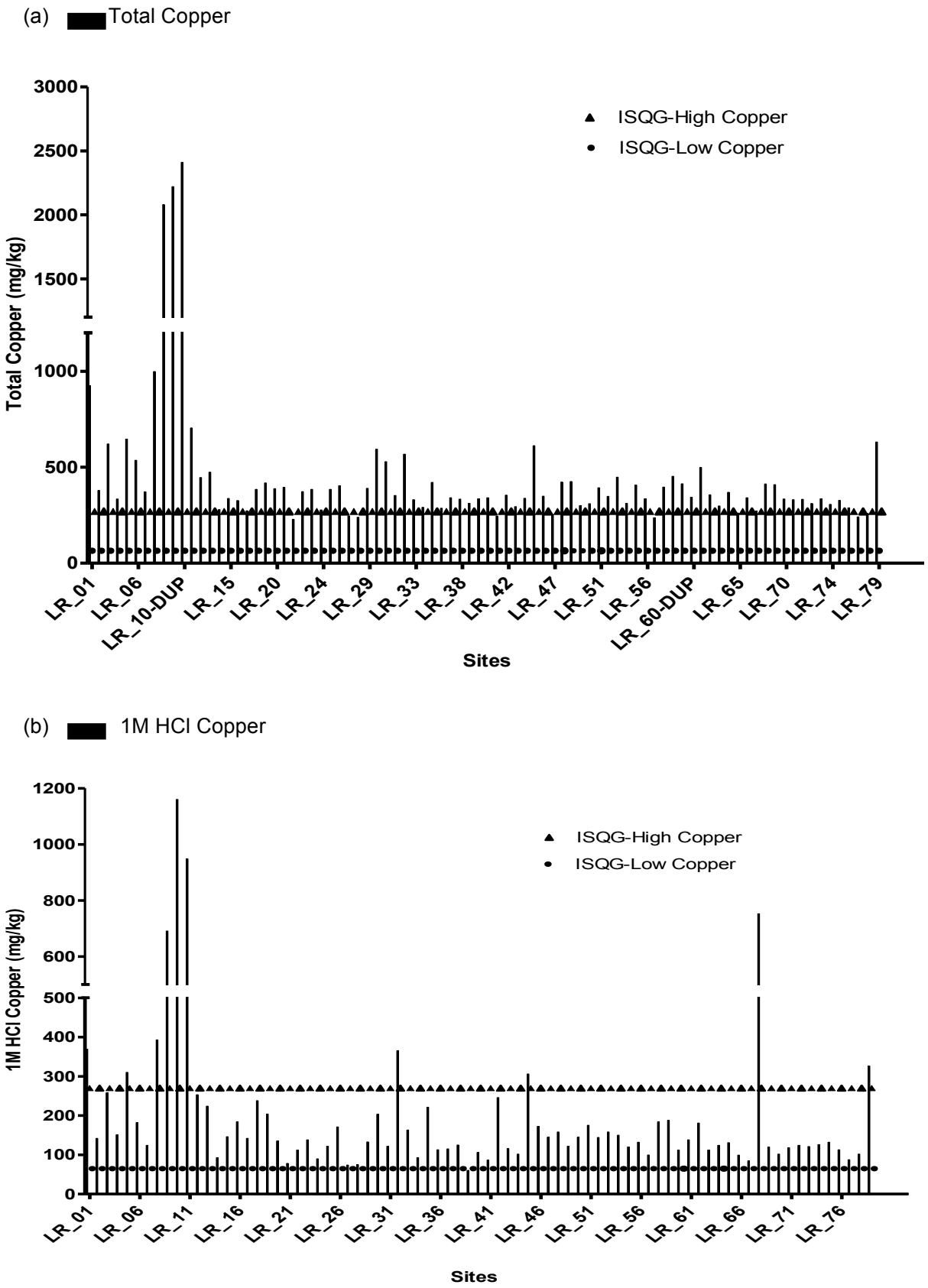



**Figure 27. Total concentration (a) and 1M HCl extraction concentration (b) of copper compared with ISQG-Low and ISQG-High for copper in sediment samples collected for the Leichhardt River Verification Program by Xstrata (13–14 November 2009)**

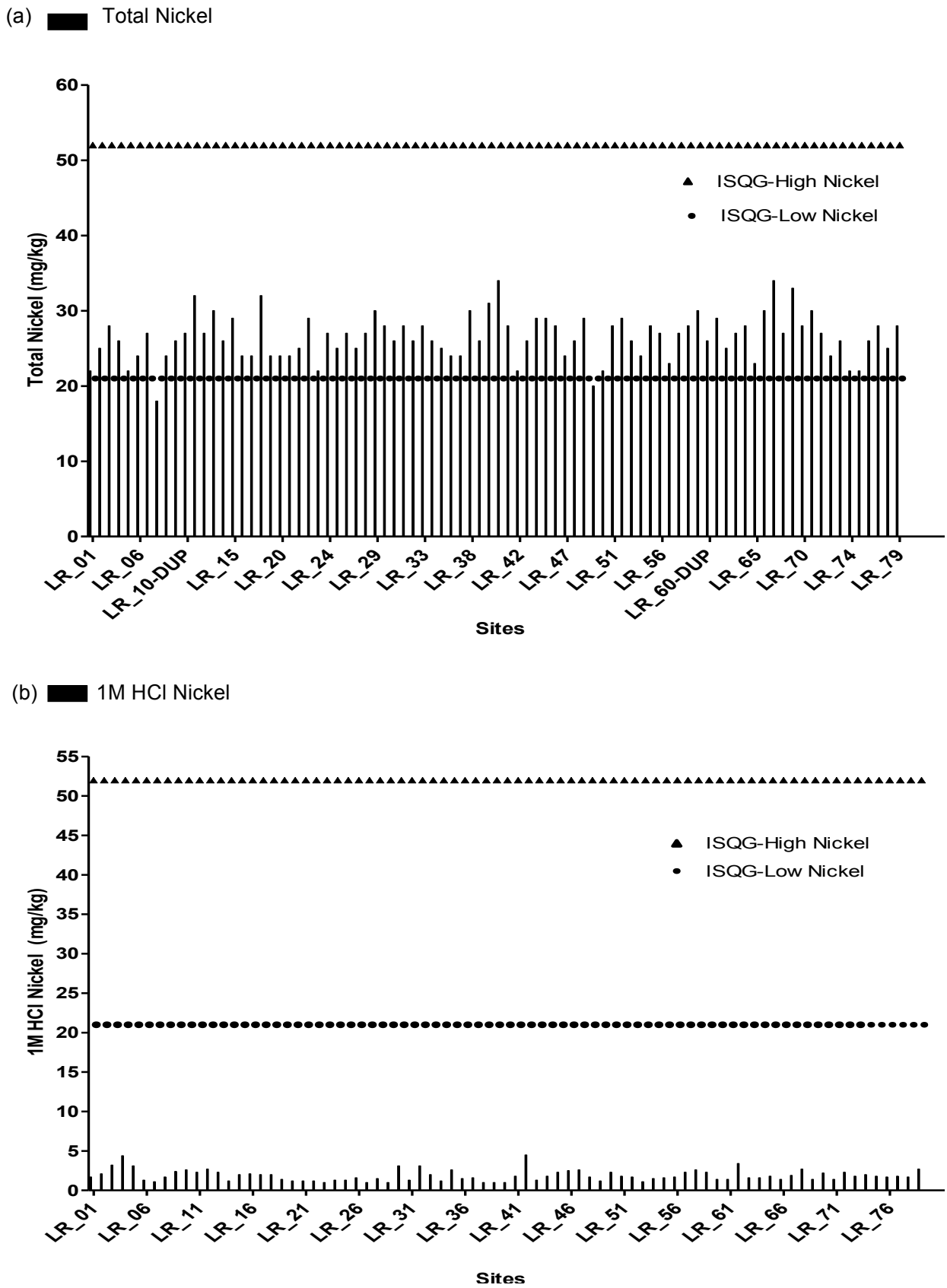



**Figure 28. Total concentration (a) and 1M HCl extraction concentration (b) of nickel compared with ISQG-Low and ISQG-High for nickel in sediment samples collected for the Leichhardt River Verification Program by Xstrata (13–14 November 2009)**

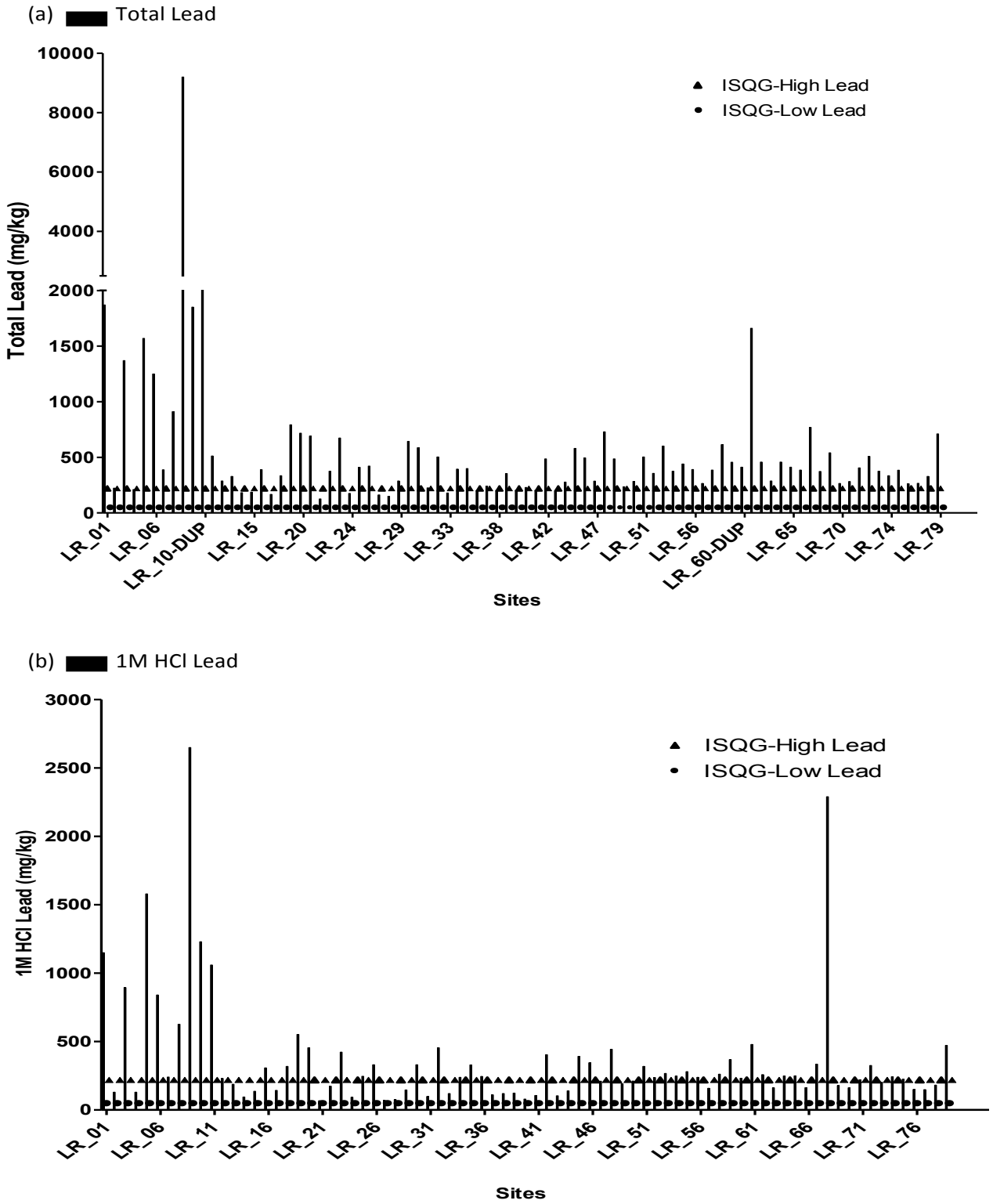



**Figure 29. Total concentration (a) and 1M HCl extraction concentration (b) of lead compared with ISQG-Low and ISQG-High for lead in sediment samples collected for the Leichhardt River Verification Program by Xstrata (13–14 November 2009)**

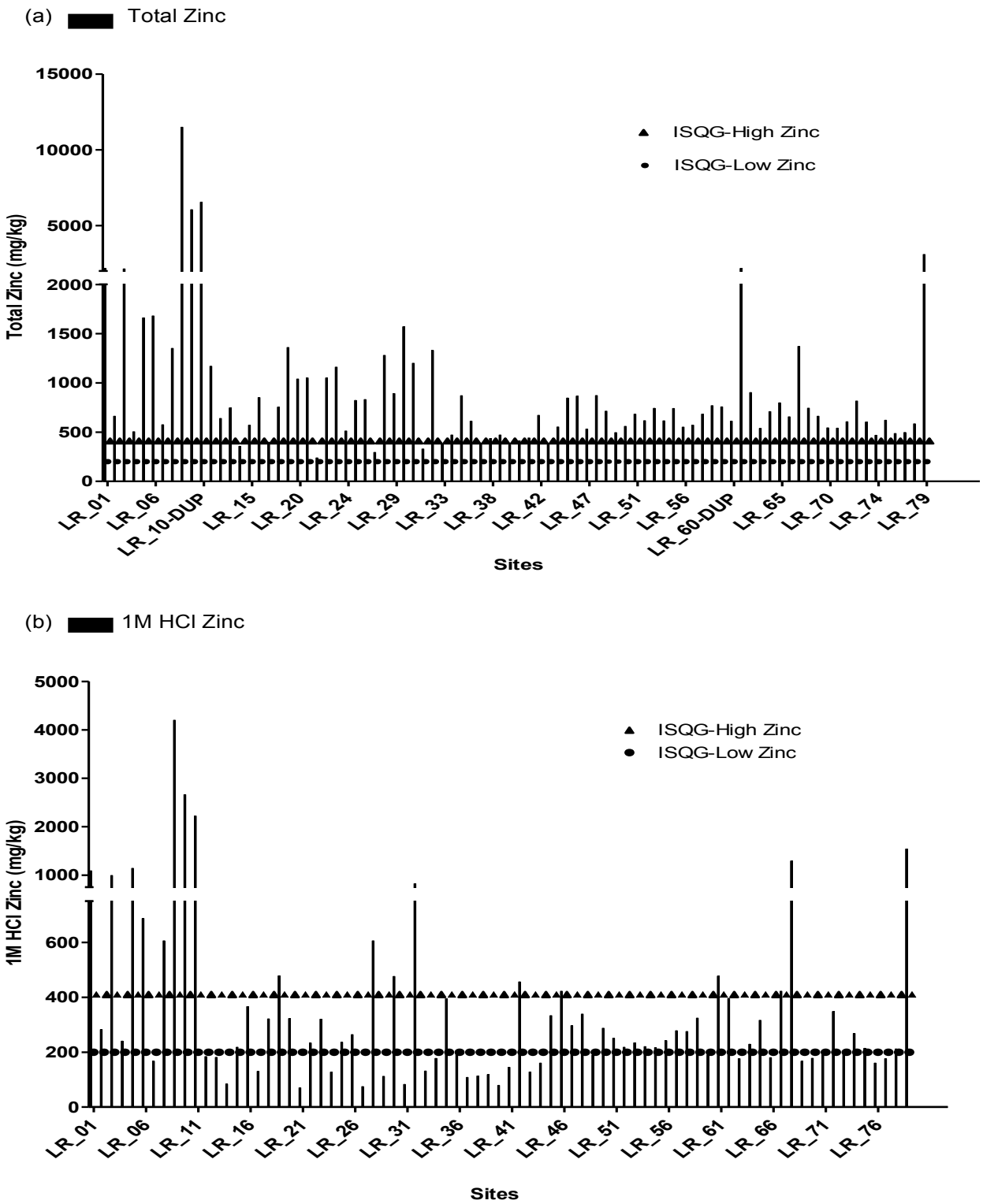



**Figure 30. Total concentration (a) and 1M HCl extraction concentration (b) of zinc compared with ISQG-Low and ISQG-High for zinc in sediment samples collected for the Leichhardt River Verification Program by Xstrata (13–14 November 2009)**

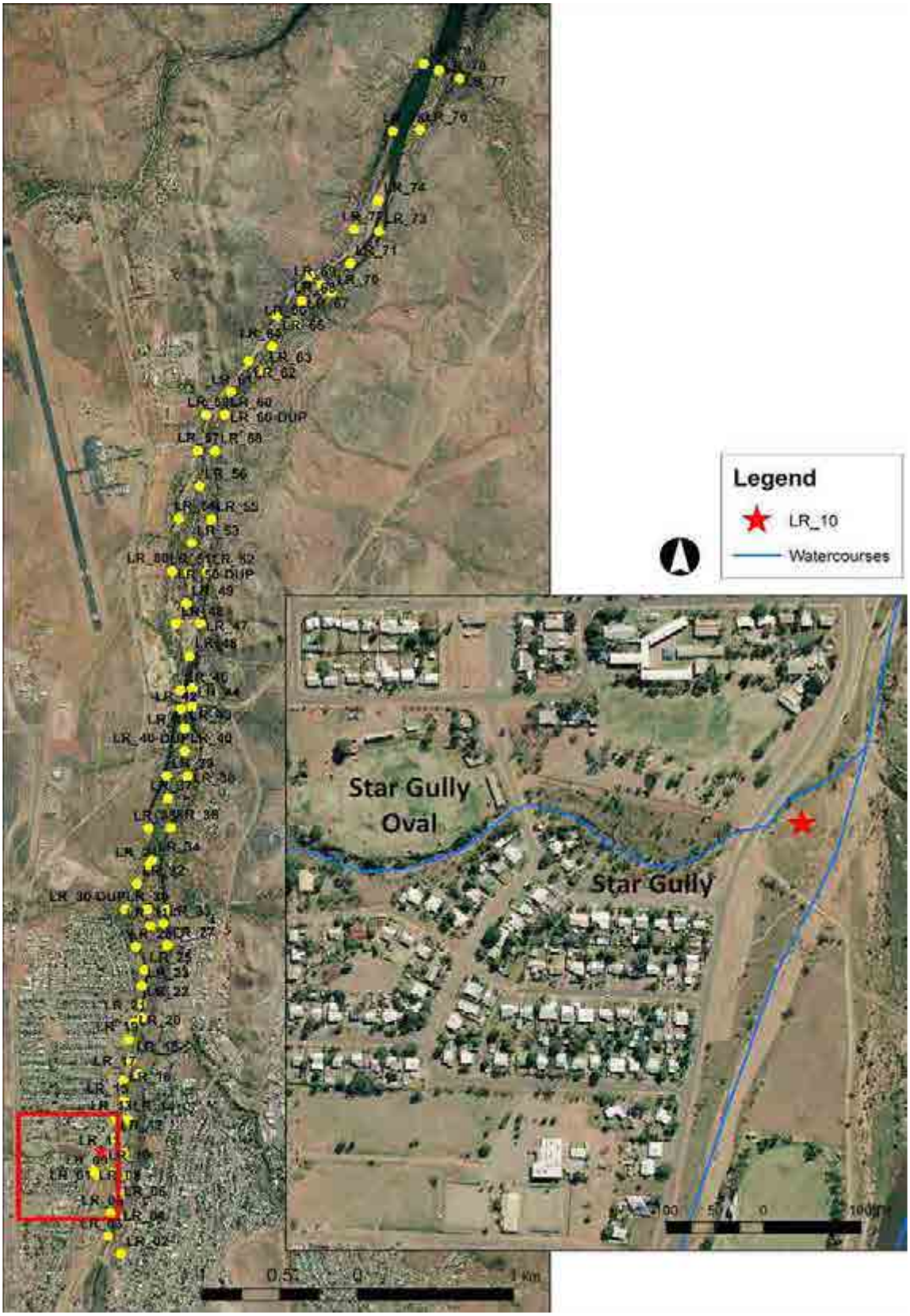



**Figure 31. Sampling sites of Leichhardt River Verification Program (13-14 November 2009). The insert map shows the LR10 site, where the concentration of arsenic exceeded ISQG-Low. LR10 is identified as being contaminated for human health**

**Table 43. Summary sites exceeding ISQG-Low and ISQG-High for total metal concentrations and 1M HCl extraction in sediment sampled for the Leichhardt River Verification Program 13–14 November 2009**

| Metal or metalloid | Sites exceeding ISQG | | ISQG-Low (mg/kg) | ISQG-High (mg/kg) | Sites with highest total concentration (mg/kg) |
|---|---|---|---|---|---|
| | ISQG-Low | ISQG-High | | | |
| **(a) Total concentration (<63 μm fraction) (mg/kg)** | | | | | |
| Arsenic | 31 | 4 | 20 | 70 | LR10 and LR10DUP (Mean ± SD 460±37) |
| Cadmium | 86 | 33 | 1.5 | 10 | LR 9 (52) |
| Copper | 86 | 77 | 65 | 270 | LR10 and LR10DUP (Mean ± SD 2300±30) |
| Lead | 86 | 72 | 50 | 220 | LR9 (9200) |
| Zinc | 86 | 77 | 200 | 410 | LR9 (11500) |
| Nickel | 84 | 0 | 21 | 52 | LR67 (34) |
| **(b) 1M HCl extraction concentration (<63 μm fraction) (mg/kg)** | | | | | |
| Arsenic | 2 | 2 | 20 | 70 | LR10 only (242) |
| Cadmium | 79 | 22 | 1.5 | 10 | LR68 (66) |
| Copper | 78 | 10 | 65 | 270 | LR10 only (1160) |
| Lead | 79 | 46 | 50 | 220 | LR9 (2650) |
| Zinc | 50 | 18 | 200 | 410 | LR9 (4200) |
| Nickel | 0 | 0 | 21 | 52 | Nil |

### 3.2.4 Sediment from Regional/Background Stream Sediment Sampling Program

The regional/background samples (Section 2.6.1.2; Figure 32 to Figure 37) were analysed for total digested and 1M HCl extracted metals and metalloids in <63 µm fractions (Section 2.6). The results in Figure 25 to Figure 30 show that the total concentration, when compared with the ISQG-Low and ISQG-High of each metal and metalloid, were exceeded in some cases. When the results for 1M HCl extraction concentrations in Figure 25 to Figure 30 and Figure 32 to Figure 37 were compared with the ISQG-Low, some samples exceeded the ISQG-Low for copper and lead. Table 43 summarises:

- the sites that have total concentrations of copper and lead exceeding the ISQG-Low
- the sites that exceeded the ISQG-Low for 1HCl extraction.

These results indicate that some sites in the upper catchment may show effects of copper and lead on aquatic biota.

Twenty-nine sediment samples were collected by Xstrata from an upstream section of the Leichhardt River comprising Mica Creek up to Rifle Creek. The sample sites are referred to as RB in Table 3 and Figure 16. An additional three sediment samples were collected at Spring Creek (SPC) Bridge, and First and Second SPC Gullies, which lie in the upper catchment of George Fisher Creek and flow to Lake Moondarra (Figure 38).

The results of total and 1M HCl extraction metal and metalloid concentrations in the regional/ background samples are presented in Figure 32 to Figure 37. Table 44 and Table 45 compared the results with ISQG-Low. Table 46 summarises the background sediment sites that exceed or comply with ISQG-Low for copper and lead. Thirteen out of twenty-nine sites had concentrations of copper and lead in sediment that exceeded the ISQG-Low trigger values. The highest concentration of copper (226 mg/kg) and lead (140 mg/kg) were found at RB8. The mean concentrations (± se) of 1M HCl extraction copper and lead for sites that exceeded the ISQG-Low were 115±38 mg/kg and 70±20mg/kg, respectively. Most of the sites exceeding ISQG-Low were located in the Mica Creek catchment and in overlies on the top of abandoned mines (Figure 38). Mean concentration (± se) of 1M HCl extraction copper and lead from sites that complied with the ISQG-Low were 39±4.9 mg/kg and 23±2.4 mg/kg,

respectively. The 1M HCl extraction metal and metalloids from the three additional sediment samples collected at SPC Bridge, First and Second SPC Gully (Figure 38), (background), also exceeded the ISQG-Low (Table 43). These sites are located above the Handlebar Hill Open Cut operations, which were also associated with abandoned copper mines (Figure 38).

ANZECC/ARMCANZ (2000) advise that for sediment in highly disturbed systems, metals should be <3 X natural background and for toxicants <3 X ISQG – Low. Comparison of the results in Table 44 and Table 45 with these two criteria shows that metal and metalloid concentrations in 1M HCl extractions do not exceed the criteria. This supports the use of all sediment data from background sites for site-specific guideline purposes.

**Table 44. Summary of sites exceeding ISQG-Low for 1M HCl metal and metalloid extraction concentrations in sediment sampled for the Regional/Background Stream Sediment Sampling Program by Xstrata (November 2009)**

| Sites | 1M HCl extraction (mg/kg) in <63 µm fraction | | | | | |
|---|---|---|---|---|---|---|
| | Arsenic | Cadmium | Copper | Nickel | Lead | Zinc |
| RB_01 | 2.1 | 0.7 | 161 | <0.1 | 67 | 22.5 |
| RB_02 | 3.5 | 0.4 | 79 | <0.1 | 41 | 13.4 |
| RB_03 | 4.8 | 0.3 | 116 | 1.5 | 51 | 18.8 |
| RB_04 | 11 | <1 | 204 | 2 | 95 | 39.7 |
| RB_05 | 3 | <1 | 125 | 2 | 63 | 23 |
| RB_06 | 5.5 | 0.3 | 72 | <1 | 46 | 19.5 |
| RB_07 | 10.7 | 0.4 | 96 | <1 | 55 | 22.3 |
| RB_08 | 8.0 | 1.1 | 226 | 3 | 140 | 90.7 |
| RB_09 | 8.9 | 0.9 | 99 | 2 | 66 | 27.8 |
| RB_10 | 9 | 1 | 197 | 1.7 | 99 | 34.3 |
| RB_11 | 8.3 | <1 | 194 | 1 | 85 | 27 |
| RB_16 | <1 | 0.1 | 84 | 1 | 15 | 4.4 |
| RB_17 | 3.6 | 0.4 | 77 | 2.4 | 54 | 22.2 |
| RB_23 | 6.3 | 0.3 | 58 | 1.7 | 68 | 18.9 |
| RB_24 | 10.1 | 0.4 | 58 | <1 | 55 | 28.5 |
| RB_25 | 2.7 | 0.4 | 59 | 1.1 | 59 | 21.6 |
| SPC Bridge | 1.8 | 0.7 | 84 | 1.2 | 79 | 30 |
| First SPC Gully | 1.1 | 0.7 | 87 | 1.2 | 91 | 40.2 |
| Second SPC Gully | 2 | 0.9 | 100 | 1.7 | 109 | 59.2 |
| Mean | 6 | 0.6 | **115** | 1.5 | **70** | 30 |
| SE | 2.4 | 0.2 | **38** | 0.5 | **20** | 13 |
| ISQG-Low | 20 | 1.5 | 65 | 21 | 50 | 200 |
| 3 X ISQG-Low | 60 | 4.5 | 195 | 63 | 150 | 600 |
| 3 X Mean | 18 | 1.8 | **345** | 4.5 | **210** | 90 |

**Table 45. Summary of sites complying with ISQG-Low for 1M HCl metal and metalloid extraction concentrations in sediment sampled for the Regional/Background Stream Sediment Sampling Program by Xstrata (November 2009)**

| Sites | 1M HCl extraction (mg/kg) in <63 µm fraction | | | | | |
|---|---|---|---|---|---|---|
| | Arsenic | Cadmium | Copper | Nickel | Lead | Zinc |
| RB_12 | 1.3 | 0.2 | 38 | 1.3 | 20 | 13.6 |
| RB_13 | <1 | 0.1 | 41 | 1.3 | 15 | 6.9 |
| RB_14 | <1 | <0.1 | 28 | 1.4 | 11 | 3.1 |
| RB_15 | <1 | 0.1 | 52 | 3 | 15 | 4.7 |
| RB_18 | <1 | 0.2 | 43 | 2.6 | 29 | 19.4 |
| RB_19 | 2.5 | 0.2 | 34 | 1.2 | 28 | 12.5 |
| RB_20 | 4.45 | 0.5 | 58 | 1.9 | 41 | 18.6 |
| RB_21 | 5.1 | 0.2 | 22 | 1.2 | 24 | 12.1 |
| RB_22 | 4.4 | 0.2 | 25 | 1.2 | 26 | 13.7 |
| RB_26 | 2.3 | 0.4 | 49 | 1.8 | 32 | 19.6 |
| RB_27 | <1 | 0.3 | 49 | 1.9 | 18 | 9.4 |
| RB_28 | <1 | 0.3 | 43 | 1.5 | 21 | 11.3 |
| RB_29 | <1 | <1 | 19 | 2.0 | 12 | 14.3 |
| Mean | 3 | 0.3 | 39 | 1.7 | 23 | 12 |
| SE | 0.9 | 0.1 | 4.9 | 0.2 | 2.4 | 1.5 |
| ISQG-Low | 20 | 1.5 | 65 | 21 | 50 | 200 |
| 3 X ISQG-Low | 60 | 4.5 | 195 | 63 | 150 | 600 |
| 3 X Mean | 9 | 0.9 | 117 | 5.1 | 69 | 36 |

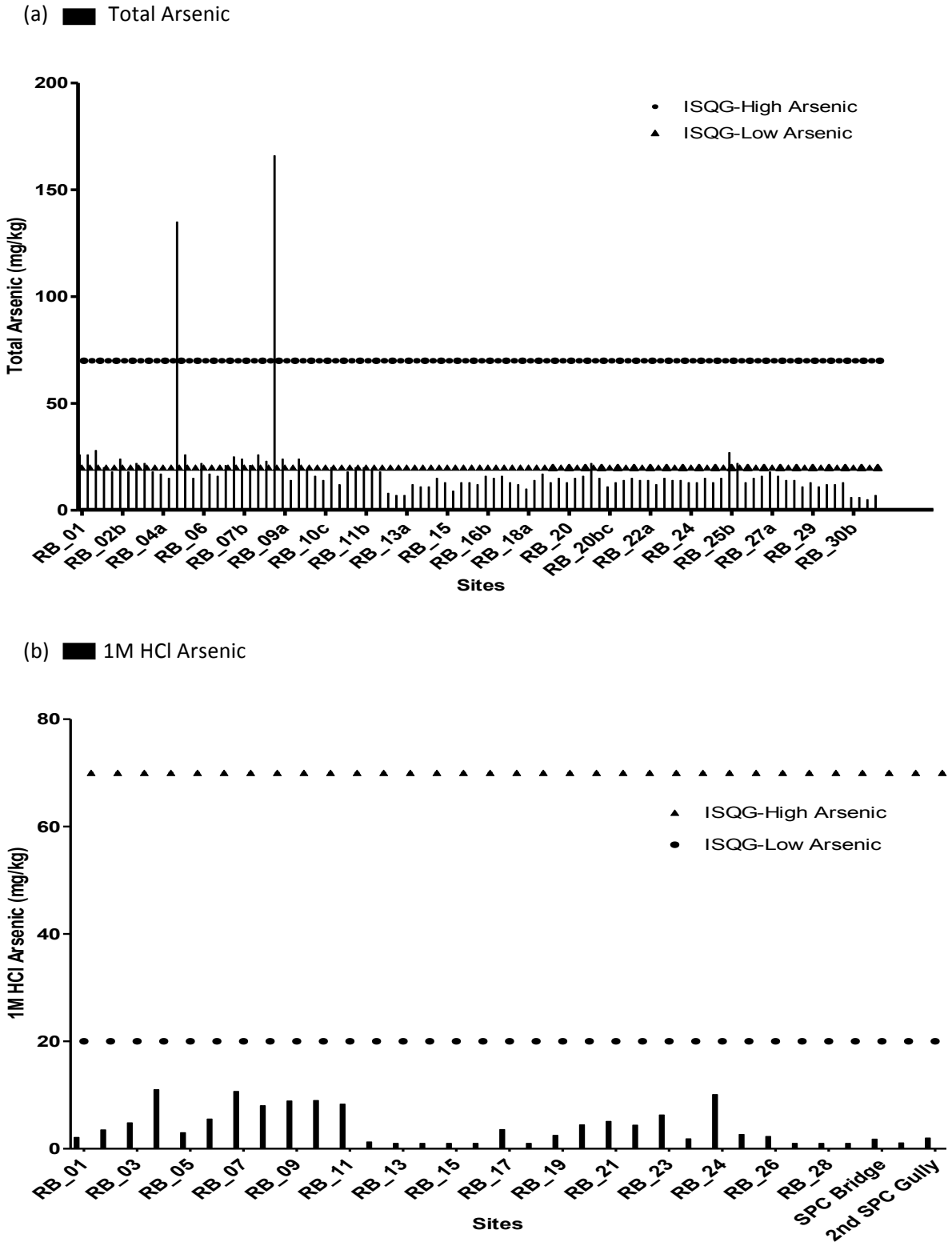
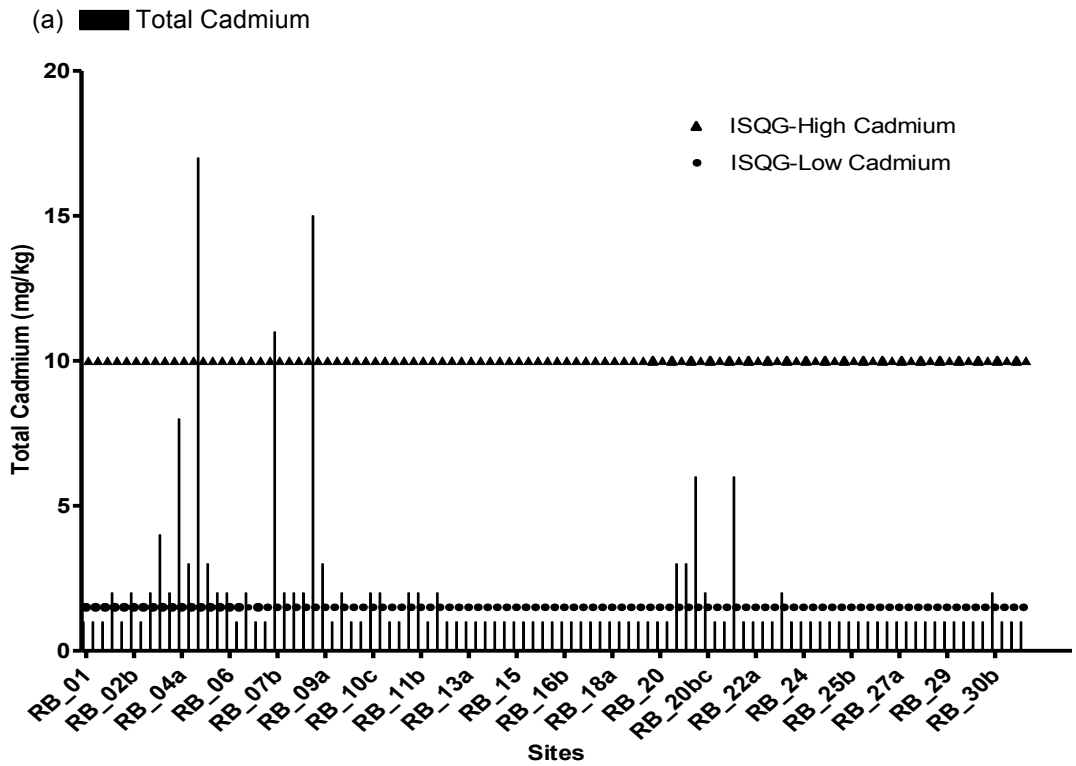



**Figure 32. Total concentration (a) and 1M HCl extraction concentration (b) of arsenic compared with ISQG-Low and ISQG-High for arsenic in sediment samples collected for the Regional/Background Stream Sediment Sampling Program by Xstrata (11 November 2009).**



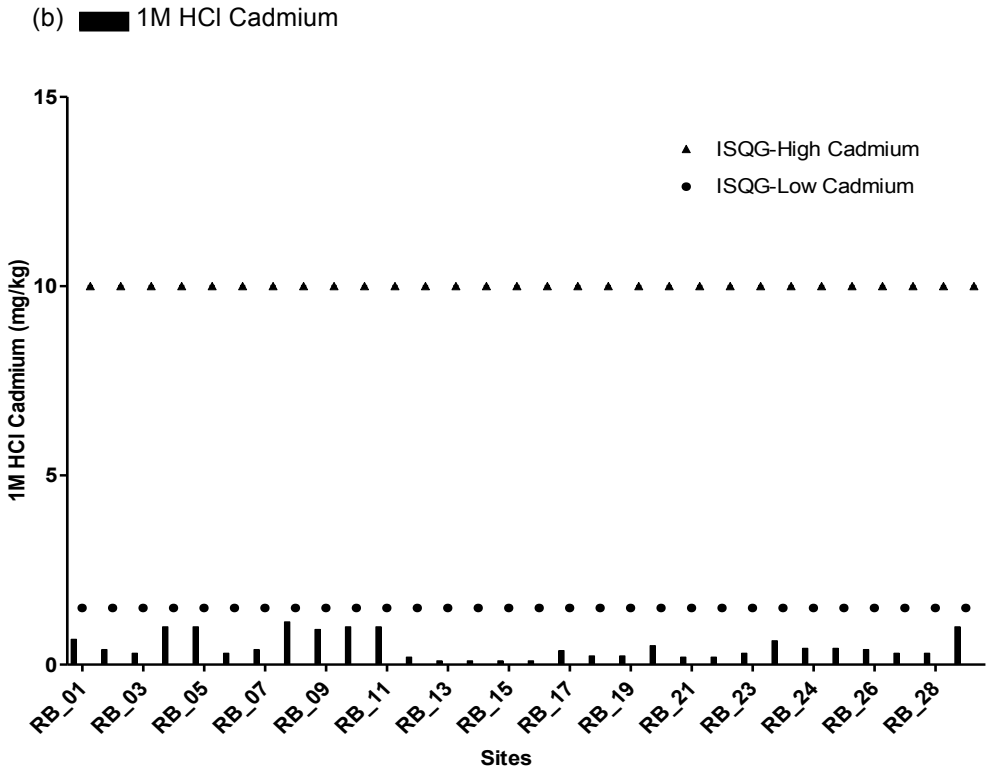




**Figure 33. Total concentration (a) and 1M HCl extraction concentration (b) of cadmium compared with ISQG-Low and ISQG-High for cadmium in sediment samples collected for the Regional/ Background Stream Sediment Sampling Program by Xstrata (11 November 2009).**

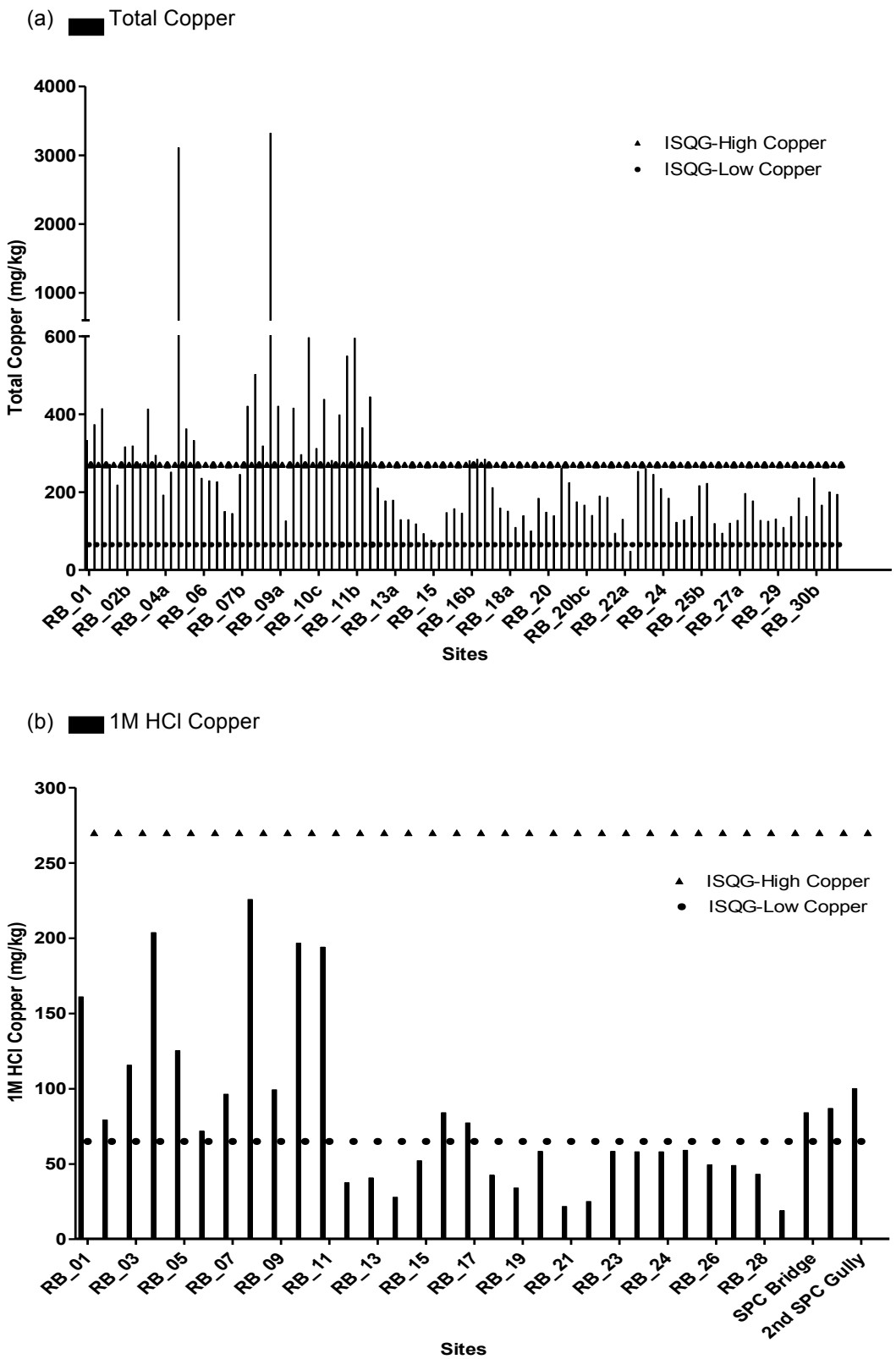



**Figure 34. Total concentration (a) and 1M HCl extraction concentration (b) of copper compared with ISQG-Low and ISQG-High for copper in sediment samples collected for the Regional/Background Stream Sediment Sampling Program by Xstrata (11 November 2009).**

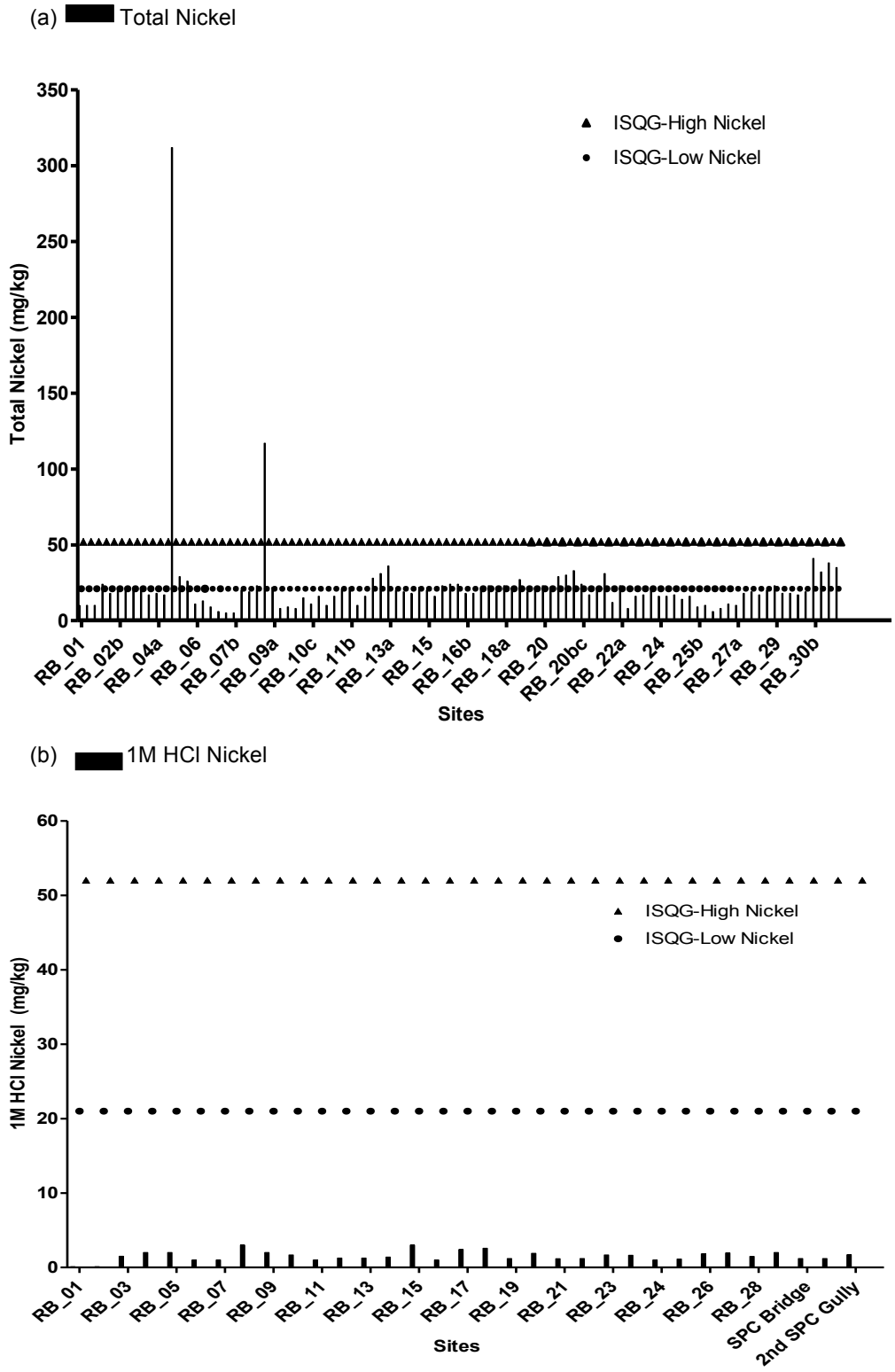
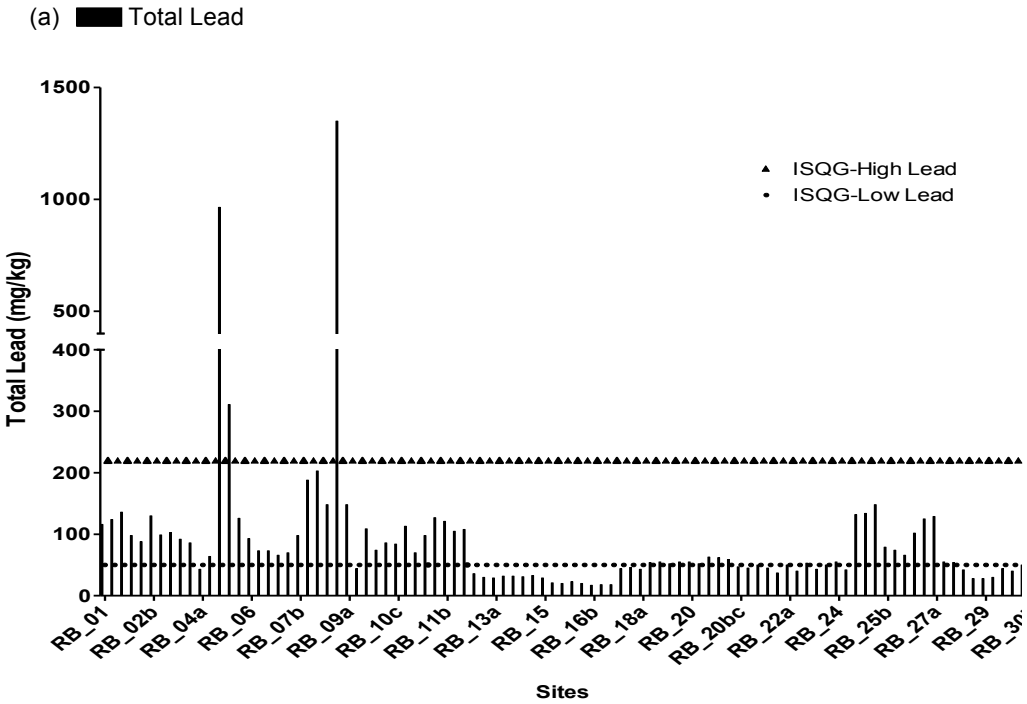



**Figure 35. Total concentration (a) and 1M HCl extraction concentration (b) of nickel compared with ISQG-Low and ISQG-High for nickel in sediment samples collected for the Regional/Background Stream Sediment Sampling Program by Xstrata (11 November 2009).**



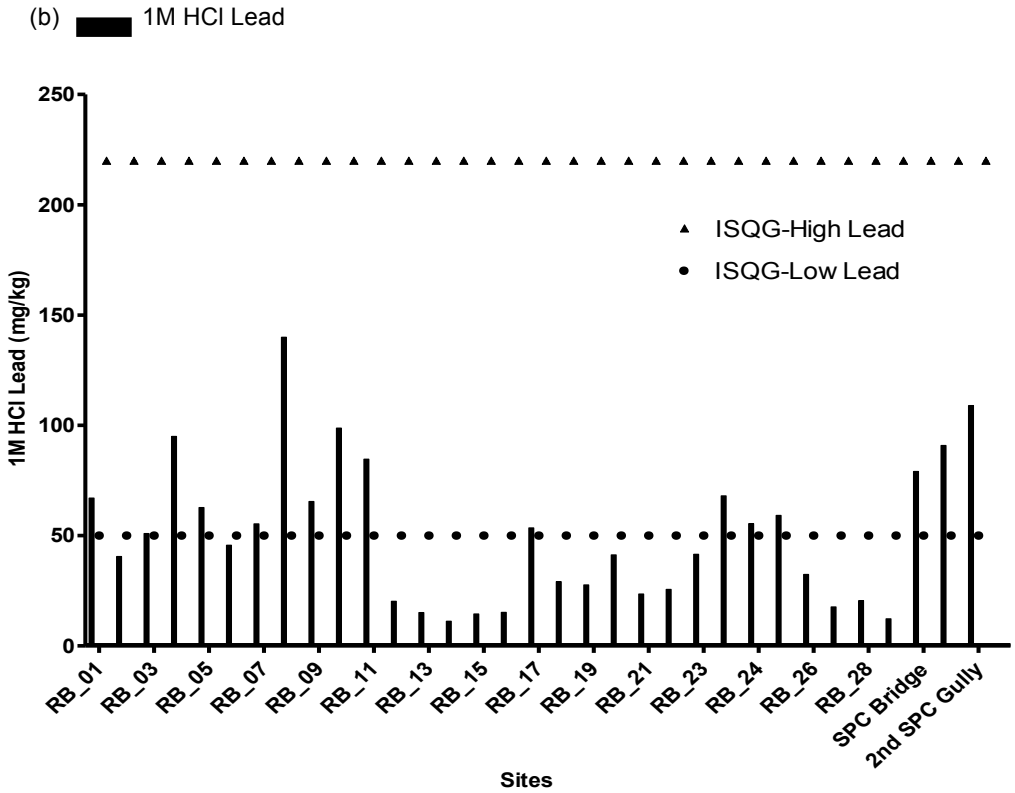




**Figure 36. Total concentration (a) and 1M HCl extraction concentration (b) of lead compared with ISQG-Low and ISQG-High for lead in sediment samples collected for the Regional/Background Stream Sediment Sampling Program by Xstrata (11 November 2009).**

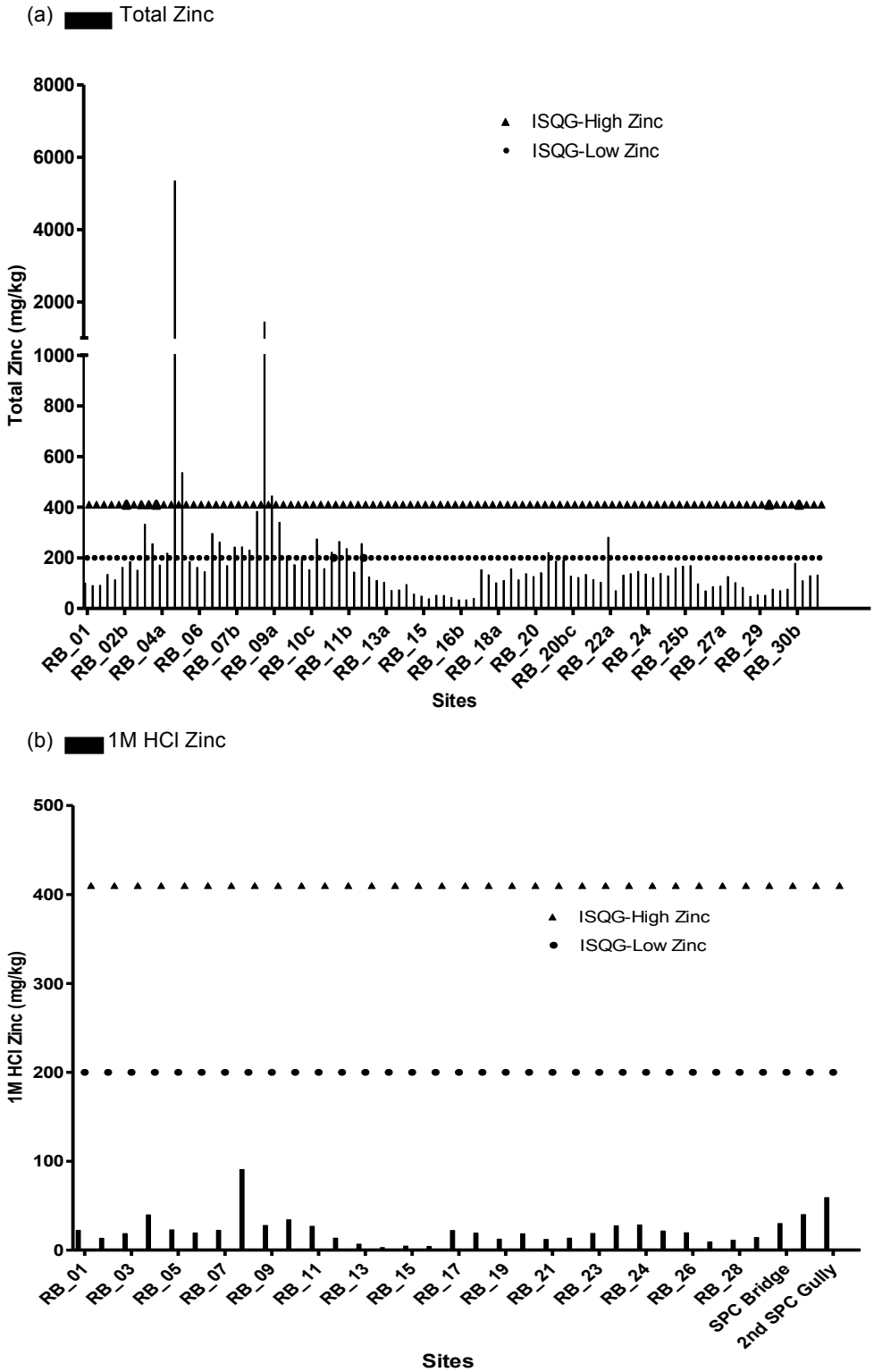



**Figure 37. Total concentration (a) and 1M HCl extraction concentration (b) of zinc compared with ISQG-Low and ISQG-High for zinc in sediment samples collected for the Regional/Background Stream Sediment Sampling Program by Xstrata (11 November 2009).**

**Table 46. Summary sites exceeding or complying with the ISQG-Low for 1M HCl extraction of copper and lead in sediment samples (<63 µm) collected for the Regional/Background Stream Sediment Sampling Program by Xstrata (November 2009).**

| Sites | 1M HCl extraction (mg/kg) | | ISQG-Low Copper | ISQG-Low Lead | Exceeded for metals | Comment |
|---|---|---|---|---|---|---|
| | Copper | Lead | | | | |
| RB01 | 161 | 67 | Exceeded | Exceeded | Copper, lead | |
| RB02 | 79 | 41 | Exceeded | Comply | Copper | |
| RB03 | 116 | 51 | Exceeded | Exceeded | Copper, lead | |
| RB04 | 204 | 95 | Exceeded | Exceeded | Copper, lead | |
| RB05 | 125 | 63 | Exceeded | Exceeded | Copper, lead | |
| RB06 | 72 | 46 | Exceeded | Comply | Copper | |
| RB07 | 96 | 55 | Exceeded | Exceeded | Copper, lead | |
| RB08 | 226 | 140 | Exceeded | Exceeded | Copper, lead | Highest |
| RB09 | 99 | 66 | Exceeded | Exceeded | Copper, lead | |
| RB10 | 197 | 99 | Exceeded | Exceeded | Copper, lead | |
| RB11 | 194 | 85 | Exceeded | Exceeded | Copper, lead | |
| RB12 | 38 | 20 | Comply | Comply | | |
| RB13 | 41 | 15 | Comply | Comply | | |
| RB14 | 28 | 11 | Comply | Comply | | |
| RB15 | 52 | 15 | Comply | Comply | | |
| RB16 | 84 | 15 | Exceeded | Comply | Copper | |
| RB17 | 77 | 54 | Exceeded | Exceeded | Copper, lead | |
| RB18 | 43 | 29 | Comply | Comply | | |
| RB19 | 34 | 28 | Comply | Comply | | |
| RB20 | 58 | 41 | Comply | Comply | | |
| RB21 | 22 | 24 | Comply | Comply | | |
| RB22 | 25 | 26 | Comply | Comply | | |
| RB23 | 58 | 42 | Comply | Comply | | |
| RB23R | 58 | 68 | Comply | Exceeded | Lead | |
| RB24 | 58 | 55 | Comply | Exceeded | Lead | |
| RB25 | 59 | 59 | Comply | Exceeded | Lead | |
| RB26 | 49 | 32 | Comply | Comply | | |
| RB27 | 49 | 18 | Comply | Comply | | |
| RB28 | 43 | 21 | Comply | Comply | | |
| RB29 | 19 | 12 | Comply | Comply | | |
| ISQG-low | **65** | **50** | | | | |

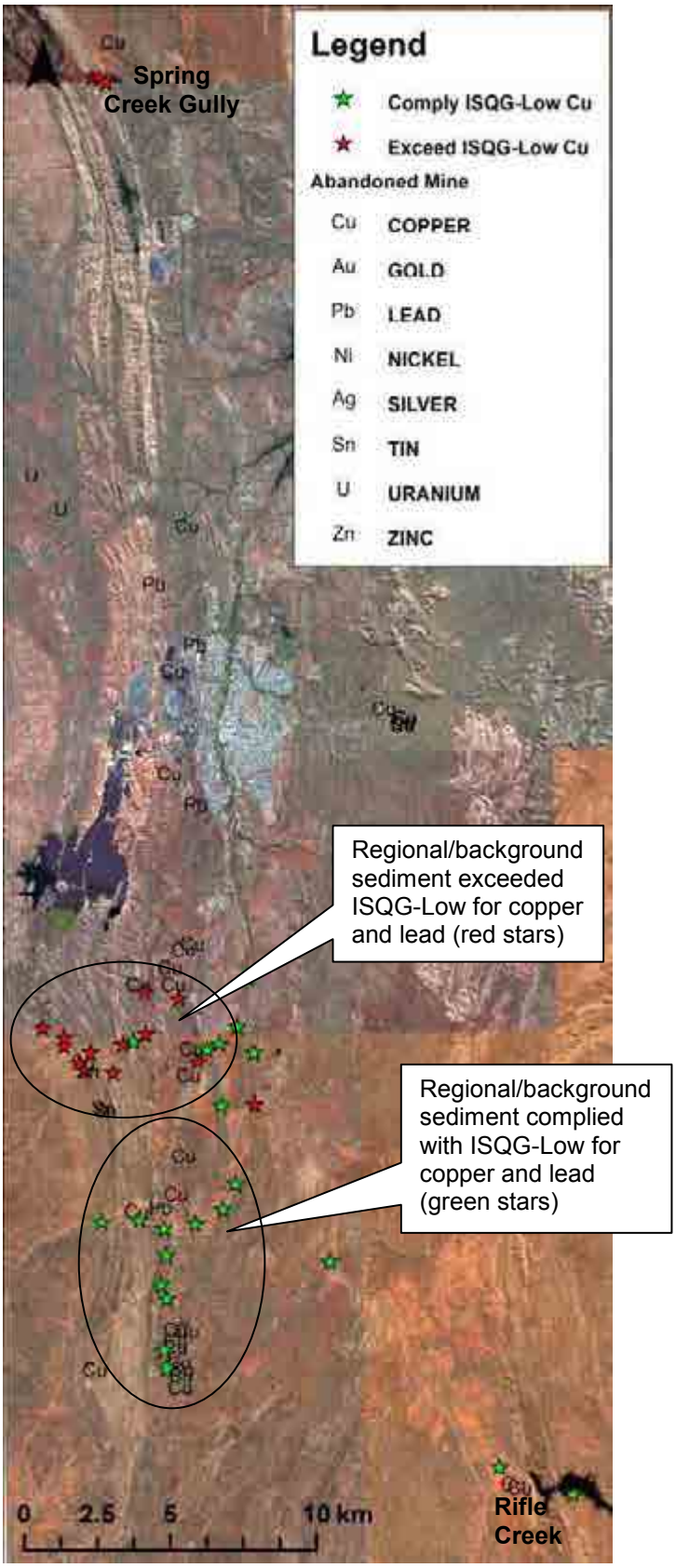



**Figure 38. Locations of regional/background sample sites of Rifle Creek and Spring Creek (SPC). Sites that exceeded ISQG-Low sediment for copper are shown by red stars and those that complied with ISQG-Low sediment for copper are shown by green stars.**

The results in Table 43 indicate that a number of regional/background sites were affected by historical mining activities or the presence of natural mineralisation. Delineation of the sites known to have been affected by historical mining (Table 44) provide the best dataset for identifying regional/background sites that only reflect the presence of natural mineralisation.

### 3.2.5 Sediment from the Rifle Creek Dam background site

Sediment was collected from Rifle Creek Dam as part of the comprehensive assessment of a background site for both water and sediment aquatic toxicity assessment (Section 3.3). The comparison of results (Table 47) for total digestion and 1M HCl extraction with ISQG-Low showed that copper and lead exceeded ISQG-Low. The suitability of this site as a background comparison depends on further toxicity assessment according to the ANZECC/ARMCANZ (2000) decision-tree process for sediment contamination (Figure 12).

**Table 47. Results for total concentration and 1M HCl extraction of metals and metalloids in sediment sample (<63 μm) collected from Rifle Creek Dam on 5 August 2009**

| Metals and metalloids | Rifle Creek Dam (mg/kg) | | Sediment ISQG-Low (mg/kg) |
|---|---|---|---|
| | Total | 1M HCl | |
| Aluminium | 14,700 | 2,030 | N/A |
| Antimony | <5 | <1 | 2 |
| Arsenic | 9 | 3 | 20 |
| Cadmium | – | 1.1 | 1.5 |
| Cobalt | 14 | 6.8 | N/A |
| Chromium | 28 | 3 | N/A |
| Copper | 122 | 83.8 | 65 |
| Iron | 28,500 | 6,000 | N/A |
| Lead | 97 | 67.3 | 50 |
| Manganese | 1,830 | 1,450 | N/A |
| Nickel | 20 | 2.9 | 52 |
| Zinc | 149 | 89 | 410 |

**Table 48. Metal and metalloid 1M HCl extractable concentrations in sediment collected upstream from Rifle Creek Dam 5 August 2010**

| Elements | Rifle Creek Dam (mg/kg) | |
|---|---|---|
| | <2 mm | <63 μm |
| Aluminium | 160 | 2030 |
| Antimony | <1.0 | <1 |
| Arsenic | <1.0 | 3 |
| Cadmium | 0.1 | 1.1 |
| Cobalt | 1.2 | 6.8 |
| Chromium | <1.0 | 3 |
| Copper | 6.8 | 83.8 |
| Iron | 930 | 6000 |
| Lead | 13.8 | 67.3 |
| Manganese | 77 | 1450 |
| Nickel | <1.0 | 2.9 |
| Zinc | 36.3 | 89 |

An additional comparison was made for metals and metalloids in the Rifle Creek Dam sediment collected on 5 August 2009 between the <2 mm and <63 µm fractions (Table 48). The results show that the <63 µm fraction has metal and metalloid concentrations that exceeds those for the <2 mm fraction, which indicates that the finer fraction is likely to be more significant with respect to effects on aquatic biota.

### 3.2.6 Summary of all sediment data

The 1M HCl extractable concentrations for metal and metalloids of six sets of samples collected in the Leichhardt River and upstream sites from 2007 to 2009 were compared against the ISQG-Low for arsenic, cadmium, copper, nickel, lead, and zinc. The locations of sites exceeding ISQG-Low (red stars) and complying (green stars) are presented in Figure 39 to Figure 44. These figures show the general trends of downstream contaminated sediment below Mount Isa City and upstream contamination from historical mining, particularly for copper and lead.

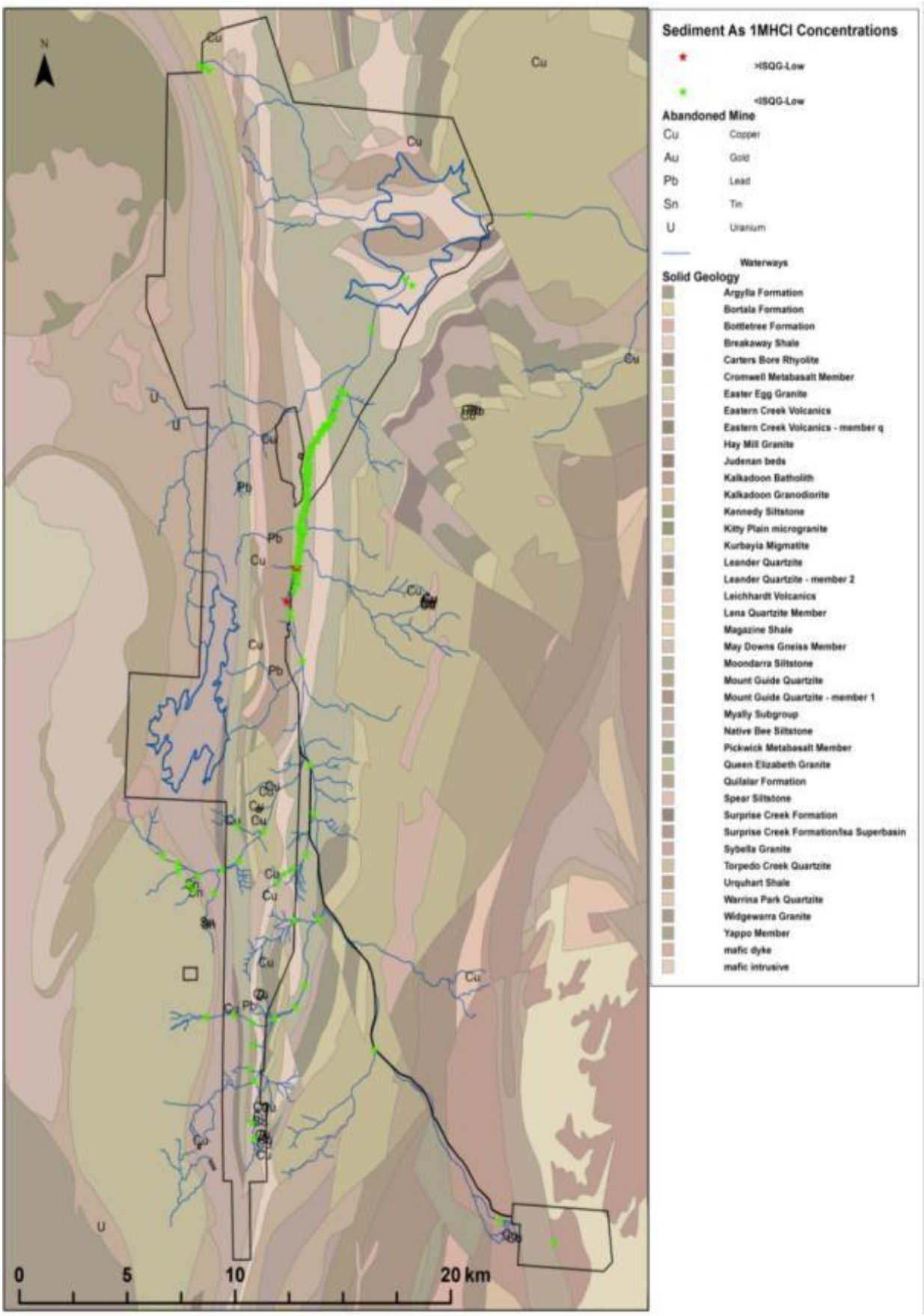



**Figure 39. Summary of sites that exceed ISQG-Low for arsenic (red stars) and sites that do not exceed ISQG-Low for arsenic (green stars)**

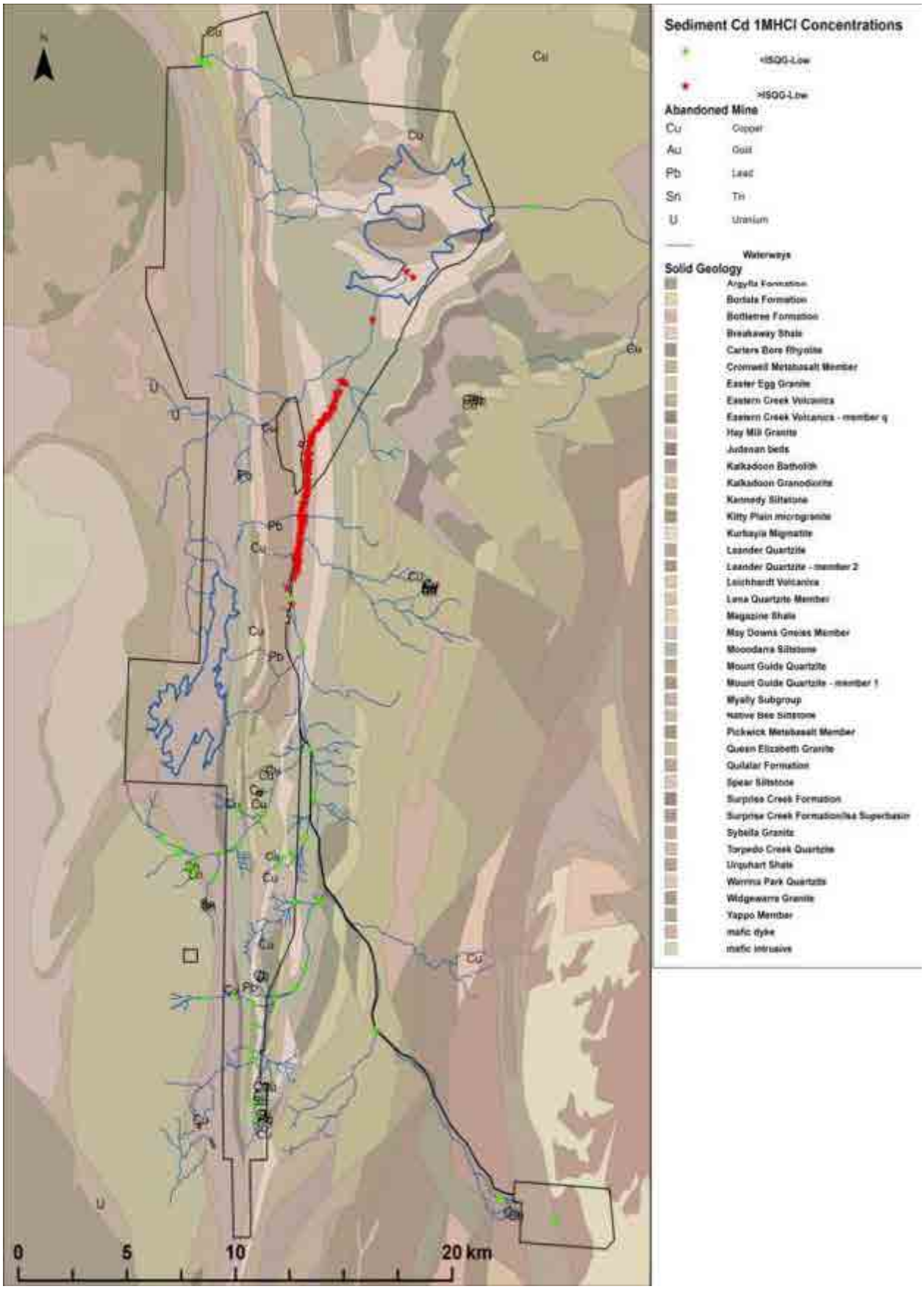



**Figure 40. Summary of sites that exceed ISQG-Low for cadmium (red stars) and sites that do not exceed ISQG-Low for cadmium (green stars)**

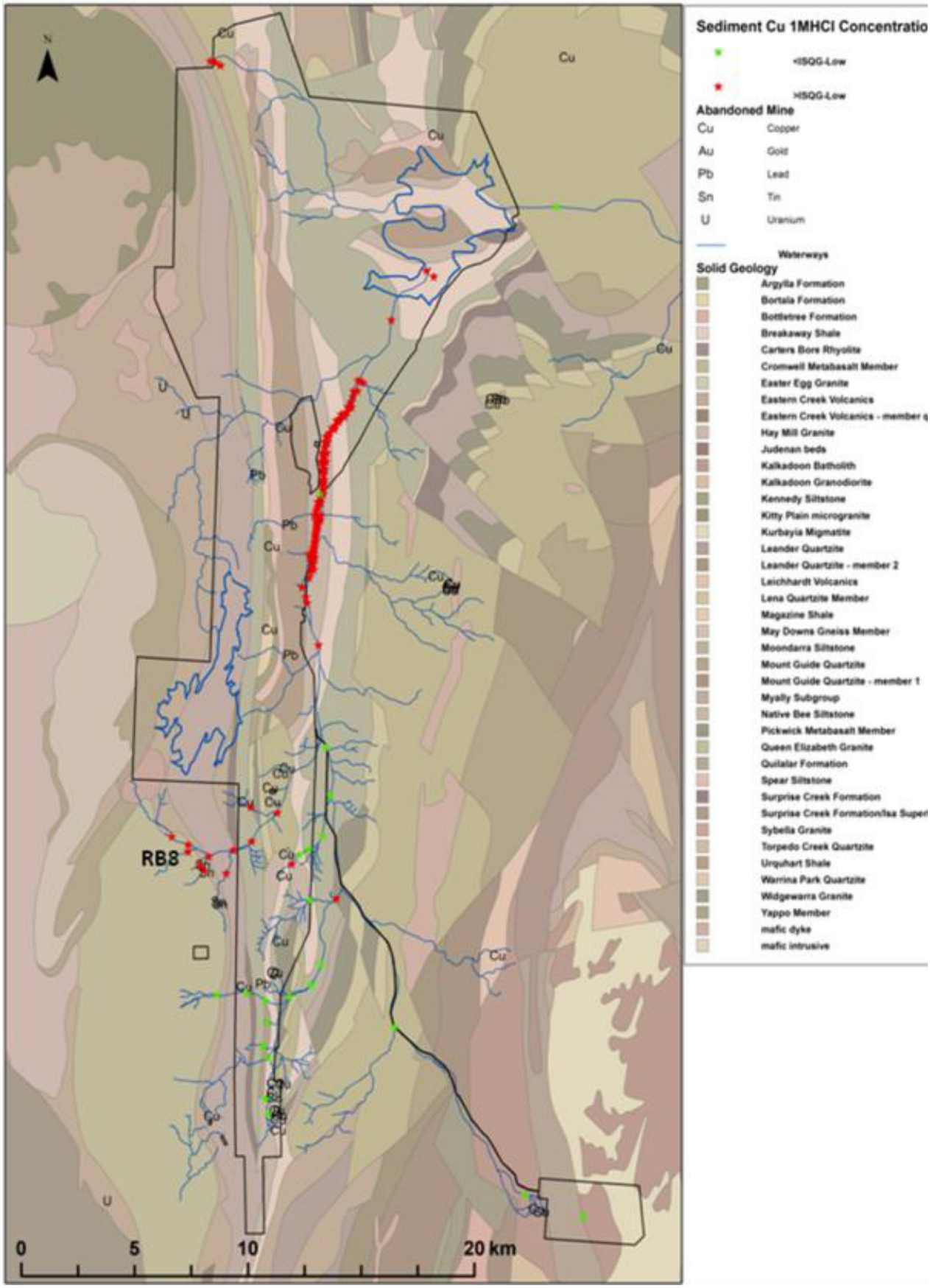



**Figure 41. Sampling sites of Leichhardt River Verification Program (13-14 November 2009). The insert map shows the LR10 site, where the concentration of arsenic exceeded ISQG-Low. LR10 is identified as being contaminated for human health**

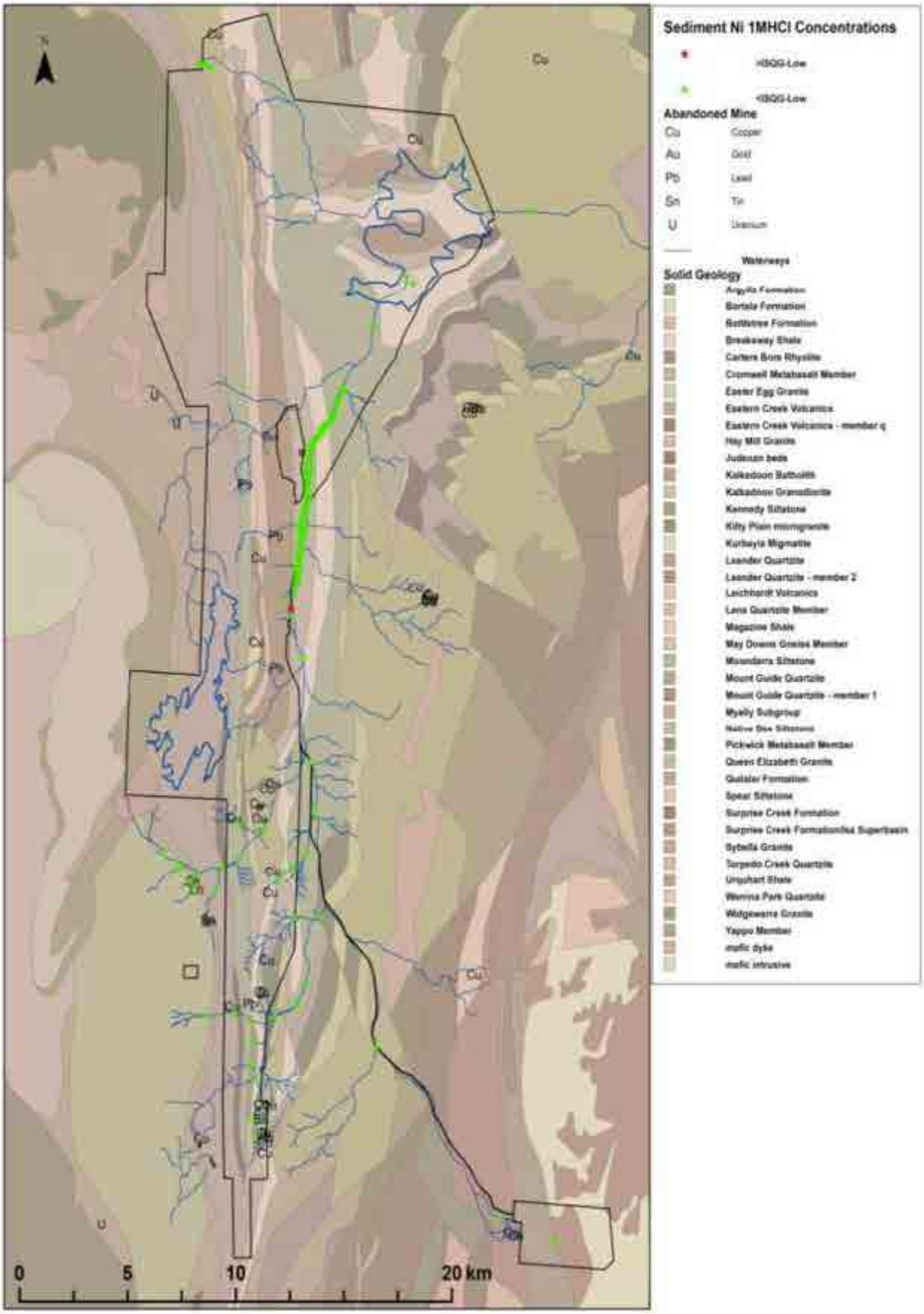



**Figure 42. Summary of sites that exceed ISQG-Low for nickel (red stars) and sites that do not exceed ISQG-Low for nickel (green stars)**

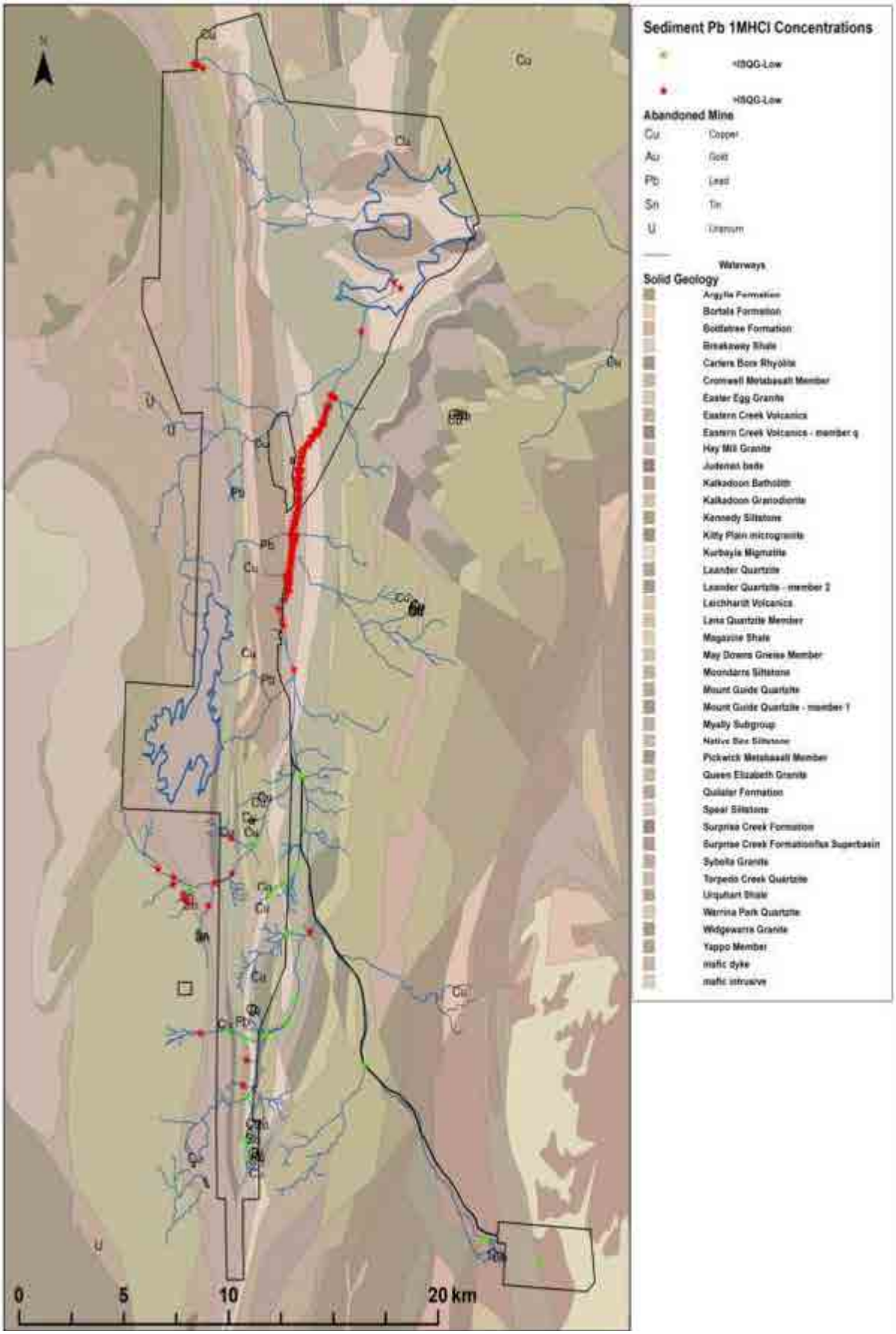



**Figure 43. Summary of sites that exceed ISQG-Low for lead (red stars), sites that do not exceed ISQG-Low for lead (green stars)**

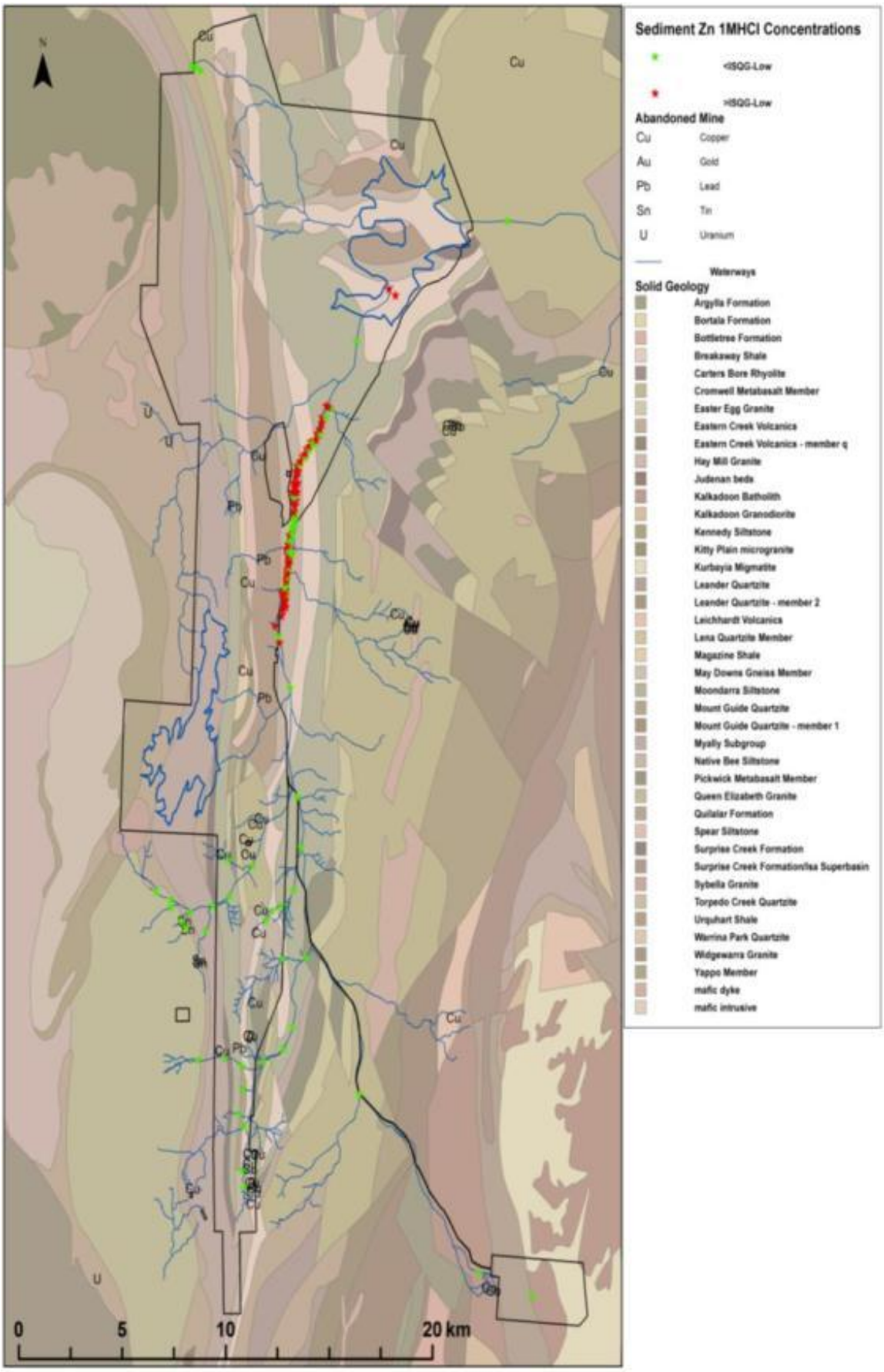



**Figure 44. Summary of sites that exceed ISQG-Low for zinc (red stars) and sites that do not exceed ISQG-Low for zinc (green stars)**

## 3.2.7 Comparison of sediment concentrations (<250 µm fraction) with NEPM Health Investigation Level E

### 3.2.7.1 Sediment samples

Table 49 gives a comparison of total concentrations and the percentage of bioaccessibility (%BAc) of metals and arsenic in the < 250 µm fraction of sediment samples (Section 2.7). The results were compared with the NEPM HIL — Level E for recreational use of land (Table 4) and indicated that none of the sites exceeded the NEPM HIL — Level E. When adjusted for bioaccessibility, the metal and arsenic concentrations were substantially lower than total the values.

**Table 49. Results for total concentration and percentage of bioaccessibility (BAc%) of arsenic, cadmium, copper, lead, and zinc in Leichhardt River sediment samples (< 250 µm fraction) collected 15–16 October 2009**

| Sites | Arsenic | | Cadmium | | Copper | | Lead | | Zinc | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Total (mg/kg) | BAc (%) | Total (mg/kg) | BAc (%) | Total (mg/kg) | BAc (%) | Total (mg/kg) | BAc (%) | Total (mg/kg) | BAc (%) |
| 23rd Avenue | <5 | 3.0 | <1 | <1 | 12 | 0.3 | 6 | 2.3 | 14 | 8 |
| Isa Crossing | <5 | 1.8 | <1 | 2 | 14 | 57 | 6 | 26 | 50 | - |
| Alma Crossing | 5 | 13 | 2 | 56 | 83 | 28 | 43 | 25 | 121 | 75 |
| Davis Crossing | <5 | 9.7 | 3 | 90 | 18 | 39 | 25 | 38 | 94 | - |
| Moondarra Crossing | <5 | 3.2 | <1 | 3 | 38 | 19 | 92 | 3 | 129 | 67 |
| Before junction | <5 | 6.8 | <1 | 93 | 21 | 48 | 49 | 40 | 98 | 63 |
| Between junction & pump station | 23 | 16 | 4 | 45 | 559 | 25 | 368 | 19 | 422 | 13 |
| Lower channel & above junction | 11 | 12 | 3 | 54 | 146 | 29 | 234 | 20 | 342 | 16 |
| Lake Moondarra | 21 | 20 | 5 | 38 | 501 | 34 | 339 | 19 | 460 | 10 |
| Clear Water Lagoon | 18 | 6 | 5 | 30 | 359 | 22 | 389 | 9 | 550 | 13 |
| NEPM Level E HIL(mg/kg) | **200** | | **40** | | **2,000** | | **600** | | **14,000** | |
| Sites exceeding NEPM Level E | Nil | | Nil | | Nil | | Nil | | Nil | |

### 3.2.7.2 Sediment from Leichhardt River Verification Program collected by Xstrata

The total metal and metalloid concentrations in the <2 mm fraction of the Leichhardt River Verification Program (LR) samples were compared against the NEPM soil investigation HIL E (Figure 45 to Figure 50). A summary of total arsenic, cadmium, copper, and lead concentrations for sites that exceeded the NEPM HIL E is presented in Table 50. As can be seen from Table 50, LR10 (mean ± se) exceeded the NEPM HIL E for arsenic (520±4 mg/kg); cadmium (43 ± 1 mg/kg); copper (2560 ± 5 mg/kg); and lead (2270 ± 8 mg/kg). These results, provided by

Australian Laboratory Services, are recorded in Table A15, Appendix 6. Two additional sites (LR5 and LR9) exceeded the NEPM HIL E for lead (Table 50).

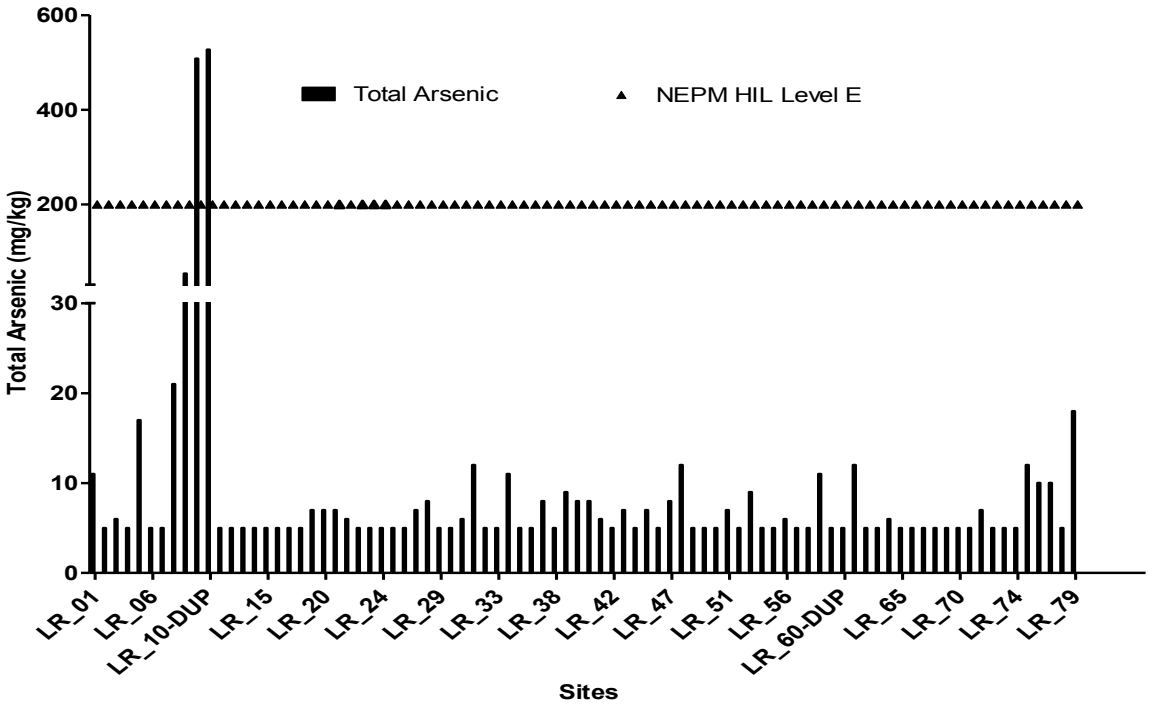



**Figure 45. Total concentration of arsenic compared with NEPM HIL Level E for arsenic in sediment (<2 mm fraction) samples collected by Xstrata for the Leichhardt River Verification Program (13–14 November 2009)**

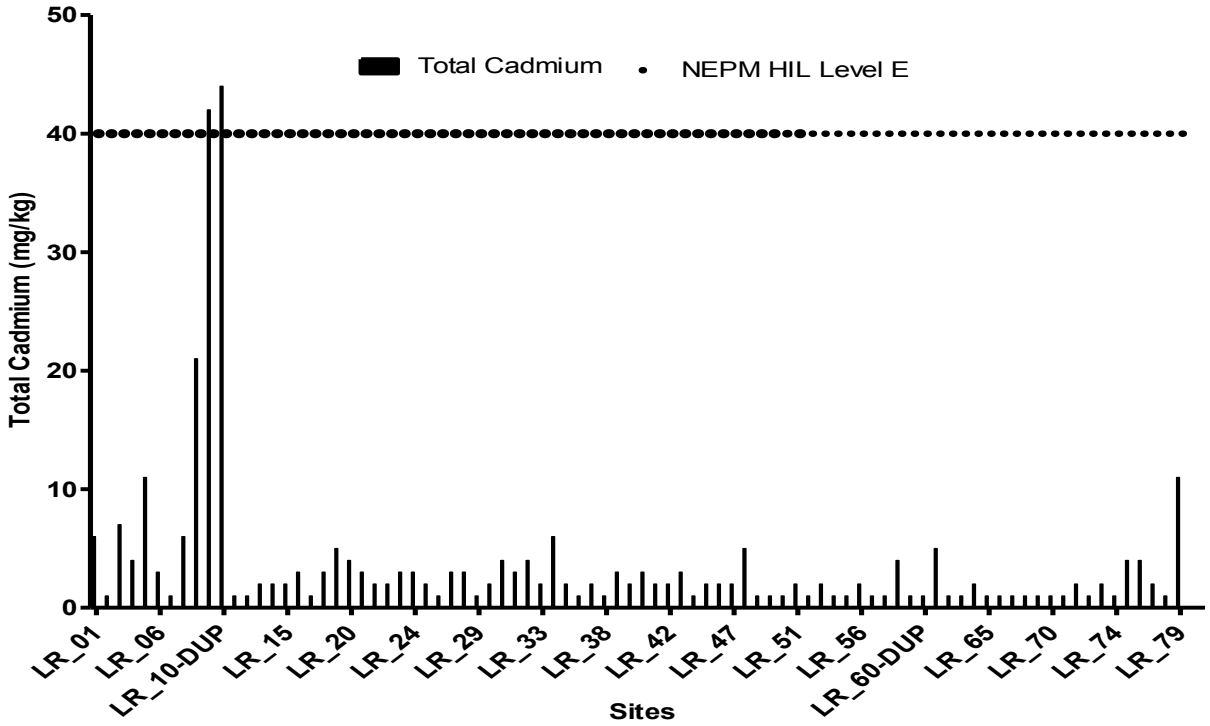



**Figure 46. Total concentration of cadmium compared with NEPM HIL Level E for cadmium in sediment samples (<2 mm fraction) collected by Xstrata for the Leichhardt River Verification Program (13–14 November 2009)**

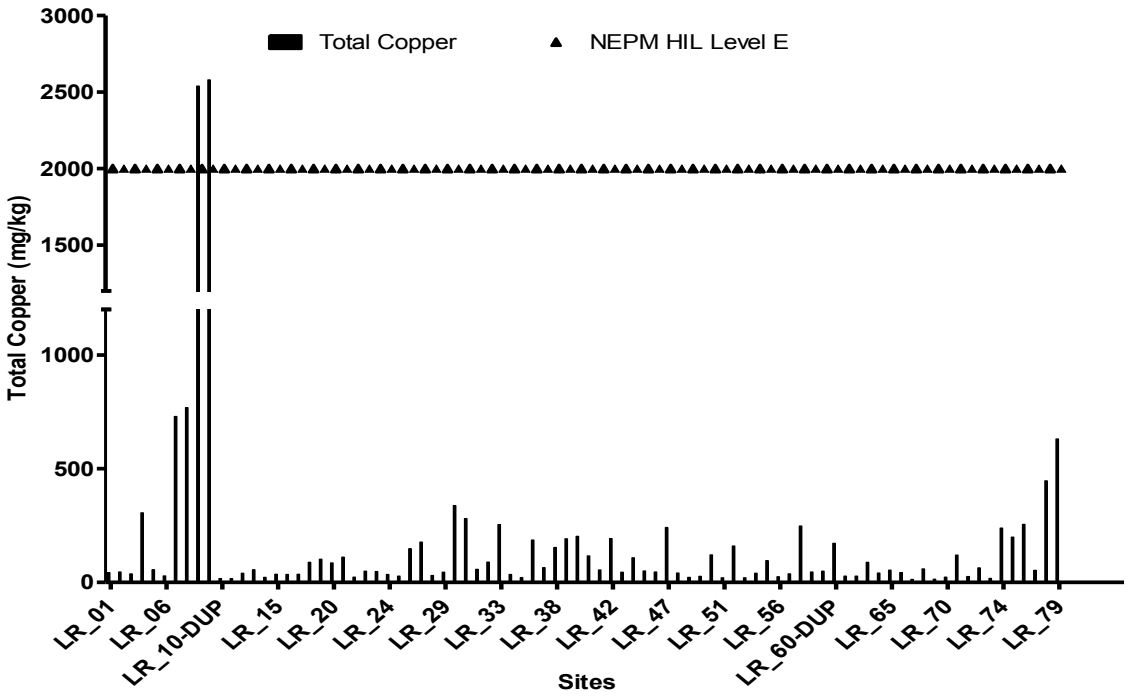



**Figure 47. Total concentration of copper compared with NEPM HIL Level E for copper in sediment (<2 mm fraction) samples collected by Xstrata for the Leichhardt River Verification Program (13–14 November 2009)**

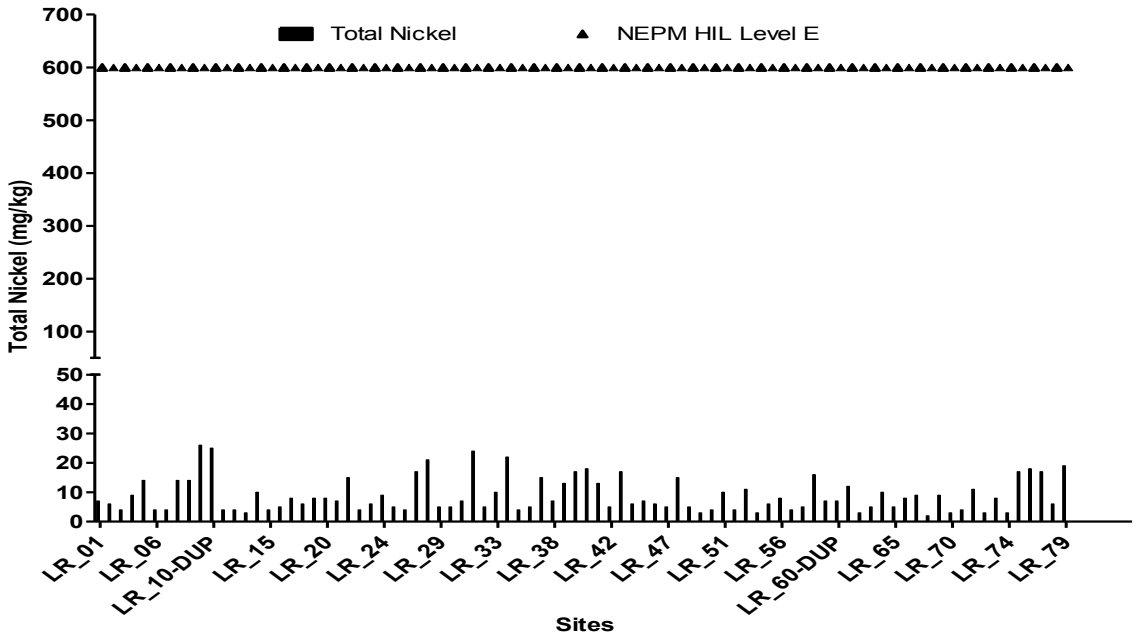



**Figure 48. Total concentration of zinc compared with NEPM HIL Level E for zinc in sediment (<2 mm fraction) samples collected by Xstrata for the Leichhardt River Verification Program (13–14 November 2009)**

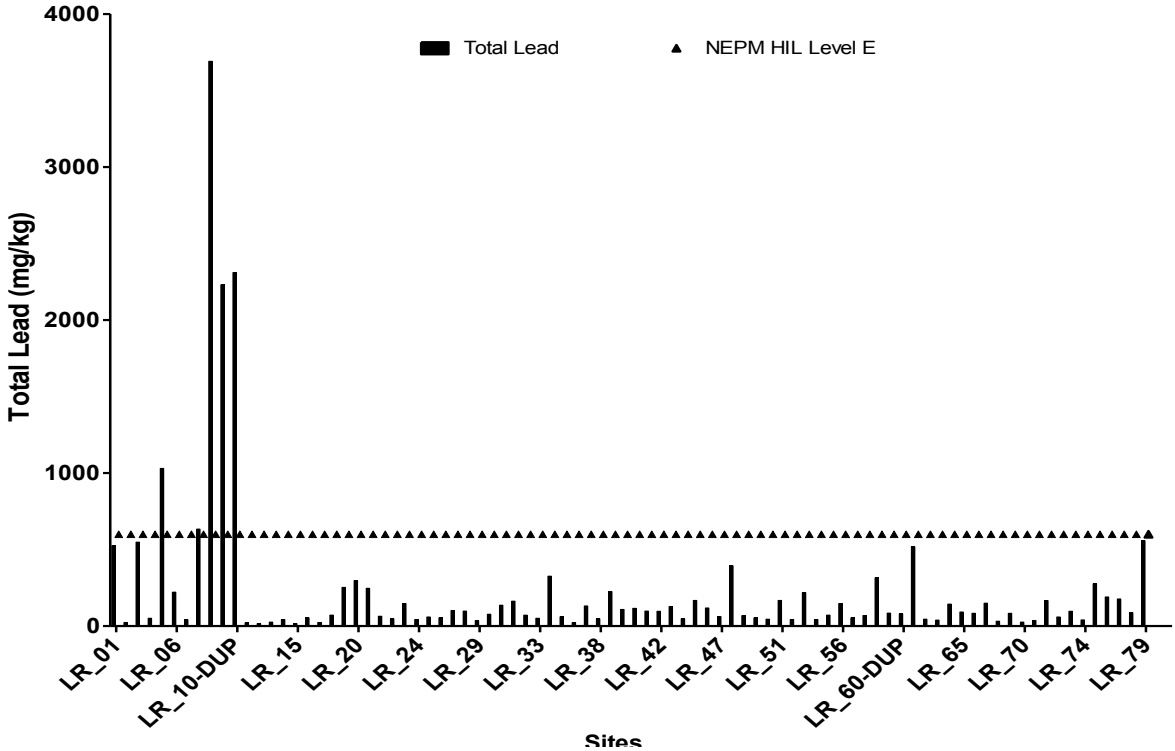



**Figure 49. Total concentration of lead compared with NEPM Level E for lead in sediment (<2 mm fraction) samples collected by Xstrata for the Leichhardt River Verification Program (13–14 November 2009)**

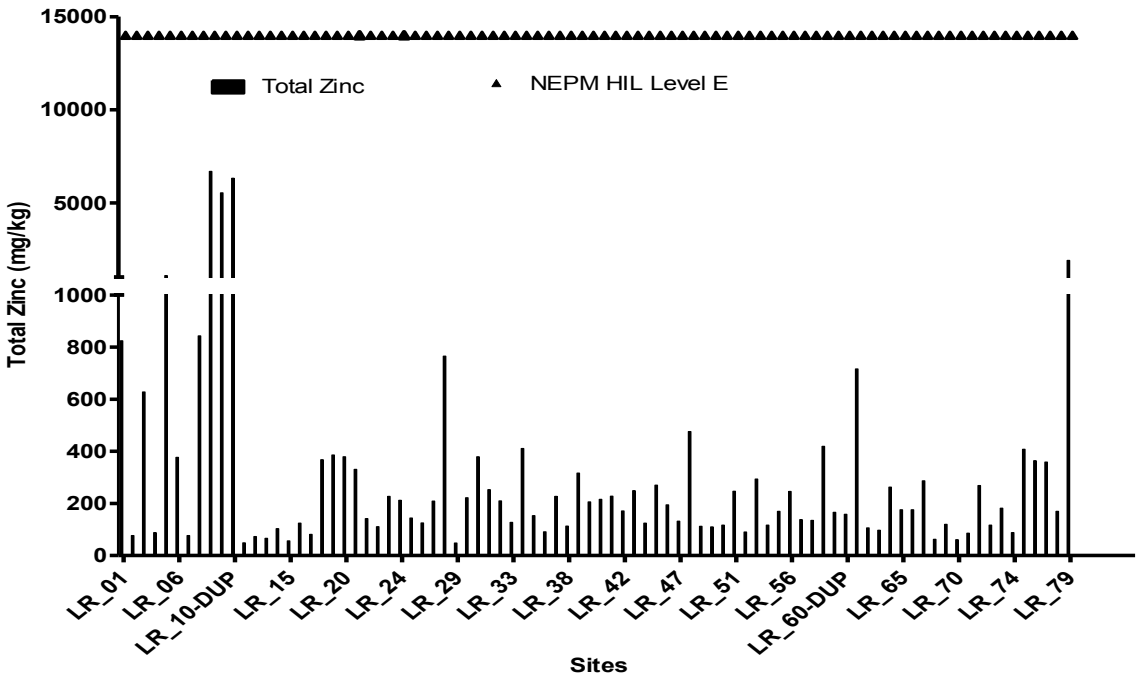



**Figure 50. Total concentration of zinc compared with NEPM HIL Level E for zinc in sediment (<2 mm fraction) samples collected by Xstrata for the Leichhardt River Verification Program (13–14 November 2009)**

**Table 50. Summary of sites (<2 mm fraction) exceeding NEPM Level E from the Leichhardt River Verification Program**

| Metal or metalloid | NEPM Level E (mg/kg) | Sites exceeding NEPM Level E | Total concentration (mg/kg) Mean or Mean ± se |
|---|---|---|---|
| Arsenic | 200 | LR10 | 520±4 |
| Cadmium | 40 | LR10 | 43 ± 1 |
| Copper | 2,000 | LR10 | 2,560 ± 5 |
| Lead | 600 | LR5<br>LR9<br>LR10 | 1,030<br>3,690<br>2,270 ± 8 |

The three samples LR5, LR9, and LR10 were analysed for bioaccessibility (BAc%) (Section 2.6.1) using a different laboratory (ENTOX, Section 2.6.1) than the laboratory that analysed the data given in Table 49. The results for total concentration and bioaccessibility of samples LR5, LR9, and LR10 are presented in Table 51. Comparing the results in Table 50 and Table 51 for the total concentration of arsenic and metals shows significant difference between the results for the same site. To resolve the discrepancy in total concentration results, portions of samples LR5, LR9, and LR10 were re-sieved to give a < 2 mm fraction and a <250 µm fraction. The two fractions were mixed and split into two portions of each fraction. These samples were analysed by the two laboratories (ALS and ENTOX) for total concentrations of metals and metalloids by aqua regia digestion. The results from the two laboratories (Table A20, Appendix 6) showed no significant differences between the respective samples. Therefore, it is considered that the bulk samples collected for the Leichhardt River Verification Program, particularly at LR5, LR 9, and LR 10 (shown as LR (V)10 in Table 51), may indicate contamination and may not have been homogeneous. The analyses for both total concentration and bioaccessibility presented in Table 51 were performed on split portions of the same sample and this concentration data was considered to be reliable for health risk assessments (Section 4.2).

The comparison of total and bioaccessibility adjusted concentrations of arsenic, copper, cadmium, lead, and zinc in the < 250 µm fraction of sediment (Table 51) showed that sample LR10 exceeded NEPM HIL E for the bioaccessibility-adjusted cadmium and lead concentrations were considered to be a health risk and indicate that remedial attention is required at this site. Sites LR5 and LR9 did not exceed soil contamination criteria when the BAc (mg/kg) was compared against the NEPM HIL – E (Table 50). However, more detailed sampling of this part of Leichhardt River should be undertaken to confirm the findings.

The results from the comparison of the two laboratories (Table A20, Appendix 6) also points to the problem of homogeneity of river sediment and the relative significance of results. It is important that samples are representative of the concentrations present.

### 3.2.7.3 Sediment X-ray absorption spectroscopy measurement of lead in sediment samples

Table 52 shows the results for fitting the Leichhardt River and Rifle Creek Dam sediment samples against the model lead compounds described in Section 2.6.3.1. These results were measured by using the X-ray absorption spectroscopy (XAS) measurement of lead compound and mineral forms using the XANES technique (see Phase II report for further details). Most of the Leichhardt River and Rifle Creek Dam sediment samples showed large proportions of lead–goethite, which appears to be the typical form of lead in river sediment. However, samples LR2, LR3, LR7, LR10, and LR21 showed the presence of other mineral and mineral-processed lead compounds, which are potentially derived from mine wastes. In particular, LR10 from the Leichhardt River Verification Program was exclusively a mixture of anglesite and magnetoplumbite, accompanied by high cadmium, copper, lead, and zinc concentrations. The presence of anglesite (lead sulfate) was also confirmed by X-ray diffraction (XRD) (see Phase II report for further details) scan but magnetoplumbite could not be detected by XRD because of the limited sensitivity of this technique. Therefore, the XANES technique was able to show differences in lead compound composition in river sediment that could be compared with properties that relate to bioaccessibility and bioavailability.

**Table 51. Results for total concentration and percentage of bioaccessibility (BAc%) of sediments in the < 250 μm fraction**

| Samples | Fraction | Arsenic | Copper | Cadmium | Lead | Zinc |
|---|---|---|---|---|---|---|
| LR5 | Total (mg/kg) | 2.8 | 38.7 | 0.8 | 84 | 35 |
| | BAc% | 7.7 | 13.3 | 40.6 | 24.9 | 20.3 |
| | Resultant total adjusted for BAc (mg/kg) | 0.22 | 5.2 | 0.32 | 21 | 7 |
| LR9 | Total (mg/kg) | 15.4 | 104 | 12 | 286 | 606 |
| | BAc% | 8.7 | 38.7 | 44.2 | 31.8 | 49.2 |
| | Resultant total adjusted for BAc (mg/kg) | 1.3 | 40.3 | 5.3 | 91 | 298 |
| LR10 | Total (mg/kg) | 251 | 4,490 | 163 | 20,930 | 9,920 |
| | BAc% | 3.0 | 28.0 | 44.0 | 17.3 | 19.9 |
| | Resultant total adjusted for BAc (mg/kg) | 7.6 | 1,260 | 45.6 | 3,620 | 1,970 |
| NEPM HIL Level E | | 200 | 2,000 | 40 | 600 | 14,000 |

### 3.2.8 Health risk assessment of metal and metalloid uptake in aquatic biota from Leichhardt River

This data, described in Section 2.7.1, is related to the previous section because there is a link between sediment and uptake by aquatic biota in the Leichhardt River in and around Mount Isa (FRC Environmental, 2010 and summarised in Appendix 9).

On average, cadmium concentrations in fish tissue were low, except at Lake Moondarra between Clear Water Lagoon and Moondarra Junction (Figure 14). A maximum cadmium concentration of 45 mg/kg was found in the muscle tissue of a spangled perch, which are omnivorous, at this site (Appendix C, FRC, Environmental 2010). This result did not correspond with the water and sediment results for cadmium and suggests the cadmium may have been accumulated from one or more food sources.

Mean lead concentration in fish tissue exceeded the ANZFSC maximum guideline level (Table 5) at 23rd Avenue, Isa Street, Moondarra Crossing, and Moondarra Junction (Figure 14). The maximum lead concentration in fish also exceeded the ANZFSC maximum guideline level at Davis Road, Clear Water Lagoon, and Lake Moondarra (Appendix 9, FRC Environmental, 2010). The highest average lead concentration in fish tissue was at Isa Street and 23rd Avenue, which was reflected in the water quality and sediment results.

Mean lead concentrations in 2010 were lower in fish than those measured between 1978 and 1992, but higher than measured in 2005 (Appendix 9, FRC Environmental, 2010). More specifically, the lead concentration exceeded the recommended ANZFSC guideline (Appendix 9, FRC Environmental, 2010) in:

- spangled perch (omnivorous) at Isa Street, 23rd Avenue, and Lake Moondarra
- sleepy cod (carnivorous) at Davis Road, Moondarra Crossing, and Moondarra Junction
- fork tail catfish (omnivorous) in Lake Moondarra;
- bony bream (detritivores) in Lake Moondarra
- barred grunter (omnivorous) in Lake Moondarra and at Moondarra Crossing
- eastern rainbow fish (omnivorous) at Davis Road (not a target species but analysed  low fish diversity).

Lead concentrations in the barramundi (piscivorous) caught from Lake Moondarra were below the laboratory limit of reporting (LOR) (FRC Environmental, 2010). The high lead concentration in omnivorous fish suggests that lead accumulation is occurring at lower trophic levels. High lead levels in carnivorous sleepy cod may also indicate accumulation through the food chain.

### 3.2.9 Overall summary of sediment quality

The summary of sites that have sediment 1M HCl metal concentrations exceeding the ISQG-Low for arsenic, cadmium, copper, lead, and zinc are presented in Figure 39 to Figure 44 and summarised in Table 42:

- two sites exceed ISQG-Low for arsenic
- 79 sites exceed ISQG-Low for cadmium
- 78 sites exceed ISQG-Low for copper
- 79 sites exceed ISQG-Low for lead
- 50 sites exceed ISQG-Low for zinc.

The summary of results in Table 44 and Table 45 indicate that further assessment is required according to the decision-tree process in Figure 12. Some of this assessment is given in Section 3.4.

The summary of locations from the Leichhardt River Verification Program (Table 50) shows one site (LR10) exceeding the NEPM HIL Level E criteria for human health risk (Table 4) for cadmium and lead, when the total concentration is adjusted for bioaccessibility. Site LR 10 requires further analysis.

The relatively high concentrations of metals and metalloids in sediment from Leichhardt River may also be linked to the uptake by fish and other aquatic biota. The study by FRC Environmental (2010) collected a range of species from twelve sites and observed that fish diversity and the abundance of juvenile fish were lowest in sites in the Leichhardt River in Mount Isa. This may have been a result of restricted breeding or high juvenile mortality at these sites due to poor water and sediment quality. It may also be related to the low flow in the Leichhardt River at the time of sampling, and a result of sampling in the dry season. In general, fish were in good condition with few skin lesions or parasites. The Leichhardt River between 23rd Avenue and Moondarra Crossing had the highest concentrations of metal in water and sediment, poor physico-chemical water quality and low fauna diversity.

## 3.3 Aquatic toxicity studies of water and sediment

Direct aquatic toxicity assessment (DTA) was applied as an assessment step on the ANZECC/ARMCANZ (2000) decision tree for water (Figure 11) and sediment (Figure 12). Four sets of water sampling programs (24 July 2008; 7 October 2009; 27–28 July 2010; and 13–16 October 2010) collected water for aquatic toxicity testing. Details of the sampling sites and test species are presented in Appendix 7, Table A21. Four sets of sediment samples were collected from the Leichhardt River (4 September 2007; 7 October 2009, 27–28 July 2010; and 13–16 October 2010 for aquatic toxicity testing. Details of this testing are in Appendix 7. Water and sediment quality of these samples were analysed. The following sections outline the aquatic toxicity assessment results and water and sediment quality data.

### 3.3.1 Aquatic toxicity assessment and metal concentrations in water

Table 53 gives the preliminary assessment of acute toxicity from the Leichhardt River using 48-hour survival of *Ceriodaphnia* cf *dubia* (48-h EC50). This sampling was undertaken after the Leichhardt River remediation undertaken in 2007 and was an outcome of the Phase I study (Noller et al., 2009). The results show that acute toxicity was observed at Davis Crossing (61.6% EC50 and 0% survival) but not upstream at 23rd Avenue or Isa Street Crossing. Copper concentration at Davis Crossing exceeds trigger value at both 95% and 90% protection of aquatic species protection. Ammonia was also analysed in these water samples (Table 53). Whilst the TV 95% for ammonia-N (µg/L) was exceeded at 23rd Avenue there was no observed toxicity and Davis Crossing showed toxicity. The ammonia concentration in water was higher at 23rd Avenue on 24 July 2008 compared with 27–28 July 2010.

Further sampling was undertaken on 7 October 2009 for acute toxicity measurement using 48-h survival of *Ceriodaphnia* cf *dubia*, which reconfirmed that toxicity was observed at Davis Crossing and to a lesser extent at the junction of Breakaway Creek and Leichhardt River (Table 54). The water metal and metalloid concentrations results show that copper concentrations (total only without 0.45 µm filtration or the DGT technique) at four sites and cadmium concentration at Davis Crossing exceeded the trigger values for 95% species protection (Table 54).

**Table 52. Results of XANES fitting for Leichhardt River sediment samples**

| Sample ID | Samples description | Total Pb concentra-tion (mg/kg) | Lead-adsorbed to goethite | Red lead $Pb_3O_4$ | Anglesite $PbSO_4$ | Cerussite ($PbCO_3$) | Galena (PbS) | Plumbojarosite $PbFe^{3+}6(SO_4)4(OH)_{12}$ | Magneto Plumbite $(Pb,Mn)_2Fe_60_{11}$ |
|---|---|---|---|---|---|---|---|---|---|
| LR2 | Death Adder Gully (West) L2 | 2,172 | 76% | | | | | 24% | |
| LR3 | Death Adder Gully (East) L3 | 2,463 | 71% | | 29% | | | | |
| LR7 | LR — Historical tailings (between Grace Street Bridge and velodrome) L8 (removed in 2008; Noller et al., 2009) | 25,010 | 43% | | | 57% | | | |
| LR19 | LR — Fluvial downstream (Moondarra) L15 | 467 | 100% | | | | | | |
| LR20 | LR — Downstream of Lake Moondarra (East Leichhardt) L16 | 50 | | | | | | | |
| LR21 | 23rd Avenue (<63 µm) | 50.8 | | 16% | | | 60% | 24% | |
| LR22 | Isa St (<63 µm) | 82.1 | 100% | | | | | | |
| LR23 | Alma St (<63 µm) | 144 | 100% | | | | | | |
| LR24 | Davis Crossing (<63 µm) | 225 | 100% | | | | | | |
| LR25 | Moondarra Crossing (<63 µm) | 282 | 100% | | | | | | |
| LM 1 | Clear Water Lagoon (<63 µm) | 389 | 100% | | | | | | |
| LM 2 | Lake Moondarra (<63 µm) | 308 | 100% | | | | | | |
| LM 3 | Lower channel and above junction (<63 µm) | 375 | 100% | | | | | | |
| LM 4 | Between junction and pump station (<63 µm) | 328 | 100% | | | | | | |
| LM 5 | Before junction (<63 µm) | 276 | 100% | | | | | | |
| LR(V) 10 | Below Davis Crossing (<250 µm) | 20930 | | | 56% | | | | 44% |
| RCD1 | Rifle Creek Dam (<63 µm) | 97 | 100% | | | | | | |

Note : *Result from Table 50

**Table 53. Aquatic toxicity results of water and water quality of samples collected by Xstrata on 24 July 2008**

| Site description | 48-hr *Cerio daphnia cf dubia* | | pH | EC (µS/cm) | Hardness mg/L $CaCO_3$ | Arsenic | Cadmium | Copper | Lead | Manganese | Nickel | Selenium | Zinc | Chloride (mg/L) | Alkalinity-Total as $CaCO_3$ (mg/L) | Ammonia-N (µg/L) | Bicarbonate as (mg/L) ($HCO_3$) | Chromium VI (mg/L) | Fluoride (mg/L) | TV 95% Ammonia-N (µg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | EC 50 (%) | Survival (%) | | | | 0.45 µm fraction (µg/L) | | | | | | | | | | | | | | |
| 23rd Avenue Crossing | >100 | 100 | 8.1 | 1,102 | 253 | <5 | <1 | **17** | <1 | 890 | <5 | <1 | 7.9 | 120 | 250 | **930** | 280 | <0.005 | 0.9 | 400 |
| Isa Street Crossing | >100 | 100 | 8.6 | 4,020 | 435 | <5 | <1 | **18** | <1 | 120 | <5 | <1 | 12 | 710 | 370 | <5 | 370 | <0.005 | 3.6 | 180 |
| Davis Crossing | 61.6 | 0 | 8.5 | 6,020 | 753 | 5 | **2.6** | **22** | <1 | 25 | <5 | <1 | 17 | 1300 | 460 | 15 | 450 | <0.005 | 1.5 | 180 |
| Moondarra Crossing | >100 | 100 | 8.5 | 4,070 | 492 | 8.1 | <1 | **17** | 2.3 | 490 | <5 | <1 | 11 | 880 | 440 | 12 | 450 | <0.005 | 1.4 | 180 |
| Moondarra Overflow | >100 | 100 | 8.6 | 535 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | 180 |
| TV 90% at water hardness (180–240) | | | | | | 94 | 2.2 | 9.4 | 66 | 2,500 | 68 | 18 | 78 | | | | | | | |
| TV 90% at water hardness (400) | | | | | | | 4 | 16.2 | 150 | 2,500 | 117 | 18 | 135 | | | | | | | |
| TV 95% at water hardness (180–240) | | | | | | 24 | 1.1 | 7.2 | 40 | 1,900 | 57 | 11 | 42 | | | | | | | |
| TV 95% at water hardness (400) | | | | | | | 2 | 12.6 | 91 | 1,900 | 99 | 11 | 72 | | | | | | | |

* Trigger values have been adjusted to site-specific water hardness

TV 95% trigger values for total ammonia-N at different pH for 95 % species protection for freshwater species Table 8.3.7 ANZECC/ARMCANZ (2000)

Bold figures: Exceed trigger values

**Table 54. Aquatic toxicity results and water quality of samples collected by Xstrata on 7 October 2009**

| Sites | pH | EC (µS/cm) | 48-h acute *cladoceran Ceriodaphnia* | | Arsenic | Cadmium | Chromium | Cobalt | Copper | Lead | Manganese | Nickel | Zinc | Mercury |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | EC50 (%) | Survival (%) | Total metals and metalloids in water (µg/L) | | | | | | | | | |
| Breakaway Creek–Leichhardt River junction | 8 | 3,720 | 100 | **70** | 4 | 0.2 | 2 | 2 | 8 | 6 | 776 | 2 | 11 | 0.1 |
| Alma Crossing | 8.5 | 2,600 | 100 | 100 | 4 | **2.1** | 2 | 2 | **28** | 34 | 249 | 3 | 46 | 0.1 |
| Davis Crossing | 7.8 | 3,380 | 100 | **30** | 2 | **3.5** | 1 | 1 | 3 | 1 | 416 | 1 | 20 | 0.1 |
| TV 90% at water hardness (180–240) | | | | | 94 | 2.2 | 6 | N/A | 9.4 | 66 | 2,500 | 67.6 | 78 | 1.9 |
| TV 90% at water hardness (400) | | | | | | 4 | 6 | N/A | 16.2 | 150 | 2,500 | 117 | 135 | 1.9 |
| TV 95% at water hardness (180–240) | | | | | 24 | 1.14 | 1 | - | 7.2 | 40 | 1,900 | 57 | 42 | 0.6 |
| TV 95% at water hardness (400) | | | | | | 2 | 1 | - | 12.6 | 907 | 1,900 | 99 | 72 | 0.6 |

* Trigger values have been adjusted to site-specific conditions for water hardness
Bold figures: Exceed trigger values

**Table 55. Aquatic toxicity results and water quality of samples collected 13–16 October 2009**

| Site | 72-h inhibition *Selenestrum capricornutum* IC50 | 48-h survival *Ceriodaphnia cf dubia* EC50 | 7-d *cladoceran Ceriodaphia cf dubia* EC50 survival | 7-d growth inhibition *Lemna minor* IC50 | | 96-hrfish imbalance *Melanotaenia splendida* | Cadmium (µg/L) | | Copper (µg/L) | | Lead (µg/L) | | Zinc (µg/L) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Growth rate | Dry weight | 96-h EC50 | Total | 0.45 µm | Total | 0.45 µm | Total | 0.45 µm | Total | 0.45 µm |
| 23rd Avenue | 91.80% | >100 % | >100% | 45.3% | >100% | >100% | 0.1 | 0.1 | 8.6 | 5.1 | 3.3 | 0.1 | 16.8 | 13.6 |
| TV 95%* | | | | | | | 1.1 | | 7.3 | | 40 | | 42 | |
| Isa Crossing | >100 % | >100 % | >100% | >100% | >100% | >100% | 0.4 | 0.2 | 9.2 | 6.5 | 2.3 | 0.4 | 34.5 | 18 |
| TV 95% | | | | | | | 2 | | 12.6 | | 91 | | 72 | |
| Alma Crossing | >100 % | >100 % | >100% | >100% | >100% | >100% | 1 | 0.4 | **27.5** | 13.9 | 19.4 | 1.6 | 36.2 | 18.1 |
| TV 95% | | | | | | | 2 | | 12.6 | | 91 | | 72 | |
| Davis Crossing | >100 % | >100 % | >100% | 95.3% | >100% | >100% | **2.8** | 1.1 | 4.2 | 2.7 | 2.7 | 0.3 | 15.6 | 10.6 |
| TV 95% | | | | | | | 2 | | 12.6 | | 91 | | 72 | |
| Moondarra Crossing | 41.8% | >100 % | >100% | >100% | 59.3% | >100% | 0.4 | 0.3 | **16.3** | 15.4 | 5.6 | 1.4 | 10.2 | 7.9 |
| TV 95% * | | | | | | | 2 | | 12.6 | | 91 | | 72 | |

* Trigger values have been adjusted to site-specific conditions for water hardness
Bold figures: Exceed trigger values

The results of further toxicity testing (7 October 2009) (Table 54) showed acute effects on *Ceriodaphia* (30% survival) that were accompanied by cadmium. The results of further toxicity testing (7 October 2009) (Table 54) showed acute effects on *Ceriodaphia* (30% survival) that were accompanied by cadmium concentrations at Davis Crossing exceeding the trigger value for 95% levels of freshwater species protection for cadmium at 3.5 µg/L compared the trigger value of 2 µg/L (Table 54). The water cadmium and copper concentrations (total only) for Alma Crossing and Davis Crossing that exceed the hardness adjusted trigger values for 95% freshwater species protection on 7 October 2009 (Table 54) can be compared with subsequent sampling on 13 – 16 October 2009 for both total and 0.45 µm filtered concentrations. This comparison showed that the 0.45 µm filtered concentration of copper exceeded the hardness adjusted trigger value for 95% freshwater species protection 13 – 16 October 2009 at Alma Crossing only but not for cadmium at both sites. Thus the acute toxicity at Davis Crossing observed with *Ceriodaphnia* on 7 October 2009 (Table 54) could not be explained by heavy metals alone.

To fully evaluate the effectiveness of the Leichhardt River Remediation Program following the Phase I study (Noller et al., 2009), using the decision tree steps (Figure 12) a comprehensive sampling of Leichhardt River water (Table 55) and sediment (Table 62) was undertaken on 13–16 October 2009. The toxicity studies showed various effects at 23 Avenue (growth inhibition to *Lemna*), Davis Crossing (chronic toxicity to *Ceriodaphnia*), and Moondarra Crossing (effects to three different species). *Selenastrum capricornutum* shows toxicity at Moondarra Crossing, but not *Ceriodaphnia* for both acute and chronic toxicity, indicating that *Selenastrum* may be affected by turbidity. Copper exceeds TVF 95% at Alma Crossing and Moondarra Crossing, but exhibits no toxicity (Table 54). The lack of toxicity probably arises from the relatively high concentrations of DOC in water at both locations (Table 55) and confirmed by BLM (Table 56).

These findings indicate that, overall, only limited toxicity to a range of aquatic species covering different trophic levels was observed in the Leichhardt River water. The metal concentrations in the water indicate that the cadmium concentration at Davis Crossing and the copper concentration at Alma Crossing and Moondarra Crossing exceeded the trigger value for the 95% level of freshwater species protection. The water quality data of these sites (Table 56) shows similarity to the data in Table 8 and Table 9.

**Table 56. Water quality of samples collected 13–16 October 2009**

| Site | pH | EC (µm/cm) | Hardness (mg/L) | Alkalinity $CaCO_3$ (mg/L) | Sulfate (mg/L) | Nitrate (mg/L) | Chloride (mg/L) | DOC (mg/L) |
|---|---|---|---|---|---|---|---|---|
| 23rd Avenue | 8.6 | 1,500 | 318 | 277 | 152 | <0.5 | 281 | 6.8 |
| Isa Crossing | 9.0 | 3,700 | 569 | 292 | 710 | <0.5 | 793 | 7.3 |
| Alma Crossing | 9.0 | 4,230 | 845 | 541 | 429 | <0.5 | 1,130 | 58 |
| Davis Crossing | 8.1 | 5,900 | 741 | 451 | 726 | <0.5 | 1,220 | 4.4 |
| Moondarra Crossing | 8.2 | 333 | 748 | 258 | 824 | <0.5 | 1,340 | 11 |

Water quality data from five sites collected 13–16 October 2009 were used in the BLM (Section 2.3.1.2) to predict the final acute values for copper and for site-specific assessments for copper. Table 57 presents site-specific water quality criteria for copper concentrations predicted to be toxic by the BLM and direct toxicity assessments on water samples collected 13–16 October 2009. The final acute test and acute toxic unit results show that copper could not explain the observed toxicity at Davis Crossing and Moondarra Crossing. This indicates that further assessment needs to be conducted at the Davis Crossing site.

Rifle Creek, located upstream of Leichhardt River (Figure 14) was chosen as background site for toxicity assessments of both water and sediment. The toxicity results and predictions of copper by the BLM show that no toxicity was observed at this site in water (Table 58). For the BLM, the CCC is greater than the measured copper concentration indicating no predicted effect on aquatic biota. The filtered copper concentration exceeds TVF 95% (Table 58) and when compared with the visual MINTEQ predicted copper speciation in Table 58 and shows that most copper is present as organic species with DOC of 9 mg/L.

This result is despite the prediction that metal concentrations in water measured in filtered fractions and calculated by visual MINTEQ exceeded the trigger values for the 95% level of freshwater species protection (Table 59). Therefore, Rifle Creek Dam is a suitable background site of the Leichhardt River for aquatic toxicity assessment.

**Table 57. Summary of site-specific water quality criteria for copper predicted by the Biotic Ligand Model and direct toxicity assessment on water samples collected 13–16 October 2009**

| Sites | Measuredcopper concentr-ation 0.45 µm fraction (µg/L) | Site-specific water quality criteria for copper (WQC) predicted by BLM | | | | Direct toxicity assessment | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 72-h inhibition *Selenestrum capricornutum* | 48-h Survival *Cerio daphnia cf dubia* | 7-d partial life-cycle (chronic) toxicity cladoceran *Ceriodaphia cf dubia* | | 7-d growth inhibition *Lemna* minor | | 96-h fish imbalance *Melanotaenia splendida* |
| | | FAV (µg/L) | CMC (µg/L) | CCC (µg/L) | Acute TUs | 72-hr IC50 | 48-hr EC50 | 8-day IC50 (survival) | 8-day IC50 (reproduction) | 7-day IC50 (growth rate) | 7-day IC50 (dry weight) | 96-hr EC50 |
| 23rd Avenue | 5.1 | 311 | 156 | 97 | 0.03 | 91.8% | >100% | >100% | >100% | 45.3 | >100% | >100% |
| Isa St Crossing | 6.5 | 398 | 199 | 123 | 0.03 | >100% | >100% | >100% | >100% | >100% | >100% | >100% |
| Alma St Crossing | **14** | 526 | 264 | 164 | 0.05 | >100% | >100% | >100% | >100% | >100% | >100% | >100% |
| Davis Crossing | 2.7 | 227 | 114 | 71 | 0.02 | >100% | >100% | >100% | **66.1%** | **95.3%** | >100% | >100% |
| Moondarra Crossing | **15.4** | 520 | 260 | 162 | 0.06 | **41.8%** | >100% | >100% | 74.2% | >100% | **59.3%** | >100% |

* Trigger value have been adjusted to site-specific conditions for water hardness
Bold figures: Exceed trigger values

- FAV: Final Acute Value.
- CMC: Criterion Maximum Concentration. An estimate of the highest concentration of a material in ambient water that an aquatic community can be exposed to briefly without an unacceptable adverse effect (CMC=FAV/2).
- CCC: Criterion Continuous Concentration. An estimate of the highest concentration of a material in ambient water that an aquatic community can be exposed to indefinitely without resulting in an unacceptable adverse effect. This is the chronic criterion. (CCC=FAV/ACR).
- ACR: Acute-Chronic Ratios.
- Acute = exposure to a 1-hour average concentration of the chemical does not exceed the criterion more than once every three years on average.
- Chronic = exposure to a 4-day average concentration of the chemical does not exceed the criterion more than once every three years on average.
- Acute Toxic Units (TU): Acute TU is the ratio of the copper in the water to the instantaneous water quality criteria for that water. If is TU > 1 it indicates a violation of the instantaneous copper WQC.

**Table 58. Summary of site-specific water quality criteria for copper predicted by the Biotic Ligand Model, direct toxicity assessment, and metal concentrations in water samples collected at Rifle Creek Dam 27–28 July 2010**

| Site | 72-h inhibition *Selenestrum capricornutum* | 48-h survival *Ceriodaphnia cf dubia* | 7-d *cladoceran Ceriodaphia cf dubia* | | 7-d growth inhibition *Lemna minor* | 96-h fish imbalance *Melanotaenia splendida* | Site-specific water quality criteria for Copper (WQC) predicted by BLM | | | | Cadmium (µg/L) | | Copper (µg/L) | | Lead (µg/L) | | Zinc (µg/L) | | DOC (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 72-hr IC50 | 48-hr EC50 | EC50 (survival) | IC50 (reproduction) | IC50 (growth rate) | 96-hr EC50 | FAV (µg/L) | CMC (µg/L) | CCC (µg/L) | Acute TUs | Total | 0.45 µm | Total | 0.45 µm | Total | 0.45 µm | Total | 0.45 µm | |
| Rifle Creek | 78.2% | >100% | >100% | >100 % | >96.8 | >100% | 540 | 270 | 168 | 0.06 | <0.1 | <0.1 | 16 | 15 | <0.1 | <0.1 | 26 | 10 | 9 |
| TV 95%* | | | | | | | | | | | 11 | | 7.3 | | 40 | | 42 | | |

* ANZECC/ARMCANZ (2000) trigger vales (TV) for 95% and 90% freshwater species protection. The TV has been adjusted for site-specific conditions of water hardness.

- FAV: Final Acute Value.
- CMC: Criterion Maximum Concentration. An estimate of the highest concentration of a material in ambient water that an aquatic community can be exposed to briefly without an unacceptable adverse effect (CMC=FAV/2).
- CCC: Criterion Continuous Concentration. An estimate of the highest concentration of a material in ambient water that an aquatic community can be exposed to indefinitely without resulting in an unacceptable adverse effect. This is the chronic criterion. (CCC=FAV/ACR).
- ACR: Acute-Chronic Ratios.
- Acute = exposure to a 1-hour average concentration of the chemical does not exceed the criterion more than once every three years on average.
- Chronic = exposure to a 4-day average concentration of the chemical does not exceed the criterion more than once every three years on average.
- Acute Toxic Units (TU): Acute TU is the ratio of the copper in the water to the instantaneous water quality criteria for that water. If is TU > 1 it indicates a violation of the instantaneous copper WQC.

**Table 59. Metal and metalloid concentrations in water samples measured in filtered fractions and calculated by visual MINTEQ from Rifle Creek Dam that exceed the trigger values for 95% species protection for copper**

| Elements | Species | Measured results in filtered fractions 0.45 μm | Visual MINTEQ calculation | | | Hardness as $CaCO_3$ (mg/L) | TV* for 95% species protection (μg/L) |
|---|---|---|---|---|---|---|---|
| | | | Free metals | Inorganic species | Organic species | | |
| Arsenic | % 0.45 μm fraction | 100 | 0 | 100 | 0 | 896 | 24 |
| | Concentration (μg/L) | 1.97 | 0 | 1.97 | 0 | | |
| Copper | % 0.45 μm fraction | 100 | 0 | 0.02 | 99.8 | 896 | 12.6 |
| | Concentration (μg/L) | **15** | 0 | 0.02 | 15 | | |
| Nickel | % 0.45 μm fraction | 100 | 32 | 93 | 7 | 896 | 99 |
| | Concentration (μg/L) | 0.42 | 0.13 | 0.39 | 0.03 | | |

Note: Bold figures exceed trigger values.

* ANZECC/ARMCANZ (2000) trigger values (TV) for lead for 95% and 90% freshwater species protection. The TV has been adjusted for site-specific conditions of water hardness.

### 3.3.2 Aquatic toxicity assessment and metal concentrations in sediment

The Phase I Study assessed sediment toxicity of the Leichhardt River (Noller et al., 2009). Table 60 summarises the results of this assessment that indicated toxic sediment at two sites downstream from Isa Crossing and nearby at the velodrome and pipe exit. The sediment quality data show that 1MHCl extraction of arsenic, cadmium, copper, zinc, and lead at these sites exceeds the ISQG-Low. The water elutriate also showed the presence of relatively high concentrations of cadmium, copper and lead. Subsequently, the sediments identified as being toxic to aquatic species were removed in 2008 as part of the Leichhardt River Remediation Program.

The water sampling toxicity assessment (Table 54) followed the Leichhardt River Remediation Program undertaken in 2007. Sediment was collected on 7 October 2009 by Xstrata and evaluated by testing acute toxicity of the water elutriate of sediment using *Ceriodaphnia* as the test species. The toxicity results in water at these sites show that acute toxicity was observed at Breakaway 'Stinky' Creek–Leichhardt River Mouth (70% survival) and Leichhardt River–East Bank–Davis Crossing (30% survival) (Table 54). However, the results on the water elutriate of sediment showed no toxicity at all three sites (Table 61). It was observed that the 1M HCl concentrations of metal and metalloid in the sediment sample collected at Davis Crossing exceeded the ISQG-Low (Table 41). These results confirmed the observation from the 2007 study (Noller et al., 2009) that sediment toxicity is a more precise measure of the significance of metals and metalloid contamination in sediment than a comparison with total and 1M HCl concentrations, according to the ANZECC/ARMCANZ decision tree process (Figure 12).

Further sampling at five sites from Leichhardt River were collected on 13–16 October 2009 (Table 62) and Rifle Creek Dam on 27–28 July 2010 (Table 64) for acute toxicity testing. These sites showed no toxicity to *Ceriodaphnia*, but there was an apparent artifact with *Selenestrum capricornutum*, which is attributable to turbidity in the test water affecting this test organism. The 1M HCl extraction concentrations of cadmium and copper at Isa Crossing, Alma Crossing, and Davis Crossing exceeded the ISQG-Low but toxicity was not observed (Table 61). These sediment samples were analysed for metal and metalloid concentrations in pore water ($C_{SOL}$) and by the DGT technique ($C_E$) (Section 2.5.6; Table 63). Comparison of pore water ($C_{SOL}$) and sediment ($C_E$) metal concentrations shows that the $C_{SOL}$ concentrations are nearly all much higher than for $C_E$. There was no comparison made with metal and metalloid concentrations in sediment water elutriates for the samples in Tables 61 and 62 as a complete sampling using the DGT technique was not undertaken. Comparisons of the metal and metalloid concentrations in pore water ($C_{SOL}$) do not exceed the hardness-adjusted trigger values for 95% freshwater species protection (Table 63).

**Table 60. Aquatic toxicity and sediment quality results of sediment sampled 4 September 2007**

| Site description | 48-h *Cerio daphnia* cf *dubia* 48h EC50 (survival)* | 10-d *Corophium sp* (survival) (%) | Arsenic | | Cadmium | | Cobalt | Copper | | Nickel | Zinc | | Lead | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 M HCl mg/kg | Water elutriate * (mg/L) | 1 M HCl mg/kg | Water elutriate * (mg/L) | 1 M HCl (mg/kg) | 1 M HCl (mg/kg) | Water elutriate * (mg/L) | 1 M HCl (mg/kg) | 1 M HCl (mg/kg) | Water elutriate * (mg/L) | 1 M HCl (mg/kg) | Water elutriate * (mg/L) |
| Control | | 92.5 ± 5.0 | | | | | | | | | | | | |
| LR — Upstream (background) L1 | >100% | 75 ± 12.9 | <0.1 | <0.02 | <0.1 | <0.001 | 5.2 | 30 | 0.002 | 3 | 22.6 | <0.003 | 32 | <0.006 |
| LR — Between Isa Street Crossing and Grace Street Bridge L7 | >100% | 90 ± 8.2 | 10 | <0.02 | 1.5 | <0.001 | 7.2 | **266** | 0.007 | 22.2 | 118 | 0.012 | **257** | <0.006 |
| LR — Downstream, east of velodrome L9 | **<6.25%** | **0.0%** | 1.1 | <0.02 | 2.7 | 0.11 | 10.3 | **228** | 0.12 | 4 | **309** | 0.78 | 188 | 0.39 |
| LR — pipe exit L12 | **<6.25%** | **0.0%** | **174** | <0.02 | **111** | 0.22 | 36.1 | **6,400** | 1.6 | 15.7 | **4,290** | <0.003 | **20,000** | 2.1 |
| LR — Fluvial downstream (Moondarra) L15 | >100% | 82.5 ± 15 | <0.1 | <0.02 | 2.6 | <0.001 | 6.8 | **128** | 0.003 | 2.6 | 271 | 0.003 | 406 | <0.006 |
| LR — Downstream of Lake Moondarra (Leichhardt River) L16 | >100% | 90 ± 0.0 | <0.1 | <0.02 | 0.1 | <0.001 | 6.5 | 26.3 | 0.002 | 2.5 | 47 | <0.003 | 42 | <0.006 |
| ISQG-Low | | | 20 | | 1.5 | | NA | 65 | | 21 | 200 | | 50 | |
| ISQG-High | | | 70 | | 10 | | NA | 270 | | 52 | 410 | | 220 | |

**water elutriate: sediment mixed with dilution water 1:4; filtered <0.45 µm*
Bold figures: Exceed trigger values

**Table 61. Toxicity results and metal and metalloid concentrations in sediment samples collected by Xstrata on 7 October 2009**

| Sites | pH | 48-h Acute Toxicity *cladoceran Ceriodaphnia* | | Arsenic | Cadmium | Copper | Lead | Nickel | Zinc |
|---|---|---|---|---|---|---|---|---|---|
| | | **EC50 (%)** | **Survival (%)** | **Total metals and metalloids in sediment (mg/kg)** | | | | | |
| Breakaway Creek – Leichhardt River Mouth | 8.3 | 100 | 100 | 10 | 6 | **294** | **161** | **24** | **353** |
| Leichhardt River–East Bank–Davis Crossing | 8.1 | 100 | 100 | **23** | **98** | **364** | **205** | **22** | **924** |
| Leichhardt River–East Bank–Alma Crossing | 8.2 | 100 | 100 | **36** | **31** | **405** | **621** | **23** | **970** |
| ISQG-Low | | | | 20 | 1.5 | 65 | 50 | 21 | 200 |
| ISQG-High | | | | 70 | 10 | 270 | 220 | 52 | 410 |

Note: Bold figures indicate total concentration exceeds ISQGs.

**Table 62. Toxicity results and metal and metalloid concentrations in sediment samples collected on 13–16 October 2009**

Metal and metalloid concentrations determined by the DGT technique and in the pore water of sediment samples collected on 13–16 October 2 **TabTable**

| Site | 48-h survival *Cerio daphnia cf dubia* EC50 | 72-h inhibition *Selenestrum capricornutum* | Antimony (mg/kg) | | Arsenic (mg/kg) | | Cadmium (mg/kg) | | Copper (mg/kg) | | Lead (mg/kg) | | Nickel (mg/kg) | | Zinc (mg/kg) | | Total organic carbon (C %) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Total | 1M HCl | Total | 1M HCl | Total | 1M HCl | Total | 1M HCl | Total | 1M HCl | Total | 1M HCl | Total | 1M HCl | |
| 23rd Avenue | >100% | >100% | | <1 | | 3 | | 0.5 | | **194** | | 50 | | 1.9 | | 42 | 1 |
| Isa Crossing | >100% | **22%** | <5 | <1 | 10 | 4.3 | 4 | **4.7** | 390 | **218** | 89 | 82 | 19 | 3.6 | 947 | **932** | **1.2** |
| Alma Crossing | >100% | **22.9%** | | <1 | | 4.2 | | **7** | | **190** | | 144 | | 2.7 | | 274 | 1.8 |
| Davis Crossing | >100% | >100% | <5 | <1 | 16 | 7.4 | 59 | **58** | 264 | **148** | 281 | **225** | 19 | 2.9 | 699 | **578** | **1.2** |
| Moondarra Crossing | >100% | **77.1%** | <11 | <1 | 19 | 4.7 | 8 | **7** | 252 | **155** | 348 | **282** | 23 | 3.2 | 500 | 294 | 1.5 |
| ISQG-Low | | | 2 | | 20 | | 1.5 | | 65 | | 50 | | 21 | | 200 | | |
| ISQG-High | | | 25 | | 70 | | 10 | | 270 | | 220 | | 52 | | 410 | | |

Note: Bold figures indicate total concentration exceeds ISQGs.

**Table 63. Metal and metalloid concentrations determined by the DGT technique and in the pore water of sediment samples collected on 13–16 October 2009**

| Site | Cadmium | | | Copper | | | Lead | | | Nickel | | | Zinc | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1M HCl (mg/kg) | $C_E$ (±SE) (µg/L) | $C_{SOL}$ (µg/L) | 1M HCl (mg/kg) | $C_E$ (±SE) (µg/L) | $C_{SOL}$ (µg/L) | 1M HCl (mg/kg) | $C_E$ (±SE) (µg/L) | $C_{SOL}$ (µg/L) | 1M HCl (mg/kg) | $C_E$ (±SE) (µg/L) | $C_{SOL}$ (µg/L) | 1M HCl (mg/kg) | $C_E$ (±SE) (µg/L) | $C_{SOL}$ (µg/L) |
| 23rd Avenue | 0.5 | 0.17 ± 0.03 | 0.4 | 194 | 2.5 ± 1.5 | 3.3 | 50 | 0.5 ± 0.2 | 0.01 | 1.9 | 3.0 ± 0.7 | 1.6 | 42 | 47 ± 14 | 19.8 |
| Isa Crossing | 4.7 | 0.07 ± 0.03 | 0.7 | 218 | 4.2 ± 3.1 | 11.3 | 82 | 0.2 ± 0.02 | 0.44 | 3.6 | 4.5 ± 0.3 | 7.4 | 932 | 67 ± 7 | 50.9 |
| Alma Crossing | 7.0 | 0.33 ± 0.02 | 0.7 | 190 | 4.5 ± 3.8 | 8.6 | 144 | 3.1 ± 0.02 | 0.61 | 2.7 | 3.3 ± 0.2 | 5 | 274 | 20 ± 3 | 31.6 |
| Davis Crossing | 58.0 | 0.17 ± 0.09 | 1.1 | 148 | 4.0 | 6 | 225 | 1.5 ± 0.8 | 0.6 | 2.9 | 2.0 ± 0.2 | 2.7 | 578 | 5 ± 3 | 18.9 |
| Moondarra Crossing | 7.0 | 0.83 ± 0.08 | 0.9 | 155 | 18.8 | 11.6 | 282 | 3.1 ± 0.8 | 2.27 | 3.2 | 3.8 ± 0.2 | 4.8 | 294 | 14 ± 3 | 25.8 |
| ISQG- Low | 1.5 | | | 65 | | | 50 | | | 21 | | | 200 | | |
| ISQG- High | 10 | | | 270 | | | 220 | | | 52 | | | 410 | | |
| TV 95% protection (µg/L)* | | | 2 | | | 13 | | | 91 | | | 99 | | | 72 |

-$C_{SOL}$: The concentrations of metals in 0.45µm filtered pore water. Sediment samples were centrifuged at 1509 g for five min and the pore water was filtered through 0.45µm filter.
-$C_E$: Effective concentration of metals. $C_E = C_{DGT}/R_{diff}$ where Rdiff is calculated using the 2D DIFS model (Section 2.5.6)
-$C_{DGT}$: Concentration of metals measured by DGT technique
- SE: Standard Error
* Trigger values have been adjusted to the site-specific conditions for water hardness

**Table 64. Aquatic toxicity and metal and metallooid concentrations in sediment at a Rifle Creek upstream site samples 27 and 28 July 2010**

| Sites | 48-h acute toxicity *Ceriodaphnia* | 72-h inhibition *Selenestrum capricornutum* | Arsenic (mg/kg) | | Cadmium (mg/kg) | | Copper (mg/kg) | | Lead (mg/kg) | | Nickel (mg/kg) | | Zinc (mg/kg) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | EC50 (%) | 72-hr IC50 | Total | 1M HCl | Total | 1M HCl | Total | 1M HCl | Total | 1M HCl | Total | 1M HCl | Total | 1M HCl |
| Rifle Creek | >100% | >100% | 9 | <1 | 1 | 0.1 | 122 | 6.8 | 97 | 13.8 | 20 | <1.0 | 149 | 36.3 |
| ISQG-Low | | | 20 | | 1.5 | | 65 | | 50 | | 21 | | 200 | |
| ISQG-High | | | 70 | | 10 | | 270 | | 220 | | 52 | | 410 | |

### 3.3.3 Overall summary of aquatic toxicity on water and sediment

Table 65 summarises the sites that show an aquatic toxicity effect of water on different test species. The effects of 72-h inhibition *Selenestrum capricornutum* and 7-d partial lifecycle (chronic) toxicity cladoceran *Ceriodaphia* cf *dubia* tests were observed at both Moondarra Crossing and Davis Crossing. The effect on 48-h survival of *Ceriodaphnia* cf *dubia* was observed at Davis Crossing and Breakaway Creek. The effects of 7-d growth inhibition on *Lemna* minor was observed at 23rd Avenue (effect on growth rate) and Moondarra Crossing (effect on dry weight).

Table 66 summaries the sites showing an aquatic toxicity effect of sediment. The effects on 48-h survival of *Ceriodaphnia* and 10-d whole sediment *Corophium spp* were observed downstream, east of the velodrome (L9) and pipe exit (L12). The effects on the 72-h inhibition of *Selenestrum capricornutum* test were observed at three sites: Isa Crossing, Alma Crossing, and Moondarra Crossing.

The results for toxicity studies on both water and sediment are able to demonstrate when acute and chronic effects may occur with a range of test species. From 2007–2010, the kind and number of test species were limited and limitations were identified with using species including *Corophium* for sediment and *Selenestrum* for water and sediment elutriates. Currently, a wider range of test species is available.

It is also clear from the toxicity studies and comparisons with metal and metalloid concentrations and other constituents, such as ammonia, that responses to organisms cannot always be explained. This applies particularly to the David Crossing on Leichhardt River. Therefore, an approach that considers contributions of difference toxicants is needed. The Toxicity Identification Method (TIE) method developed by the USEPA (2007b) may be used to identify of constituents causing observed toxicity. The TIE approach uses physical and chemical manipulation of a sample to isolate or change the potency of different groups of toxicants potentially present in a sample. In developing the TIE procedures for aquatic toxicity in waters, further detailed study of water and sediment toxicity will require the use of such approaches.

**Table 65. A summary of the aquatic-toxicity test results of water at sites showing toxicity effects.**

| Aquatic-toxicity test species | | Sites showing toxicity effects |
|---|---|---|
| 72-h inhibition<br>*Selenestrum capricornutum* | 72-h IC50 <100% | Moondarra Crossing and 23rd Avenue (98%) |
| 48-h survival<br>*Cerio daphnia cf dubia* | 48-h EC50 <100% | Davis Crossing and Breakaway Creek |
| 7-d partial life-cycle (chronic) toxicity cladoceran<br>*Ceriodaphia* cf *dubia* (survival) | 8-d EC 50 <100% | Nil |
| 7-d partial life-cycle (chronic) toxicity cladoceran<br>*Ceriodaphia* cf *dubia* | 8-d IC 50 <100% (reproduction) | Moondarra Crossing and Davis Crossing |
| 7-d growth inhibition<br>*Lemna minor* | 7-d IC50 < 100%<br>(growth rate) | 23rd Avenue and Davis Crossing |
| 7-d growth inhibition<br>*Lemna minor* | 7-d IC50 <100%<br>(dry weight) | Moondarra Crossing |
| 96-h fish imbalance<br>*Melanotaenia splendida* | 96-h EC 50 <100% | Nil |

**Table 66. A summary on sediment toxicity test results at sites show toxicity effects**

| Sediment Toxicity Tests | | Sites showing toxicity effects | |
|---|---|---|---|
| | | 2007 | 2009 |
| 48-h survival of *Ceriodaphnia* | 48-h EC50 <100% | Downstream, east of the velodrome (L9), pipe exit (L12) | |
| 72-h inhibition of *Selenestrum capricornutum* | 72-h IC50 <100% | | Isa Crossing<br>Alma Crossing<br>Moondarra Crossing |
| 10-d whole sediment *Corophium spp.* | | Downstream East of Velodrome (L9), Pipe exit (L12) | |

# 4. Discussion

## 4.1 Natural mineralisation and its significance.

The Leichhardt River Basin commonly has occurrences of natural mineralisation and, as a consequence, mining and mineral processing from both historical and current activities that may have impacts on the aquatic ecosystem. There are two key issues for assessing the significance of metals and metalloids for total and 1M HCl extractable concentrations in the sediment from the upper Leichhardt River Basin, based on the ANZECC/ARMCANZ (2000) decision tree for assessing contamination of aquatic ecosystems. These key issues are:

1. Sites that may be affected by historical or current mining activities with upstream, background sediment with natural mineralisation make it problematic to identify background sites to compare metal and metalloid sediment concentrations against downstream sites, when sites exceed ISQGs.
2. The significance of metal and metalloid concentrations in sediment that exceed ISQG-High and ISQG-Low for the 1M HCl extraction need to be further assessed by measuring toxicity to aquatic biota to demonstrate if there is a real effect, according to the ANZECC/ARMCANZ (2000) decision tree process.

Comparing the background and mining-affected sites with unaffected sites shows the differences for metals and metalloid concentrations in sediment from the Leichhardt River Basin (Table 46). Some sites exceeded ISQGs for total concentrations of metals and metalloids, but no sites exceeded the totals for 1M HCl extractable concentrations. This result implies that all background sites, rather than just the unaffected sites alone, could be used as the basis to describe background sediment metal and metalloid concentrations. According to the QWQG (2009), the 80th percentile values for metal and metalloid concentrations are the applicable data set to create a site-specific guideline.

Comparison with <3 X natural background and for toxicants <3 X ISQG–Low for metals and metalloid concentrations in 1M HCl extracts of sediment for highly disturbed systems, as advised by the ANZECC/ARMCANZ (2000), shows that regional sites do not exceed both 3 X criteria. This result supports using all sediment data from background sites for developing site-specific guidelines.

It is also observed that the <2 mm fraction gives lower metal concentrations than the <63 µm fraction for the Rifle Creek Dam site (Table 48) on the Leichhardt River, indicating that the finer <63 µm fraction gives a better indication of predicted effects on aquatic biota via ingestion. However, the <63 µm fraction is relatively small compared with the bed load of fluvial material in the Leichhardt River and will only be of significance when associated with processed materials. Natural mineralisation will also be present in coarse sediment.

Comparison of aquatic toxicity testing results show, generally, that upstream background sediments were not toxic to the tested species and showed the sites that exceeded ISQG–Low for 1M HCl extract did not imply that the sediment was toxic to the aquatic test biota. In particular, sediment from Rifle Creek Dam exhibited little or no toxicity, even though there was historical mining in its catchment (Table 58 through to Table 64).

Exceeding the ISQG-High is indicative of a high probability of biological effects. The Phase I Study showed sediment toxicity of the Leichhardt River (Noller et al., 2009), summarised in Table 60 at two sites downstream from Isa Crossing and nearby at the velodrome (L9) and pipe exit (L12). This was the only toxicity observed with the burrowing amphipod *Corophium spp.* at concentrations above the ISQG-High in most cases. The sediment quality data shows that 1M HCl extraction of arsenic, cadmium, copper, zinc, and lead at these sites exceeds the ISQG-Low and, in most cases, exceeds the ISQG-High. Subsequently, the sediments identified as being toxic to aquatic species were removed in 2008 as part of the Leichhardt River Remediation Program. No other sediment was found to be as toxic as the pre-existing sediment from sites L9 and L12.

Thus, an approach that takes into account both the presence of natural mineralisation and some effects of historical mining is applicable for using background sediment quality data for the Leichhardt River to derive site-specific guidelines for sediment. This approach is in line with the advice given in the ANZECC/ARMCANZ (2000) guidelines to take natural mineralisation into account. It is therefore considered appropriate to use all upstream sediment metal and metalloid concentration data for developing site-specific guidelines for the Leichhardt River Basin because aquatic toxicity is not generally demonstrated with the presence of natural mineralisation or sediment associated with historical mining.

## 4.2 Health risk assessment associated with drinking water

The results for water and sediment (Table 31 and Figure 23) show that some sites in the Leichhardt River exceeded Australian Water Quality Guidelines (ADWG, 2004) for water and some sites exceeded the NEPM HIL—Level E for recreational use of land (NEPC,1999) for sediment (<2 mm fraction). In addition, a detailed health risk assessment of exposure to lead and other heavy metals and metalloids in Leichhardt River sediment at Mount Isa and other recreational areas has been provided in Phase I (Noller et al. 2009). This section considers the health-risk implications of occasional consumption of water from the Leichhardt River and contact with or ingestion of river sediment dispersed in the water.

For this project, a default body weight of 70 kg has been assumed for an adult and 14 kg for a child (enHealth, 2004). Water metal and metalloid concentrations were compared with the Australian Drinking Water Guidelines (ADWG, 2004). River sediment is treated as soil when the riverbed is dry. Metal and metalloid concentrations were compared with NEPM HIL—Level E (NEPC, 1999). The conservative approach was to assume that residents could be exposed to this contamination source from the river bed in the dry season as they would in a park or recreation facility.

Bioaccessibility (BAc) data, which predict bioavailability, were obtained where possible (Table 51)). Generally, BAc is a more conservative value than bioavailability (Section 3.2.7.1 ). In the absence of BA or BAc data, the USEPA (2007c) uses 0.3 (30% bioavailability) as a default for lead exposure to soil or dust. Food lead bioavailability is 50% for children and 10% for adults (USEPA, 2007c).

To ensure that all exposure pathways were taken into considerations, lead exposure was combined with realistic estimates of food (IPCS, 1995) and water exposure for an adult (70 kg) and a child (14 kg) (enHealth, 2004). Estimates of lead (see IPCS, 1995) absorbed from food were 10 µg/day (0.01 mg/day) for adults and 25 µg/day (0.025 mg/day) for children, based on 10% bioavailability in adults and 50% bioavailability (conservative estimate) in children (Table 67). The corresponding estimates of lead absorbed by from drinking water from the Leichhardt River were 2 µg/day (0.002 mg/day) for adults and 5 µg/day (0.005 mg/day) for children. The estimates of lead intake from water aligned with the calculation based on the current Australian Drinking Water Guideline value (0.01 mg/L) (ADWG, 2004). For water, a daily consumption of 2 L for an adult and 0.5 L for a child was used to calculating lead exposure, assuming 10% bioavailability as suggested by the IPCS expert task group (IPCS, 1995).

From a survey of PM10 annual moving average of lead concentration in air quality monitoring between January 2005 and January 2009 in Mount Isa City, the average ambient concentration of lead was less than 0.3 µg/m$^3$ (EPP, 2008) and should not exceed annual average; QLD DERM 2010). This value was used for the calculation of the inhalation exposure dose coupled to the default of 30% bioavailability as adopted by USEPA (2007c). A further assumption was made that the total suspended PM10 particulates in air was at the NEPM maximum daily average of 50 µg/m$^3$ (NEPC, 2004).

**Table 67. Standards and assumptions used for the calculations of exposure data of lead**

| Variable | Symbol | Value | Unit | Reference |
|---|---|---|---|---|
| Tolerable Daily Intake (or Reference Dose, Acceptable Daily Intake) | TDI / ADI | 0.00357 | mg/kg bw-day | ADWG, 2004; WHO, 1989 |
| Soil ingestion — adult | IR | 0.000025 | kg/day | Kimbrough et al., 1984; enHealth, 2004 |
| Soil ingestion — child | IR | 0.0001 | kg/day | |
| Inhalation volume | IR | 20 (adult)<br>12 (child) | $m^3$/day | enHealth, 2004 |
| Food lead intake | EDFood | 10<br>25 | µg/day | IPCS, 1995 |
| Water lead intake | EDWater | 2<br>5 | µg/day | ADWG, 2004; IPCS, 1995 |
| Body weight — adult | BW | 70 | kg | enHealth, 2004 |
| Body weight — child | BW | 14 | kg | enHealth, 2004 |
| Bioavailability food ingestion | BA | 0.5 (child) 0.1 (adult) | No unit | USEPA, 2007c |
| Bioavailability soil ingestion | BA | 0.3 (default) or as determined | No unit | USEPA, 2007c |
| Bioavailability dust inhalation | BA | 0.3 (default) or as determined | No unit | USEPA, 2007c |

Note: Bioavailability can be expressed as a fraction, as shown in the table, or as a percentage (e.g. BA fraction of 0.5 is 50%); TDI =Tolerable Daily Intake; ADI = Allowable (average) Daily Intake; IR = Intake Rate, ED = Exposure Dose; BW = Body Weight; BA = Bioavailability.

### 4.2.1 Tolerable daily intake of lead

The tolerable dose for lead is set at 25 µg Pb/kg bw-week (WHO, 1989). This is equivalent to a tolerable daily intake (TDI) of 3.57 µg Pb/kg bw-day (0.00357 mg/kg bw-day). This equates to an allowable daily intake (ADI) of 0.25 mg Pb/day or a TDI of 0.05 mg Pb/day for an adult of 70 kg body weight and a child of 14 kg body weight (Table 67).

A Hazard Index (HI) was derived by comparing actual exposure to the TDI. For a health risk assessment, when the HI is equal to or less than 1, it is considered to be no risk; when the HI is greater than 1, it is considered to be a potential risk. Generally, the TDI is set with precautionary safety factors and, therefore, it is a conservative value. According to Equation (4)

$$HI = ED/TDI \qquad (4)$$

Where:
HI ≤ 1 there is no health risk
HI > 1 but < 10 there is a potential health risk (low to moderate probability of risk)
HI > 10 there is a real health risk (high probability of risk).

Table 68 is a look-up table showing daily intakes derived from all ingestible sources and bioavailability data. The red cells indicate where the daily intake for a particular concentration of soil lead for a given bioavailability is exceeded.

**Table 68. Look-up table showing daily intakes derived from all ingestible sources and bioavailability data. Red cells indicate where the daily intake for a particular concentration of soil lead for a given bioavailability is exceeded**

| Pb (mg/kg) | Chronic lead – (soil+food+water) | | | | | |
|---|---|---|---|---|---|---|
| | HIL A 300 | HIL E 600 | HIL D 1200 | > HIL F 2400 | > HIL F 6000 | > HIL F 35000 |
| **BA** | **Adult** | | | | | |
| 1 | 0.020 | 0.027 | 0.042 | 0.072 | 0.162 | 0.887 |
| 0.9 | 0.019 | 0.026 | 0.039 | 0.066 | 0.147 | 0.800 |
| 0.8 | 0.018 | 0.024 | 0.036 | 0.060 | 0.132 | 0.712 |
| 0.7 | 0.017 | 0.023 | 0.033 | 0.054 | 0.117 | 0.625 |
| 0.6 | 0.017 | 0.021 | 0.030 | 0.048 | 0.102 | 0.537 |
| 0.5 | 0.016 | 0.020 | 0.027 | 0.042 | 0.087 | 0.450 |
| 0.4 | 0.015 | 0.018 | 0.024 | 0.036 | 0.072 | 0.362 |
| 0.3 | 0.014 | 0.017 | 0.021 | 0.030 | 0.057 | 0.275 |
| 0.2 | 0.014 | 0.015 | 0.018 | 0.024 | 0.042 | 0.187 |
| 0.1 | 0.013 | 0.014 | 0.015 | 0.018 | 0.027 | 0.100 |
| | **Child** | | | | | |
| 1 | 0.060 | 0.090 | 0.150 | 0.270 | 0.630 | 3.530 |
| 0.9 | 0.057 | 0.084 | 0.138 | 0.246 | 0.570 | 3.180 |
| 0.8 | 0.054 | 0.078 | 0.126 | 0.222 | 0.510 | 2.830 |
| 0.7 | 0.051 | 0.072 | 0.114 | 0.198 | 0.450 | 2.480 |
| 0.6 | 0.048 | 0.066 | 0.102 | 0.174 | 0.390 | 2.130 |
| 0.5 | 0.045 | 0.060 | 0.090 | 0.150 | 0.330 | 1.780 |
| 0.4 | 0.042 | 0.054 | 0.078 | 0.126 | 0.270 | 1.430 |
| 0.3 | 0.039 | 0.048 | 0.066 | 0.102 | 0.210 | 1.080 |
| 0.2 | 0.036 | 0.042 | 0.054 | 0.078 | 0.150 | 0.730 |
| 0.1 | 0.033 | 0.036 | 0.042 | 0.054 | 0.090 | 0.380 |

LEGEND:

Lead value = NEPC HIL 'A' (Standard residential with garden)
Lead value = NEPC HIL 'E' (Parks, recreational, playing fields)
Lead value = NEPC HIL 'D' (Residential with minimal soil access)
Lead value > NEPC HIL 'F' (Commercial/Industrial: 1500 mg/kg)
Estimated ingestion value for lead exceeds ADI (mg)
Available fraction of soil lead (e.g. 0.1 = 10 % Absolute Bioavailability)
Adult (70 kg) subject has ADI of 0.25 mg of lead (IPCS, 1995)
Child (14 kg) subject has ADI of 0.05 mg of lead (IPCS, 1995)
Food intake by adult=10 µg/d; child=25 µg/d
Potable Water 10% bioavailable: Water Pb intake by adult=2 µg/d; child=5 µg/d

From the sediment metal and metalloid concentration data (Table 50), total concentrations exceeded the NEPM HIL—Level E at site LR10. The BAc of this sample is given in Table 51 and showed a similar mean %BAc (24.7) for lead in sediments previously surveyed on 15–16 October 2009 (Table 49)). The 75% percentile of the previously surveyed sediment for BAc was found to be 29%, compared with 28.7% for sites LR9 and LR10. The calculated intake of lead from the sediment, in addition to normal food and water lead intake, gave the total lead exposure as shown in Table 69.

The red cells (Table 69) indicate that the potential risk for children at LR10 exceeded the NEPM HIL— Level E with a hazard index of 7.8 of measured BAc, 12.7 for the 75th percentile of BAc, and 8.8 for median BAc. The HI indicate there is potential health risk, but the probability of the risk is low to moderate. This conclusion is based on local residents being exposed to the dry sediment regularly over a lifetime, which is a far more realistic scenario of occasional exposure. The risk is lower when the river is flowing.

Based on this observation, sediment with lead higher than 1000 mg/kg should be removed or access to these sites should be restricted. This risk assessment is conservative because the BAc is taken as bioavailability with frequent exposure. The actual bioavailability of lead in sediment may well be less than 10% (see Phase II Report). The X-ray absorption spectroscopy model compound fitting results for Leichhardt River sediment (Table 52)) show that lead is predominantly found as lead-goethite, including upstream at Rifle Creek Dam. The results only show variable composition when the lead concentration is high and clearly associated with historical tailings, as is the case for site LR10. Lead-goethite is well known as having low bioavailability, and this is confirmed by data for Leichhardt River sediments (Table 52).

**Table 69. Total intake of lead from exposure to sediment (LR 10, <250 μm fraction) when the Leichhardt River bed is dry**

| | Chronic lead – (LR10 sediment+food+water) | | |
|---|---|---|---|
| **Pb mg/kg** | **LR_10 20910** | | **Hazard Index** |
| **BAc** | **Adult** | | |
| 0.173 | Measured | 0.102 | 0.41 |
| 0.29 | 75% Percentile | 0.164 | 0.66 |
| 0.195 | Median | 0.114 | 0.46 |
| **BAc** | **Child** | | |
| 0.173 | Measured | 0.392 | 7.8 |
| 0.29 | 75% Percentile | 0.636 | 12.7 |
| 0.195 | Median | 0.438 | 8.8 |

Estimated ingestion value for lead exceeds ADI (mg): Adult 0.25, Child 0.05
Adult (70 kg) subject has ADI of 0.25 mg of lead (IPCS, 1995)
Child (14 kg) subject has ADI of 0.05 mg of lead (IPCS, 1995)
Food intake by adult=10 μg/d; child=25 μg/d

### 4.2.2 Cadmium in Leichhardt River sediment

Cadmium in the sediment samples was marginally higher than the NEPM HIL—Level E of 40 mg/kg (Table 50) for the <2 mm fraction with a total concentration of 163 mg/kg and a bioaccessibility-adjusted concentration of 45.6 mg/kg at site LR10 based on the <250 μm fraction (Table 51). Given the samples are from river sediment, the opportunity for exposure will only occur during the dry season when the river bed is dry. The bioaccessibility and bioavailability of cadmium is a fraction of 100% (mean 43.2% for LR samples (Table 51)). Therefore, the potential health risk due to cadmium from LR sediment is considered low.

### 4.2.3 Copper in Leichhardt River sediment

The highest copper level found in Leichhardt River sediment samples was at site LR10, with a total concentration of 4490 mg/kg, which was 1260 mg/kg for the bioaccessibility-adjusted concentration and below the NEPM HIL—Level E of 2000 mg/kg (Table 51). Given that copper bioavailability is less than 100% (mean 27.9% for LR samples) and that the opportunity for exposure will only occur during the dry season when the river bed is dry, the potential health risk due to copper from LR sediment is considered low.

### 4.2.4 Lead in Leichhardt River water

A daily consumption of 2 L of water for adults and 0.5 L of water for a child (14 kg) was used to calculate lead exposure. It was assumed that the bioavailability of lead from water is 10%, as recommended by the IPCS Expert Task Group (IPCS, 1995).

Exposure to lead from direct consumption of Leichhardt River water and sediment is mutually exclusive. Therefore, the total lead exposure, as shown in Table 23 and Table 24, can be recalculated by replacing the drinking water intake with the Leichhardt River water as a conservative approach, assuming that Leichhardt River water was the only source of drinking water. However, to counteract for being overly conservative, the soil/sediment intake was removed. Table 70 shows the potential associated with drinking Leichhardt River water, adjusted for 10% bioavailability and normal food lead intake. Only Leichhardt River water samples with lead higher than the ADWG (2004) were calculated.

The total intakes of lead (LR water + food) were all below TDI 0.25 mg/d for adults and TDI of 0.05 mg/d for children. However, a number of Leichhardt River water samples could pose a risk if soil lead is included in this calculation.

### 4.2.5 Arsenic in Leichhardt River sediment and water

The highest total concentration of arsenic in sediment collected at site LR10 was 251 mg/kg, which marginally exceeded HIL—Level E of 200 mg/kg. The BAc of Leichhardt River sediments ranged from 2% to 20% (Table 49) with a 75th percentile of 13.8%. The bioaccessibility-adjusted arsenic concentration found at site LR10 was 7.6 mg/kg with BAc of 3.0% (Table 51). Therefore, arsenic in Leichhardt River sediment represents a low health risk.

Forty Leichhardt River water samples exceeded the drinking water guidelines (ADWG,2004) for arsenic (7 µg/L) (Table 23). Arsenic concentrations ranged from 0.2 to 46.6 µg/L with a median of 4.6 µg/L and a 75th percentile of 11.8 µg/L. If people were exposed to the highest arsenic concentration, then the HI =6.7 represents a potential health risk. However, residents are unlikely to use water as their only source of drinking water. Exposure is more likely to be via accidental ingestion or recreational exposure. Therefore, the health risk for Leichhardt River water for arsenic exposure is considered low. This conclusion is further supported by the median arsenic concentration of 4.6 µg/L, which is below the ADWG (2004) and a 75th percentile of 11.8 µg/L, although higher than the ADWG (2004).

### 4.2.6 Zinc in Leichhardt River sediment and water

Zinc (Zn) is an essential element for normal bodily functioning. The daily requirement of zinc is 12–15 mg/day; however, zinc can be toxic if exposure is excessive. Ingestion is the main source of excessive exposure that could result in toxicity. Dermal absorption of zinc is very low; therefore, dermal toxicity is extremely unlikely. No haematological (blood) effect has been observed after dermal exposure to zinc. There was no dermal irritation from a skin patch of 25% zinc oxide (2.9 mg/cm$^2$) for 48 hours, which is a very high concentration. The highest zinc sediment concentrations found were 9,920 mg/kg at sites LR9 and LR10 (Table 51). These concentrations are well below the current NEPM HIL—Level E of 14,000 mg/kg (NEPC, 1999). The highest zinc concentration found in Leichhardt River water was 407 µg/L, which is well below the ADWG (2004) of 3,000 µg/L (ADWG, 2004).

**Table 70. Potential associated lead with drinking Leichhardt River water adjusted for 10% bioavailability and normal food lead intake**

| Chronic lead – (LR water+food) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Pb µg/L** | **11** | **18** | **21** | **33** | **39** | **108** | **158** | **158** | **191** | **417** | **444** |
| **BAc** | **Adult (mg/day)** | | | | | | | | | | |
| **0.1** | 0.012 | 0.014 | 0.014 | 0.017 | 0.018 | 0.032 | 0.042 | 0.042 | 0.048 | 0.093 | 0.099 |
| **BAc** | **Child (mg/day)** | | | | | | | | | | |
| **0.1** | 0.026 | 0.026 | 0.026 | 0.027 | 0.027 | 0.030 | 0.033 | 0.033 | 0.035 | 0.046 | 0.047 |

Pb = Estimated amount of lead (mg/day) intake via soil ingestion
BAc = Available fraction of soil lead (e.g. 0.1 = 10 % absolute bioavailability)
Adult (70 kg) subject has ADI of 0.25 mg of lead (IPCS, 1995) — no soil ingestion allowed for this exposure table
Child (14 kg) subject has ADI of 0.05 mg of lead (IPCS, 1995) — no soil ingestion allowed for this table
Food intake by adult=10 µg/d; child=25 µg/d
Potable water 10% bioavailable

## 4.3 Health risk assessment of metal and metalloid uptake in aquatic biota from Leichhardt River

The results for metals and metalloids in aquatic biota taken from the Leichhardt River exceeded the guidelines levels for cadmium and lead at some sites (Section 3.2.6). No maximum permissible level (MPC) or maximum level (ML) has been set for cadmium in fish (ANZFA, 1994; FSANZ, 2010, FSANZ, 2004). However, the ML for cadmium in vegetables, including leafy, root, and tuber vegetables is set at 0.1 mg/kg (FSANZ, 2004). For the health risk assessment, the TDI for cadmium is 0.07 mg/day for an 70 kg adult or 0.014 mg/day for a 14kg child, regardless of the dietary source. The ML for lead in fish is 0.5 mg/kg (FSANZ, 2010; 2004) and the TDI is set at 0.25 mg/day for an adult or 0.05 mg/day for a child. Table 71 lists some of the most elevated levels of cadmium

in fish and lead concentrations exceeding the ML found in the fish, for the sample sites. More detailed results are given in Appendix 9.

**Table 71. Most elevated levels of cadmium in fish and lead concentrations exceeding maximum level (ML) (0.5 mg/kg) in fish**

| Species | Location | Cadmium (mg/kg) |
|---|---|---|
| Spangled perch (whole fish) | Lake Moondarra | 45 |
| Spangled perch (liver) | Rifle Creek Dam | 4.7 |
| Bony bream (liver) | Lake Moondarra | 24 |
| Bony bream (liver) | Lake Moondarra | 4.8 |
| Bony bream (liver) | Lake Moondarra | 22 |
| Bony bream (liver) | Lake Moondarra | 1.3 |
| Bony bream (liver) | Lake Moondarra | 1.2 |
| Bony bream (liver) | Lake Moondarra | 12 |
| Bony bream (liver) | Lake Moondarra | 7.6 |
| Forked-tail catfish (liver) | Lake Moondarra | 3.2 |
| Forked-tail catfish (liver) | Lake Moondarra | 1.7 |
| Forked-tail catfish (liver) | Lake Moondarra | 0.88 |
| Barramundi (liver) | Lake Moondarra | 0.88 |
| Sleepy cod (liver) | Isa Street | 2.8 |
| Sleepy cod (liver) | Lake Moondarra | 1.1 |
| Tandan (liver) | Moondarra Junction | 1.8 |
| **Species** | **Location** | **Lead (mg/kg)** |
| Barred grunter (muscle) | Moondarra Crossing | 1.2 |
| Barred grunter (muscle) | Lake Moondarra | 0.61 |
| Bony bream (muscle) | Lake Moondarra | 0.67 |
| Bony bream (liver) | Lake Moondarra | 2.8 |
| Bony bream (liver) | Lake Moondarra | 2.4 |
| Sleepy cod (muscle) | Lake Moondarra | 0.86 |
| Sleepy cod (muscle) | Davis Road | 0.69 |
| Spangled perch (muscle) | 23rd Avenue | 1.70 |
| Spangled perch (muscle) | Isa Street | 4.7 |
| Spangled perch (whole fish) | Lake Moondarra | 0.78 |
| Bony bream (liver) | Lake Moondarra | 3.2 |
| Forked-tail catfish (liver) | Lake Moondarra | 2.7 |
| Rendahl's catfish (liver) | Lake Moondarra | 1.1 |
| Rainbow (whole fish) | Davis Road | 0.73 |
| Tandan (whole fish) | Moondarra Junction | 1.1 |

### 4.3.1 Risk assessment

The risk of acute toxicity due to consumption of contaminated fish is unlikely. The ADI is set on chronic exposure. Occasional consumption may be acceptable, but frequent or regular consumption of fish that exceed MLs is not recommended. Table 72 is based on the highest concentrations of cadmium and lead found and corresponds to the worst-case scenario of people who would consume fish everyday of their life. Table 73 is based on the median and 75th percentile of lead and cadmium found and illustrates how much of a particular contaminated fish could be consumed without affecting health. This amount is calculated from the total dietary intake of cadmium or lead derived from fish caught from Leichhardt River alone (see Equation 5).

Other sources of cadmium and lead intake will reduce the amount of fish a person could consume:

$$A \times C = TDI \qquad (5)$$
$$A = TDI/C$$

Where A = amount consumed (g)/day
TDI = mg/day
C = cadmium or lead concentration in fish (mg/kg) e.g. mg/1,000g

Table 73 is an alternative way of examining the cadmium and lead data based on the median and 75th percentile concentrations for all fish from all sites based on the worst-case scenario for residents who will consume their catch everyday of their life with similar data to Table 72 based on highest concentrations only.

Table 74 compares both cadmium and lead in all fish having the highest median and 75th percentile concentrations all Leichhardt River sites excluding background sites, and Lake Moondarra sites with the upper and lower background sites (Appendix 9). Therefore, fish taken from the part of the Leichhardt River that is adjacent to Mount Isa City and Lake Moondarra are likely to have the higher cadmium and lead concentrations, than fish taken from the river near the background sites. As sediment is a likely source of the uptake of cadmium and lead for transfer through the food chain (Sections 4.2.2 and 4.2.4) by fish it may be appropriate to examine the cycle of these metals in more detail.

**Table 72. Amount (g) of fish for safe consumption assuming fish/biota is the only exposure pathway based on highest cadmium and lead found**

| Species | Location | Cadmium (mg/kg) (wet wt) | Adults | | Children | |
|---|---|---|---|---|---|---|
| | | | Daily (g) | Yearly (g) | Daily (g) | Yearly (g) |
| Spangled perch (whole fish) | Lake Moondarra | 45 | 1.6 | 568 | 0.3 | 114 |
| Spangled perch (liver) | Rifle Creek Dam | 4.7 | 14.9 | 5,440 | 3.0 | 1,090 |
| Bony bream (liver) | Lake Moondarra | 24 | 2.9 | 1,070 | 0.6 | 213 |
| Bony bream (liver) | Lake Moondarra | 4.8 | 14.6 | 5,320 | 2.9 | 1,070 |
| Bony bream (liver) | Lake Moondarra | 22 | 3.2 | 1,160 | 0.6 | 232 |
| Bony bream (liver) | Lake Moondarra | 1.3 | 53.8 | 19,700 | 10.8 | 3,930 |
| Bony bream (liver) | Lake Moondarra | 1.2 | 58.3 | 21,300 | 11.7 | 4,260 |
| Bony bream (liver) | Lake Moondarra | 12 | 5.8 | 2,130 | 1.2 | 426 |
| Bony bream (liver) | Lake Moondarra | 7.6 | 9.2 | 3,360 | 1.8 | 672 |
| Forked-tail catfish (liver) | Lake Moondarra | 3.2 | 21.9 | 7,980 | 4.4 | 1,600 |
| Forked-tail catfish | Lake Moondarra | 1.7 | 41.2 | 15,000 | 8.2 | 3,010 |
| Forked-tail catfish | Lake Moondarra | 0.88 | 79.5 | 29,000 | 15.9 | 5,810 |
| Barramundi (liver) | Lake Moondarra | 0.88 | 79.5 | 29,000 | 15.9 | 5,810 |
| Sleepy cod (liver) | Isa Street | 2.8 | 25.0 | 9,130 | 5.0 | 1,830 |

| Species | Location | Cadmium (mg/kg) (wet wt) | Adults | | Children | |
|---|---|---|---|---|---|---|
| | | | Daily (g) | Yearly (g) | Daily (g) | Yearly (g) |
| Sleepy cod (liver) | Lake Moondarra | 1.1 | 63.6 | 23,227 | 12.7 | 4,645 |
| Tandan (liver) | Moondarra Junction | 1.8 | 38.9 | 14,194 | 7.8 | 2,839 |
| **Species** | **Location** | **Lead (mg/kg) (wet wt)** | **Adults** | | **Children** | |
| | | | **Daily (g)** | **Yearly (g)** | **Daily (g)** | **Yearly (g)** |
| Barred grunter (muscle) | Moondarra Crossing | 1.2 | 208 | 76,000 | 41.7 | 15,200 |
| | Lake Moondarra | 0.61 | 410 | 150,000 | 82.0 | 29,990 |
| Bony bream (muscle) | Lake Moondarra | 0.67 | 373 | 136,000 | 74.6 | 27,200 |
| Bony bream (liver) | Lake Moondarra | 3.2 | 78.1 | 28,500 | 15.6 | 5,700 |
| Bony bream (liver) | Lake Moondarra | 2.8 | 89.3 | 32,600 | 17.9 | 6,520 |
| Bony bream (liver) | Lake Moondarra | 2.4 | 104 | 38,000 | 20.8 | 7,600 |
| Sleepy cod (muscle) | Lake Moondarra | 0.86 | 291 | 106,000 | 58.1 | 21,220 |
| Sleepy cod (muscle) | Davis Road | 0.69 | 362 | 132,000 | 72.5 | 26,440 |
| Spangled perch (muscle or whole fish) | 23rd Ave | 1.70 | 147 | 53,700 | 29.4 | 10,700 |
| | Isa Street | 4.7 | 53.2 | 19,400 | 10.6 | 3,880 |
| | Lake Moondarra | 0.78 | 321 | 117,000 | 64.1 | 23,400 |
| Forked-tail catfish (liver) | Lake Moondarra | 2.7 | 92.6 | 33,800 | 18.5 | 6,760 |
| Rendahl's catfish (liver) | Lake Moondarra | 1.1 | 227 | 83,000 | 45.5 | 16,600 |
| Rainbow (whole fish) | Davis Road | 0.73 | 343 | 125,000 | 68.5 | 25,000 |
| Tandan (liver) | Moondarra Junction | 1.1 | 227 | 83,000 | 45.5 | 16,600 |

Note: The daily or yearly consumption (g) derived should not to be exceeded considering other exposure pathways (soil, water, and other food) will be added to the intake.

The likelihood of consuming the highest concentrations of lead and cadmium in fish or biota is limited. A more realistic scenario is based on the median and 75th percentile of cadmium and lead concentrations in the biota. The calculated daily rates for safe consumption are shown in Table 73.

**Table 73. Amount (g) of fish from all sites for safe consumption, assuming fish or biota is the only exposure pathway based on the median and 75th percentile of lead and cadmium found**

| | | | Cadmium Concentration (mg/kg) | | | Adults (g/day) | | Children (g/day) | |
|---|---|---|---|---|---|---|---|---|---|
| **Species** | **Tissue** | **n** | **M** | **75P** | **R** | **M** | **75P** | **M** | **75P** |
| Spangled perch | Muscle | 26 | 0.125 | 0.388 | 0.01–45* | 560 | 180 | 112 | 36 |
| | Liver | 5 | 0.18 | 0.18 | 0.11–4.7 | 389 | 389 | 78 | 78 |
| Catfish | Muscle | 4 | 0.076 | 0.096 | 0.041–0.1 | 921 | 729 | 184 | 146 |
| Sleepy cod | Muscle | 41 | 0.034 | 0.320 | 0.01–0.72 | 2059 | 219 | 412 | 44 |
| | Liver | 18 | 0.185 | 0.358 | 0.01–2.8 | 378 | 196 | 76 | 39 |
| Barramundi | Muscle | 1 | 0.01 | 0.010 | 0.01–0.01 | 7,000 | 7,000 | 1,400 | 1,400 |
| | Liver | 1 | 0.88 | 0.880 | 0.88–0.88 | 80 | 80 | 16 | 16 |
| Barred grunter | Muscle | 39 | 0.01 | 0.128 | 0.01–0.71 | 7,000 | 547 | 1,400 | 109 |
| | Liver | 5 | 0.35 | 0.450 | 0.22–2.3 | 200 | 156 | 40 | 31 |
| Rainbow | Muscle | 8 | 0.36 | 0.478 | 0.18–0.63 | 194 | 146 | 39 | 29 |
| Tandan | Muscle | 2 | 0.017 | 0.020 | 0.01–0.023 | 4,118 | 3,500 | 824 | 700 |
| | Liver | 2 | 0.939 | 1.370 | 0.077–1.8 | 75 | 51 | 15 | 10 |
| Bony bream | Muscle | 16 | 0.01 | 0.010 | 0.01–0.029 | 7,000 | 7,000 | 1,400 | 1,400 |
| | Liver | 16 | 0.545 | 2.850 | 0.01–24* | 128 | 25 | 26 | 5 |
| Forked-tail catfish | Muscle | 3 | 0.01 | 0.010 | 0.01–0.01 | 7,000 | 7,000 | 1,400 | 1,400 |
| | Liver | 3 | 1.7 | 2.450 | 0.88–3.2 | 41 | 29 | 8 | 6 |
| Eel-tailed Catfish | Muscle | 3 | 0.16 | 0.175 | 0.01–0.19 | 438 | 400 | 88 | 80 |
| | Liver | 1 | 0.64 | 0.640 | 0.64–0.64 | 109 | 109 | 22 | 22 |
| Red claw | Muscle | 10 | 0.026 | 0.094 | 0.01–0.35 | 2,692 | 745 | 538 | 149 |
| Shrimp | Muscle | 5 | 0.01 | 0.010 | 0.01–0.056 | 7,000 | 7,000 | 1,400 | 1,400 |
| Mussel | Muscle | 1 | 0.051 | 0.051 | 0.051–0.051 | 1,373 | 1,373 | 275 | 275 |
| | | | **Lead Concentration (mg/kg)** | | | **Adults (g/day)** | | **Children (g/day)** | |
| **Species** | **Tissue** | **n** | **M** | **75P** | **R** | **M** | **75P** | **M** | **75P** |
| Spangled perch | Muscle | 23 | 0.05 | 1.4 | 0.05-4.7 | 5,000 | 179 | 1,000 | 36 |
| | Liver | 5 | 0.05 | 0.05 | 0.05-0.11 | 5,000 | 5,000 | 1,000 | 1,000 |
| Catfish | Muscle | 4 | 0.195 | 0.21 | 0.18-0.24 | 1,282 | 1,190 | 256 | 238 |

| | | | Lead Concentration (mg/kg) | | | Adults (g/day) | | Children (g/day) | |
|---|---|---|---|---|---|---|---|---|---|
| **Species** | **Tissue** | **n** | **M** | **75P** | **R** | **M** | **75P** | **M** | **75P** |
| Sleepy cod | Muscle | 41 | 0.13 | 0.38 | 0.05-0.86 | 1,923 | 658 | 385 | 132 |
| | Liver | 18 | 0.05 | 0.05 | 0.05-0.29 | 5,000 | 5,000 | 1,000 | 1,000 |
| Barramundi | Muscle | 1 | 0.05 | 0.05 | 0.05-0,05 | 5,000 | 5,000 | 1,000 | 1,000 |
| | Liver | 1 | 0.1 | 0.1 | 0.1-0.1 | 2,500 | 2,500 | 500 | 500 |
| Barred grunter | Muscle | 40 | 0.05 | 0.14 | 0.05-1.2 | 5,000 | 1,786 | 1,000 | 357 |
| | Liver | 5 | 0.05 | 0.14 | 0.05-0.49 | 5,000 | 1,786 | 1,000 | 357 |
| Rainbow | Muscle | 8 | 0.315 | 0.748 | 0.05-0.85 | 794 | 334 | 159 | 67 |
| Tandan | Muscle | 2 | 0.05 | 0.05 | 0.05-0.05 | 5,000 | 5,000 | 1,000 | 1,000 |
| | Liver | 2 | 0.575 | 0.838 | 0.05-1.1 | 435 | 298 | 87 | 60 |
| Bony bream | Muscle | 16 | 0.05 | 0.155 | 0.05-0.67 | 5,000 | 1,613 | 1,000 | 323 |
| | Liver | 16 | 0.18 | 0.428 | 0.05-3.2 | 1,389 | 584 | 278 | 117 |
| Forked-tail catfish | Muscle | 3 | 0.05 | 0.05 | 0.05-0.05 | 5,000 | 5,000 | 1,000 | 1,000 |
| | Liver | 2 | 1.83 | 2.265 | 0.96-2.7 | 137 | 110 | 27 | 22 |
| Eel-tailed catfish | Muscle | 3 | 0.21 | 0.26 | 0.05-0.31 | 1190 | 962 | 238 | 192 |
| | Liver | 1 | 0.17 | 0.17 | 0.17-0.17 | 1,471 | 1,471 | 294 | 294 |
| Red claw | Muscle | 10 | 0.075 | 0.143 | 0.05-0.22 | 3,333 | 1,748 | 667 | 350 |
| Shrimp | Muscle | 5 | 0.05 | 0.05 | 0.05-0.05 | 5,000 | 5,000 | 1,000 | 1,000 |
| Mussel | Muscle | 1 | 0.43 | 0.43 | 0.43-0.43 | 581 | 581 | 116 | 116 |

Where M=median; 75P=75th percentile; R=range; and * indicates probable outlier (refer to Appendix 9 and full data set (FRC Environmental, 2010)): the outlier concentration seemed unusually high compared to biota tested for this species within the region of the Leichhardt River.

**Table 74. Amount (g) of fish according to location for safe consumption assuming fish/biota is the only exposure pathway based on median and 75th percentile of lead and cadmium found**

| | | Cadmium concentration (mg/kg) | | | | | | Adults (g/day) | | Children (g/day) | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Location** | **Tissue** | **n** | **Minimum** | **Median** | **75th percentile** | **95th percentile** | **Maximum** | **M** | **75P** | **M** | **75P** |
| All sites without background sites (sites H, B, A, C, E, J, F, I, G, LM) | Muscle or whole fish | 127 | 0.01 | 0.056 | 0.325 | 0.627 | 45 | 1,250 | 215 | 250 | 43 |
| | Liver | 29 | 0.01 | 0.88 | 2.2 | 10.24 | 24 | 79.55 | 32 | 16 | 6 |
| Lake Moondarra (Sites I, G, LM) | Muscle or whole fish | 57 | 0.01 | 0.01 | 0.023 | 0.152 | 45 | 7,000 | 3,044 | 1,400 | 609 |
| | Liver | 26 | 0.01 | 0.77 | 2.075 | 10.9 | 24 | 91 | 34 | 18 | 7 |
| Upper Background Rifle Creek Dam (Site D) | Muscle or whole fish | 16 | 0.01 | 0.01 | 0.01 | 0.345 | 0.36 | 7,000 | 7,000 | 1,400 | 1,400 |
| | Liver | 7 | 0.045 | 0.11 | 0.145 | 3.344 | 4.7 | 636 | 483 | 127 | 97 |
| Lower Background Lake Julius (Site K) | Muscle or whole fish | 17 | 0.01 | 0.01 | 0.01 | 0.0182 | 0.051 | 7,000 | 7,000 | 1,400 | 1,400 |
| | Liver | 15 | 0.077 | 0.21 | 0.295 | 0.38 | 0.45 | 333 | 237 | 67 | 48 |
| | | **Lead concentration (mg/kg)** | | | | | | **Adults (g/day)** | | **Children (g/day)** | |
| **Location** | **Tissue** | **n** | **Minimum** | **Median** | **75th percentile** | **95th percentile** | **Maximum** | **M** | **75P** | **M** | **75P** |
| All sites without controls (Sites H, B, A, C, E, J, F, I, G, LM) | Muscle or whole fish | 124 | 0.05 | 0.175 | 0.49 | 1.185 | 4.7 | 1,429 | 510 | 286 | 102 |
| | Liver | 28 | 0.05 | 0.16 | 0.4275 | 2.765 | 3.2 | 1,563 | 585 | 313 | 117 |
| Lake Moondarra (Sites I, G, LM) | Muscle or whole fish | 57 | 0.05 | 0.05 | 0.18 | 0.562 | 0.78 | 5,000 | 1,389 | 1,000 | 278 |
| | Liver | 26 | 0.05 | 0.12 | 0.325 | 2.775 | 3.2 | 2,083 | 769 | 417 | 154 |
| Upper Background Rifle Creek Dam (Site D) | Muscle or whole fish | 16 | 0.05 | 0.05 | 0.05 | 0.0625 | 0.1 | 5,000 | 5,000 | 1,000 | 1,000 |
| | Liver | 7 | 0.05 | 0.05 | 0.05 | 0.092 | 0.11 | 5,000 | 5,000 | 1,000 | 1,000 |
| Lower Background Lake Julius (Site K) | Muscle or whole fish | 17 | 0.05 | 0.05 | 0.05 | 0.166 | 0.43 | 5,000 | 5,000 | 1,000 | 1,000 |
| | Liver | 15 | 0.05 | 0.05 | 0.05 | 0.182 | 0.49 | 5,000 | 5,000 | 1,000 | 1,000 |

Where M=median; 75P=75th percentile; R=range; and * indicates probable outliner (refer to Appendix 9 and full data set (FRC Environment, 2010)): the outlier concentration seemed unusually high compared to biota tested for this species within the region of the Leichhardt River.

Table 73 indicates that, in most instances, residents of Mount Isa will be able to consume fish from the Leichhardt River, including from the test sites, on a regular basis without appreciable risk. In general, the liver of the fish have higher cadmium and lead concentrations compared to the muscle. Daily consumption of fish liver exceeding the calculated allowable rates (g/day) is not recommended, although the scenario of eating liver of the biota on a daily basis is unlikely to occur.

The frequency and consumption rates of fish among Mount Isa residents are not known. For a healthy diet, FSANZ recommends the consumption of fish once or twice a week. Among the Australian population, it is estimated that approximately 25% consume fish once a week, with an average serving size of 80–120 g (FSANZ, 2004).

Cook et al., (2001) compared data on food and nutrient intake data from national nutrition surveys undertaken in 1983, 1985, and 1995. Fish and fish product consumption data were collated from several regions including Australia, New Zealand, UK/Ireland, Europe, Asia, and other areas. The survey targetted the 25–64 year age group. The survey results showed that Australians increased their consumption of fish and fish products between 1983 to 1995 by 19 g per day for males and 6 g per day for females. In 1995, the daily average fish consumption by Australian males was 31 g and 25 g for females. If these consumption rates are used and are coupled with a consumption frequency of once or twice a week, then the risk from cadmium and lead in the muscle of locally caught fish is limited. Moderate risk could be associated with the consumption of liver tissue from Bony bream and Catfish if the consumption is more frequent than once a week. If the consumption of fish liver is limited to no more than once a month, then the risk associated with cadmium and lead from the biota is expected to be minimal. It is not known how often and how much of the liver is consumed, if at all.

This risk assessment for fish and biota consumption is semi-quantitative. For a more refined risk assessment of cadmium and lead consumption via the aquatic biota pathway for the local population, regional survey data would have been useful, including statistics on:

- how often fish are caught
- how many fish are caught
- the size of the fish
- the number of fish consumed
- the weight of the fish consumed
- the parts of the fish that are consumed (muscle, liver etc.).

## 4.4 Ecological risk assessment of aquatic ecosystems

### 4.4.1 Water

The general lack of toxicity at upstream Leichhardt River sites indicates with test acquatic species that historical mines sites and non-mined background river sites with natural mineralisation do not significantly show the effects of metals and metalloids on aquatic biota. This indicates that an upper city Leichhardt River site such as 23rd Avenue (Figure 23), which showed no effects to aquatic biota from tests undertaken and may be used for comparative purposes with sites further downstream in the Leichhardt River within the zone that may be affected by mining and urban activities. While toxicity is indicated, there is no clear delineation of the source of the aquatic toxicity. A lack of a toxicity response could still mean that bioaccumulation occurs as some organisms regulate metals. This may be an issue for aquatic biota, such as fish in the Leichhardt River from 23rd Avenue down to Moondarra Crossing, as fish are demonstrated to accumulate heavy metals in this section of the river.

The results for DGT measured concentrations ($C_{DGT}$) in water and comparisons with hardness corrected guidelines indicate the need to proceed to the next step in the decision process and to measure toxicity. This step is best achieved by applying sensitive toxicity tests as there is a range of responses. The results in Chapter 3 show this is indeed the case and follows what the ANZECC/ARMCANZ (2000) recommends. In particular, *Ceriodaphnia* cf *dubia* is identified as a sensitive cladoceran that is easily applied to measure both acute and chronic toxicity of water. While chronic tests are required for the ANZECC/ARMCANZ (2000) guidelines to give no observable effect values, acute tests are required in the first instance to indicate a direct impact of toxcity.

Exceedence of the DGT-measured bioavailable fraction can therefore trigger toxicity testing. Because *Ceriodaphnia* is demonstrated to be a sensitive aquatic test species and likely to give a response, it appears to be a good test species to use for screening purposes. Following aquatic toxicity testing and if there is no chronic toxicity, then there is no further problem according to the ANZECC/AMCANZ (2000) decision tree process. The issue of multiple contaminants is one that may cause problems because of variation in response from different toxicants and require toxicity testing. There may be a need to use a TIE procedure (USEPA, 2007b) to identify the significant toxicants at the worst sites and whether ammonia is indeed a contributor.

### 4.4.2 Sediment

Section 3.2.3 identified that several sites from the Leichhardt River sediment Verification Study have exceeded the ISQG-Low for cadmium (79 sites), copper (78 sites), lead (79 sites), and a lesser number of sites for zinc (50 sites) for 1M hydrochloric acid extraction concentrations. Comparison of these sediment results with ISQG-High shows exceedance for cadmium (22 sites), copper (10 sites), lead (46 sites), and a lesser number of sites for zinc (18 sites) for 1M hydrochloric acid extraction concentrations. Exceedence of the ISQG-High is indicative of a high probability of biological effects. As the lower ISQG-Low guidelines are very conservative and may be driven in their derivation by the presence of co-occurring contaminants, laboratory toxicity testing for the ISQG-High exceedances assumes importance. The sites indicating contamination of sediment will require further assessment, including toxicity assessment according to the ANZECC/ARMCANZ decision tree process (Figure 12) and may require remediation based on ecological effects.

Section 4.1 identifies that the sediment toxicity assessment according to the ANZECC/ARMCANZ decision tree process (Figure 12) gives an accurate measure of effect to the test species used in this study. There is a limitation to sediment toxicity assessment in this study identified in Section 3.3.3, due to the availability of relevant test species. While five species from four taxonomic groups were available for aquatic testing of water, only five taxa were available based on testing of water elutriates of sediment samples but no test species for direct sediment testing apart from *Corophium spp.* The testing of Leichhardt River sediment using burrowing species found in the river is a key issue for sediment toxicity assessment because of the ephemeral conditions. Using *Corophium spp* (Noller et al., 2009) was not continued due to the effects on the test organism from sharp edges on particles found in the sediment.

A potential solution to the problem of availability of the test species is to identify potential species and try to isolate, identify, and culture local burrowing species. In July 2010, a search was made in the Leichhardt River sediment for Chironomid species, which are identified as a suitable burrowing test species because they spend up to 20 days of their lifecycle in sediment and are food for fish. *Chironomids* were found to be present during a survey undertaken (Somparn, 2010) in July 2010 in relatively low numbers (e.g. <50/m$^2$) at upstream sites, including 23rd Avenue, but at much higher numbers (up to 298/m$^2$) downstream at Moondarra Crossing, particularly below the points of urban water discharge containing higher nutrient levels (Table 10). An existing protocol for sediment toxicity testing using *Chironomid sp.* as a test species is available and can be applied using local Leichhardt River species. Other burrowing species can also be identified for suitability as test species from earlier surveys (Ecowise, 2005, 2006).

### 4.4.3 Future needs for ecotoxicity testing

The results for toxicity studies on both water and sediment demonstrate when acute and chronic effects may occur with a range of test species. From 2007–2010 the number of test species was limited. Limitations were identified with using certain species including *Corophium* (injury from sharp sediment edges) for sediment and *Selenestrum* (turbidity effect) for water and sediment elutriates. Currently, a wider range of test species is available.

It is also clear that the cause and effect relationship between observed toxicity and measured metal and metalloid contaminants cannot always be explained and may be due to other stressors or constraints, e.g. ammonia. This particularly applies to the Davis Crossing on the Leichhardt River. An approach that considers contributions from different toxicants is needed. The TIE method developed by the USEPA (2007b) may be used to identify constituents causing observed toxicity. The TIE approach uses physical and chemical manipulation of a sample to isolate or change the potency of different groups of toxicants that are potentially present in a sample. In developing the TIE procedures for aquatic toxicity in waters, further detailed study of water and sediment toxicity will be required.

## 4.5 Development of site-specific guidelines

The process used in this report followed the ANZECC/ARMCANZ (2000) decision trees for water and sediment. To determine the effects of Mount Isa City mining and urban activities on the Leichhardt River catchment, the first point of the assessment in Queensland is to follow the QWQG (2009) process, which is derived directly from ANZECC/ARMCANZ (2000).

QWQG (2009) uses a step-wise process described in Section 1.4.3; however, no site-specific guidelines exist for the Gulf region in which the Leichhardt River catchment is found. Appendix A in QWQG (2009) gives the decision process to follow when site-specific guidelines have to be derived.

The Leichhardt River sediment study data may provide a basis for assigning site-specific guidelines. Using the 80th percentile values for toxicants, including metals and metalloids, the background sediment concentrations may be used as default TVs only if the 80th percentile exceeds the TVs.

The development of site-specific guidelines for water may require additional monitoring to fill in gaps after following the procedure given in Appendix A of QWQG (2009). This step has not been a part of the Phase III study because the review of monitoring data for water quality was not included in ther study objectives.

The water studies in this report indicate the following issues:

*Drinking water*

- Six sites at the Leichhardt River (19th Avenue, 23rd Avenue, Davis Crossing, Moondarra Crossing, Moondarra Junction); four sites at tributaries from the mine lease (King Gully Creek, Lena Creek, Downstream North Tailing Dams 3 and 5) and two seepage ponds (Tailing Dams 5 and 8) exceeded the drinking water guidelines for arsenic, cadmium, and lead.

*Livestock, recreational use, and irrigation water*

- No site exceeds the ANZECC/ARMCANZ livestock drinking water guidelines or the recreational use and irrigation water guidelines.

*Protection of the aquatic ecosystem*

The results show that concentrations of cadmium in the 0.45 µm fraction, measured by DGT technique and inorganic species calculated by MINTEQ modelling of water samples collected at Davis and Alma Crossings exceeded the trigger values for cadmium for both the 90% or 95% species protection. Two upstream sites (Mica Creek and upstream Leichhardt River); three sites within Mount Isa City (Alma Crossing and Isa Crossing); one downstream site at Moondarra Junction; five sites at tributaries from the mine lease (King Gully Creek, Lena Creek, George Fisher Creek, Downstream North Tailing Dams 3 and 5); two seepage ponds (Tailing Dams 5 and 8) and one urban discharge site (Breakaway Creek) exceeded the trigger values of copper for 95% species protection. Only the seepage pond at Tailing Dam 5 exceeds the trigger values for arsenic and the downstream north Tailing Dams 3 and 5 exceed the trigger values for lead for 95% species protection. These results indicate that further investigation needs to be conducted at these sites.

The decision process for assessing the effects of metals and metalloids on the aquatic ecosystem of Leichhardt River has been extended by using the combination of DGT technique plus MINTEQ equilibrium modelling of soluble metal species and the BLM for copper. The major features identified are that the comparison of aquatic toxicity testing with the DGT technique and predicted metal and metalloid species concentrations and BLM is a useful alternative to aquatic toxicity testing where the predicted data were obtained for comparative purposes.

The sediment studies in this report indicated the following issues:

- *Leichhardt River*: The specific issue of contamination of Leichhardt River sediment has been identified, particularly in the lower part of Mount Isa City (Figure 40 to Figure 45). These sites may require further delineation and clean-up of river sediment based on both health and ecological guidelines and risk assessments. There is an apparent link with high levels of cadmium and lead in fish in Leichhardt River and safe quantities of fish for human consumption.

- *Tributaries to Leichhardt River from mine lease*: The five sites at tributaries from the mine lease (King Gully Creek, Lena Creek, George Fisher Creek, Downstream North Tailing Dams 3 and 5) that showed exceedance for arsenic, cadmium, copper, nickel, lead, and zinc compared with drinking water guidelines (ADWG, 2004) and trigger values for 95% species protection and requires further assessment of the sediment metal and metalloid concentrations according to the ANZECC/ARMCANZ (2000) decision process (Figure 12).

# 5. Conclusions and recommendations

The Lead Pathways Study — Phase III: Water Sources and pathways of contaminants to the Leichhardt River investigated:

1. the potential sources and pathways of lead and other heavy metals and metalloids in water from the study area comprising the Leichhardt River catchment, particularly at, and below, Mount Isa City and the Mount Isa Mines lease area down to and including Lake Moondarra
2. the risk to human, agricultural pastoral, and ecological health from the contributions of lead and other heavy metals and metalloids.

The human health risk assessment was undertaken according to guidelines set by the National Health and Medical Research Council, the Australian Drinking Water Guidelines, and the National Environmental Protection Council.

No site exceeded the ANZECC/ARMCANZ livestock watering guidelines for the metals and metalloids that were measured.

The overall results of the water quality assessments show that the Leichhardt River water, at the time of testing, was alkaline and the water pH varied from 7.0 to 8.5 over five sampling periods. The electrical conductivity (EC) of samples at upstream sites (Leichhardt River upstream and Mica Creek upstream) and downstream sites (Moondarra Junction, Lake Moondarra and Clear Water Lagoon were within the limits for drinking water (<1000 µS/cm), which applies to palatability associated with total dissolved salts. However, the EC of water sampled at the Leichhardt River sites within Mount Isa City were >1000 µS/cm. The EC values of water collected at all sites in the wet season were significant lower than pre-wet and post-wet season samples indicating a reduction in total dissolved salts with renewed river flow.

Total concentrations of metals and metalloids in water were compared with Australian Drinking Water Guidelines. The results show that six sites from the Leichhardt River (19th Avenue, 23rd Avenue, Davis Crossing, Moondarra Crossing, Moondarra Junction) and four sites at tributaries from the mine lease (King Gully Creek, Lena Creek, Downstream North Tailing Dams 3 and 5) exceeded the guideline values. Two seepage ponds (Tailing Dams 5 and 8) exceeded the Australian Drinking Water Guidelines for arsenic, cadmium, and lead; however, these ponds are not accessible by the general public or livestock.

Total concentrations of metals and metalloids in the water were compared with the ANZECC/ARMCANZ Water Quality Guidelines trigger values for fresh water species at two levels: to protect 90% of all freshwater specifies and to protect 95% of all freshwater species. The trigger values were also adjusted for site-specific water hardness, as stipulated by the ANZECC/ARMCANZ decision-tree process. The filtered concentrations (0.45 µm fraction) and dissolved species, measured by DGT technique, at sites with a total concentration of a heavy metal or arsenic exceeding the trigger values, were compared with the site-specific trigger values. The results show that concentrations of heavy metals in the 0.45 µm fraction, measured by the DGT technique, and inorganic species, calculated by the MINTEQ multi-equilibrium program that correspond to the decision step of the 'bioavailable' heavy metal or arsenic toxicants in water:

- exceeded the trigger values of cadmium for 95% species protection at:
  - » Davis Crossing in the post-wet season in 2009
  - » Alma Crossing in the wet season in 2010
- exceeded the site-specific trigger values for copper for fresh water species at 95% protection level at:
  - » two upstream sites (Mica Creek and Leichhardt River upstream)
  - » three sites within Mount Isa City (Alma Crossing and Isa Crossing)
  - » one downstream site (Moondarra Junction)
  - » five sites at tributaries from the mine lease (King Gully Creek, Lena Creek, George Fisher Creek, Downstream North Tailing Dams 3 and 5)
  - » two seepage ponds (Tailing Dams 5 and 8)
  - » one urban discharge site (Breakaway creek)
- exceeded the site-specific trigger values for arsenic for 95% species protection at:
  - » seepage Tailing Dam 5 exceeded the site-specific trigger values of arsenic
- exceeded the site-specific trigger values of lead for fresh water species at 95% protection level at:
  - » Downstream North Tailing Dam 3 and Downstream North Tailing Dam 5.

These results indicate that further investigation needs to be conducted at these sites for biological effects following the ANZECC/ARMCANZ decision-tree process.

During the 2010 wet season, five sites at Leichhardt River (upstream and within Mount Isa City) showed that no site exceeded the Australian Drinking Water Guidelines for arsenic, cadmium, copper, nickel, lead and zinc. However, water samples collected from five sites at tributaries from the mine lease at the same exceeded the Australian Drinking Water Guidelines for arsenic, cadmium, and lead. The public should be advised not to drink water at these tributary creeks.

The overall results of the sediment quality assessment show there are several sites from the Leichhardt River that exceeded the Interim Sediment Quality Guidelines (ISQG)-Low for arsenic (2 sites); cadmium (79 sites); copper (78 sites); lead (79 sites); and at a lesser number of sites for zinc (50 sites) for 1M HCl extraction concentrations. These sites will require further assessment of contamination, including a toxicity assessment according to the ANZECC/ARMCANZ decision-tree process for sediment. Comparison of these sediment results with ISQG-High shows exceedance for cadmium (22 sites); copper (10 sites); lead (46 sites); and a lesser number of sites for zinc (18 sites) for 1M HCl extractable concentrations. Exceedence of the ISQG-High is indicative of a high probability of biological effects. These sites may collectively require remediation if they show toxicity to aquatic test species following the ANZECC/ARMCANZ decision tree process for sediment. The five sites at tributaries from the mine lease (King Gully Creek, Lena Creek, George Fisher Creek, Downstream North Tailing Dams 3 and 5) also requires further assessment of the sediment metal and metalloid concentrations according to the ANZECC/ARMCANZ (2000) decision process. Site LR10 (Leichhardt River at exit from Star Gully) is the only site from 79 sites assessed by the Mount Isa Mines Verification Program that exceeded the NEPM HIL—Level E criteria for human health risk for cadmium and lead, when the total concentration was adjusted for bioaccessibility. Therefore, site LR10 requires further evaluation to define the extent of potential human contact with contaminated sediment and to enable a remediation plan to be implemented.

Direct consumption of Leichhardt River water or sediment may result in exposure to lead. The total lead exposure was recalculated by replacing drinking water with Leichhardt River water. As a conservative approach, it was assumed that Leichhardt River water was the only source of water consumed. The potential total intake of lead was below the tolerable daily intake of 0.25 mg/day for adults as well as TDI of 0.05 mg/day for children, adjusted for 10% bioavailability and normal food lead intake. However, a number of Leichhardt River water samples could pose a risk if soil lead was included in this calculation.

An additional risk from particulate matter in river sediment is that acute toxicity from the consumption of fish contaminated with metals and metalloids is unlikely. The potential risk was assessed by comparing with the allowable daily intake (ADI). In general, the liver of the fish have higher heavy metal and metalloid concentrations compared to the muscle. Frequent or regular consumption of fish from the Leichhardt River that exceed maximum levels (MLs) of heavy metals and metalloids is not recommended.

The aquatic toxicity in Leichhardt River water collected in 2008 was assessed using the acute 48-h survival of *Ceriodaphnia* cf *dubia* test for acute toxicity (short-term effects). The 48-h LC50 showed that acute toxicity was observed at Davis Crossing (61.6 % LC50 and 0% survival). This sample was taken after the Leichhardt River Remediation Program, which was completed in 2007. Further sampling in 2009 for acute toxicity reconfirmed that toxicity was observed at Davis Crossing and, to a lesser extent, at the junction of Breakaway Creek and Leichhardt River. The water metal and metalloid concentration results showed that copper concentrations (0.45 µm fraction) at four sites and cadmium concentration at Davis Crossing exceeded the trigger values for 95% species protection. Ammonia could also not be ruled out as a toxicant. The results of further toxicity testing and water quality measurements also reconfirmed that cadmium concentrations of 3.5 µg/L at Davis Crossing exceeded the trigger value of 2 µg/L for 95% species protection.

To fully evaluate the effectiveness of the Leichhardt River Remediation Program, a second sampling was undertaken for both water and sediment in October 2009. The decision-tree process recommends that five species in water and five in sediment are tested. The aquatic toxicity studies show various effects at 23rd Avenue (growth inhibition to *Lemna*); Davis Crossing (chronic toxicity to *Ceriodaphnia*); and Moondarra Crossing (effects with three different species). These findings indicate that, overall, only limited toxicity was observed in the Leichhardt River water for a range of aquatic species covering the five taxa. The water metal concentrations confirmed that the cadmium concentration at Davis Crossing and copper concentration at Alma Crossing and Moondarra Crossing exceeded the trigger value for 95% freshwater species protection.

Rifle Creek Dam, located furthest upstream Leichhardt River, was chosen as a background site relative to Leichhardt River downstream from above Mount Isa City to below Lake Moondarra for aquatic toxicity assessment in both water and sediment. The toxicity results showed that no toxicity was observed at Rifle Creek Dam in both

water and sediment making it a suitable for comparing with any effects of metals and metalloids on aquatic biota downstream.

Comparison of aquatic toxicity testing results showed, in general, that upstream background sediments were not toxic to aquatic test species and confirmed that exceedances of ISQG–Low for 1M HCl extract do not always indicate that the sediment will be toxic to aquatic test biota. In particular, Rifle Creek Dam sediment concentration data for 1M HCl extract demonstrated little or nil toxicity, even though there was historical mining in its sub-catchment.

An approach that takes into account both the presence of natural mineralisation and some effects of historical mining is suggested for deriving background water quality data and site-specific guidelines for the Leichhardt River. It is considered appropriate to use all upstream sediment metal and metalloid concentration data for developing site-specific guidelines because aquatic toxicity was not generally demonstrated with the presence of natural mineralisation or historical mining in upstream Leichhardt River sediment.

Specific recommendations for further work are:

- Identify the specific source(s) of toxicity observed in the lower part of the Leichhardt River, adjacent to Mount Isa City, particularly at Davis Crossing and the mine lease. The aquatic toxicity studies and comparisons with metal and metalloid concentrations and other constituents, such as ammonia, indicate that responses to organisms cannot always be explained. The metal concentrations in the water indicate that the cadmium concentration at Davis Crossing and the copper concentration at Alma Crossing and Moondarra Crossing exceeded the trigger value for the 95% level of freshwater species protection. To better understand the sources of arsenic, copper, cadmium, lead, and other toxicants including ammonia the Toxicity Identification Evaluations (TIE) procedure from the USEPA may be used to identify constituents causing observed toxicity by using physical/chemical manipulation of a sample to isolate or change the potency of different groups of toxicants potentially present in a sample. In developing the TIE procedures for aquatic toxicity in waters, further detailed study of water and sediment toxicity is required.
- Investigate the ecological effects of the sites from the Leichhardt River that exceeded the (ISQG)-Low for arsenic (2 sites); cadmium (79 sites); copper (78 sites); lead (79 sites); and zinc (50 sites) for 1M HCl extraction concentrations. These sites require further assessment of contamination, including a toxicity assessment according to the ANZECC/ARMCANZ decision-tree process for sediment. Comparison of these sediment results with ISQG-High showing exceedance for arsenic (2); cadmium (22 sites); copper (10 sites); lead (46 sites); and a lesser number of sites for zinc (18 sites) for 1M hydrochloric acid extractable concentrations should also be made. These sites may collectively require remediation if they show toxicity to aquatic test species following the ANZECC/ARMCANZ decision tree process for sediment. The five sites at tributaries from the mine lease (King Gully Creek, Lena Creek, George Fisher Creek, Downstream North Tailing Dams 3 and 5) also requires further assessment of the sediment metal and metalloid concentrations according to the ANZECC/ARMCANZ (2000) decision-tree process.
- Investigate the section of the Leichhardt River where contaminated sediment, which could impact on human health, has been identified for possible remedial attention. Site LR10 (Leichhardt River at exit from Star Gully) is one site from 79 sites assessed by the Mount Isa Mines Verification Program that exceeded the NEPM HIL—Level E criteria for human health risk for cadmium and lead, when the total concentration was adjusted for bioaccessibility. Site LR10 requires further evaluation to define the extent of potential human contact with contaminated sediment and to enable a remediation plan to be implemented. This site may require further delineation and clean-up of river sediment based on both health and ecological guidelines and risk assessments. There is an apparent link with high levels of cadmium and lead in fish in Leichhardt River and safe quantities of fish for human consumption which should also be investigated.
- Evaluate the frequency of water and sediment monitoring programs to enable collection of sufficient data including aquatic toxicity testing for developing adequate site-specific guidelines undertaken according to the *Queensland Water Quality Guideline* procedure. The results for DGT measured concentrations ($C_{DGT}$) in water and comparisons with hardness corrected guidelines indicate the need to proceed to the next step in the decision process and to measure toxicity. *Ceriodaphnia* cf *dubia* is identified as a sensitive cladoceran to use for testing purposes that is easily applied to measure both acute and chronic toxicity of water. Chronic tests are required for the ANZECC/ARMCANZ (2000) guidelines to give no observable effect values.

- Continue work on aquatic toxicity species for assessing effects from whole sediment testing. The kind and number of test species was limited due to lack of availability of test species that are suitable for whole sediment testing. Certain species including *Corophium* (injury from sharp sediment edges) for sediment and *Selenestrum* (turbidity effect) for water and sediment elutriates. A potential solution to the limited availability of local burrowing test species is to identify potential species and isolate, identify, and culture them. The Chironomid species, which are found to be present in Leichhardt River sediment may now be isolated and used with an existing protocol for sediment toxicity testing. Other burrowing species can also be identified for suitability as test species from earlier surveys.

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# 6. Professional background

## 6.1 Centre for Mined Land Rehabilitation

Established in 1993, the Centre for Mined Land Rehabilitation (CMLR) within the Sustainable Minerals Institute (SMI) at The University of Queensland is a collaborative and multi-disciplinary group of research, teaching and support staff and postgraduate students dedicated to delivering excellence in environmental research and education to the Queensland, national, and international minerals industry and associated government sectors.

The Centre is widely recognised as a source of quality research into cutting edge environmental management and sustainability in mining issues. It translates research outcomes into practices that lead to continual improvement of rehabilitation and environmental practices. CMLR focuses on preventing, minimising and remediating mining impacts by providing education and professional development in the sustainability area; engaging industry, government and community; and delivering research solutions developed through science.

CMLR is one of seven research centres at SMI (www.smi.uq.edu.au), which provides knowledge-based solutions to meet sustainability challenges in the global mining industry. The Institute was established in 2001 as a joint initiative of the Queensland Government, University and the minerals industry to provide an overarching framework for progressing minerals industry research and education.

## 6.2 Experience of consultants

**Associate Professor Barry Noller**

Associate Professor Noller has a PhD (1978) in Environmental Chemistry from the University of Tasmania. He worked as a Research Fellow at the Australian National University (1978–1980); Senior Research Scientist at the Alligator Rivers Region Research Institute, Jabiru, Northern Territory (1980–1990); and as Principal Environmental Chemist for the Department of Mines and Energy, Darwin Northern Territory (1990–1998). During this period with the Department of Mines and Energy, Associate Professor Noller was involved with the environmental management and regulation of all mines in the Northern Territory and was technical manager of the Northern Territory study, *Bird Usage Patterns on Mining Tailings and their Management to Reduce Mortalities* (1998). He was also a co-author and reviewer of the *Best Practice Environmental Management in Mining — Handbook on Cyanide Management*. From 1998–2006, Associate Professor Noller was Deputy Director of the National Research Centre for Environmental Toxicology (EnTox) at The University of Queensland, Coopers Plains, Queensland. EnTox has a strong involvement with using the risk assessment process to deal with toxicological hazards, including in environmental systems. In November 2006, Associate Professor Noller was appointed as an Honorary Research Consultant and Principal Research Fellow at the Centre of Mined Land Rehabilitation.

Associate Professor Noller has been working and publishing in the field of environmental chemistry and industrial toxicology for the past 32 years and has presented more than 200 conference papers and published more than 130 papers. His professional activities undertaken at four different centres have covered processes and fates of trace substances in the environment, particularly in tropical environmental systems with special reference to risk management associated with their application and studies of the bioavailability of toxic elements in mine wastes, including waters. He has undertaken a number of consulting activities in Queensland, Tasmania, New South Wales, and the Northern Territory. In 2007 Associate Professor Noller was appointed as lead author of the *Australian Government Leading Practice Sustainable Development Program for the Mining Industry — Handbook on Cyanide Management*.

**Dr Trang Huynh**

Dr Trang Huynh has a PhD (2008) in Environmental Science from the University of Melbourne. Her PhD research project was on *Bioavailability of heavy metals in soil and biosolids during phytoextraction*. She completed her Master of Science Degree majoring in Soil Science at The University of Sydney (2001) with her thesis on *Crystallographic and chemical properties of copper and cadmium substituted goethites using X-ray Synchrotron technique*. She worked as a researcher and lecturer on soil and environmental chemistry in Vietnam for seven years. During this period, she was involved in several internationally funded projects as a project coordinator, researcher, and project evaluator. Dr Trang Huynh is currently a Postdoctoral Research Fellow with the CMLR at The University of Queensland, working on the Lead Pathways Project at Mount Isa.

Dr Trang Huynh's research interests are principally in biogeochemistry, environmental, and water/soil chemistry, plant-soil interaction, and the behaviour of heavy metals and metalloids in the environment. She is also interested in understanding and applying advanced techniques such as Diffusion Gradients in Thin Films (DGT) and the synchrotron technique to measure heavy metal and metalloid speciation in the environment, especially at mining sites. One of her current research focuses is on the impacts of contaminants from mining activities on human and ecological health.

**Professor Jack Ng**

Professor Ng is a certified toxicologist (Diplomate of the American Board of Toxicology) and is the Program Manager for Metals and Metalloids (M&M) Research at EnTox. His major research themes include chemical speciation of arsenic species in environmental and biological media, bioavailability in relationship to toxicities using various animal models, carcinogenicity and mechanistic studies of chronic arsenic toxicity in both humans and animals. Professor Ng and his team have recently demonstrated that a methylated metabolite (MMAIII) of arsenic is the proximal carcinogen in an *in-vivo* model. This is a landmark study in arsenic research in addition to his initial proof of the carcinogenic effect of inorganic arsenic *in-vivo*. One of his current interests is to identify early biomarkers for the diagnosis of arsenicosis in humans and animals using both chemical and molecular biological tools. Other research interests include toxicity of mixed metals, the transfer of heavy metals via the food chain from mine tailings, and other mining wastes in addition to study on natural toxins in plants relevant to human health. Professor Ng's projects are a combination of independent effort, as well as linkages through national and international collaboration.

Professor Ng is also the Program Leader for Risk Assessment in the Co-operative Research Centre — Contamination Assessment and Remediation of the Environment (CRC-CARE). Professor Ng has over 270 publications including journal papers, book chapters, and technical reports.

**Dr Hugh Harris**

Dr Hugh Harris is an Australian Research Council Queen Elizabeth II Fellow in the School of Chemistry and Physics at the University of Adelaide. He has a PhD in Chemistry (2000) from the University of New South Wales, and has worked as a postdoctoral fellow at Stanford University and the University of Sydney. His main research focus is on using synchrotron-based techniques, such as x-ray absorption spectroscopy and x-ray fluorescence imaging, to understand the roles that metals play in biological systems. This focus spans work on fundamental biochemical and structural studies of metalloproteins, deciphering modes of action of metal-based pharmaceuticals, and the relationship between intake of essential or toxic heavy elements and the development and progression of a range of diseases. He has demonstrated the advantages of x-ray techniques in the area by determining the chemical form of mercury in fish for human consumption, showing that mercury from dental amalgams can migrate through teeth to the bloodstream and by mapping intracellular targets for elements, such as selenium and arsenic.

Dr Harris is the author of nearly forty journal publications, including papers in highly regarded journals such as *Science, Environmental Science and Technology and Chemical Research in Toxicology*. He serves on a number of committees for the Australian Synchrotron including the X-ray Fluorescence Microscopy Proposal Advisory Committee (chair), the User Advisory Committee and the National Science Consultative Group.

**Ms Jiajia Zheng**

Ms Jiajia Zheng is currently doing a PhD with the CMLR at The University Of Queensland, and is working on the Lead Pathway Project at Mount Isa. Ms Zheng has a Masters Degree in Environmental Geochemistry (2010) from The University of Queensland. Her Masters research project was on *Peat Deposits of Moreton Bay: Natural Archives of Environmental Pollution*. Before studying in Australia, Ms Zheng studied at the China University of Geosciences (Wuhan), majoring in Economic Geology.

Ms Zheng's research interests are principally in environmental risk assessment and the mining and minerals industry, using various techniques such as synchrotron technique and isotope measurement, air/soil pollutions, to determine the impacts of contaminants from mining activities on humans.

# 7. Limitations

CMLR has prepared this report for the use of Xstrata Mount Isa Mines Limited. It was prepared in accordance with the scope of work.

This report should be read in full. No responsibility is accepted for use of any part of this report in any other context or for any other purpose or by third parties. This report does not purport to give legal advice. Legal advice can only be given by qualified legal practitioners.

The methodology adopted and sources of information used by CMLR are outlined in this report. Our conclusions are based on the analytical data presented in this report and on our experience. Opinions and recommendations presented in this report apply to the information available at the time of our investigation and cannot necessarily apply to matters of which CMLR is not aware and has not had the opportunity to evaluate.

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# Appendices

**Appendix 1.Water and sediment sampling maps (from Figure 17 and Table 3)**


Figure A1: DGT-T map: sites *In situ* DGT deployment in water and water sampling and aquatic toxicity test in October 2009.

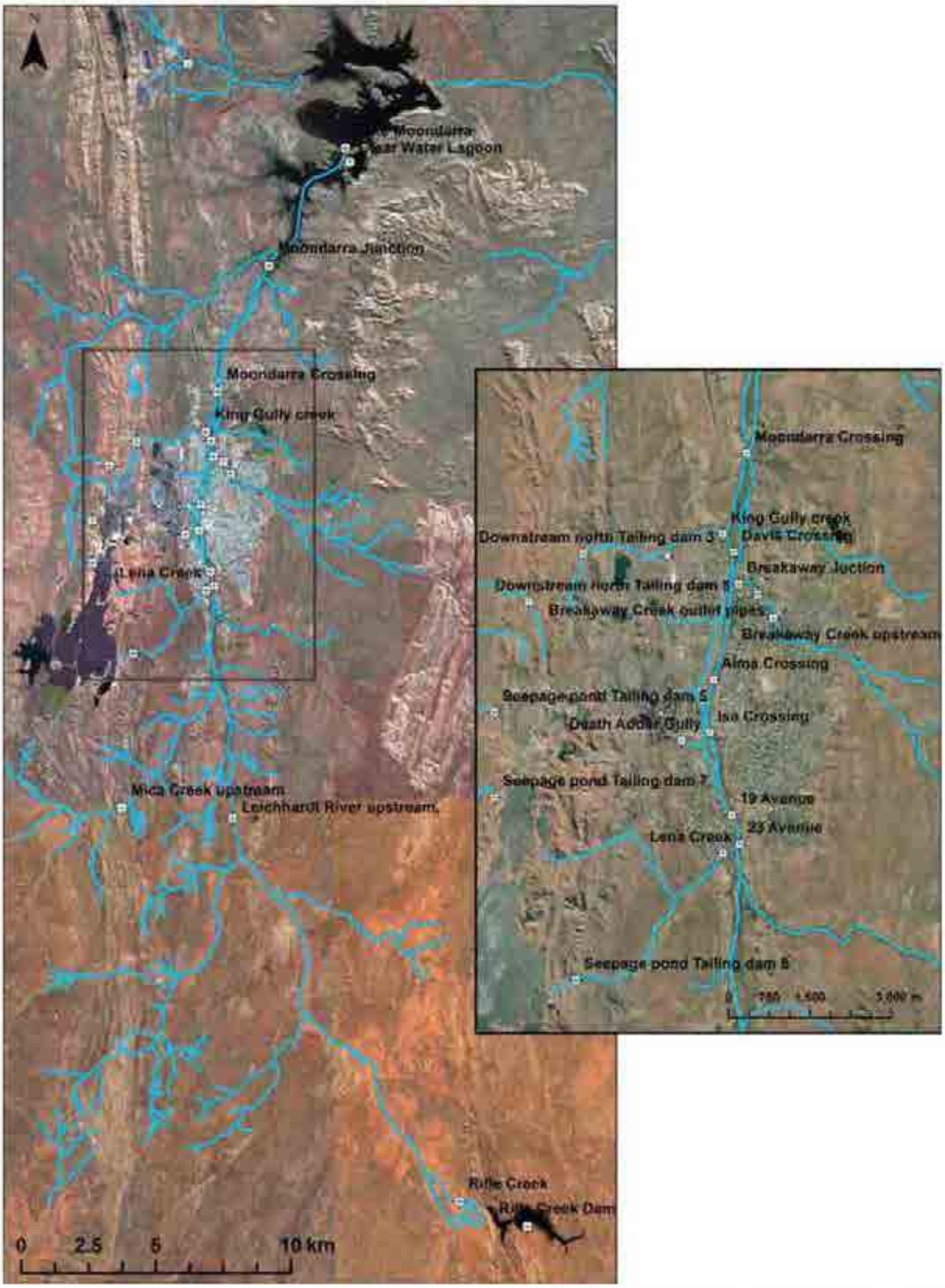


Figure A2: DGT-W map: *In situ* DGT deployment in water and water sampling in 5 seasons (November 2008–June 2010)


Figure A3: T-W and DGT-S map: At Rifle creek and Rifle creek dam only Aquatic toxicity test for water sediment.


Figure A4: Sediment sampling site 15-16 October 2009


Figure A5: L-map and T-S map

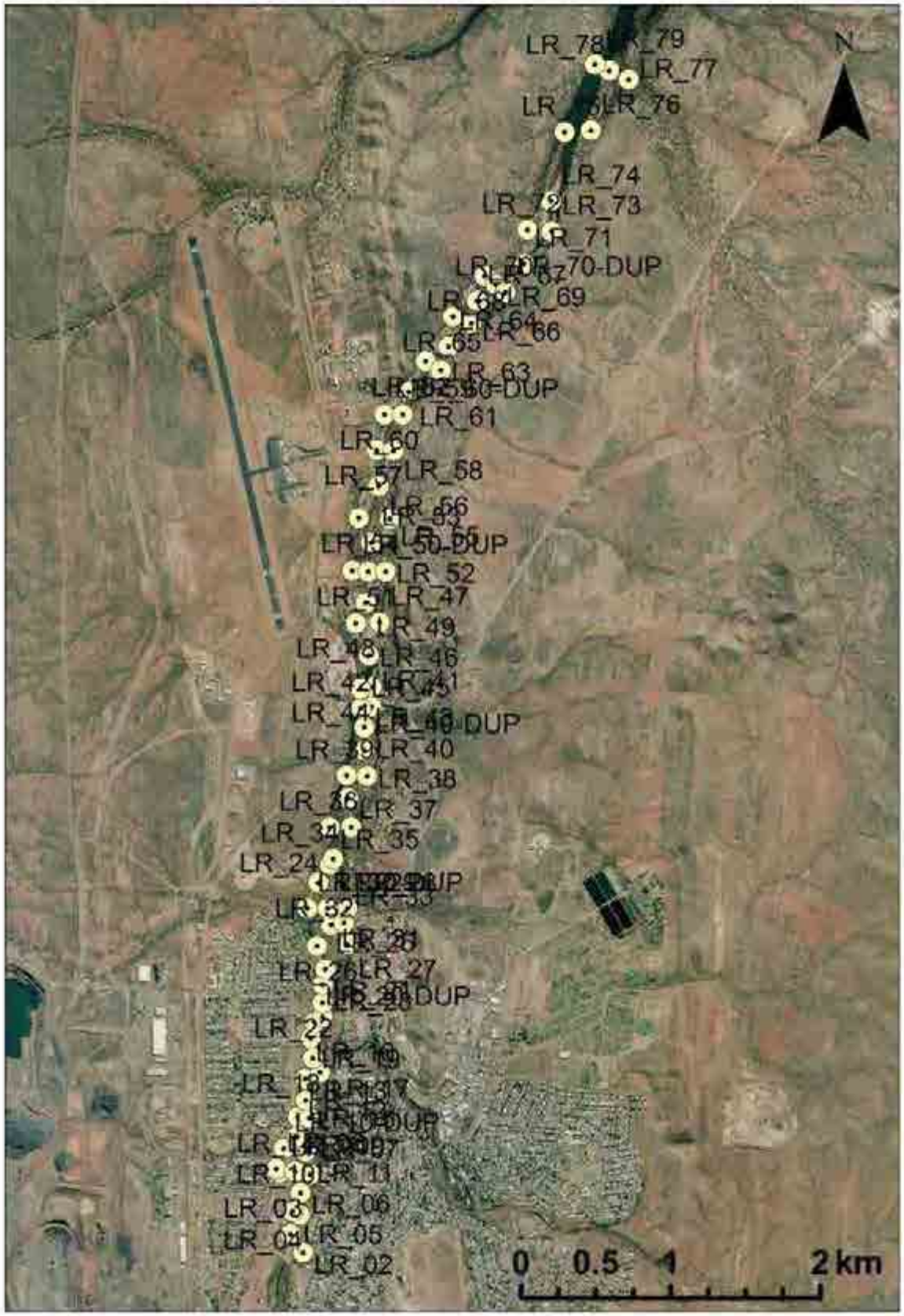


Figure A6: LR-map Leichhardt River Verification Samples – taken along a great length of the Leichhardt River (13-14 November 2009) (Site details are presented in Table A12 – Appendix 6)

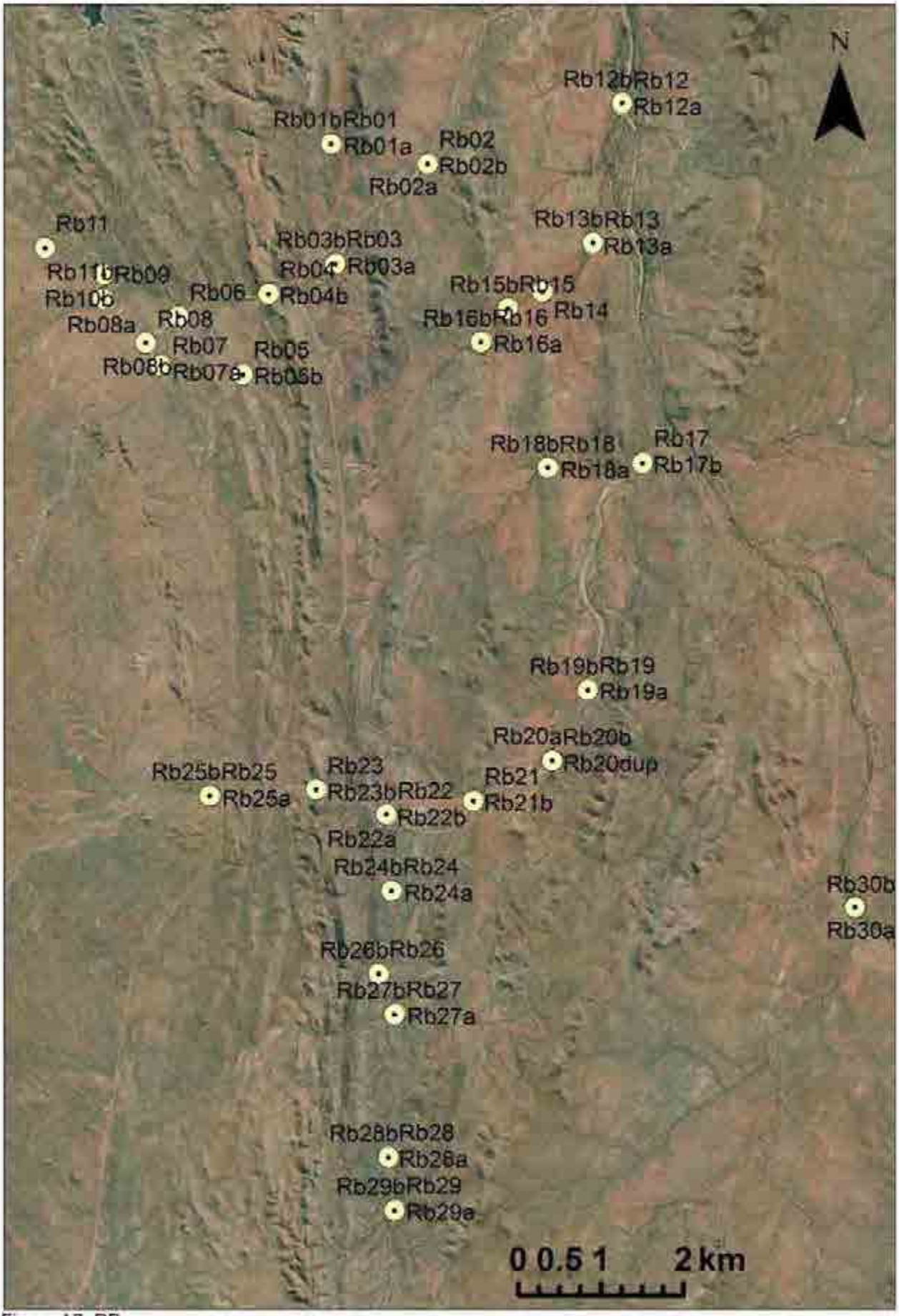


Figure A7: RB map

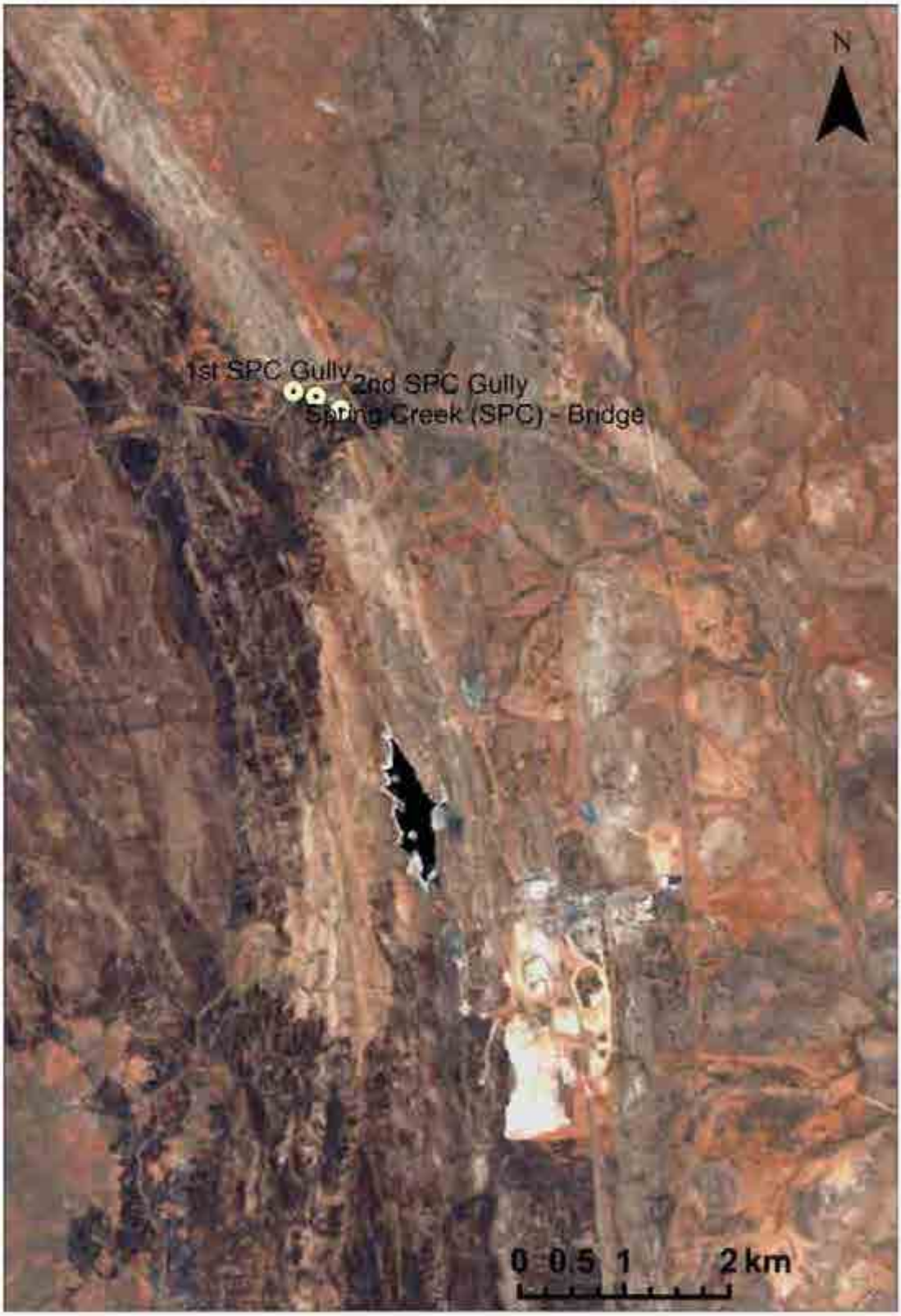


Figure A8: SS map

**Appendix 2.Hardness correction procedure for water**

**Table A1 Approximate factors to apply to soft water trigger values for selected metals in freshwaters of varying water hardness[a] (ANZECC/ARMCANZ, 2000)**

| Hardness category[b] (mg/L as $CaCO_3$) | Water hardness[c] (mg/L as $CaCO_3$) | Cd | Cr(III) | Cu | Pb | Ni | Zn |
|---|---|---|---|---|---|---|---|
| Soft (0–59) | 30 | TV | TV | TV | TV | TV | TV |
| Moderate (60–119) | 90 | X 2.7 | X 2.5 | X 2.5 | X 4.0 | X 2.5 | X 2.5 |
| Hard (120–179) | 150 | X 4.2 | X 3.7 | X 3.9 | X 7.6 | X 3.9 | X 3.9 |
| Very hard (180–240) | 210 | X 5.7 | X 4.9 | X 5.2 | X 11.8 | X 5.2 | X 5.2 |
| Extremely hard (400) | 400 | X 10.0 | X 8.4 | X 9.0 | X 26.7 | X 9.0 | X 9.0 |

[a] Trigger values from table 3.4.1 (ANZECC/ARMCANZ, 2000)v

[b] Range of water hardness (mg/L as $CaCO_3$) for each category as defined by CCREM (1987);

[c] Mid-range value of each water hardness category. For example, a copper trigger value of 1.4 µg/L (from table 3.4.1) with 95% protection level chosen (e.g. slightly–moderately disturbed system) is applied to a site with very hard water (e.g. 210 mg/L as $CaCO_3$) by multiplying the trigger value by 5.2 to give a site-specific trigger value of 7.3 µg/L. If the hardness is away from the mid-range, it may be preferable to use the algorithm.

**Appendix 3.ICP-MS procedure**

**Table A2 Standard Preparation for Multi-Element ICP-MS Analysis**

| Std soln. Final Concentration. | 0.0 ng/mL | 0.5 ng/mL | 1.0 ng/mL | 3.0 ng/mL | 5.0 ng/mL | 10 ng/mL | 20 ng/mL | 50 ng/mL | 100 ng/mL |
|---|---|---|---|---|---|---|---|---|---|
| Concentration of Stock Standard. required | -- | 10 ng/mL Stock Standard | | | | 100 ng/mL Stock Standard | | | 1000 ng/mL Stock Standard |
| Amount required | -- | 0.25 mL | 0.5 mL | 1.5 mL | 2.5 mL | 0.5 mL | 1.0 mL | 2.5 mL | 0.5 mL |
| Amount of 2% $HNO_3$ (mL) | 5.0 mL | 4.75 mL | 4.5 mL | 3.5 mL | 2.5 mL | 4.5 mL | 4.0 mL | 2.5 mL | 4.5 mL |
| 500 ng/mL Int. Std | 0.1mL | 0.1mL | 0.1mL | 0.1mL | 0.1mL | 0.1mL | 0.1mL | 0.1mL | 0.1mL |

## Trace Water Sample Preparation for Multi-Element ICP-MS Analysis

## (2% $HNO_3$, 10 ng/mL multi-element internal standard)

1. Defrost water samples. Water samples should be preserved with HNO3, approximate 1 - 2 % $HNO_3$ final concentration.
2. If required, filter water samples with 0.2 μm filter unit or centrifuge the sample.
3. Transfer 4.0 mL of water sample to a labelled 5mL tube
4. Add 1.0 mL 2% $HNO_3$ to each 5mL sample tube
5. Add 0.1 mL of 500 ng/mL Internal Standard mix (prepared in 10% $HNO_3$ in Milli-Q water)
6. Cap and mix all tubes
7. Centrifuge the samples using the bench-top centrifuge at 2500 rpm for 15 minutes (if required)
8. Load into auto-sampler tray as detailed in sequence log for ICP-MS analysis.

## Spike Water Sample Preparation for Multi-Element ICP-MS Analysis

**(10x dilution, 2% $HNO_3$, 10 ng/mL mixed internal standard, 10 ng/mL spike)**

1. Transfer 4.0 mL water sample to a labelled 5mL tube
2. Add 0.5 mL 100 ng/mL Stock Standard Solution (in 2% $HNO_3$)
3. Add 0.5 mL 2% $HNO_3$
4. Add 0.1 mL of 500ng/mL Internal Standard mix
5. Cap and mix all tubes
6. Centrifuge the samples using the bench centrifuge at 2500 rpm for 15 minutes if required

Prepare spike samples for every 10 - 15 samples in the run sequence and run them in a matching pair, using same water sample. One sample will be prepared with a 10ng/L spike and one in the normal way without a spike. Samples were spiked where both high and low levels are expected.

## Appendix 4.Quality assurance reports for water and sediment analysis

**Table A3 Quality assurance report for water analysis: Recovery % of certificated reference water TM 28.3**

| Certificated Reference TM 28.3 | | Arsenic | Cadmium | Copper | Nickel | Lead | Zinc |
|---|---|---|---|---|---|---|---|
| Measured concentrations | mean | 6.67 | 2 | 6.66 | 9.35 | 3.36 | 30 |
| | ± SD | 0.004 | 0.004 | 0.05 | 0.04 | 0.05 | 0.4 |
| Certificated concentrations | Mean | 6.22 | 1.91 | 6.15 | 9.8 | 3.97 | 27.5 |
| | ± SD | 0.85 | 0.23 | 0.86 | 1.16 | 0.57 | 3.37 |
| Recovery (%) | | 107 | 105 | 108 | 95 | 85 | 109 |

TM 28.3 is certified reference material provided by Environment Canada (lot 1107)

**Table A4 Quality assurance report for water analysis: Recovery % of certificated reference water TM 24.3**

| Certificated Reference TM 24.3 | | Arsenic | Cadmium | Cobalt | Copper | Nickel | Lead | Manganese |
|---|---|---|---|---|---|---|---|---|
| Measured concentrations | Mean | 5.07 | 3.6 | 6.48 | 6.6 | 5.19 | 4.4 | 8.09 |
| | ± SD | 0.005 | 0.01 | 0.01 | 0.7 | 0.05 | 0.75 | 0.02 |
| Certificated concentrations | mean | 5.21 | 3.97 | 6.29 | 6.79 | 5.12 | 5.82 | 8.12 |
| | ± SD | 0.53 | 0.37 | 0.5 | 0.64 | 0.61 | 0.45 | 0.72 |
| Recovery (%) | | 97 | 91 | 103 | 97 | 101 | 75 | 100 |

TM 24.3 is certified reference material provided by Environment Canada (lot 0510)

**Table A5 Quality assurance report for water analysis: Recovery % of certificated reference water spike sample**

| Spike samples | Arsenic | Cadmium | Copper | Nickel | Thallium | Lead | Zinc |
|---|---|---|---|---|---|---|---|
| Spike (µg/L) | 20.3 | 20.4 | 20.3 | 20.5 | 19.8 | 19.2 | 20 |
| Spike recovery (%) | 102 | 102 | 101.5 | 102.7 | 99 | 96 | 100 |
| Blank* | <DL | <DL | <DL | 8.8 | <DL | <DL | 0 |

SD: Standard deviations are those obtained from the 3 measurement replicates

Blank*: Blank is Milli-Q water filtered through the same system - Blank result is an average of 3 replicates.

DL: detection limit

Page: 3 of 5
Work Order: EB0910010
Client: THE UNIVERSITY OF QUEENSLAND
Project: PATHWAY PROJECT

## Laboratory Duplicate (DUP) Report

The quality control term Laboratory Duplicate refers to a separate sample preparation and Laboratory Duplicate provide information regarding method precision and sample heterogeneity. The permitted ranges for the Relative Percent Deviation (RPD) of Laboratory Duplicates are specified in ALS Method QW-EG005 and are dependent on the magnitude of results in comparison to the level of reporting. Result > 10 times LOR: No Limit; Result between 5 and 10 times LOR: 0% - 50%; Result > 20 times LOR: 0% - 20%.

Sub-Matrix: SOIL

| Laboratory sample ID | Client sample ID | Method / Compound | CAS Number | LOR | Unit | Laboratory Duplicate (DUP) Report: Original Result | Duplicate Result | RPD (%) | Recovery Limits (%) |
|---|---|---|---|---|---|---|---|---|---|
| EG005-SOH: 1M HCl Extractable Metals by ICPAES (QC Lot: 1186022) | | | | | | | | | |
| EB0910010-001 | LM 1 | EG005-SOH: Cadmium | 7440-43-9 | 0.1 | mg/kg | 4.3 | 4.3 | 0.0 | 0% - 20% |
| | | EG005-SOH: Cobalt | 7440-48-4 | 0.5 | mg/kg | 9.8 | 9.8 | 0.0 | 0% - 50% |
| | | EG005-SOH: Molybdenum | 7439-98-7 | 1.0 | mg/kg | 11.0 | 11.0 | 0.0 | No Limit |
| | | EG005-SOH: Arsenic | 7440-38-2 | 1.0 | mg/kg | 4.2 | 4.3 | 1.4 | No Limit |
| | | EG005-SOH: Copper | 7440-50-8 | 1.0 | mg/kg | 223 | 221 | 0.8 | 0% - 20% |
| | | EG005-SOH: Lead | 7439-92-1 | 1.0 | mg/kg | 338 | 338 | 0.1 | 0% - 20% |
| | | EG005-SOH: Nickel | 7440-02-0 | 1.0 | mg/kg | 4.4 | 4.4 | 0.0 | No Limit |
| | | EG005-SOH: Zinc | 7440-66-6 | 1.0 | mg/kg | 327 | 326 | 0.4 | 0% - 20% |

Page: 2 of 5
Work Order: EB0910010
Client: THE UNIVERSITY OF QUEENSLAND
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## Quality Control Parameter Frequency Compliance

The following report summarises the frequency of laboratory QC samples analysed within the analytical batch in which the submitted samples were analysed. Actual rate should be greater than or equal to the expected rate. A listing of breaches is provided in the Summary of Outliers.

Matrix: SOIL

Evaluation: × = Quality Control frequency not within specifications ; ✓ = Quality Control frequency within specifications.

| Quality Control Sample Type / Analytical Methods | Method | Count: QC | Count: Regular | Rate (%): Actual | Rate (%): Expected | Evaluation | Quality Control Specification |
|---|---|---|---|---|---|---|---|
| Laboratory Duplicate (DUP) | | | | | | | |
| 1M HCl Extractable Metals | EG005-SOH | 1 | 10 | 10.0 | 10.0 | ✓ | NEPM 1999 Schedule B(3) and ALS QCS3 requirement |
| Laboratory Control Samples (LCS) | | | | | | | |
| Total Metals by ICP-AES | EG005-T | 1 | 8 | 12.5 | 5.0 | ✓ | NEPM 1999 Schedule B(3) and ALS QCS3 requirement |
| Method Blanks (MB) | | | | | | | |
| 1M HCl Extractable Metals | EG005-SOH | 1 | 10 | 10.0 | 5.0 | ✓ | NEPM 1999 Schedule B(3) and ALS QCS3 requirement |
| Total Metals by ICP-AES | EG005-T | 1 | 8 | 12.5 | 5.0 | ✓ | NEPM 1999 Schedule B(3) and ALS QCS3 requirement |

**Appendix 5.Water quality study results**

**Table A7 GPS coordinates of water sampling sites over five sampling periods**

| Site names | Site ID | GPS coordinates | |
|---|---|---|---|
| | | **Easting** | **Northing** |
| Leichhardt River upstream | LR UP | 343821 | 7696311 |
| Mica Creek upstream | MC UP | 339709 | 7696698 |
| 19 Avenue crossing | 19 Ave | 342994 | 7705462 |
| 23 Avenue crossing | 23 Ave | 343134 | 7704929 |
| Isa Crossing | ISA | 342583 | 7706983 |
| Alma Crossing | ALS | 342653 | 7707956 |
| Davis Crossing | DC | 343027 | 7710315 |
| Moondarra Crossing | MC | 343260 | 7712131 |
| Moondarra Junction | MJ | 345160 | 7716810 |
| Lake Moondarra | LM | 348004 | 7721168 |
| Clear Water lagoon | CWL | 348163 | 7720660 |
| Breakaway Creek upstream | BACS | 343751 | 7709089 |
| Breakaway Creek outlet pipes | BAC1 | 343468 | 7709533 |
| Breakaway junction | BAC2 | 343114 | 7709721 |
| George Fisher Creek | GF | 342154 | 7724313 |
| King Gully Creek | KGC | 342820 | 7710642 |
| Lena Creek | LC | 342828 | 7704760 |
| Downstream north Tailing Dam 3 | DSNTD3 | 340255 | 7710284 |
| Downstream north Tailing Dam 5 | DSNTD5 | 339250 | 7709397 |
| Seepage pond Tailing Dam 5 | TD5 | 338610 | 7707353 |
| Seepage pond Tailing Dam 7 | TD7 | 338622 | 7705787 |
| Seepage pond Tailing Dam 8 | TD8 | 340120 | 7702422 |

**Table A8 pH of water samples collected over five sampling periods**

| Site names | Pre-wet season 2008 | Wet season 2009 | Post-wet season 2009 | Wet season 2010 | Post-wet season 2010 |
|---|---|---|---|---|---|
| Leichhardt River upstream | - | 7.4 | 7.9 | 7.3 | - |
| Mica Creek upstream | - | 7.5 | 8.1 | 7.5 | - |
| 19 Avenue Crossing | 8.5 | 8.2 | 8 | 7.1 | 8.1 |
| 23 Avenue Crossing | 7.9 | - | 8 | 7.6 | 8.6 |
| Isa Crossing | 8.3 | 8.2 | 8.3 | 7.3 | 8 |
| Alma Crossing | - | 7.3 | 8.3 | 7.4 | 9.3 |
| Davis Crossing | - | - | 8.1 | 8 | 8.6 |
| Moondarra Crossing | 8 | 8.1 | 8.2 | 7.7 | 8 |
| Moondarra Junction | 7.9 | 8 | 8.3 | 7.7 | 9.3 |
| Lake Moondarra | 8.3 | 7.3 | 8.1 | 7.7 | 8.4 |
| Clear Water lagoon | 8.4 | 7.3 | 8 | 8 | 7.9 |
| Breakaway Upstream | - | - | 8.2 | 7.5 | 8.6 |
| Breakaway Creek outlet pipes | - | - | 8.2 | 7.3 | 8 |
| Breakaway junction | - | - | 8.4 | 7.4 | 8.6 |
| Mining discharge | | | | | |
| George Fisher Creek | - | - | - | 7.8 | 9.1 |
| King gully Creek | - | - | - | 8.2 | 7.4 |
| Lena Creek | - | - | - | 7.62 | - |
| Downstream north Tailing Dam 3 | - | - | - | 8.04 | - |
| Downstream north Tailing Dam 5 | - | - | - | 7.74 | 8.1 |
| Seepage pond Tailing Dam 5 | 8.4 | 8.3 | 8.1 | 7.2 | 8.3 |
| Seepage pond Tailing Dam 7 | 8 | 7.8 | 8.1 | 7.1 | 7.4 |
| Seepage pond Tailing Dam 8 | 7.8 | 7.7 | 8.1 | 7.1 | 10.4 |

'-' data is not available

**Table A9 EC (µS/cm) of water samples collected over five sampling periods**

| Sampling site names | Pre-wet season 2008 | Wet season 2009 | Post-wet season 2009 | Wet season 2010 | Post-wet season 2010 |
|---|---|---|---|---|---|
| Leichhardt River upstream | - | 114 | 420 | 200 | - |
| Mica Creek upstream | - | 230 | 530 | 277 | - |
| 19 Avenue Crossing | 11,040 | 718 | 3,920 | 690 | 4,960 |
| 23 Avenue Crossing | 434 | 560 | 1,037 | 192 | 401 |
| Isa Crossing | 3,530 | 189 | 1,943 | 565 | 1,505 |
| Alma Crossing | - | 203 | 958 | 555 | 867 |
| Davis Crossing | 5,720 | - | 5,900 | 2,952 | 2,830 |
| Moondarra Crossing | 6,900 | 1,224 | 350 | 364 | 4,010 |
| Moondarra Junction | 7,500 | 649 | 410 | 455 | 360 |
| Lake Moondarra | 499 | 409 | 285 | 253 | 303 |
| Clear Water lagoon | 160 | 245 | 280 | 194 | 322 |
| Breakaway Creek upstream | - | - | 7,480 | 4,165 | 2,610 |
| Breakaway Creek outlet pipes | - | - | 7,110 | 1,724 | 1,697 |
| Breakaway junction | - | - | 6,220 | 1,983 | 4,990 |
| George Fisher Creek | - | 703 | - | 334 | 153 |
| King gully Creek | - | - | - | 346 | 1,860 |
| Lena Creek | - | - | - | 161 | - |
| Downstream north Tailing Dam 3 | - | - | - | 345 | - |
| Downstream north Tailing Dam 5 | 14,750 | - | - | 451 | 10,950 |
| Seepage Tailing Dam 5 | 10,080 | 4,260 | 9,840 | 11,620 | 8,710 |
| Seepage Tailing Dam 7 | 6,900 | 11,440 | 12,650 | 13,280 | 11,710 |
| Seepage Tailing Dam 8 | - | 7,430 | 8,210 | 8,127 | 4,120 |

'-' data is not available

**Table A10 Water hardness (as mg/L $CaCO_3$) of water samples collected over five sampling periods**

| Sampling site names | Pre-wet season 2008 | Wet season 2009 | Post-wet season 2009 | Wet season 2010 | Post-wet season 2010 |
|---|---|---|---|---|---|
| Leichhardt River upstream | - | 32 | 84 | 128 | - |
| Mica Creek upstream | - | 21 | 58 | 94 | - |
| 19 Ave crossing | 263 | - | 411 | 679 | 842 |
| 23 Ave crossing | 281 | 161 | 128 | 202 | 123 |
| Isa Crossing | 485 | 187 | 221 | 339 | 194 |
| Alma Crossing | - | 51 | 90 | 230 | 208 |
| Davis Crossing | 801 | - | 519 | 873 | 392 |
| Moondarra Crossing | 1,096 | 265 | 338 | 526 | 611 |
| Moondarra Junction | 294 | | 61 | 94 | 86 |
| Lake Moondarra | 122 | 84 | 43 | 69 | 78 |
| Clear Water lagoon | 55 | 64 | 44 | 71 | 73 |
| Breakaway Creek upstream | - | - | 622 | 580 | 501 |
| Breakaway Creek outlet pipes | - | - | 623 | 282 | 785 |
| Breakaway junction | - | - | 524 | 257 | 375 |
| George Fisher Creek | - | 264 | - | 144 | 54 |
| King gully Creek | - | - | - | 94 | 436 |
| Lena Creek | - | - | - | 65 | - |
| Downstream north Tailing Dam 3 | - | - | - | 1,635 | - |
| Downstream north Tailing Dam 5 | - | - | - | 132 | 8,468 |
| Seepage Tailing Dam 5 | 9183 | 1,794 | 2,713 | 5,404 | 4,537 |
| Seepage Tailing Dam 7 | 6165 | 6,780 | 3,307 | 7,317 | 6,096 |
| Seepage Tailing Dam 8 | 3287 | 3,083 | 1,819 | 3,178 | 935 |

'-' data is not available

**Appendix 6.Sediment quality study results**

**Table A11 GPS coordinates of Leichhardt River sediment samples collected in 2007 on the phase 1 study**

| Sampling Site Details | Site ID | Easting | Northing |
|---|---|---|---|
| LR - Upstream (background) | L1 | 343416 | 7700904 |
| Death Adder Gully (West) | L2 | 342156 | 7706812 |
| Death Adder Gully (East) | L3 | 342468 | 7706754 |
| Skate Park (grassed area at depth) Swimming Pool Area | L4 | 342336 | 7707040 |
| Skate Park (ungrassed parking area) Swimming Pool Area | L5 | 342275 | 7706970 |
| Kruttschnitt Oval adjacent to Swimming Pool Area | L6 | 342416 | 7706878 |
| LR - Between Isa Street Crossing and Grace Street Bridge | L7 | 342523 | 7707217 |
| LR - Historical Tailings (between Grace street bridge and Velodrome) | L8 | 342452 | 7707513 |
| LR - Downstream/East of Velodrome | L9 | 342676 | 7708051 |
| LR - Velodrome East (Acid Gen Material) | L10 | 342539 | 7707664 |
| LR - Velodrome West (Acid Gen Material) | L11 | 342417 | 7707666 |
| LR - Pipe exit | L12 | 342357 | 7707643 |
| LR - Historical Tailings West embankment | L13 | 342386 | 7707891 |
| LR - Historical Tailings deposition (mid channel) | L14 | 342555 | 7708232 |
| LR - Fluvial downstream (Moondarra) | L15 | 343454 | 7713760 |
| LR - Downstream of Lake Moondarra (Leichhardt River) | L16 | 353578 | 7723640 |

**Table A12 GPS coordinates of Leichhardt River Verification Samples collected 13-14 November 2009 by Xstrata**

| Sites ID | Easting | Northing |
|---|---|---|
| LR_01 | 342716 | 7708911 |
| LR_02 | 342871 | 7708377 |
| LR_03 | 342787 | 7708498 |
| LR_04 | 342849 | 7708627 |
| LR_05 | 342802 | 7708652 |
| LR_06 | 342855 | 7708774 |
| LR_07 | 342919 | 7708899 |
| LR_08 | 342691 | 7708937 |
| LR_09 | 342816 | 7708918 |
| LR_10 | 342742 | 7709072 |
| LR_10-DUP | 342742 | 7709072 |
| LR_11 | 342888 | 7709054 |
| LR_12 | 342833 | 7709154 |
| LR_13 | 342836 | 7709283 |
| LR_14 | 342914 | 7709278 |
| LR_15 | 342889 | 7709397 |
| LR_16 | 342886 | 7709540 |
| LR_17 | 342985 | 7709583 |
| LR_18 | 342936 | 7709678 |
| LR_19 | 342922 | 7709812 |
| LR_20 | 342949 | 7709919 |
| LR_20-DUP | 342949 | 7709919 |
| LR_21 | 343003 | 7709956 |
| LR_22 | 343002 | 7710049 |
| LR_23 | 343005 | 7710172 |
| LR_24 | 343051 | 7710976 |
| LR_25 | 343021 | 7710276 |
| LR_26 | 342966 | 7710431 |
| LR_27 | 343169 | 7710441 |
| LR_28 | 343167 | 7710682 |
| LR_29 | 343037 | 7710683 |
| LR_30 | 342899 | 7710684 |
| LR_30-DUP | 342899 | 7710684 |
| LR_31 | 343060 | 7710573 |
| LR_32 | 342973 | 7710855 |
| LR_33 | 343145 | 7710587 |
| LR_34 | 343074 | 7711016 |
| LR_35 | 343048 | 7711225 |
| LR_36 | 343193 | 7711228 |
| LR_37 | 343173 | 7711424 |
| LR_38 | 343300 | 7711571 |
| LR_39 | 343163 | 7711575 |
| LR_40 | 343281 | 7711742 |

| Site ID | Easting | Northing |
|---|---|---|
| LR_40-DUP | 343281 | 7711742 |
| LR_41 | 343328 | 7712032 |
| LR_42 | 343258 | 7712022 |
| LR_43 | 343281 | 7711894 |
| LR_44 | 343330 | 7712162 |
| LR_45 | 343254 | 7712152 |
| LR_46 | 343313 | 7712375 |
| LR_47 | 343383 | 7712596 |
| LR_48 | 343225 | 7712591 |
| LR_49 | 343290 | 7712728 |
| LR_50 | 343199 | 7712943 |
| LR_50-DUP | 343199 | 7712943 |
| LR_51 | 343308 | 7712937 |
| LR_52 | 343424 | 7712937 |
| LR_53 | 343326 | 7713131 |
| LR_54 | 343244 | 7713297 |
| LR_55 | 343452 | 7713290 |
| LR_56 | 343377 | 7713510 |
| LR_57 | 343366 | 7713751 |
| LR_58 | 343476 | 7713747 |
| LR_59 | 343417 | 7713989 |
| LR_60 | 343539 | 7713989 |
| LR_60-DUP | 343539 | 7713989 |
| LR_61 | 343580 | 7714143 |
| LR_62 | 343692 | 7714349 |
| LR_63 | 343794 | 7714288 |
| LR_64 | 343845 | 7714447 |
| LR_65 | 343875 | 7714648 |
| LR_66 | 343997 | 7714603 |
| LR_67 | 344034 | 7714753 |
| LR_68 | 344087 | 7714920 |
| LR_69 | 344162 | 7714863 |
| LR_70 | 344226 | 7714809 |
| LR_70-DUP | 344226 | 7714809 |
| LR_71 | 344348 | 7715002 |
| LR_72 | 344373 | 7715231 |
| LR_73 | 344534 | 7715217 |
| LR_74 | 344529 | 7715423 |
| LR_75 | 344622 | 7715886 |
| LR_76 | 344798 | 7715897 |
| LR_77 | 345051 | 7716238 |
| LR_78 | 344920 | 7716297 |
| LR_79 | 344823 | 7716339 |

**Table A13 Concentrations of metal and metalloid in 1M HCl extraction of Leichhardt River Verification Samples collected 13-14 November 2009 by Xstrata**

| Site | Aluminium | Antimony | Arsenic | Cadmium | Chromium | Cobalt | Copper | Iron | Lead | Manganese | Nickel | Silver | Vanadium | Zinc |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | mg/kg (1M HCl extraction in <63µm fraction) | | | | | | | | | | | | | |
| LR_01 | 660 | 3.1 | 7.8 | 14.2 | <1.0 | 8.2 | 369 | 1580 | 1150 | 371 | 1.7 | 3.6 | 7 | 1090 |
| LR_02 | 720 | <1.0 | 4.1 | 6.9 | <1.0 | 5.7 | 142 | 2010 | 130 | 853 | 2.1 | <1.0 | 10 | 282 |
| LR_03 | 810 | <1.0 | 10.1 | 14.6 | <1.0 | 7.5 | 258 | 1850 | 894 | 646 | 3.2 | 1.8 | 9 | 991 |
| LR_04 | 1740 | <1.0 | 3.7 | 14 | 3.2 | 8.2 | 151 | 4570 | 130 | 561 | 4.4 | <1.0 | 16.7 | 240 |
| LR_05 | 1660 | 1.3 | 7.4 | 12.5 | 2.1 | 9.1 | 310 | 4260 | 1580 | 364 | 3.1 | 8.5 | 12.2 | 1140 |
| LR_06 | 520 | <1.0 | 4.4 | 9.2 | <1.0 | 6.5 | 182 | 1470 | 840 | 268 | 1.3 | 1.8 | 7 | 687 |
| LR_07 | 520 | <1.0 | 3.4 | 3 | <1.0 | 4 | 124 | 840 | 241 | 191 | 1.1 | <1.0 | 5.5 | 167 |
| LR_08 | 840 | <1.0 | 8 | 5.2 | <1.0 | 5.2 | 393 | 580 | 627 | 204 | 1.7 | 2 | 3.4 | 606 |
| LR_09 | 650 | 1.9 | 12.1 | 24.3 | <1.0 | 7.5 | 691 | 2160 | 2650 | 211 | 2.4 | 11.5 | 5.5 | 4200 |
| LR_10 | 720 | 1.8 | 242 | 25.1 | <1.0 | 7.8 | 1160 | 2610 | 1230 | 192 | 2.6 | 4.3 | 9 | 2660 |
| LR_11 | 710 | 1.4 | 175 | 20.5 | <1.0 | 7.7 | 948 | 2190 | 1060 | 223 | 2.3 | 3.5 | 8.1 | 2220 |
| LR_12 | 730 | <1.0 | 11.4 | 7.1 | 2.3 | 6.2 | 253 | 1480 | 230 | 660 | 2.7 | <1.0 | 9 | 184 |
| LR_13 | 670 | <1.0 | 6 | 12.1 | 1.1 | 5.4 | 224 | 1850 | 188 | 405 | 2.3 | <1.0 | 10.5 | 181 |
| LR_14 | 680 | <1.0 | 2.3 | 2.5 | <1.0 | 4 | 92.3 | 1070 | 94.8 | 184 | 1.2 | <1.0 | 7 | 83.5 |
| LR_15 | 760 | <1.0 | 3.5 | 14.1 | <1.0 | 9 | 146 | 2490 | 136 | 847 | 2 | <1.0 | 11.6 | 218 |
| LR_16 | 870 | <1.0 | 5.2 | 21.3 | <1.0 | 7.2 | 184 | 2520 | 308 | 1020 | 2.1 | <1.0 | 12.5 | 366 |
| LR_17 | 1070 | <1.0 | 3.3 | 5.8 | <1.0 | 7.1 | 142 | 2840 | 143 | 398 | 2 | <1.0 | 13.4 | 130 |
| LR_18 | 930 | <1.0 | 5.4 | 15 | 1.6 | 6.9 | 238 | 1820 | 319 | 635 | 2 | <1.0 | 10.1 | 321 |
| LR_19 | 700 | <1.0 | 5.1 | 10.8 | <1.0 | 5.4 | 204 | 1430 | 552 | 302 | 1.4 | 1.5 | 8 | 478 |
| LR_20 | 760 | <1.0 | 3 | 6.9 | <1.0 | 4.2 | 135 | 1200 | 454 | 220 | 1.2 | 1.2 | 7.1 | 322 |
| LR_21 | 680 | <1.0 | 1.6 | 1.9 | <1.0 | 3.9 | 78.1 | 940 | 67.5 | 222 | 1.2 | <1.0 | 7.5 | 69.9 |
| LR_22 | 700 | <1.0 | 5.1 | 17 | <1.0 | 4.2 | 112 | 1410 | 174 | 410 | 1.2 | <1.0 | 7.1 | 233 |
| LR_23 | 540 | <1.0 | 4 | 7.4 | <1.0 | 3.9 | 138 | 1040 | 423 | 236 | <1.0 | <1.0 | 5.8 | 320 |
| LR_24 | 680 | <1.0 | 2.6 | 7.7 | <1.0 | 4 | 89.8 | 1180 | 92.6 | 542 | 1.3 | <1.0 | 9 | 127 |
| LR_25 | 580 | <1.0 | 4 | 10.8 | <1.0 | 4.7 | 122 | 1480 | 246 | 510 | 1.3 | <1.0 | 8.1 | 236 |

**Table A13** (continue)

| Site | Aluminium | Antimony | Arsenic | Cadmium | Chromium | Cobalt | Copper | Iron | Lead | Manganese | Nickel | Silver | Vanadium | Zinc |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | mg/kg (1M HCl extraction in <63µm fraction) | | | | | | | | | | | | | |
| LR_26 | 560 | <1.0 | 4.9 | 6.2 | <1.0 | 5.1 | 171 | 1270 | 331 | 256 | 1.6 | <1.0 | 7 | 264 |
| LR_27 | 430 | <1.0 | 1 | 1.9 | <1.0 | 3.2 | 73.9 | 580 | 69.8 | 167 | <1.0 | <1.0 | 4.9 | 74.3 |
| LR_28 | 660 | <1.0 | 1.6 | 2.1 | <1.0 | 4.7 | 74.6 | 1200 | 74.8 | 260 | 1.5 | <1.0 | 7.5 | 606 |
| LR_29 | 560 | <1.0 | 3 | 1.6 | <1.0 | 4.6 | 133 | 720 | 146 | 217 | <1.0 | <1.0 | 5.2 | 112 |
| LR_30 | 1050 | <1.0 | 7.4 | 17.8 | <1.0 | 8.9 | 203 | 4730 | 331 | 3610 | 3.1 | <1.0 | 16.6 | 476 |
| LR_31 | 870 | <1.0 | 2 | 2.2 | <1.0 | 4.1 | 122 | 1020 | 98.6 | 207 | 1.3 | <1.0 | 7.3 | 82.3 |
| LR_32 | 960 | <1.0 | 10.5 | 38.6 | 1.2 | 9.7 | 365 | 3830 | 454 | 991 | 3.1 | 1.1 | 20.6 | 822 |
| LR_33 | 890 | <1.0 | 3.3 | 3.9 | 1 | 6.2 | 163 | 2950 | 120 | 410 | 2 | <1.0 | 16.2 | 131 |
| LR_34 | 530 | <1.0 | 2.2 | 3.4 | <1.0 | 4 | 92.7 | 1050 | 239 | 204 | 1.2 | <1.0 | 6.8 | 177 |
| LR_35 | 1090 | <1.0 | 6.5 | 14.6 | 1 | 8.3 | 221 | 3140 | 329 | 1150 | 2.6 | <1.0 | 16.9 | 395 |
| LR_36 | 610 | <1.0 | 3.3 | 4.8 | <1.0 | 5 | 113 | 1970 | 245 | 453 | 1.5 | <1.0 | 9.4 | 198 |
| LR_37 | 660 | <1.0 | 2.6 | 3.6 | <1.0 | 5.5 | 115 | 2010 | 110 | 295 | 1.6 | <1.0 | 11.2 | 108 |
| LR_38 | 580 | <1.0 | 1.6 | 2.6 | <1.0 | 3.9 | 125 | 630 | 120 | 188 | <1.0 | <1.0 | 4.7 | 113 |
| LR_39 | 320 | <1.0 | 1.1 | 2 | <1.0 | 2.7 | 60.2 | 540 | 123 | 123 | <1.0 | <1.0 | 3.7 | 118 |
| LR_40 | 520 | <1.0 | 1.6 | 2.2 | <1.0 | 3.4 | 106 | 660 | 79.1 | 167 | <1.0 | <1.0 | 5.3 | 78.9 |
| LR_41 | 720 | 1.7 | 1.8 | 2.6 | <1.0 | 6.5 | 86.3 | 1680 | 106 | 304 | 1.8 | <1.0 | 10.5 | 145 |
| LR_42 | 1430 | <1.0 | 7.5 | 10.5 | 1.9 | 11.8 | 246 | 3980 | 404 | 1520 | 4.5 | 1.3 | 25.1 | 456 |
| LR_43 | 760 | <1.0 | 1.6 | 3 | <1.0 | 5 | 116 | 1050 | 104 | 243 | 1.3 | <1.0 | 6.8 | 128 |
| LR_44 | 750 | <1.0 | 2.3 | 2.8 | <1.0 | 6.2 | 102 | 1920 | 140 | 294 | 1.8 | <1.0 | 10.6 | 160 |
| LR_45 | 790 | <1.0 | 5.4 | 5.8 | 1.2 | 7.6 | 306 | 2800 | 392 | 366 | 2.3 | 1.4 | 12.8 | 333 |
| LR_46 | 1130 | <1.0 | 4.3 | 7 | 1.6 | 8.8 | 172 | 2730 | 345 | 584 | 2.5 | 1.2 | 14 | 422 |
| LR_47 | 1200 | <1.0 | 4.1 | 7.2 | 1.6 | 8.5 | 145 | 2630 | 210 | 587 | 2.6 | <1.0 | 12.7 | 296 |
| LR_48 | 700 | <1.0 | 2.6 | 5 | <1.0 | 6.2 | 158 | 1720 | 444 | 259 | 1.7 | 1.8 | 9 | 339 |
| LR_49 | 500 | <1.0 | 1.9 | 3.1 | <1.0 | 5.4 | 122 | 980 | 191 | 251 | 1.2 | <1.0 | 6.5 | 189 |
| LR_50 | 880 | <1.0 | 5.6 | 10.3 | 1.1 | 7.9 | 145 | 2500 | 211 | 1570 | 2.3 | <1.0 | 11.7 | 287 |
| LR_51 | 690 | <1.0 | 3.7 | 5 | <1.0 | 5.9 | 175 | 2150 | 319 | 349 | 1.8 | 1.2 | 12.4 | 251 |
| LR_52 | 720 | <1.0 | 2.9 | 3.9 | <1.0 | 5.7 | 144 | 1870 | 236 | 280 | 1.7 | <1.0 | 11 | 218 |

**Table A13 Concentrations of metal and metalloid in 1M HCl extraction of Leichhardt River Verification Samples collected 13-14 November 2009 by Xstrata**

| Site | Aluminium | Antimony | Arsenic | Cadmium | Chromium | Cobalt | Copper | Iron | Lead | Manganese | Nickel | Silver | Vanadium | Zinc |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | mg/kg (1M HCl extraction in <63µm fraction) | | | | | | | | | | | | | |
| LR_01 | 660 | 3.1 | 7.8 | 14.2 | <1.0 | 8.2 | 369 | 1580 | 1150 | 371 | 1.7 | 3.6 | 7 | 1090 |
| LR_02 | 720 | <1.0 | 4.1 | 6.9 | <1.0 | 5.7 | 142 | 2010 | 130 | 853 | 2.1 | <1.0 | 10 | 282 |
| LR_03 | 810 | <1.0 | 10.1 | 14.6 | <1.0 | 7.5 | 258 | 1850 | 894 | 646 | 3.2 | 1.8 | 9 | 991 |
| LR_04 | 1740 | <1.0 | 3.7 | 14 | 3.2 | 8.2 | 151 | 4570 | 130 | 561 | 4.4 | <1.0 | 16.7 | 240 |
| LR_05 | 1660 | 1.3 | 7.4 | 12.5 | 2.1 | 9.1 | 310 | 4260 | 1580 | 364 | 3.1 | 8.5 | 12.2 | 1140 |
| LR_06 | 520 | <1.0 | 4.4 | 9.2 | <1.0 | 6.5 | 182 | 1470 | 840 | 268 | 1.3 | 1.8 | 7 | 687 |
| LR_07 | 520 | <1.0 | 3.4 | 3 | <1.0 | 4 | 124 | 840 | 241 | 191 | 1.1 | <1.0 | 5.5 | 167 |
| LR_08 | 840 | <1.0 | 8 | 5.2 | <1.0 | 5.2 | 393 | 580 | 627 | 204 | 1.7 | 2 | 3.4 | 606 |
| LR_09 | 650 | 1.9 | 12.1 | 24.3 | <1.0 | 7.5 | 691 | 2160 | 2650 | 211 | 2.4 | 11.5 | 5.5 | 4200 |
| LR_10 | 720 | 1.8 | 242 | 25.1 | <1.0 | 7.8 | 1160 | 2610 | 1230 | 192 | 2.6 | 4.3 | 9 | 2660 |
| LR_11 | 710 | 1.4 | 175 | 20.5 | <1.0 | 7.7 | 948 | 2190 | 1060 | 223 | 2.3 | 3.5 | 8.1 | 2220 |
| LR_12 | 730 | <1.0 | 11.4 | 7.1 | 2.3 | 6.2 | 253 | 1480 | 230 | 660 | 2.7 | <1.0 | 9 | 184 |
| LR_13 | 670 | <1.0 | 6 | 12.1 | 1.1 | 5.4 | 224 | 1850 | 188 | 405 | 2.3 | <1.0 | 10.5 | 181 |
| LR_14 | 680 | <1.0 | 2.3 | 2.5 | <1.0 | 4 | 92.3 | 1070 | 94.8 | 184 | 1.2 | <1.0 | 7 | 83.5 |
| LR_15 | 760 | <1.0 | 3.5 | 14.1 | <1.0 | 9 | 146 | 2490 | 136 | 847 | 2 | <1.0 | 11.6 | 218 |
| LR_16 | 870 | <1.0 | 5.2 | 21.3 | <1.0 | 7.2 | 184 | 2520 | 308 | 1020 | 2.1 | <1.0 | 12.5 | 366 |
| LR_17 | 1070 | <1.0 | 3.3 | 5.8 | <1.0 | 7.1 | 142 | 2840 | 143 | 398 | 2 | <1.0 | 13.4 | 130 |
| LR_18 | 930 | <1.0 | 5.4 | 15 | 1.6 | 6.9 | 238 | 1820 | 319 | 635 | 2 | <1.0 | 10.1 | 321 |
| LR_19 | 700 | <1.0 | 5.1 | 10.8 | <1.0 | 5.4 | 204 | 1430 | 552 | 302 | 1.4 | 1.5 | 8 | 478 |
| LR_20 | 760 | <1.0 | 3 | 6.9 | <1.0 | 4.2 | 135 | 1200 | 454 | 220 | 1.2 | 1.2 | 7.1 | 322 |
| LR_21 | 680 | <1.0 | 1.6 | 1.9 | <1.0 | 3.9 | 78.1 | 940 | 67.5 | 222 | 1.2 | <1.0 | 7.5 | 69.9 |
| LR_22 | 700 | <1.0 | 5.1 | 17 | <1.0 | 4.2 | 112 | 1410 | 174 | 410 | 1.2 | <1.0 | 7.1 | 233 |
| LR_23 | 540 | <1.0 | 4 | 7.4 | <1.0 | 3.9 | 138 | 1040 | 423 | 236 | <1.0 | <1.0 | 5.8 | 320 |
| LR_24 | 680 | <1.0 | 2.6 | 7.7 | <1.0 | 4 | 89.8 | 1180 | 92.6 | 542 | 1.3 | <1.0 | 9 | 127 |
| LR_25 | 580 | <1.0 | 4 | 10.8 | <1.0 | 4.7 | 122 | 1480 | 246 | 510 | 1.3 | <1.0 | 8.1 | 236 |

**Table A13** (continue)

| Site | Aluminium | Antimony | Arsenic | Cadmium | Chromium | Cobalt | Copper | Iron | Lead | Manganese | Nickel | Silver | Vanadium | Zinc |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | mg/kg (1M HCl extraction in <63µm fraction) | | | | | | | | | | | | | |
| LR_53 | 530 | <1.0 | 2.2 | 3.6 | <1.0 | 5.1 | 158 | 1130 | 267 | 240 | 1.1 | <1.0 | 7.1 | 234 |
| LR_54 | 650 | <1.0 | 3.2 | 4.2 | <1.0 | 5.4 | 150 | 1500 | 247 | 295 | 1.5 | <1.0 | 8.9 | 220 |
| LR_55 | 660 | <1.0 | 2.3 | 3.1 | <1.0 | 5.5 | 120 | 1810 | 280 | 258 | 1.6 | <1.0 | 9.2 | 216 |
| LR_56 | 780 | <1.0 | 2.2 | 3.9 | <1.0 | 6.5 | 132 | 1600 | 239 | 290 | 1.7 | <1.0 | 10.3 | 242 |
| LR_57 | 940 | <1.0 | 2.8 | 7.1 | 1.4 | 6.6 | 99.6 | 2080 | 158 | 667 | 2.3 | <1.0 | 10.9 | 278 |
| LR_58 | 1040 | <1.0 | 3.8 | 4.2 | 1.2 | 8.2 | 184 | 2710 | 262 | 552 | 2.6 | <1.0 | 13.2 | 275 |
| LR_59 | 1000 | <1.0 | 3.4 | 4.8 | 1.1 | 7.2 | 188 | 2310 | 368 | 345 | 2.3 | 1.6 | 13 | 324 |
| LR_60 | 580 | <1.0 | 2.2 | 2.8 | <1.0 | 5.1 | 112 | 1470 | 232 | 245 | 1.4 | <1.0 | 8.2 | 190 |
| LR_61 | 590 | <1.0 | 2.9 | 5 | <1.0 | 5.4 | 138 | 1460 | 479 | 252 | 1.4 | 2.2 | 7.6 | 477 |
| LR_62 | 860 | <1.0 | 9.1 | 12.4 | 1.4 | 9 | 181 | 5770 | 258 | 1450 | 3.4 | <1.0 | 20.9 | 396 |
| LR_63 | 700 | <1.0 | 2.6 | 3.6 | <1.0 | 4.7 | 112 | 1520 | 162 | 258 | 1.6 | <1.0 | 9.7 | 176 |
| LR_64 | 610 | <1.0 | 2.1 | 3.3 | <1.0 | 5.5 | 124 | 1590 | 248 | 262 | 1.6 | <1.0 | 8.8 | 229 |
| LR_65 | 800 | <1.0 | 3.4 | 8.2 | 1.6 | 5.9 | 131 | 1990 | 249 | 557 | 1.8 | <1.0 | 10.5 | 316 |
| LR_66 | 580 | <1.0 | 1.6 | 3 | <1.0 | 5.5 | 99.2 | 1240 | 163 | 271 | 1.4 | <1.0 | 8.1 | 180 |
| LR_67 | 650 | <1.0 | 2.2 | 4.8 | <1.0 | 5.9 | 84.4 | 1060 | 335 | 292 | 1.9 | 1.7 | 6.6 | 422 |
| LR_68 | 980 | 1.1 | 8.4 | 65.6 | 1.6 | 9.1 | 752 | 2820 | 2290 | 639 | 2.7 | 7.9 | 10.1 | 1290 |
| LR_69 | 580 | <1.0 | 1.7 | 2.6 | <1.0 | 4.8 | 120 | 840 | 178 | 280 | 1.4 | <1.0 | 4 | 167 |
| LR_70 | 730 | <1.0 | 2.4 | 3.3 | <1.0 | 6.3 | 102 | 1760 | 162 | 403 | 2.2 | <1.0 | 10.2 | 178 |
| LR_71 | 680 | <1.0 | 2 | 3.2 | <1.0 | 5.2 | 118 | 1240 | 221 | 261 | 1.4 | <1.0 | 8.1 | 203 |
| LR_72 | 760 | <1.0 | 3.9 | 5.2 | 1.4 | 8.3 | 124 | 3990 | 325 | 386 | 2.3 | 1.3 | 15.5 | 348 |
| LR_73 | 570 | <1.0 | 2.8 | 4.2 | <1.0 | 5.6 | 121 | 2260 | 201 | 419 | 1.8 | <1.0 | 10.8 | 198 |
| LR_74 | 580 | <1.0 | 2.8 | 5 | <1.0 | 5.8 | 126 | 1930 | 243 | 546 | 2 | <1.0 | 10.1 | 268 |
| LR_75 | 630 | <1.0 | 3.3 | 3.5 | <1.0 | 5.9 | 132 | 3930 | 224 | 303 | 1.8 | <1.0 | 13.6 | 214 |
| LR_76 | 580 | <1.0 | 2.9 | 3.2 | <1.0 | 5.7 | 113 | 3400 | 150 | 352 | 1.7 | <1.0 | 13.9 | 160 |
| LR_77 | 640 | <1.0 | 1.9 | 2.8 | <1.0 | 5.9 | 87.4 | 2860 | 149 | 295 | 1.8 | <1.0 | 12.2 | 176 |
| LR_78 | 590 | <1.0 | 1.9 | 3.5 | <1.0 | 5.8 | 102 | 1960 | 182 | 402 | 1.7 | <1.0 | 9.5 | 212 |
| LR_79 | 780 | <1.0 | 4.3 | 11.8 | 1.1 | 7.2 | 326 | 3810 | 472 | 294 | 2.7 | 1.3 | 14.7 | 1540 |

**Table A14 Total concentrations of metal and metalloid in of Leichhardt River Verification Samples collected 13-14 November 2009 by Xstrata**

| Site | Aluminium | Antimony | Arsenic | Cadmium | Chromium | Copper | Lead | Molybdenum | Nickel | Silver | Zinc |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | mg/kg (total concentrations in <63µm fraction) | | | | | | | | | | |
| LR_01 | 18600 | <5 | 39 | 20 | 32 | 925 | 1870 | <2 | 22 | 5 | 2180 |
| LR_02 | 24500 | <5 | 16 | 9 | 37 | 379 | 223 | <2 | 25 | <2 | 662 |
| LR_03 | 29800 | <5 | 38 | 19 | 43 | 621 | 1370 | <2 | 28 | 3 | 2140 |
| LR_04 | 23600 | <5 | 14 | 22 | 40 | 334 | 210 | <2 | 26 | <2 | 504 |
| LR_05 | 16200 | <5 | 32 | 16 | 33 | 646 | 1570 | <2 | 22 | 5 | 1660 |
| LR_06 | 28000 | <5 | 28 | 15 | 36 | 536 | 1250 | <2 | 24 | 3 | 1680 |
| LR_07 | 32900 | <5 | 16 | 5 | 39 | 371 | 388 | <2 | 27 | <2 | 575 |
| LR_08 | 12300 | <5 | 29 | 8 | 19 | 998 | 910 | <2 | 18 | 3 | 1350 |
| LR_09 | 17500 | <5 | 119 | 52 | 33 | 2080 | 9200 | <2 | 24 | 26 | 11500 |
| LR_10 | 17900 | <5 | 434 | 34 | 35 | 2220 | 1850 | <2 | 26 | 7 | 6050 |
| LR_10-DUP | 18100 | <5 | 487 | 37 | 35 | 2410 | 2030 | 2 | 27 | 7 | 6540 |
| LR_10-Mean | 18000 | <5 | 461 | 35.5 | 35 | 2315 | 1940 | 2 | 26.5 | 7 | 6295 |
| LR_10-SD | 141 | N/A | 37 | 2 | 0 | 134 | 127 | - | 1 | 0 | 346 |
| LR_11 | 61700 | <5 | 76 | 7 | 47 | 704 | 512 | 2 | 32 | <2 | 1170 |
| LR_12 | 37900 | 14 | 27 | 5 | 40 | 446 | 288 | <2 | 27 | <2 | 638 |
| LR_13 | 46700 | 6 | 20 | 18 | 45 | 474 | 328 | <2 | 30 | <2 | 746 |
| LR_14 | 20000 | <5 | 13 | 6 | 38 | 279 | 182 | <2 | 26 | <2 | 356 |
| LR_15 | 32200 | <5 | 15 | 16 | 44 | 337 | 187 | <2 | 29 | <2 | 570 |
| LR_16 | 24200 | <5 | 16 | 25 | 36 | 326 | 389 | <2 | 24 | <2 | 851 |
| LR_17 | 24400 | <5 | 15 | 6 | 36 | 273 | 167 | <2 | 24 | <2 | 397 |
| LR_18 | 39300 | <5 | 17 | 20 | 52 | 384 | 335 | <2 | 32 | <2 | 753 |
| LR_19 | 19800 | <5 | 24 | 17 | 35 | 418 | 793 | <2 | 24 | 2 | 1360 |
| LR_20 | 18800 | <5 | 20 | 12 | 36 | 388 | 717 | <2 | 24 | <2 | 1040 |
| LR_20-DUP | 18900 | <5 | 19 | 12 | 35 | 395 | 691 | <2 | 24 | <2 | 1050 |
| LR_21 | 18000 | <5 | 10 | 3 | 36 | 228 | 126 | <2 | 25 | <2 | 238 |
| LR_22 | 31100 | <5 | 20 | 26 | 38 | 372 | 375 | <2 | 29 | <2 | 1050 |

**Table A14 (continue)**

| Site | Aluminium | Antimony | Arsenic | Cadmium | Chromium | Copper | Lead | Molybdenum | Nickel | Silver | Zinc |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | mg/kg (total concentrations in <63µm fraction) | | | | | | | | | | |
| LR_23 | 22900 | 2180 | 21 | 13 | 32 | 384 | 673 | <2 | 22 | <2 | 1160 |
| LR_24 | 23800 | 662 | 12 | 12 | 38 | 277 | 176 | <2 | 27 | <2 | 511 |
| LR_25 | 30200 | 2140 | 17 | 18 | 35 | 384 | 410 | <2 | 25 | <2 | 822 |
| LR_26 | 39600 | 504 | 21 | 12 | 38 | 403 | 421 | <2 | 27 | <2 | 830 |
| LR_27 | 18100 | 1660 | 11 | 4 | 37 | 246 | 162 | <2 | 25 | <2 | 294 |
| LR_28 | 19100 | 1680 | 11 | 4 | 37 | 239 | 149 | <2 | 27 | <2 | 1280 |
| LR_29 | 25600 | 575 | 16 | 3 | 42 | 390 | 288 | <2 | 30 | <2 | 891 |
| LR_30 | 33000 | 1350 | 25 | 19 | 39 | 594 | 644 | <2 | 28 | 2 | 1570 |
| LR_30-DUP | 28000 | 11500 | 23 | 18 | 37 | 528 | 587 | <2 | 26 | <2 | 1200 |
| LR_31 | 21300 | 6050 | 16 | 4 | 42 | 352 | 225 | <2 | 28 | <2 | 329 |
| LR_32 | 27400 | 6540 | 24 | 47 | 39 | 567 | 504 | <2 | 26 | <2 | 1330 |
| LR_33 | 20600 | 1170 | 11 | 5 | 40 | 331 | 180 | <2 | 28 | <2 | 376 |
| LR_34 | 18700 | 638 | 15 | 6 | 38 | 291 | 394 | <2 | 26 | <2 | 471 |
| LR_35 | 23000 | 746 | 19 | 18 | 36 | 420 | 399 | <2 | 25 | <2 | 870 |
| LR_36 | 17800 | 356 | 15 | 11 | 31 | 286 | 200 | <2 | 24 | <2 | 612 |
| LR_37 | 17600 | 570 | 13 | 4 | 34 | 341 | 242 | <2 | 24 | <2 | 386 |
| LR_38 | 22400 | 851 | 14 | 6 | 41 | 333 | 202 | <2 | 30 | <2 | 434 |
| LR_39 | 19800 | 397 | 16 | 5 | 37 | 312 | 354 | <2 | 26 | <2 | 471 |
| LR_40 | 24100 | 753 | 17 | 5 | 42 | 335 | 204 | <2 | 31 | <2 | 369 |
| LR_40-DUP | 26000 | 1360 | 17 | 5 | 46 | 341 | 229 | <2 | 34 | <2 | 412 |
| LR_41 | 21200 | 1040 | 14 | 5 | 38 | 245 | 204 | <2 | 28 | <2 | 441 |
| LR_42 | 20100 | 1050 | 21 | 12 | 31 | 354 | 486 | <2 | 22 | <2 | 670 |
| LR_43 | 20500 | 238 | 14 | 5 | 36 | 294 | 196 | <2 | 26 | <2 | 376 |
| LR_44 | 22700 | 1050 | 16 | 6 | 38 | 338 | 277 | <2 | 29 | <2 | 552 |

**Table A14 (continue)**

| Site | Aluminium | Antimony | Arsenic | Cadmium | Chromium | Copper | Lead | Molybdenum | Nickel | Silver | Zinc |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | mg/kg (total concentrations in <63µm fraction) | | | | | | | | | | |
| LR_45 | 24400 | <5 | 28 | 8 | 38 | 612 | 580 | <2 | 29 | <2 | 846 |
| LR_46 | 23100 | <5 | 21 | 13 | 40 | 349 | 495 | <2 | 28 | <2 | 866 |
| LR_47 | 21600 | <5 | 16 | 10 | 35 | 253 | 286 | <2 | 24 | <2 | 531 |
| LR_48 | 20900 | <5 | 25 | 9 | 37 | 422 | 729 | <2 | 26 | <2 | 872 |
| LR_49 | 23600 | <5 | 20 | 6 | 39 | 425 | 486 | <2 | 29 | <2 | 713 |
| LR_50 | 35400 | <5 | 14 | 9 | 27 | 300 | 235 | <2 | 20 | <2 | 495 |
| LR_50-DUP | 32600 | <5 | 18 | 13 | 33 | 310 | 284 | <2 | 22 | <2 | 559 |
| LR_51 | 24300 | <5 | 22 | 8 | 40 | 392 | 503 | <2 | 28 | <2 | 682 |
| LR_52 | 27100 | <5 | 18 | 6 | 40 | 348 | 356 | <2 | 29 | <2 | 616 |
| LR_53 | 21400 | <5 | 24 | 7 | 38 | 448 | 601 | <2 | 26 | <2 | 741 |
| LR_54 | 21200 | <5 | 18 | 6 | 34 | 312 | 376 | <2 | 24 | <2 | 614 |
| LR_55 | 26400 | <5 | 20 | 7 | 38 | 407 | 440 | <2 | 28 | <2 | 740 |
| LR_56 | 20800 | <5 | 18 | 6 | 36 | 335 | 390 | <2 | 27 | <2 | 551 |
| LR_57 | 20000 | <5 | 17 | 9 | 30 | 236 | 265 | <2 | 23 | <2 | 571 |
| LR_58 | 25800 | <5 | 21 | 7 | 37 | 396 | 385 | <2 | 27 | <2 | 682 |
| LR_59 | 23900 | <5 | 25 | 8 | 41 | 452 | 614 | <2 | 28 | <2 | 768 |
| LR_60 | 28400 | <5 | 21 | 7 | 41 | 413 | 456 | <2 | 30 | <2 | 756 |
| LR_60-DUP | 23200 | <5 | 18 | 6 | 37 | 343 | 411 | <2 | 26 | <2 | 612 |
| LR_61 | 24400 | <5 | 44 | 14 | 42 | 498 | 1660 | <2 | 29 | 5 | 2170 |
| LR_62 | 24700 | <5 | 25 | 19 | 31 | 356 | 457 | <2 | 25 | <2 | 902 |
| LR_63 | 25700 | <5 | 16 | 5 | 37 | 298 | 287 | <2 | 27 | <2 | 537 |
| LR_64 | 24900 | <5 | 20 | 6 | 39 | 369 | 458 | <2 | 28 | <2 | 708 |
| LR_65 | 26900 | <5 | 14 | 13 | 31 | 261 | 412 | <2 | 23 | <2 | 797 |
| LR_66 | 24100 | <5 | 18 | 6 | 41 | 341 | 385 | <2 | 30 | <2 | 655 |

**Table A14 (continue)**

| Site | Aluminium | Antimony | Arsenic | Cadmium | Chromium | Copper | Lead | Molybdenum | Nickel | Silver | Zinc |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | mg/kg (total concentrations in <63µm fraction) | | | | | | | | | | |
| LR_67 | 24400 | <5 | 21 | 9 | 47 | 272 | 769 | <2 | 34 | 2 | 1370 |
| LR_68 | 29400 | <5 | 18 | 13 | 40 | 412 | 373 | <2 | 27 | <2 | 743 |
| LR_69 | 24500 | <5 | 22 | 6 | 47 | 409 | 541 | <2 | 33 | <2 | 661 |
| LR_70 | 31900 | <5 | 14 | 4 | 36 | 334 | 265 | <2 | 28 | <2 | 544 |
| LR_70-DUP | 36600 | <5 | 15 | 5 | 38 | 331 | 283 | <2 | 30 | <2 | 541 |
| LR_71 | 19800 | <5 | 18 | 6 | 37 | 332 | 405 | <2 | 27 | <2 | 605 |
| LR_72 | 26800 | <5 | 21 | 7 | 34 | 311 | 509 | <2 | 24 | <2 | 816 |
| LR_73 | 22400 | <5 | 19 | 6 | 36 | 335 | 376 | <2 | 26 | <2 | 603 |
| LR_74 | 15500 | <5 | 14 | 5 | 31 | 306 | 334 | <2 | 22 | <2 | 468 |
| LR_75 | 32700 | <5 | 15 | 6 | 30 | 327 | 384 | <2 | 22 | <2 | 621 |
| LR_76 | 18100 | <5 | 13 | 5 | 34 | 288 | 263 | <2 | 26 | <2 | 486 |
| LR_77 | 19500 | <5 | 14 | 5 | 38 | 241 | 266 | <2 | 28 | <2 | 496 |
| LR_78 | 17200 | <5 | 13 | 5 | 33 | 259 | 328 | <2 | 25 | <2 | 585 |
| LR_79 | 20600 | <5 | 22 | 17 | 37 | 631 | 711 | <2 | 28 | <2 | 3100 |

**Table A15 Total metal and metalloid concentrations in Leichhardt River Verification Samples collected 13-14 November 2009 by Xstrata (<2mm fraction)**

| Sites | Aluminium | Antimony | Arsenic | Cadmium | Chromium | Copper | Lead | Molybdenum | Nickel | Silver | Zinc | Mercury |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | mg/kg (total concentrations in <2mm fraction) | | | | | | | | | | | |
| LR_01 | 3580 | <5 | 11 | 6 | 11 | 171 | 526 | <2 | 7 | <2 | 824 | <0.1 |
| LR_02 | 3150 | <5 | <5 | 1 | 10 | 43 | 23 | <2 | 6 | <2 | 77 | <0.1 |
| LR_03 | 2040 | <5 | 6 | 7 | 6 | 46 | 549 | <2 | 4 | 6 | 628 | 0.1 |
| LR_04 | 3200 | <5 | <5 | 4 | 9 | 38 | 51 | <2 | 9 | <2 | 88 | <0.1 |
| LR_05 | 7980 | <5 | 17 | 11 | 19 | 306 | 1030 | <2 | 14 | <2 | 1090 | <0.1 |
| LR_06 | 2630 | <5 | <5 | 3 | 7 | 56 | 222 | <2 | 4 | <2 | 377 | <0.1 |
| LR_07 | 2450 | <5 | <5 | <1 | 7 | 29 | 42 | <2 | 4 | <2 | 77 | <0.1 |
| LR_08 | 7510 | <5 | 21 | 6 | 16 | 730 | 634 | <2 | 14 | <2 | 843 | <0.1 |
| LR_09 | 7850 | 10 | 54 | 21 | 18 | 769 | 3690 | <2 | 14 | 9 | 6690 | 0.3 |
| LR_10 | 16200 | <5 | 508 | 42 | 33 | 2540 | 2230 | 2 | 26 | 7 | 5530 | 0.3 |
| LR_10-DUP | 16000 | <5 | 527 | 44 | 32 | 2580 | 2310 | 2 | 25 | 7 | 6320 | 0.3 |
| LR_10-Mean | 16100 | <5 | 517.5 | 43 | 32.5 | 2560 | 2270 | 2 | 25.5 | 7 | 5925 | 0.3 |
| LR_10-SD | 141 | N/A | 13 | 1 | 1 | 28 | 57 | 0 | 1 | 0 | 559 | 0 |
| LR_11 | 2100 | <5 | <5 | <1 | 6 | 17 | 21 | <2 | 4 | <2 | 49 | <0.1 |
| LR_12 | 2010 | <5 | <5 | <1 | 6 | 17 | 16 | <2 | 4 | <2 | 73 | <0.1 |
| LR_13 | 1820 | <5 | <5 | 2 | 5 | 40 | 26 | <2 | 3 | <2 | 66 | <0.1 |
| LR_14 | 6350 | <5 | <5 | 2 | 17 | 56 | 43 | <2 | 10 | <2 | 103 | <0.1 |
| LR_15 | 2400 | <5 | <5 | 2 | 7 | 22 | 16 | <2 | 4 | <2 | 56 | <0.1 |
| LR_16 | 3230 | <5 | <5 | 3 | 8 | 36 | 53 | <2 | 5 | <2 | 124 | <0.1 |
| LR_17 | 4720 | <5 | <5 | 1 | 12 | 35 | 24 | <2 | 8 | <2 | 81 | <0.1 |
| LR_18 | 2480 | <5 | 5 | 3 | 8 | 36 | 71 | <2 | 6 | <2 | 368 | <0.1 |
| LR_19 | 4810 | <5 | 7 | 5 | 12 | 88 | 253 | <2 | 8 | <2 | 386 | <0.1 |
| LR_20 | 5040 | <5 | 7 | 4 | 13 | 102 | 297 | <2 | 8 | <2 | 379 | <0.1 |
| LR_20-DUP | 4390 | <5 | 7 | 3 | 15 | 86 | 247 | <2 | 7 | <2 | 331 | <0.1 |
| LR_21 | 9620 | <5 | 6 | 2 | 22 | 111 | 64 | <2 | 15 | <2 | 142 | <0.1 |
| LR_22 | 2080 | <5 | <5 | 2 | 6 | 23 | 47 | <2 | 4 | <2 | 111 | <0.1 |
| LR_23 | 3360 | <5 | 5 | 3 | 9 | 49 | 147 | <2 | 6 | <2 | 227 | <0.1 |
| LR_24 | 4340 | <5 | <5 | 3 | 12 | 48 | 43 | <2 | 9 | <2 | 212 | <0.1 |
| LR_25 | 2880 | <5 | <5 | 2 | 7 | 35 | 59 | <2 | 5 | <2 | 144 | <0.1 |
| NEPM HIL level E | N/A | N/A | 200 | 40 | N/A | 2000 | 600 | N/A | 600 | N/A | 14000 | N/A |

**Table A15 (continue)**

| Sites | Aluminium | Antimony | Arsenic | Cadmium | Chromium | Copper | Lead | Molybdenum | Nickel | Silver | Zinc | Mercury |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | mg/kg (total concentrations in <2 mm fraction) | | | | | | | | | | | |
| LR_26 | 2570 | <5 | <5 | 1 | 7 | 28 | 54 | <2 | 4 | <2 | 125 | <0.1 |
| LR_27 | 10600 | <5 | 7 | 3 | 24 | 148 | 102 | <2 | 17 | <2 | 209 | <0.1 |
| LR_28 | 12800 | <5 | 8 | 3 | 27 | 177 | 98 | <2 | 21 | <2 | 765 | <0.1 |
| LR_29 | 3080 | <5 | <5 | <1 | 8 | 30 | 35 | <2 | 5 | <2 | 48 | <0.1 |
| LR_30 | 2540 | <5 | <5 | 2 | 7 | 45 | 78 | <2 | 5 | <2 | 222 | <0.1 |
| LR_30-DUP | 3640 | <5 | 6 | 4 | 12 | 338 | 136 | <2 | 7 | <2 | 379 | <0.1 |
| LR_31 | 15700 | <5 | 12 | 3 | 33 | 281 | 163 | <2 | 24 | <2 | 253 | <0.1 |
| LR_32 | 2590 | <5 | <5 | 4 | 8 | 58 | 71 | <2 | 5 | <2 | 210 | <0.1 |
| LR_33 | 6320 | <5 | <5 | 2 | 14 | 89 | 51 | <2 | 10 | <2 | 127 | <0.1 |
| LR_34 | 13800 | <5 | 11 | 6 | 30 | 254 | 326 | <2 | 22 | <2 | 411 | <0.1 |
| LR_35 | 2430 | <5 | <5 | 2 | 7 | 35 | 61 | <2 | 4 | <2 | 153 | <0.1 |
| LR_36 | 2180 | <5 | <5 | 1 | 6 | 21 | 22 | <2 | 5 | <2 | 91 | <0.1 |
| LR_37 | 9950 | <5 | 8 | 2 | 21 | 186 | 131 | <2 | 15 | <2 | 227 | <0.1 |
| LR_38 | 4410 | <5 | <5 | 1 | 11 | 65 | 47 | <2 | 7 | <2 | 113 | <0.1 |
| LR_39 | 8360 | <5 | 9 | 3 | 18 | 154 | 225 | <2 | 13 | <2 | 316 | <0.1 |
| LR_40 | 11400 | <5 | 8 | 2 | 23 | 192 | 109 | <2 | 17 | <2 | 206 | <0.1 |
| LR_40-DUP | 11900 | <5 | 8 | 3 | 24 | 203 | 116 | <2 | 18 | <2 | 216 | <0.1 |
| LR_41 | 8490 | <5 | 6 | 2 | 18 | 117 | 98 | <2 | 13 | <2 | 228 | 0.8 |
| LR_42 | 3030 | <5 | <5 | 2 | 8 | 55 | 97 | <2 | 5 | <2 | 171 | <0.1 |
| LR_43 | 11300 | <5 | 7 | 3 | 22 | 193 | 128 | <2 | 17 | <2 | 249 | <0.1 |
| LR_44 | 3500 | <5 | <5 | <1 | 9 | 45 | 48 | <2 | 6 | <2 | 124 | <0.1 |
| LR_45 | 3880 | <5 | 7 | 2 | 11 | 108 | 168 | <2 | 7 | <2 | 270 | <0.1 |
| LR_46 | 3180 | <5 | <5 | 2 | 8 | 50 | 118 | <2 | 6 | <2 | 195 | <0.1 |
| LR_47 | 3040 | <5 | 8 | 2 | 8 | 46 | 62 | <2 | 5 | <2 | 132 | <0.1 |
| LR_48 | 9490 | <5 | 12 | 5 | 20 | 242 | 393 | <2 | 15 | <2 | 476 | <0.1 |
| LR_49 | 2980 | <5 | <5 | <1 | 8 | 41 | 68 | <2 | 5 | <2 | 112 | <0.1 |
| LR_50 | 1570 | <5 | <5 | <1 | 6 | 22 | 54 | <2 | 3 | <2 | 110 | <0.1 |
| LR_50-DUP | 1870 | <5 | <5 | <1 | 5 | 27 | 45 | <2 | 4 | <2 | 117 | <0.1 |
| LR_51 | 6420 | <5 | 7 | 2 | 14 | 121 | 168 | <2 | 10 | <2 | 247 | <0.1 |
| LR_52 | 2040 | <5 | <5 | <1 | 6 | 20 | 43 | <2 | 4 | <2 | 90 | <0.1 |
| **NEPM HIL level E** | **N/A** | **N/A** | **200** | **40** | **N/A** | **2000** | **600** | **N/A** | **600** | **N/A** | **14000** | **N/A** |

**Table A15 (continue)**

| Sites | Aluminium | Antimony | Arsenic | Cadmium | Chromium | Copper | Lead | Molybdenum | Nickel | Silver | Zinc | Mercury |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | mg/kg (total concentrations in <2mm fraction) | | | | | | | | | | | |
| LR_53 | 7240 | <5 | 9 | 2 | 16 | 160 | 218 | <2 | 11 | <2 | 294 | <0.1 |
| LR_54 | 1720 | <5 | <5 | <1 | 4 | 20 | 43 | <2 | 3 | <2 | 117 | <0.1 |
| LR_55 | 3240 | <5 | <5 | 1 | 9 | 40 | 71 | <2 | 6 | <2 | 170 | <0.1 |
| LR_56 | 5480 | <5 | 6 | 2 | 13 | 96 | 147 | <2 | 8 | <2 | 246 | <0.1 |
| LR_57 | 1840 | <5 | <5 | 1 | 5 | 25 | 54 | <2 | 4 | <2 | 138 | <0.1 |
| LR_58 | 3150 | <5 | <5 | <1 | 9 | 38 | 69 | <2 | 5 | <2 | 135 | <0.1 |
| LR_59 | 10500 | <5 | 11 | 4 | 22 | 248 | 316 | <2 | 16 | <2 | 419 | <0.1 |
| LR_60 | 3960 | <5 | <5 | <1 | 11 | 46 | 85 | <2 | 7 | <2 | 166 | <0.1 |
| LR_60-DUP | 4120 | 6 | <5 | 1 | 11 | 49 | 80 | <2 | 7 | <2 | 158 | <0.1 |
| LR_61 | 7440 | <5 | 12 | 5 | 17 | 172 | 518 | <2 | 12 | <2 | 716 | <0.1 |
| LR_62 | 1880 | <5 | <5 | 1 | 5 | 28 | 45 | <2 | 3 | <2 | 106 | <0.1 |
| LR_63 | 2820 | <5 | <5 | <1 | 8 | 28 | 39 | <2 | 5 | <2 | 97 | <0.1 |
| LR_64 | 6420 | <5 | 6 | 2 | 15 | 88 | 144 | <2 | 10 | <2 | 263 | <0.1 |
| LR_65 | 2600 | <5 | <5 | 1 | 8 | 41 | 92 | <2 | 5 | <2 | 176 | <0.1 |
| LR_66 | 4440 | <5 | <5 | 1 | 12 | 54 | 84 | <2 | 8 | <2 | 176 | <0.1 |
| LR_67 | 5820 | <5 | <5 | 1 | 14 | 43 | 149 | <2 | 9 | <2 | 287 | <0.1 |
| LR_68 | 990 | <5 | <5 | <1 | 3 | 13 | 32 | <2 | 2 | <2 | 62 | <0.1 |
| LR_69 | 5560 | <5 | <5 | <1 | 14 | 59 | 83 | <2 | 9 | <2 | 120 | <0.1 |
| LR_70 | 1810 | <5 | <5 | <1 | 5 | 14 | 26 | <2 | 3 | <2 | 61 | <0.1 |
| LR_70-DUP | 2640 | <5 | <5 | <1 | 8 | 23 | 37 | <2 | 4 | <2 | 86 | <0.1 |
| LR_71 | 7120 | <5 | 7 | 2 | 16 | 120 | 166 | <2 | 11 | <2 | 269 | <0.1 |
| LR_72 | 1930 | <5 | <5 | <1 | 5 | 26 | 60 | <2 | 3 | <2 | 117 | <0.1 |
| LR_73 | 4550 | <5 | <5 | 2 | 11 | 64 | 97 | <2 | 8 | <2 | 182 | <0.1 |
| LR_74 | 1560 | <5 | <5 | <1 | 4 | 18 | 40 | <2 | 3 | <2 | 88 | <0.1 |
| LR_75 | 11400 | <5 | 12 | 4 | 24 | 239 | 276 | <2 | 17 | <2 | 408 | <0.1 |
| LR_76 | 12400 | <5 | 10 | 4 | 25 | 199 | 190 | <2 | 18 | <2 | 364 | <0.1 |
| LR_77 | 11000 | <5 | 10 | 2 | 24 | 255 | 177 | <2 | 17 | <2 | 359 | <0.1 |
| LR_78 | 4130 | <5 | <5 | 1 | 10 | 53 | 87 | <2 | 6 | <2 | 170 | <0.1 |
| LR_79 | 14000 | <5 | 18 | 11 | 27 | 447 | 557 | <2 | 19 | <2 | 1900 | <0.1 |
| **NEPM HIL level E** | **N/A** | **N/A** | **200** | **40** | **N/A** | **2000** | **600** | **N/A** | **600** | **N/A** | **14000** | **N/A** |

Red values: Sites exceed NEPM HIL level E

**Table A16 GPS coordinates of regional/background sediment and Annual Stream Sediment sites collected 13-14 November 2009 by Xstrata**

| Sample ID | Easting | Northing |
|---|---|---|
| RB_01 | 340084.7 | 7698396 |
| RB_02 | 341262.7 | 7698165 |
| RB_03 | 340134.4 | 7696956 |
| RB_04 | 339332.6 | 7696592 |
| RB_05 | 339012.7 | 7695618 |
| RB_06 | 338240.6 | 7696318 |
| RB_07 | 338032.4 | 7695726 |
| RB_08 | 337851 | 7695969 |
| RB_09 | 337324.2 | 7696525 |
| RB_10 | 337322.9 | 7696821 |
| RB_11 | 336610.7 | 7697149 |
| RB_12 | 343605.9 | 7698889 |
| RB_13 | 343254.5 | 7697195 |
| RB_14 | 342647.2 | 7696613 |
| RB_15 | 342228.8 | 7696412 |
| RB_16 | 341904.1 | 7696009 |
| RB_17 | 343858.9 | 7694542 |
| RB_18 | 342717.2 | 7694480 |
| RB_19 | 343197.6 | 7691794 |
| RB_20 | 342758.2 | 7690930 |
| RB_21 | 341815.3 | 7690441 |
| RB_22 | 340754.9 | 7690264 |

| Sample ID | Easting | Northing |
|---|---|---|
| RB_23 | 339910.6 | 7690575 |
| RB_23Z | 340822.3 | 7689352 |
| RB_24 | 338616.4 | 7690498 |
| RB_25 | 340650.6 | 7688348 |
| RB_26 | 340858.8 | 7687860 |
| RB_27 | 340766 | 7686130 |
| RB_28 | 340853.1 | 7685490 |
| RB_29 | 346429.6 | 7689151 |
| **Annual Stream Sediment Locations** | | |
| **Sample ID** | **Easting** | **Northing** |
| Spring Creek (SPC) - Bridge | 338315 | 7729763 |
| 1st SPC Gully | 338530 | 7729713 |
| 2nd SPC Gully | 338767 | 7729584 |

**Table A17 Concentrations of metal and metalloid 1M HCl extraction in regional/background sediment (<63mm fraction) collected by Xstrata 11 November 2009**

| Site | Aluminium | Antimony | Arsenic | Cadmium | Chromium | Cobalt | Copper | Iron | Lead | Manganese | Mercury | Molybdenum | Nickel | Selenium | Vanadium | Zinc |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | mg/kg (1M HCl extraction concentration in <63µm fraction) | | | | | | | | | | | | | | | |
| RB_01 | 673 | <1.0 | 2.1 | 0.7 | <1 | 2.0 | 161.0 | 1127 | 67 | 60 | <0.1 | <0.5 | <0.1 | <0.5 | 3.4 | 22.5 |
| RB_02 | 880 | <1.0 | 3.5 | 0.4 | <1 | 3.1 | 79.2 | 1010 | 41 | 204 | <0.1 | <0.5 | <0.1 | 0.67 | 4.6 | 13.4 |
| RB_03 | 1007 | <1.0 | 4.8 | 0.3 | 2 | 3.3 | 115.6 | 1390 | 51 | 199 | <0.1 | <0.5 | 1.5 | 0.8 | 5.9 | 18.8 |
| RB_04 | 1390 | <1.0 | 11.0 | <1 | 2 | 6.3 | 203.7 | 3740 | 95 | 395 | <0.1 | <0.5 | 2.0 | 3 | 9.0 | 39.7 |
| RB_05 | 1623 | <1.0 | 3.0 | <1 | 1 | 6.0 | 125.3 | 1853 | 63 | 246 | <0.1 | <0.5 | 2.0 | <1 | 9.3 | 23.0 |
| RB_06 | 950 | <1.0 | 5.5 | 0.3 | 2 | 2.2 | 71.9 | 1180 | 46 | 249 | <0.1 | <0.5 | <1 | 0.8 | 3.8 | 19.5 |
| RB_07 | 1317 | <1.0 | 10.7 | 0.4 | 2 | 2.2 | 96.3 | 1487 | 55 | 308 | <0.1 | <0.5 | <1 | 1.2 | 3.5 | 22.3 |
| RB_08 | 1823 | <1.0 | 8.0 | 1.1 | 4 | 4.7 | 225.7 | 2923 | 140 | 291 | <0.1 | <0.5 | 3.0 | 1.5 | 8.8 | 90.7 |
| RB_09 | 1303 | <1.0 | 8.9 | 0.9 | 1 | 5.1 | 99.3 | 1877 | 66 | 716 | <0.1 | <0.5 | 2.0 | 1 | 6.4 | 27.8 |
| RB_10 | 1543 | <1.0 | 9.0 | 1.0 | 2 | 4.7 | 196.7 | | 99 | 374 | <0.1 | <0.5 | 1.7 | <1 | 8.7 | 34.3 |
| RB_11 | 1187 | <1.0 | 8.3 | <1 | 2 | 3.0 | 194.0 | 1377 | 85 | 231 | <0.1 | <0.5 | 1.0 | <1 | 5.7 | 27.0 |
| RB_12 | 1020 | <1.0 | 1.3 | 0.2 | <1 | 4.2 | 37.6 | 883 | 20 | 238 | <0.1 | <0.5 | 1.3 | <0.5 | 7.4 | 13.6 |
| RB_13 | 610 | <1.0 | <1.0 | 0.1 | 1 | 5.6 | 40.7 | 443 | 15 | 212 | <0.1 | <0.5 | 1.3 | <0.5 | 4.8 | 6.9 |
| RB_14 | 643 | <1.0 | <1.0 | <0.1 | <1 | 5.0 | 27.9 | 240 | 11 | 149 | <0.1 | <0.5 | 1.4 | <0.5 | 6.9 | 3.1 |
| RB_15 | 1867 | <1.0 | <1.0 | 0.1 | 1 | 12.1 | 52.1 | 1267 | 15 | 342 | <0.1 | <0.5 | 3.0 | <0.5 | 11.7 | 4.7 |
| RB_16 | 1427 | <1.0 | <1.0 | 0.1 | <1 | 8.6 | 84.0 | 797 | 15 | 287 | <0.1 | <0.5 | 1.0 | 0 | 6.6 | 4.4 |
| RB_17 | 1720 | <1.0 | 3.6 | 0.4 | 1.6 | 6.7 | 77.2 | 2547 | 54 | 350 | <0.1 | <0.5 | 2.4 | 0 | 11.6 | 22.2 |
| RB_18 | 1303 | <1.0 | <1.0 | 0.2 | 1 | 9.9 | 42.6 | 1537 | 29 | 500 | <0.1 | <0.5 | 2.6 | 0 | 10.0 | 19.4 |
| RB_19 | 1030 | <1.0 | 2.5 | 0.2 | 1 | 4.1 | 34.0 | 1157 | 28 | 231 | <0.1 | <0.5 | 1.2 | 0 | 5.9 | 12.5 |
| RB_20 | 1333 | <1.0 | 4.5 | 0.5 | 1.6 | 5.8 | 58.4 | 1823 | 41 | 304 | <0.1 | <0.5 | 1.9 | <1 | 7.8 | 18.6 |
| RB_21 | 1340 | <1.0 | 5.1 | 0.2 | 1 | 3.3 | 21.8 | 1553 | 24 | 235 | <0.1 | <0.5 | 1.2 | 0 | 6.4 | 12.1 |
| RB_22 | 1183 | <1.0 | 4.4 | 0.2 | 1 | 4.5 | 25.0 | 1537 | 26 | 253 | <0.1 | <0.5 | 1.2 | <1 | 5.6 | 13.7 |
| RB_23 | 1510 | <1.0 | 6.3 | 0.3 | 1.3 | 4.4 | 58.4 | 1863 | 42 | 250 | <0.1 | <0.5 | 1.7 | <1 | 7.0 | 18.9 |
| RB_23Z | 1620 | <1.0 | 1.9 | 0.6 | <1 | 6.2 | 58.1 | 3180 | 68 | 257 | <0.1 | <0.5 | 1.6 | 0 | 9.8 | 27.6 |
| RB_24 | 2387 | <1.0 | 10.1 | 0.4 | <1 | 3.7 | 58.1 | 2550 | 55 | 367 | <0.1 | <0.5 | <1 | 0 | 7.0 | 28.5 |
| RB_25 | 1343 | <1.0 | 2.7 | 0.4 | 1.3 | 3.1 | 59.1 | 4480 | 59 | 98 | <0.1 | <0.5 | 1.1 | 0 | 9.7 | 21.6 |
| RB_26 | 1093 | <1.0 | 2.3 | 0.4 | 2 | 5.2 | 49.4 | 1627 | 32 | 279 | <0.1 | <0.5 | 1.8 | <1 | 6.0 | 19.6 |
| RB_27 | 647 | <1.0 | <1.0 | 0.3 | <1 | 6.2 | 49.0 | 850 | 18 | 170 | <0.1 | <0.5 | 1.9 | <1 | 4.6 | 9.4 |
| RB_28 | 687 | <1.0 | <1.0 | 0.3 | <1 | 4.5 | 43.1 | 1083 | 21 | 154 | <0.1 | <0.5 | 1.5 | <1 | 3.3 | 11.3 |
| RB_29 | 1097 | <1.0 | 1 | <1 | 2 | 5.5 | 19.0 | 2047 | 12 | 600 | <0.1 | <0.5 | 2.0 | <1 | 10.3 | 14.3 |

**Table A17 (continue)**

| | Aluminium | Antimony | Arsenic | Cadmium | Chromium | Cobalt | Copper | Iron | Lead | Manganese | Mercury | Molybdenum | Nickel | Selenium | Vanadium | Zinc |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | mg/kg (1M HCl extraction concentration in <63µm fraction) | | | | | | | | | | | | | | | |
| Spring creek bridge | 550 | <1.0 | 1.8 | 0.7 | <1.0 | 5.4 | 84.0 | 1200 | 79 | 260 | <0.10 | <0.5 | 1.2 | | 5.1 | 30 |
| 1st SPC Gully | 540 | <1.0 | 1.1 | 0.7 | <1.0 | 3.8 | 86.9 | 400 | 91 | 105 | <0.10 | <0.5 | 1.2 | | <2.0 | 40.2 |
| 2nd SPC Gully | 950 | <1.0 | 2.0 | 0.9 | <1.0 | 6.4 | 100 | 2880 | 109 | 158 | <0.10 | <0.5 | 1.7 | | 12.4 | 59.2 |

**Table A18 Total metal and metalloid concentrations in regional/background sediment samples (<63µm fraction) collected by Xstrata 11 November 2009**

| Sites | Aluminium | Antimony | Arsenic | Cadmium | Chromium | Copper | Lead | Molybdenum | Nickel | Silver | Zinc |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | mg/kg (total concentration in <63µm fraction) | | | | | | | | | | |
| RB_01 | 7900 | <5 | 26 | 1 | 21 | 332 | 116 | <2 | 10 | <2 | 100 |
| RB_01a | 9240 | <5 | 26 | 1 | 20 | 373 | 124 | <2 | 10 | <2 | 90 |
| RB_01b | 9470 | <5 | 28 | 1 | 22 | 414 | 136 | 4 | 10 | <2 | 91 |
| RB_02 | 23400 | <5 | 20 | 2 | 30 | 271 | 98 | <2 | 24 | <2 | 134 |
| RB_02a | 17800 | <5 | 18 | 1 | 24 | 218 | 88 | <2 | 18 | <2 | 113 |
| RB_02b | 24100 | <5 | 24 | 2 | 26 | 316 | 130 | <2 | 22 | <2 | 162 |
| RB_03 | 26600 | <5 | 18 | 1 | 29 | 318 | 99 | <2 | 22 | <2 | 184 |
| RB_03a | 24600 | <5 | 22 | 2 | 26 | 273 | 103 | <2 | 20 | <2 | 151 |
| RB_03b | 42300 | 9 | 22 | <4 | 58 | 413 | 92 | <7 | 22 | <7 | 332 |
| RB_04 | 34000 | 5 | 18 | <2 | 46 | 294 | 86 | <4 | 17 | <4 | 255 |
| RB_04a | 36000 | <17 | <17 | <8 | 77 | 192 | 43 | <17 | 18 | <17 | 171 |
| RB_04b | 45000 | 7 | 15 | <3 | 54 | 251 | 64 | <5 | 17 | <5 | 218 |
| RB_05 | 433000 | 204 | 135 | 17 | 421 | 3110 | 965 | <24 | 312 | <24 | 5340 |
| RB_05a | 32200 | <5 | 26 | 3 | 33 | 362 | 311 | <2 | 29 | <2 | 536 |
| RB_05b | 34000 | 7 | 15 | <2 | 34 | 332 | 126 | <3 | 26 | <3 | 185 |
| RB_06 | 24000 | <5 | 22 | 2 | 15 | 235 | 93 | <2 | 11 | <2 | 162 |
| RB_06a | 29000 | <5 | 17 | <1 | 18 | 229 | 73 | <2 | 13 | <2 | 145 |
| RB_06b | 31300 | 10 | 16 | <2 | 23 | 226 | 73 | <3 | 9 | <3 | 296 |
| RB_07 | 25100 | <5 | 21 | <1 | 13 | 150 | 66 | 2 | 6 | <2 | 262 |
| RB_07a | 21600 | <5 | 25 | 1 | 9 | 145 | 70 | <2 | 5 | <2 | 169 |
| RB_07b | 32600 | 6 | 24 | 11 | 8 | 245 | 98 | <5 | 5 | <5 | 242 |
| RB_08 | 33700 | <5 | 21 | 2 | 26 | 420 | 188 | <2 | 20 | <2 | 243 |
| RB_08a | 25300 | <5 | 26 | 2 | 26 | 502 | 203 | <2 | 19 | <2 | 230 |
| RB_08b | 37000 | <5 | 23 | 2 | 39 | 318 | 148 | <3 | 23 | <3 | 383 |
| RB_09 | 148000 | <5 | 166 | 15 | 145 | 3320 | 1350 | 10 | 117 | <3 | 1440 |
| RB_09a | 55300 | 51 | 24 | <3 | 33 | 420 | 148 | <6 | 22 | <6 | 444 |
| RB_09b | 20000 | 11 | 14 | <1 | 18 | 126 | 44 | <2 | 8 | <2 | 340 |
| RB_10 | 20800 | <5 | 24 | 2 | 12 | 415 | 109 | <2 | 9 | <2 | 207 |
| RB_10a | 18700 | <5 | 19 | 1 | 12 | 296 | 74 | <2 | 8 | <2 | 173 |
| RB_10b | 27400 | <5 | 16 | 1 | 20 | 596 | 86 | <2 | 15 | <2 | 196 |
| RB_10c | 17100 | <5 | 14 | <2 | 22 | 312 | 84 | <3 | 11 | <3 | 152 |

**Table A18 (continue)**

| Sites | Aluminium | Antimony | Arsenic | Cadmium | Chromium | Copper | Lead | Molybdenum | Nickel | Silver | Zinc |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | mg/kg (total concentration in <63µm fraction) | | | | | | | | | | |
| RB_10ac | 29600 | 15 | 20 | <2 | 41 | 438 | 113 | <3 | 16 | <3 | 274 |
| RB_10bc | 19400 | 18 | 12 | <1 | 19 | 281 | 70 | <2 | 10 | <2 | 157 |
| RB_11 | 28500 | <5 | 18 | <1 | 47 | 398 | 98 | <3 | 16 | <3 | 222 |
| RB_11a | 38500 | 6 | 20 | 2 | 29 | 549 | 127 | <3 | 21 | <3 | 264 |
| RB_11b | 45000 | 7 | 20 | <2 | 31 | 595 | 121 | <4 | 22 | <4 | 236 |
| RB_12 | 29200 | <5 | 19 | 1 | 18 | 365 | 105 | <2 | 10 | <2 | 143 |
| RB_12a | 45800 | 10 | 18 | <2 | 29 | 444 | 108 | <4 | 16 | <4 | 256 |
| RB_12b | 27300 | <5 | 8 | <1 | 46 | 210 | 36 | <2 | 28 | <2 | 124 |
| RB_13 | 27700 | <5 | 7 | <1 | 48 | 177 | 30 | <2 | 31 | <2 | 110 |
| RB_13a | 29600 | <5 | 7 | <1 | 58 | 179 | 29 | <2 | 36 | <2 | 103 |
| RB_13b | 20100 | <5 | 12 | <1 | 31 | 129 | 32 | <2 | 20 | <2 | 71 |
| RB_14 | 23200 | <5 | 11 | <1 | 32 | 129 | 32 | <2 | 19 | <2 | 73 |
| RB_14a | 19800 | <5 | 11 | <1 | 30 | 118 | 31 | <2 | 18 | <2 | 94 |
| RB_14b | 24400 | <5 | 15 | <1 | 38 | 93 | 33 | <2 | 22 | <2 | 56 |
| RB_15 | 21200 | <5 | 13 | <1 | 35 | 76 | 29 | <2 | 20 | <2 | 49 |
| RB_15a | 15700 | <5 | 9 | <1 | 25 | 68 | 21 | <2 | 16 | <2 | 38 |
| RB_15b | 24900 | <5 | 13 | <1 | 39 | 147 | 20 | <2 | 23 | <2 | 52 |
| RB_16 | 22900 | <5 | 13 | <1 | 39 | 157 | 23 | <2 | 24 | <2 | 51 |
| RB_16b | 23300 | <5 | 16 | <1 | 33 | 280 | 17 | <2 | 18 | <2 | 34 |
| RB_17 | 21600 | <5 | 15 | <1 | 31 | 284 | 18 | <2 | 18 | <2 | 34 |
| RB_17a | 24800 | <5 | 16 | <1 | 36 | 284 | 18 | <2 | 20 | <2 | 40 |
| RB_17b | 29500 | <5 | 13 | <1 | 35 | 211 | 44 | <2 | 23 | <2 | 152 |
| RB_18 | 27200 | <5 | 12 | <1 | 28 | 159 | 46 | <2 | 19 | <2 | 133 |
| RB_18a | 26100 | <5 | 10 | <1 | 36 | 151 | 43 | <2 | 23 | <2 | 101 |
| RB_18b | 22800 | <5 | 14 | <1 | 33 | 109 | 54 | <2 | 20 | <2 | 110 |
| RB_19 | 30000 | <5 | 17 | <1 | 41 | 139 | 55 | <2 | 27 | <2 | 156 |
| RB_19a | 21200 | <5 | 13 | <1 | 30 | 100 | 52 | <2 | 19 | <2 | 113 |
| RB_19b | 35100 | <5 | 15 | <1 | 36 | 184 | 55 | <2 | 22 | <2 | 137 |
| RB_20 | 30600 | <5 | 13 | <1 | 35 | 148 | 55 | <2 | 23 | <2 | 126 |
| RB_20a | 30700 | <5 | 15 | <1 | 33 | 139 | 52 | <2 | 21 | <2 | 141 |
| RB_20b | 56100 | <5 | 16 | <3 | 45 | 261 | 63 | <5 | 29 | <5 | 220 |

**Table A18 (continue)**

| Sites | Aluminium | Antimony | Arsenic | Cadmium | Chromium | Copper | Lead | Molybdenum | Nickel | Silver | Zinc |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | mg/kg (total concentration in <63µm fraction) | | | | | | | | | | |
| RB_20c | 59200 | 14 | 22 | <3 | 46 | 224 | 62 | <7 | 30 | <7 | 186 |
| RB_20ac | 63600 | <12 | 15 | <6 | 75 | 175 | 59 | <12 | 33 | <12 | 190 |
| RB_20bc | 46600 | 20 | 11 | <2 | 36 | 166 | 47 | <4 | 24 | <4 | 127 |
| RB_21 | 32200 | <5 | 13 | <1 | 26 | 140 | 45 | <2 | 17 | <2 | 122 |
| RB_21a | 48400 | <5 | 14 | <1 | 31 | 190 | 50 | <2 | 20 | <2 | 134 |
| RB_21b | 53700 | 31 | 15 | <6 | 45 | 186 | 45 | <11 | 31 | <11 | 114 |
| RB_22 | 31800 | <5 | 14 | <1 | 18 | 94 | 37 | <2 | 12 | <2 | 103 |
| RB_22a | 36500 | <5 | 14 | <1 | 37 | 130 | 50 | <2 | 23 | <2 | 281 |
| RB_22b | 12000 | <5 | 12 | <1 | 9 | 48 | 40 | <2 | 8 | <2 | 70 |
| RB_23 | 46900 | <5 | 15 | <1 | 22 | 253 | 53 | 2 | 16 | <2 | 131 |
| RB_23a | 50000 | 10 | 14 | <2 | 28 | 260 | 43 | <4 | 17 | <4 | 137 |
| RB_23b | 54200 | <5 | 14 | <1 | 28 | 245 | 50 | 2 | 20 | <2 | 146 |
| RB_24 | 40100 | <5 | 13 | <1 | 24 | 209 | 55 | <2 | 16 | <2 | 136 |
| RB_24a | 44500 | <5 | 13 | <1 | 22 | 184 | 42 | <2 | 16 | <2 | 121 |
| RB_24b | 18400 | <5 | 15 | <1 | 24 | 122 | 132 | <2 | 17 | <2 | 138 |
| RB_25 | 15600 | <5 | 13 | <1 | 22 | 128 | 134 | <2 | 14 | <2 | 128 |
| RB_25a | 16500 | <5 | 15 | <1 | 21 | 137 | 148 | <2 | 16 | <2 | 160 |
| RB_25b | 39100 | <5 | 27 | <1 | 17 | 216 | 79 | 3 | 9 | <2 | 167 |
| RB_26 | 39100 | <5 | 22 | <1 | 19 | 222 | 74 | 2 | 10 | <2 | 169 |
| RB_26a | 28100 | <5 | 13 | <1 | 12 | 119 | 66 | <2 | 6 | <2 | 97 |
| RB_26b | 8740 | <5 | 15 | <1 | 15 | 94 | 102 | <2 | 8 | <2 | 69 |
| RB_27 | 11400 | <5 | 16 | <1 | 18 | 120 | 125 | <2 | 11 | <2 | 86 |
| RB_27a | 11300 | <5 | 18 | <1 | 18 | 127 | 129 | <2 | 10 | <2 | 88 |
| RB_27b | 33400 | <5 | 16 | <1 | 27 | 196 | 55 | <2 | 18 | <2 | 126 |
| RB_28 | 17000 | <5 | 14 | <1 | 26 | 177 | 54 | <2 | 19 | <2 | 102 |
| RB_28a | 17100 | <5 | 14 | <1 | 23 | 127 | 42 | <2 | 17 | <2 | 83 |
| RB_28b | 15800 | <5 | 11 | <1 | 21 | 125 | 28 | <2 | 20 | <2 | 47 |
| RB_29 | 18100 | <5 | 13 | <1 | 22 | 131 | 28 | <2 | 23 | <2 | 53 |
| RB_29a | 13900 | <5 | 11 | <1 | 21 | 109 | 30 | <2 | 18 | <2 | 52 |
| RB_29b | 17800 | <5 | 12 | <1 | 27 | 137 | 44 | <2 | 18 | <2 | 76 |
| RB_30 | 18500 | <5 | 12 | <1 | 26 | 185 | 40 | <2 | 17 | <2 | 70 |

**Table A18 (continue)**

| Sites | Aluminium | Antimony | Arsenic | Cadmium | Chromium | Copper | Lead | Molybdenum | Nickel | Silver | Zinc |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | mg/kg (total concentration in <63µm fraction) | | | | | | | | | | |
| RB_30a | 17100 | <5 | 13 | <1 | 28 | 137 | 50 | <2 | 19 | <2 | 76 |
| RB_30b | 58100 | 8 | 6 | <2 | 69 | 236 | 32 | <4 | 41 | <4 | 178 |
| RB_30c | 38000 | <5 | 6 | <1 | 53 | 166 | 26 | <2 | 32 | <2 | 109 |
| RB_30ac | 44600 | <5 | <5 | <1 | 68 | 200 | 29 | <2 | 38 | <2 | 129 |
| RB_30bc | 45800 | <5 | 7 | <1 | 64 | 194 | 30 | <2 | 35 | <2 | 132 |

**Table A19 Total metal and metalloid concentrations in regional/background sediment samples (<2mm fraction) collected by Xstrata 11 November 2009**

| Sites | Aluminium | Antimony | Arsenic | Cadmium | Chromium | Copper | Lead | Molybdenum | Nickel | Silver | Zinc |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | mg/kg (total concentrations in <2mm fraction) | | | | | | | | | | |
| RB_01a | 2640 | <5 | 20 | <1 | 12 | 94 | 44 | <2 | 6 | <2 | 31 |
| RB_01b | 2490 | <5 | 21 | <1 | 14 | 83 | 37 | <2 | 6 | <2 | 25 |
| RB_02 | 3190 | <5 | <5 | <1 | 5 | 17 | 9 | <2 | 4 | <2 | 17 |
| RB_02a | 4830 | <5 | <5 | <1 | 8 | 35 | 16 | <2 | 6 | <2 | 27 |
| RB_02b | 4180 | <5 | <5 | <1 | 8 | 28 | 15 | <2 | 5 | <2 | 25 |
| RB_03 | 1590 | <5 | <5 | <1 | 2 | 8 | 8 | <2 | <2 | <2 | 11 |
| RB_03a | 3720 | <5 | <5 | <1 | 6 | 20 | 13 | <2 | 4 | <2 | 24 |
| RB_03b | 2300 | <5 | <5 | <1 | 3 | 10 | 9 | <2 | 2 | <2 | 16 |
| RB_04 | 1480 | <5 | <5 | <1 | <2 | 6 | 6 | <2 | <2 | <2 | 10 |
| RB_04a | 1870 | <5 | <5 | <1 | <2 | 6 | 6 | <2 | <2 | <2 | 11 |
| RB_04b | 1890 | <5 | <5 | <1 | 2 | 8 | 7 | <2 | <2 | <2 | 12 |
| RB_05 | 2740 | 5 | <5 | <1 | 4 | 12 | 8 | <2 | 4 | <2 | 12 |
| RB_05a | 2630 | <5 | <5 | <1 | 3 | 10 | 7 | <2 | 4 | <2 | 14 |
| RB_05b | 2950 | <5 | <5 | <1 | 4 | 17 | 10 | <2 | 4 | <2 | 13 |
| RB_06 | 3050 | <5 | <5 | <1 | <2 | 17 | 12 | <2 | <2 | <2 | 24 |
| RB_06a | 2290 | <5 | <5 | <1 | <2 | 9 | 8 | <2 | <2 | <2 | 17 |
| RB_06b | 1140 | <5 | <5 | <1 | <2 | <5 | <5 | <2 | <2 | <2 | 9 |
| RB_07 | 1740 | <5 | <5 | <1 | <2 | <5 | 7 | <2 | <2 | <2 | 14 |
| RB_07a | 2720 | <5 | <5 | <1 | <2 | 8 | 9 | <2 | <2 | <2 | 22 |
| RB_07b | 1950 | <5 | <5 | <1 | <2 | <5 | 6 | <2 | <2 | <2 | 18 |
| RB_08 | 4060 | <5 | <5 | <1 | 4 | 35 | 21 | <2 | 4 | <2 | 34 |
| RB_08a | 3160 | <5 | <5 | <1 | 3 | 26 | 17 | <2 | 2 | <2 | 26 |
| RB_08b | 2490 | <5 | <5 | <1 | 2 | 11 | 12 | <2 | <2 | <2 | 22 |
| RB_09 | 1940 | <5 | <5 | <1 | <2 | 7 | 8 | <2 | <2 | <2 | 18 |
| RB_09a | 3060 | <5 | <5 | <1 | <2 | 11 | 13 | <2 | <2 | <2 | 26 |
| RB_09b | 3740 | <5 | <5 | <1 | 3 | 16 | 14 | <2 | 2 | <2 | 35 |
| RB_10 | 1900 | <5 | <5 | <1 | 4 | 11 | 8 | <2 | <2 | <2 | 13 |
| RB_10a | 2210 | <5 | <5 | <1 | 4 | 14 | 14 | <2 | 2 | <2 | 15 |
| RB_10b | 1570 | <5 | <5 | <1 | 2 | 8 | 7 | <2 | <2 | <2 | 11 |
| RB_10c | 2080 | <5 | <5 | <1 | 4 | 13 | 9 | <2 | 2 | <2 | 14 |
| RB_10ac | 2300 | <5 | <5 | <1 | 6 | 20 | 13 | <2 | 3 | <2 | 16 |

**Table A19 (continue)**

| Sites | Aluminium | Antimony | Arsenic | Cadmium | Chromium | Copper | Lead | Molybdenum | Nickel | Silver | Zinc |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | mg/kg (total concentrations in <2mm fraction) | | | | | | | | | | |
| RB_10bc | 1680 | <5 | <5 | <1 | <2 | 8 | 6 | <2 | <2 | <2 | 11 |
| RB_11 | 2210 | <5 | <5 | <1 | 3 | 12 | 10 | <2 | 2 | <2 | 16 |
| RB_11a | 2830 | <5 | <5 | <1 | 3 | 15 | 13 | <2 | <2 | <2 | 22 |
| RB_11b | 2450 | <5 | <5 | <1 | 3 | 13 | 11 | <2 | 2 | <2 | 18 |
| RB_12 | 2990 | <5 | <5 | <1 | 8 | 13 | <5 | <2 | 5 | <2 | 14 |
| RB_12a | 2980 | <5 | <5 | <1 | 9 | 11 | <5 | <2 | 6 | <2 | 14 |
| RB_12b | 2480 | <5 | <5 | <1 | 7 | 9 | <5 | <2 | 4 | <2 | 12 |
| RB_13 | 4460 | <5 | 17 | <1 | 38 | 71 | 26 | <2 | 18 | <2 | 41 |
| RB_13a | 4040 | <5 | 12 | <1 | 36 | 84 | 25 | <2 | 18 | <2 | 36 |
| RB_13b | 4360 | <5 | 12 | <1 | 38 | 59 | 22 | <2 | 18 | <2 | 38 |
| RB_14 | 7480 | <5 | 11 | <1 | 29 | 60 | 22 | <2 | 16 | <2 | 30 |
| RB_14a | 6950 | <5 | 9 | <1 | 30 | 47 | 20 | <2 | 15 | <2 | 26 |
| RB_14b | 6500 | <5 | 10 | <1 | 34 | 70 | 36 | <2 | 18 | <2 | 31 |
| RB_15 | 6140 | <5 | 15 | <1 | 37 | 93 | 22 | <2 | 19 | <2 | 36 |
| RB_15a | 5720 | <5 | 8 | <1 | 31 | 80 | 20 | <2 | 18 | <2 | 23 |
| RB_15b | 6870 | <5 | 14 | <1 | 37 | 94 | 40 | <2 | 21 | <2 | 27 |
| RB_16a | 6630 | <5 | 12 | <1 | 24 | 140 | 17 | <2 | 12 | <2 | 20 |
| RB_16b | 9040 | <5 | 14 | <1 | 29 | 178 | 16 | <2 | 16 | <2 | 19 |
| RB_17 | 1370 | <5 | <5 | <1 | 3 | <5 | 5 | <2 | <2 | <2 | 11 |
| RB_17a | 1880 | <5 | <5 | <1 | 4 | 8 | 7 | <2 | 3 | <2 | 16 |
| RB_17b | 1830 | <5 | <5 | <1 | 4 | 5 | 6 | <2 | 2 | <2 | 14 |
| RB_18 | 4060 | <5 | 9 | <1 | 29 | 33 | 35 | <2 | 16 | <2 | 63 |
| RB_18a | 3810 | <5 | 11 | <1 | 30 | 29 | 34 | <2 | 15 | <2 | 54 |
| RB_18b | 3910 | <5 | 12 | <1 | 31 | 36 | 38 | <2 | 16 | <2 | 66 |
| RB_19 | 2070 | <5 | <5 | <1 | 4 | 7 | 7 | <2 | 3 | <2 | 17 |
| RB_19a | 2910 | <5 | <5 | <1 | 6 | 9 | 8 | <2 | 3 | <2 | 20 |
| RB_19b | 2900 | <5 | <5 | <1 | 6 | 11 | 10 | <2 | 4 | <2 | 19 |
| RB_20 | 990 | <5 | <5 | <1 | 2 | 6 | <5 | <2 | <2 | <2 | 8 |
| RB_20a | 1200 | <5 | <5 | <1 | 2 | <5 | 14 | <2 | <2 | <2 | 9 |
| RB_20b | 1860 | <5 | <5 | <1 | 2 | 5 | 6 | <2 | <2 | <2 | 13 |
| RB_20c | 850 | <5 | <5 | <1 | 2 | <5 | <5 | <2 | <2 | <2 | 6 |

**Table A19 (continue)**

| Sites | Aluminium | Antimony | Arsenic | Cadmium | Chromium | Copper | Lead | Molybdenum | Nickel | Silver | Zinc |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | mg/kg (total concentrations in <2mm fraction) | | | | | | | | | | |
| RB_20ac | 1620 | <5 | <5 | <1 | 2 | 5 | 8 | <2 | <2 | <2 | 28 |
| RB_20bc | 1860 | <5 | <5 | <1 | 2 | 6 | 6 | <2 | <2 | <2 | 14 |
| RB_21 | 1360 | <5 | <5 | <1 | <2 | <5 | <5 | <2 | <2 | <2 | 10 |
| RB_21a | 2680 | <5 | <5 | <1 | 3 | 7 | 7 | <2 | <2 | <2 | 21 |
| RB_21b | 2850 | <5 | <5 | <1 | 3 | 7 | 7 | <2 | 2 | <2 | 21 |
| RB_22 | 2310 | <5 | <5 | <1 | <2 | 6 | 8 | <2 | <2 | <2 | 15 |
| RB_22a | 1690 | <5 | <5 | <1 | <2 | <5 | <5 | <2 | <2 | <2 | 11 |
| RB_22b | 1410 | <5 | <5 | <1 | <2 | <5 | <5 | <2 | <2 | <2 | 10 |
| RB_23 | 1990 | <5 | <5 | <1 | 2 | <5 | <5 | <2 | <2 | <2 | 12 |
| RB_23a | 1240 | <5 | <5 | <1 | <2 | <5 | <5 | <2 | <2 | <2 | 18 |
| RB_23b | 1750 | <5 | <5 | <1 | <2 | <5 | <5 | <2 | <2 | <2 | 11 |
| RB_24 | 2410 | <5 | 6 | <1 | 9 | 22 | 42 | <2 | 4 | <2 | 38 |
| RB_24a | 2810 | <5 | 6 | <1 | 9 | 28 | 49 | <2 | 5 | <2 | 50 |
| RB_24b | 2240 | <5 | 6 | <1 | 8 | 19 | 94 | <2 | 5 | <2 | 57 |
| RB_25 | 2150 | <5 | <5 | <1 | <2 | <5 | 6 | <2 | <2 | <2 | 18 |
| RB_25a | 2030 | <5 | <5 | <1 | <2 | <5 | 6 | <2 | <2 | <2 | 16 |
| RB_25b | 2780 | <5 | <5 | <1 | 2 | 7 | 10 | <2 | <2 | <2 | 12 |
| RB_26 | 2030 | <5 | 11 | <1 | 8 | 17 | 74 | <2 | 3 | <2 | 46 |
| RB_26a | 2400 | <5 | 19 | <1 | 11 | 26 | 247 | <2 | 5 | <2 | 68 |
| RB_26b | 2180 | <5 | 13 | <1 | 10 | 27 | 59 | <2 | 4 | <2 | 58 |
| RB_27 | 1970 | <5 | 5 | <1 | 7 | 26 | 9 | <2 | 4 | <2 | 20 |
| RB_27a | 2500 | <5 | 8 | <1 | 12 | 28 | 20 | <2 | 7 | <2 | 28 |
| RB_27b | 2570 | <5 | 6 | <1 | 11 | 22 | 12 | <2 | 6 | <2 | 27 |
| RB_28 | 3840 | <5 | 6 | <1 | 12 | 39 | 13 | <2 | 8 | <2 | 18 |
| RB_28a | 2900 | <5 | 6 | <1 | 12 | 29 | 11 | <2 | 8 | <2 | 17 |
| RB_28b | 3720 | <5 | 6 | <1 | 16 | 36 | 14 | <2 | 9 | <2 | 23 |
| RB_29 | 2140 | <5 | <5 | <1 | 11 | 14 | 9 | <2 | 5 | <2 | 15 |
| RB_29a | 2320 | <5 | 5 | <1 | 13 | 21 | 8 | <2 | 6 | <2 | 23 |
| RB_29b | 2490 | <5 | 5 | <1 | 13 | 17 | 10 | <2 | 6 | <2 | 20 |
| RB_30 | 4460 | <5 | <5 | <1 | 13 | 10 | <5 | <2 | 7 | <2 | 17 |
| RB_30a | 5540 | <5 | <5 | <1 | 18 | 18 | 5 | <2 | 11 | <2 | 22 |

**Table A19 (continue)**

| Sites | Aluminium | Antimony | Arsenic | Cadmium | Chromium | Copper | Lead | Molybdenum | Nickel | Silver | Zinc |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | mg/kg (total concentrations in <2mm fraction) | | | | | | | | | | |
| RB_30b | 5120 | <5 | <5 | <1 | 14 | 14 | <5 | <2 | 9 | <2 | 20 |
| RB_30c | 4310 | <5 | <5 | <1 | 13 | 11 | <5 | <2 | 8 | <2 | 20 |
| RB_30ac | 5020 | <5 | <5 | <1 | 15 | 14 | <5 | <2 | 10 | <2 | 21 |
| RB_30bc | 5000 | <5 | <5 | <1 | 14 | 13 | <5 | <2 | 8 | <2 | 19 |

**Table A20 Comparison of total metal and metalloid concentrations in Leichhardt River Verification Samples LR5, LR9 and LR10 collected 13-14 November 2009 by Xstrata for split homogeneous sub-samples of <2mm and <250 µm fractions analysed independently by ALS and EnTOX laboratories, August 2011.**

| Sites | Laboratory | Aluminium | Antimony | Arsenic | Cadmium | Chromium | Copper | Lead | Molybdenum | Nickel | Silver | Zinc | Mercury |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | mg/kg (total concentrations in <2mm fraction) | | | | | | | | | | | |
| LR_05 | ENTOX Mean±SD | 3000±360 | 0.10±0.10 | 2.1±0.7 | 0.14±0.06 | 5.7±0.3 | 16±1.2 | 16±1.0 | 0.13±0.01 | 3.6±0.3 | - | 20±2.4 | <0.1 |
| LR_09 | ENTOX Mean±SD | 6700±1500 | 1.2±0.1 | 14±1.5 | 11±0.8 | 11±1.8 | 100±11 | 190±22 | 0.32±0.04 | 7±1.2 | - | 540±50 | 0.20±0.04 |
| LR_10 | ENTOX Mean±SD | 12000±3000 | 71±4 | 216±22 | 145±7 | 30±5 | 4100±570 | 13000±2800 | 1.7±1.6 | 11±1.7 | - | 7800±940 | 14±1.5 |
| LR_05 | ALS | 2130 | 6 | 5 | <1 | 6 | 19 | 12 | <2 | 10±1.8 | - | 22 | <0.1 |
| LR_09 | ALS | 5030 | 5 | 13 | 9 | 11 | 107 | 155 | <2 | 7 | - | 535 | <0.1 |
| LR_10 | ALS | 8650 | 71 | 230 | 164 | 32 | 5180 | 15400 | <3 | 14 | - | 10500 | 2.7 |

| Sites | Laboratory | Aluminium | Antimony | Arsenic | Cadmium | Chromium | Copper | Lead | Molybdenum | Nickel | Silver | Zinc | Mercury |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | mg/kg (total concentrations in <250 µm fraction) | | | | | | | | | | | |
| LR_05 | ENTOX Mean±SD | 8700±210 | 0.15±0.08 | 4.9±0.7 | 13±3.2 | 18±3.1 | 200±24 | 130±19 | 0.9±0.2 | 10±1.8 | - | 72±5.3 | 0.16±0.02 |
| LR_09 | ENTOX Mean±SD | 16000±6000 | 2.9±0.1 | 20±2.5 | 33±1.1 | 30±9.5 | 400±51 | 510±48 | 0.75±0.003 | 18±5.5 | - | 1000±120 | 0.63±0.08 |
| LR_10 | ENTOX Mean±SD | 12000±3300 | 99±2.7 | 280±30 | 170±5.6 | 36±6.4 | 4800±690 | 16000±2900 | 3±1.6 | 12±2.1 | - | 11000±1400 | 17±1.3 |
| LR_05 | ALS | 6330 | <9 | 14 | 5 | 20 | 224 | 92 | <9 | 11 | - | 77 | <0.5 |
| LR_09 | ALS | 13600 | 6 | 26 | 32 | 31 | 465 | 499 | <3 | 21 | - | 1250 | <0.2 |
| LR_10 | ALS | 8320 | 93 | 313 | 185 | 40 | 6380 | 20500 | 3 | 14 | - | 14700 | 3.8 |

**Appendix 7.Aquatic toxicity results.**

**Table A21 Summary sampling dates for toxicity test and GPS coordinates for water samples**

| Sampling date/team | Test | Site description | Site ID | GPS coordinates | |
|---|---|---|---|---|---|
| | | | | x | y |
| 24 July 2008 by Xstrata | 48hr Survival Cerio daphnia cf dubia | Moondarra Overflow | MO | | |
| | | Moondarra Crossing | MC | 343191 | 7711959 |
| | | Davis Crossing | DC | 343013 | 7710113 |
| | | Isa street Crossing | ISA | 342574 | 7707125 |
| | | 23 Avenue Crossing | 23rd Av | 343081 | 7705206 |
| 7 October 2009 by Xstrata | 48hr Survival Cerio daphnia cf dubia | Davis Crossing | DC_T_1-36073 | 343003 | 7710027 |
| | | Stinky Creek | SC-J_T_01-36077 | 343106 | 7709719 |
| | | Alma Crossing | AC_T_1-36081 | 342838 | 7708662 |
| 13 October 2009 by CMLR | - 72-hr Inhibition Selenestrum capricornutum<br>- 48hr Survival Cerio daphnia cf dubia<br>- 7-day partial life-cycle (chronic) toxicity cladoceran *Ceriodaphia* cf dubia<br>- 7-day Growth Inhibition *Lemna minor*<br>-96-hr fish Imbalance *Melanotaenia splendida* | 23 Avenue Isa Crossing | 23 ave ISA | 348163 | 7720710 |
| | | | | 347853 | 7720956 |
| | | Alma Crossing | ALM | 344837 | 7716299 |
| | | Davis Crossing | DC | 346299 | 7718882 |
| | | Moondarra Crossing | MC | 344618 | 7715647 |
| 28 July 2010 by CMLR | -72-hr *Selenastrum capricornutum*<br>- 48hr Survival *Cerio daphnia* cf *dubia*<br>-7-day Growth inhibition of the freshwater aquatic duckweed *Lemna Disperma*<br>- 7-day Growth Inhibition *Lemna minor*<br>-96-hr fish imbalance toxicity test using the rainbowfish *Melanotaenia Splendid* | Riffle creek dam | | 354742 | 7681168 |

**Table A22 Toxicity test reports on 48hr *Survival Cerio daphnia* cf *dubia* for water samples collected by Xstrata (24 July 2008)**

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## Toxicity Test Report: TR0399/1

(page 1 of 2)

| | | | |
|---|---|---|---|
| **Client:** | University of Queensland<br>CMLR UQ<br>St Lucia QLD 4072 | **ESA Job #:** | PR0399 |
| | | **Date Sampled:** | 24 July 2008 |
| | | **Date Received:** | 25 July 2008 |
| **Attention:** | Prof. Barry Noller | **Sampled By:** | Client |
| **Contract #:** | | **ESA Quote #:** | PL0383_q01 |

| Lab ID No.: | Sample Name: | Sample Description: |
|---|---|---|
| 2812 | MO (34335) | Aqueous sample, pH 8.6, conductivity 535µS/cm |
| 2813 | MC (34336) | Aqueous sample, pH 8.5, conductivity 4070µS/cm |
| 2814 | DC (34337) | Aqueous sample, pH 8.5, conductivity 6020µS/cm |
| 2815 | 15A (34338) | Aqueous sample, pH 8.6, conductivity 4020µS/cm |
| 2816 | 23rd (34339) | Aqueous sample, pH 8.1, conductivity 1102µS/cm |

| | |
|---|---|
| **Test Performed:** | 48-hr acute (survival) toxicity test using the freshwater cladoceran *Ceriodaphnia cf dubia* |
| **Test Protocol:** | ESA SOP 101, based on USEPA (1993) |
| **Deviations from Protocol:** | Nil |
| **Source of Test Organisms:** | ESA Laboratory culture |
| **Test Initiated:** | 25 July 2008 at 1300h |

| Sample 2812: *MO (34335)* | | Sample 2813: *MC (34336)* | | Sample 2814: *DC (34337)* | |
|---|---|---|---|---|---|
| **Concentration (%)** | **% Survival (at 48 hr)** | **Concentration (%)** | **% Survival (at 48 hr)** | **Concentration (%)** | **% Survival (at 48 hr)** |
| 0 (control) | 100 ± 0.0 | 0 (control) | 100 ± 0.0 | 0 (control) | 100 ± 0.0 |
| 6.25 | 100 ± 0.0 | 6.25 | 100 ± 0.0 | 6.25 | 100 ± 0.0 |
| 12.5 | 100 ± 0.0 | 12.5 | 100 ± 0.0 | 12.5 | 100 ± 0.0 |
| 25 | 100 ± 0.0 | 25 | 100 ± 0.0 | 25 | 100 ± 0.0 |
| 50 | 100 ± 0.0 | 50 | 100 ± 0.0 | 50 | 80.0 ± 16.3 |
| 100 | 100 ± 0.0 | 100 | 100 ± 0.0 | 100 | 0.0 ± 0.0 |
| **48 hr EC50 = >100%** | | **48 hr EC50 = >100%** | | **48 hr EC50 = 61.6 (54.4-69.7)%** | |
| **(TSK trim value = n/a)** | | **(TSK trim value = n/a)** | | **(TSK trim value = 0.0%)** | |
| **NOEC = 100%** | | **NOEC = 100%** | | **NOEC = 50%** | |
| **LOEC = >100%** | | **LOEC = >100%** | | **LOEC = 100%** | |

**Table A22 (continue)**

## Toxicity Test Report: TR0399/1

(page 2 of 2)

| Sample 2815: *15A* | | Sample 2816: *23* | | *Vacant* |
|---|---|---|---|---|
| **Concentration (%)** | **% Survival (at 48 hr)** | **Concentration (%)** | **% Survival (at 48 hr)** | |
| 0 (control) | 100 ± 0.0 | 0 (control) | 100 ± 0.0 | |
| 6.25 | 100 ± 0.0 | 6.25 | 100 ± 0.0 | |
| 12.5 | 100 ± 0.0 | 12.5 | 100 ± 0.0 | |
| 25 | 100 ± 0.0 | 25 | 100 ± 0.0 | |
| 50 | 100 ± 0.0 | 50 | 100 ± 0.0 | |
| 100 | 100 ± 0.0 | 100 | 100 ± 0.0 | |
| **48 hr EC50 = >100%** | | **48 hr EC50 = >100%** | | |
| **(TSK trim value = n/a)** | | **(TSK trim value = n/a)** | | |
| **NOEC = 100%** | | **NOEC = 100%** | | |
| **LOEC = >100%** | | **LOEC = >100%** | | |

| QA/QC Parameter | Criterion | This Test | Criterion met? |
|---|---|---|---|
| Control minimum % survival | ≥90 % | 100% | Yes |
| Test Temperature limits | 25.0 ± 1 °C | 25.5-26.0°C | Yes |
| Reference Toxicant within cusum chart limits | 160.3-271.7mg KCl/L | 204.9mg KCl/L | Yes |

Test Report Authorised by: Dr Rick Krassoi, Director on 30 July 2008

Results are based on the samples in the condition as received by ESA

**Table A22 Toxicity test reports on 48hr *Survival Cerio daphnia* cf *dubia* for water samples collected by Xstrata (24 July 2008)**

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## Toxicity Test Report: TR0399/1

(page 1 of 2)

| | | | |
|---|---|---|---|
| **Client:** | University of Queensland<br>CMLR UQ<br>St Lucia QLD 4072 | **ESA Job #:**<br>**Date Sampled:**<br>**Date Received:** | PR0399<br>24 July 2008<br>25 July 2008 |
| **Attention:** | Prof. Barry Noller | **Sampled By:** | Client |
| **Contract #:** | | **ESA Quote #:** | PL0383_q01 |

| Lab ID No.: | Sample Name: | Sample Description: |
|---|---|---|
| 2812 | MO (34335) | Aqueous sample, pH 8.6, conductivity 535µS/cm |
| 2813 | MC (34336) | Aqueous sample, pH 8.5, conductivity 4070µS/cm |
| 2814 | DC (34337) | Aqueous sample, pH 8.5, conductivity 6020µS/cm |
| 2815 | 15A (34338) | Aqueous sample, pH 8.6, conductivity 4020µS/cm |
| 2816 | 23rd (34339) | Aqueous sample, pH 8.1, conductivity 1102µS/cm |

| | |
|---|---|
| **Test Performed:** | 48-hr acute (survival) toxicity test using the freshwater cladoceran *Ceriodaphnia cf dubia* |
| **Test Protocol:** | ESA SOP 101, based on USEPA (1993) |
| **Deviations from Protocol:** | Nil |
| **Source of Test Organisms:** | ESA Laboratory culture |
| **Test Initiated:** | 25 July 2008 at 1300h |

| Sample 2812: *MO (34335)* | | Sample 2813: *MC (34336)* | | Sample 2814: *DC (34337)* | |
|---|---|---|---|---|---|
| **Concentration (%)** | **% Survival (at 48 hr)** | **Concentration (%)** | **% Survival (at 48 hr)** | **Concentration (%)** | **% Survival (at 48 hr)** |
| 0 (control) | 100 ± 0.0 | 0 (control) | 100 ± 0.0 | 0 (control) | 100 ± 0.0 |
| 6.25 | 100 ± 0.0 | 6.25 | 100 ± 0.0 | 6.25 | 100 ± 0.0 |
| 12.5 | 100 ± 0.0 | 12.5 | 100 ± 0.0 | 12.5 | 100 ± 0.0 |
| 25 | 100 ± 0.0 | 25 | 100 ± 0.0 | 25 | 100 ± 0.0 |
| 50 | 100 ± 0.0 | 50 | 100 ± 0.0 | 50 | 80.0 ± 16.3 |
| 100 | 100 ± 0.0 | 100 | 100 ± 0.0 | 100 | 0.0 ± 0.0 |
| **48 hr EC50 = >100%**<br>**(TSK trim value = n/a)**<br>**NOEC = 100%**<br>**LOEC = >100%** | | **48 hr EC50 = >100%**<br>**(TSK trim value = n/a)**<br>**NOEC = 100%**<br>**LOEC = >100%** | | **48 hr EC50 = 61.6 (54.4-69.7)%**<br>**(TSK trim value = 0.0%)**<br>**NOEC = 50%**<br>**LOEC = 100%** | |

**Table A23 Toxicity test reports on 48hr *Survival Cerio daphnia* cf *dubia* for water samples collected by Xstrata (7 October 2009)**

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## Toxicity Test Report: TR0505/1

(page 1 of 2)

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| | | | |
|---|---|---|---|
| **Client:** | Xstrata Copper Ltd<br>PMB6<br>Mt Isa QLD 4825 | **ESA Job #:**<br>**Date Sampled:**<br>**Date Received:** | PR0505<br>7 October 2009<br>8 October 2009 |
| **Attention:** | Alex Sexton | **Sampled By:** | Client |
| **Client Ref:** | Not supplied | **ESA Quote #:** | PL0505_q03 |

| Lab ID No.: | Sample Name: | Sample Description: |
|---|---|---|
| 3782 | DC_T_1-36073 | Aqueous sample, pH 8.0, conductivity 5660µS/cm, total ammonia <2.0mg/L*. Sample received at 10.5°C in apparent good condition. |
| 3783 | SC_J_T_01-36077 | Aqueous sample, pH 8.2, conductivity 6360µS/cm, total ammonia <2.0mg/L*. Sample received at 10.5°C in apparent good condition. |
| 3784 | AC_T_1-36081 | Aqueous sample, pH 8.6, conductivity 4100µS/cm, total ammonia <2.0mg/L*. Sample received at 10.5°C in apparent good condition. |

*Ammonia analysis is not covered by Ecotox Services Australasia's scope of accreditation.

| | |
|---|---|
| **Test Performed:** | 48-hr acute (survival) toxicity test using the freshwater cladoceran *Ceriodaphnia cf dubia* |
| **Test Protocol:** | ESA SOP 101 (ESA 2008), based on USEPA (2002) and Bailey *et al.* (2000) |
| **Deviations from Protocol:** | Nil |
| **Comments on Solution Preparation:** | The samples were serially diluted with Dilute Mineral Water (DMW) to achieve the test concentrations. A DMW control was tested concurrently with the samples. |
| **Source of Test Organisms:** | ESA Laboratory culture |
| **Test Initiated:** | 16 October 2009 at 1600h |

| Sample 3782: *DC_T_1-36073* | | Sample 3783: *SC_J_T_01-36077* | | Sample 3784: *AC_T_1-36081* | |
|---|---|---|---|---|---|
| **Concentration (%)** | **% Survival at 48 hr (Mean ± SD)** | **Concentration (%)** | **% Survival at 48 hr (Mean ± SD)** | **Concentration (%)** | **% Survival at 48 hr (Mean ± SD)** |
| DMW Control | 100 ± 0.0 | DMW Control | 100 ± 0.0 | DMW Control | 100 ± 0.0 |
| 6.3 | 90.0 ± 11.6 | 6.3 | 100 ± 0.0 | 6.3 | 100 ± 0.0 |
| 12.5 | 100 ± 0.0 | 12.5 | 95.0 ± 10.0 | 12.5 | 100 ± 0.0 |
| 25 | 100 ± 0.0 | 25 | 100 ± 0.0 | 25 | 100 ± 0.0 |
| 50 | 95.0 ± 10.0 | 50 | 90.0 ± 11.6 | 50 | 100 ± 0.0 |
| 100 | 30.0 ± 20.0 * | 100 | 70.0 ± 34.6 | 100 | 100 ± 0.0 |
| **48 hr EC10 = 23.8% **** | | **48 hr EC10 = 42.5 (15.9-75.6)%** | | **48 hr EC10 = >100%** | |
| **48 hr EC50 = >100%** | | **48 hr EC50 = >100%** | | **48 hr EC50 = >100%** | |
| **NOEC = 50%** | | **NOEC = 100%** | | **NOEC = 100%** | |
| **LOEC = 100%** | | **LOEC = >100%** | | **LOEC = >100%** | |

*Significantly lower percent survival compared with the DMW Control (Steel's Many-One Rank Test, 1-tailed, P=0.05)
** 95% confidence limits not available

| QA/QC Parameter | Criterion | This Test | Criterion met? |
|---|---|---|---|
| Control mean % survival | >90.0% | 100% | Yes |
| Reference Toxicant within cusum chart limits | 177.7-266.1mg KCl/L | 204.9mg KCl/L | Yes |

**Table A24 Toxicity test reports on 72-hr Inhibition *Selenestrum capricornutum* for water samples collected by CMLR (13 October 2009)**

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## Toxicity Test Report: TR0535/1

(page 1 of 2)

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| | | | |
|---|---|---|---|
| **Client:** | University of Queensland<br>Centre for Mined Land Rehabilitation<br>Brisbane QLD 4072 | **ESA Job #:**<br>**Date Sampled:**<br>**Date Received:** | PR0535<br>13 October 2009<br>14 October 2009 |
| **Attention:** | Barry Noller | **Sampled By:** | Client |
| **Client Ref:** | Not supplied | **ESA Quote #:** | PL0535_q01 |

| Lab ID No.: | Sample Name: | Sample Description: |
|---|---|---|
| 3798 | 23rd Avenue L.R | Aqueous sample, pH 8.2, conductivity 1721µS/cm, total ammonia <2.0mg/L*. Sample received at 20.0°C in apparent good condition |
| 3799 | Isa Street Crossing L.R | Aqueous sample, pH 8.3, conductivity 4190µS/cm, total ammonia <2.0mg/L*. Sample received at 20.0°C in apparent good condition. |
| 3800 | Alma Street Crossing L.R | Aqueous sample, pH 8.6, conductivity 4520µS/cm, total ammonia <2.0mg/L*. Sample received at 20.0°C in apparent good condition. |
| 3801 | Davis Street Crossing L.R | Aqueous sample, pH 8.2, conductivity 5740µS/cm, total ammonia <2.0mg/L*. Sample received at 20.0°C in apparent good condition. |
| 3802 | Moondarra Crossing L.R | Aqueous sample, pH 8.7, conductivity 5760µS/cm, total ammonia <2.0mg/L*. Sample received at 20.0°C in apparent good condition. |

*Ammonia analysis is not covered by Ecotox Services Australasia's scope of accreditation

| | |
|---|---|
| **Test Performed:** | 72-hr microalgal growth inhibition test using the green alga *Selenastrum capricornutum* |
| **Test Protocol:** | ESA SOP 103 (ESA 2009), based on USEPA (2002) |
| **Deviations from Protocol:** | Samples were centrifuged prior to testing to remove particulates. |
| **Comments on Solution Preparation:** | The samples were serially diluted with USEPA media to achieve the test concentrations. A diluent control (USEPA media) was tested concurrently with the samples. |
| **Source of Test Organisms:** | ESA Laboratory culture, originally sourced from CSIRO Microalgal Supply Service, TAS |
| **Test Initiated:** | 23 October 2009 at 1510h |

| Sample 3798: *23rd Avenue L.R* | | Sample 3799: *Isa Street Crossing L.R* | | Sample 3800: *Alma Street Crossing L.R* | |
|---|---|---|---|---|---|
| **Concentration (%)** | **Cell Yield x10⁴ cells/mL (Mean ± SD)** | **Concentration (%)** | **Cell Yield x10⁴ cells/mL (Mean ± SD)** | **Concentration (%)** | **Cell Yield x10⁴ cells/mL (Mean ± SD)** |
| Diluent Control | 49.6 ± 5.2 | Diluent Control | 49.6 ± 5.2 | Diluent Control | 49.6 ± 5.2 |
| Colour Control | 65.4 ± 6.8 | Colour Control | 44.5 ± 7.5 | Colour Control | 67.6 ± 14.8 |
| 6.3 | 71.7 ± 14.2 | 6.3 | 50.5 ± 16.1 | 6.3 | 66.6 ± 13.0 |
| 12.5 | 61.5 ± 13.4 | 12.5 | 61.6 ± 18.1 | 12.5 | 86.3 ± 21.1 |
| 25 | 64.2 ± 10.9 | 25 | 57.4 ± 12.5 | 25 | 61.3 ± 12.9 |
| 50 | 56.7 ± 9.9 | 50 | 60.3 ± 9.5 | 50 | 57.8 ± 6.3 |
| 100 | 26.8 ± 12.7 * | 100 | 58.4 ± 16.0 | 100 | 38.6 ± 16.6 |
| **72-hr IC10 = 51.9 (0.0-65.4)%** | | **72-hr IC10 = >100%** | | **72-hr IC10 = 29.2 (11.3-82.0)%** | |
| **72-hr IC50 = 91.8%**** | | **72-hr IC50 = >100%** | | **72-hr IC50 = >100%** | |
| **NOEC = 50%** | | **NOEC = 100%** | | **NOEC = 100%** | |
| **LOEC = 100%** | | **LOEC = >100%** | | **LOEC = >100%** | |

*Significantly lower cell yield compared with the Diluent Control (Dunnett's Test, 1-tailed, P=0.05)
** 95% confidence limits are not available

**Table A24 (continue)**

## Toxicity Test Report: TR0535/1

(page 2 of 2)

| Sample 3801: *Davis Street Crossing L.R* | | Sample 3802: *Moondarra Crossing L.R* | | *Vacant* |
|---|---|---|---|---|
| **Concentration (%)** | **Cell Yield x10$^4$ cells/mL (Mean ± SD)** | **Concentration (%)** | **Cell Yield x10$^4$ cells/mL (Mean ± SD)** | |
| Diluent Control | 49.6 ± 5.2 | Diluent Control | 49.6 ± 5.2 | |
| Colour Control | 56.7 ± 7.9 | Colour Control | 65.1 ± 10.8 | |
| 6.3 | 61.9 ± 12.2 | 6.3 | 72.4 ± 19.9 | |
| 12.5 | 82.7 ± 14.8 | 12.5 | 46.8 ± 18.2 | |
| 25 | 89.8 ± 9.3 | 25 | 42.9 ± 10.0 | |
| 50 | 81.0 ± 10.4 | 50 | 13.7 ± 6.7 * | |
| 100 | 64.4 ± 12.2 | 100 | 35.2 ± 12.8 | |
| **72-hr IC10 = 92.4%**** | | **72-hr IC10 = 9.0 (7.1-25.3)%** | | |
| **72-hr IC50 = >100%** | | **72-hr IC50 = 41.8%**** | | |
| **NOEC = 100%** | | **NOEC = 25%** | | |
| **LOEC = >100%** | | **LOEC = 50%** | | |

*Significantly lower cell yield compared with the Diluent Control (Steel's Many One Rank Test, 1-tailed, P=0.05)
** 95% confidence limits are not available

| QA/QC Parameter | Criterion | This Test | Criterion met? |
|---|---|---|---|
| Control mean cell density | >16.0x10$^4$ cells/mL | 50.6x10$^4$ cells/mL | Yes |
| Control coefficient of variation | <20% | 10.5% | Yes |
| Reference Toxicant within cusum chart limits | 1.0-3.7g KCl/L | 2.5g KCl/L | Yes |

**Table A25 Toxicity test reports on - 48hr Survival *Cerio daphnia* cf *dubia* for water samples collected by CMLR (13 October 2009)**

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## Toxicity Test Report: TR0535/2

(page 1 of 2)

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| | | | |
|---|---|---|---|
| **Client:** | University of Queensland<br>Centre for Mined Land Rehabilitation<br>Brisbane QLD 4072 | **ESA Job #:**<br>**Date Sampled:**<br>**Date Received:** | PR0535<br>13 October 2009<br>14 October 2009 |
| **Attention:** | Barry Noller | **Sampled By:** | Client |
| **Client Ref:** | Not supplied | **ESA Quote #:** | PL0535_q01 |

| Lab ID No.: | Sample Name: | Sample Description: |
|---|---|---|
| 3798 | 23rd Avenue L.R | Aqueous sample, pH 8.2, conductivity 1721µS/cm, total ammonia <2.0mg/L*. Sample received at 20.0°C in apparent good condition. |
| 3799 | Isa Street Crossing L.R | Aqueous sample, pH 8.3, conductivity 4190µS/cm, total ammonia <2.0mg/L*. Sample received at 20.0°C in apparent good condition. |
| 3800 | Alma Street Crossing L.R | Aqueous sample, pH 8.6, conductivity 4520µS/cm, total ammonia <2.0mg/L*. Sample received at 20.0°C in apparent good condition. |
| 3801 | Davis Street Crossing L.R | Aqueous sample, pH 8.2, conductivity 5740µS/cm, total ammonia <2.0mg/L*. Sample received at 20.0°C in apparent good condition. |
| 3802 | Moondarra Crossing L.R | Aqueous sample, pH 8.7, conductivity 5760µS/cm, total ammonia <2.0mg/L*. Sample received at 20.0°C in apparent good condition. |

*Ammonia analysis is not covered by Ecotox Services Australasia's scope of accreditation

| | |
|---|---|
| **Test Performed:** | 48-hr acute (survival) toxicity test using the freshwater cladoceran *Ceriodaphnia cf dubia* |
| **Test Protocol:** | ESA SOP 101 (ESA 2008), based on USEPA (2002) and Bailey *et al.* (2000) |
| **Deviations from Protocol:** | Nil |
| **Comments on Solution Preparation:** | The samples were serially diluted with Dilute Mineral Water (DMW) to achieve the test concentrations. A DMW control was tested concurrently with the samples. |
| **Source of Test Organisms:** | ESA Laboratory culture |
| **Test Initiated:** | 20 October 2009 at 1730h |

| Sample 3798: *23rd Avenue L.R* | | Sample 3799: *Isa Street Crossing L.R* | | Sample 3800: *Alma Street Crossing L.R* | |
|---|---|---|---|---|---|
| **Concentration (%)** | **% Survival at 48 h (Mean ± SD)** | **Concentration (%)** | **% Survival at 48 h (Mean ± SD)** | **Concentration (%)** | **% Survival at 48 h (Mean ± SD)** |
| DMW Control | 100 ± 0.0 | DMW Control | 100 ± 0.0 | DMW Control | 100 ± 0.0 |
| 6.3 | 100 ± 0.0 | 6.3 | 100 ± 0.0 | 6.3 | 100 ± 0.0 |
| 12.5 | 100 ± 0.0 | 12.5 | 100 ± 0.0 | 12.5 | 100 ± 0.0 |
| 25 | 100 ± 0.0 | 25 | 100 ± 0.0 | 25 | 100 ± 0.0 |
| 50 | 100 ± 0.0 | 50 | 100 ± 0.0 | 50 | 100 ± 0.0 |
| 100 | 100 ± 0.0 | 100 | 90.0 ± 11.6 | 100 | 100 ± 0.0 |
| **48-hr EC10 = >100%**<br>**48-hr EC50 = >100%**<br>**NOEC = 100%**<br>**LOEC = >100%** | | **48-hr EC10 = >100%**<br>**48-hr EC50 = >100%**<br>**NOEC = 100%**<br>**LOEC = >100%** | | **48-hr EC10 = >100%**<br>**48-hr EC50 = >100%**<br>**NOEC = 100%**<br>**LOEC = >100%** | |

**Table A25 (continue)**

## Toxicity Test Report: TR0535/2 (page 2 of 2)

| Sample 3801: *Davis Street Crossing L.R* Concentration (%) | % Survival at 48 h (Mean ± SD) | Sample 3802: *Moondarra Crossing L.R* Concentration (%) | % Survival at 48 h (Mean ± SD) | *Vacant* |
|---|---|---|---|---|
| DMW Control | 100 ± 0.0 | DMW Control | 100 ± 0.0 | |
| 6.3 | 100 ± 0.0 | 6.3 | 100 ± 0.0 | |
| 12.5 | 100 ± 0.0 | 12.5 | 100 ± 0.0 | |
| 25 | 100 ± 0.0 | 25 | 100 ± 0.0 | |
| 50 | 95.0 ± 10.0 | 50 | 100 ± 0.0 | |
| 100 | 85.0 ± 19.2 | 100 | 90.0 ± 20.0 | |
| **48-hr EC10 = 78.2%*** | | **48-hr EC10 = >100%** | | |
| **48-hr EC50 = >100%** | | **48-hr EC50 = >100%** | | |
| **NOEC = 100%** | | **NOEC = 100%** | | |
| **LOEC = >100%** | | **LOEC = >100%** | | |

* 95% confidence limits are not available

| QA/QC Parameter | Criterion | This Test | Criterion met? |
|---|---|---|---|
| Control mean % survival | >90.0% | 100% | Yes |
| Reference Toxicant within cusum chart limits | 177.6-269.2mg KCl/L | 219.6mg KCl/L | Yes |

**Table A26 Toxicity test reports on - 7-day partial life-cycle (chronic) toxicity cladoceran *Ceriodaphia* cf *dubia* for water samples collected by CMLR (13 October 2009)**

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## Toxicity Test Report: TR0535/3

(page 1 of 2)

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| | | | |
|---|---|---|---|
| **Client:** | University of Queensland<br>Centre for Mined Land Rehabilitation<br>Brisbane QLD 4072 | **ESA Job #:**<br>**Date Sampled:**<br>**Date Received:** | PR0535<br>13 October 2009<br>14 October 2009 |
| **Attention:** | Barry Noller | **Sampled By:** | Client |
| **Client Ref:** | Not supplied | **ESA Quote #:** | PL0535 q01 |

| Lab ID No.: | Sample Name: | Sample Description: |
|---|---|---|
| 3798 | 23rd Avenue L.R | Aqueous sample, pH 8.2, conductivity 1721µS/cm, total ammonia <2.0mg/L*. Sample received at 20.0°C in apparent good condition. |
| 3799 | Isa Street Crossing L.R | Aqueous sample, pH 8.3, conductivity 4190µS/cm, total ammonia <2.0mg/L*. Sample received at 20.0°C in apparent good condition. |

*Ammonia analysis is not covered by Ecotox Services Australasia's scope of accreditation

| | |
|---|---|
| **Test Performed:** | 7-day partial life-cycle (chronic) toxicity test using the freshwater cladoceran *Ceriodaphnia cf dubia* |
| **Test Protocol:** | ESA SOP 102 (ESA 2008), based on USEPA (2002) and Bailey *et al.* (2000) |
| **Deviations from Protocol:** | Nil |
| **Comments on Solution Preparation:** | The samples were serially diluted with Dilute Mineral Water (DMW) to achieve the test concentrations. A DMW control was tested concurrently with the samples. |
| **Source of Test Organisms:** | ESA Laboratory culture |
| **Test Initiated:** | 20 October 2009 at 1730h |

Sample 3798: *23rd Avenue L.R*

| Concentration (%) | % Survival at 8 days (Mean ± SD) |
|---|---|
| DMW Control | 100 ± 0.0 |
| 6.3 | 100 ± 0.0 |
| 12.5 | 100 ± 0.0 |
| 25 | 100 ± 0.0 |
| 50 | 100 ± 0.0 |
| 100 | 100 ± 0.0 |

**8 day EC10 (survival) = >100%**
**8 day EC50 (survival) = >100%**
**NOEC = 100%**
**LOEC = >100%**

Sample 3798: *23rd Avenue L.R*

| Concentration (%) | Number of Young (Mean ± SD) |
|---|---|
| DMW Control | 21.3 ± 1.1 |
| 6.3 | 30.8 ± 6.0 |
| 12.5 | 23.2 ± 3.8 |
| 25 | 25.0 ± 4.9 |
| 50 | 36.1 ± 7.0 |
| 100 | 32.8 ± 9.5 |

**8 day IC10 (reproduction) = >100%**
**8 day IC50 (reproduction) = >100%**
**NOEC = 100%**
**LOEC = >100%**

**Table A26 (continue)**

## Toxicity Test Report: TR0535/3 (page 2 of 2)

Sample 3799: *Isa Street Crossing L.R*

| Concentration (%) | % Survival at 8 days (Mean ± SD) | | |
|---|---|---|---|
| DMW Control | 100 | ± | 0.0 |
| 6.3 | 90.0 | ± | 31.6 |
| 12.5 | 90.0 | ± | 31.6 |
| 25 | 100 | ± | 0.0 |
| 50 | 100 | ± | 0.0 |
| 100 | 100 | ± | 0.0 |

**8 day EC10 (survival) = >100%**
**8 day EC50 (survival) = >100%**
**NOEC = 100%**
**LOEC = >100%**

Sample 3799: *Isa Street Crossing L.R*

| Concentration (%) | Number of Young (Mean ± SD) | | |
|---|---|---|---|
| DMW Control | 21.3 | ± | 1.1 |
| 6.3 | 25.8 | ± | 8.4 |
| 12.5 | 29.6 | ± | 6.3 |
| 25 | 33.2 | ± | 8.9 |
| 50 | 37.9 | ± | 6.9 |
| 100 | 37.2 | ± | 5.6 |

**8 day IC10 (reproduction) = >100%**
**8 day IC50 (reproduction) = >100%**
**NOEC = 100%**
**LOEC = >100%**

| QA/QC Parameter | Criterion | This Test | Criterion met? |
|---|---|---|---|
| Control mean % survival | >80.0% | 100% | Yes |
| Control mean number of young | >15.0 | 21.3 | Yes |
| Reference Toxicant within cusum chart limits | 71.0-500.1mg KCl/L | 214.7mg KCl/L | Yes |

**Table A26 (continue)**

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## Toxicity Test Report: TR0535/4

(page 1 of 3)

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| | | | |
|---|---|---|---|
| **Client:** | University of Queensland<br>Centre for Mined Land Rehabilitation<br>Brisbane QLD 4072 | **ESA Job #:**<br>**Date Sampled:**<br>**Date Received:** | PR0535<br>13 October 2009<br>14 October 2009 |
| **Attention:** | Barry Noller | **Sampled By:** | Client |
| **Client Ref:** | Not supplied | **ESA Quote #:** | PL0535_q01 |

| Lab ID No.: | Sample Name: | Sample Description: |
|---|---|---|
| 3800 | Alma Street Crossing L.R | Aqueous sample, pH 8.6, conductivity 4520µS/cm, total ammonia <2.0mg/L*. Sample received at 20.0°C in apparent good condition. |
| 3801 | Davis Street Crossing L.R | Aqueous sample, pH 8.2, conductivity 5740µS/cm, total ammonia <2.0mg/L*. Sample received at 20.0°C in apparent good condition. |
| 3802 | Moondarra Crossing L.R | Aqueous sample, pH 8.7, conductivity 5760µS/cm, total ammonia <2.0mg/L*. Sample received at 20.0°C in apparent good condition. |

*Ammonia analysis is not covered by Ecotox Services Australasia's scope of accreditation

| | |
|---|---|
| **Test Performed:** | 7-day partial life-cycle (chronic) toxicity test using the freshwater cladoceran *Ceriodephnia cf dubia* |
| **Test Protocol:** | ESA SOP 102 (ESA 2008), based on USEPA (2002) and Bailey *et al.* (2000) |
| **Deviations from Protocol:** | Test undertaken with the 'Moondarra Crossing L.R' sample was renewed every 48 h instead of 24 h |
| **Comments on Solution Preparation:** | The samples were serially diluted with Dilute Mineral Water (DMW) to achieve the test concentrations. A DMW control was tested concurrently with the samples. |
| **Source of Test Organisms:** | ESA Laboratory culture |
| **Test Initiated:** | 29 October 2009 at 1700h |

Sample 3800: *Alma Street Crossing L.R*

| Concentration (%) | % Survival at 7 days (Mean ± SD) |
|---|---|
| DMW Control | 90.0 ± 31.6 |
| 6.3 | 100 ± 0.0 |
| 12.5 | 100 ± 0.0 |
| 25 | 100 ± 0.0 |
| 50 | 100 ± 0.0 |
| 100 | 100 ± 0.0 |

**7 day EC10 (survival) = >100%**
**7 day EC50 (survival) = >100%**
**NOEC = 100%**
**LOEC = >100%**

Sample 3800: *Alma Street Crossing L.R*

| Concentration (%) | Number of Young (Mean ± SD) |
|---|---|
| DMW Control | 17.1 ± 6.6 |
| 6.3 | 24.8 ± 3.7 |
| 12.5 | 25.5 ± 2.3 |
| 25 | 24.4 ± 5.5 |
| 50 | 23.2 ± 6.1 |
| 100 | 13.7 ± 6.9 |

**7 day IC10 (reproduction) = 62.4 (41.1-72.1)%**
**7 day IC50 (reproduction) = >100%**
**NOEC = 100%**
**LOEC = >100%**

**Table A26 (continue)**

## Toxicity Test Report: TR0535/4 (page 2 of 3)

Sample 3801: *Davis Street Crossing L.R*

| Concentration (%) | % Survival at 7 days (Mean ± SD) |
|---|---|
| DMW Control | 90.0 ± 31.6 |
| 6.3 | 100 ± 0.0 |
| 12.5 | 100 ± 0.0 |
| 25 | 100 ± 0.0 |
| 50 | 90.0 ± 31.6 |
| 100 | 100 ± 0.0 |

**7 day EC10 (survival) = >100%**
**7 day EC50 (survival) = >100%**
**NOEC = 100%**
**LOEC = >100%**

Sample 3801: *Davis Street Crossing L.R*

| Concentration (%) | Number of Young (Mean ± SD) |
|---|---|
| DMW Control | 17.1 ± 6.6 |
| 6.3 | 20.7 ± 3.9 |
| 12.5 | 21.8 ± 4.5 |
| 25 | 18.3 ± 5.4 |
| 50 | 13.0 ± 6.1 |
| 100 | 3.5 ± 2.5 * |

**7 day IC10 (reproduction) = 27.0 (17.1-40.4)%**
**7 day IC50 (reproduction) = 66.1 (48.5-76.8)%**
**NOEC = 50%**
**LOEC = 100%**

* Significantly lower number of young compared to the Diluent Control (Wilcoxon Rank Sum Test, 1-tailed, P=0.05)

Sample 3802: *Moondarra Crossing L.R*

| Concentration (%) | % Survival at 7 days (Mean ± SD) |
|---|---|
| DMW Control | 90.0 ± 31.6 |
| 6.3 | 100 ± 0.0 |
| 12.5 | 100 ± 0.0 |
| 25 | 100 ± 0.0 |
| 50 | 100 ± 0.0 |
| 100 | 60.0 ± 51.6 |

**7 day EC10 (survival) = 72.7%****
**7 day EC50 (survival) = >100%**
**NOEC = 100%**
**LOEC = >100%**

Sample 3802: *Moondarra Crossing L.R*

| Concentration (%) | Number of Young (Mean ± SD) |
|---|---|
| DMW Control | 17.1 ± 6.6 |
| 6.3 | 13.0 ± 2.6 |
| 12.5 | 15.9 ± 3.3 |
| 25 | 15.8 ± 4.2 |
| 50 | 17.4 ± 2.9 |
| 100 | 1.1 ± 1.2 * |

**7 day IC10 (reproduction) = 50.4 (2.6-55.6)%**
**7 day IC50 (reproduction) = 74.2 (68.4-78.0)%**
**NOEC = 50%**
**LOEC = 100%**

* Significantly lower number of young compared to the Diluent Control (Wilcoxon Rank Sum Test, 1-tailed, P=0.05)
** 95% confidence limits are not available

| QA/QC Parameter | Criterion | This Test | Criterion met? |
|---|---|---|---|
| Control mean % survival | >80.0% | 90.0% | Yes |
| Control mean number of young | >15.0 | 17.1 | Yes |
| Reference Toxicant within cusum chart limits | 71.1-497.5mg KCl/L | 211.0mg KCl/L | Yes |

**Table A27 Toxicity test reports on 7-day Growth Inhibition *Lemna minor* for water samples collected by CMLR (13 October 2009)**

## Toxicity Test Report: TR0535/5

(page 1 of 3)

| | | | |
|---|---|---|---|
| **Client:** | University of Queensland<br>Centre for Mined Land Rehabilitation<br>Brisbane QLD 4072 | **ESA Job #:**<br>**Date Sampled:**<br>**Date Received:** | PR0535<br>13 October 2009<br>14 October 2009 |
| **Attention:** | Barry Noller | **Sampled By:** | Client |
| **Client Ref:** | Not supplied | **ESA Quote #:** | PL0535_q01 |

| Lab ID No.: | Sample Name: | Sample Description: |
|---|---|---|
| 3798 | 23rd Avenue L.R | Aqueous sample, pH 8.2, conductivity 1721µS/cm, total ammonia <2.0mg/L*. Sample received at 20.0°C in apparent good condition. |
| 3799 | Isa Street Crossing L.R | Aqueous sample, pH 8.3, conductivity 4190µS/cm, total ammonia <2.0mg/L*. Sample received at 20.0°C in apparent good condition. |
| 3800 | Alma Street Crossing L.R | Aqueous sample, pH 8.6, conductivity 4520µS/cm, total ammonia <2.0mg/L*. Sample received at 20.0°C in apparent good condition. |
| 3801 | Davis Street Crossing L.R | Aqueous sample, pH 8.2, conductivity 5740µS/cm, total ammonia <2.0mg/L*. Sample received at 20.0°C in apparent good condition. |
| 3802 | Moondarra Crossing L.R | Aqueous sample, pH 8.7, conductivity 5760µS/cm, total ammonia <2.0mg/L*. Sample received at 20.0°C in apparent good condition. |

*Ammonia analysis is not covered by Ecotox Services Australasia's scope of accreditation

| | |
|---|---|
| **Test Performed:** | 7-day Growth inhibition of the freshwater aquatic duckweed *Lemna minor* |
| **Test Protocol:** | ESA SOP 112 (ESA 2008), based on OECD method 221 (2006) |
| **Deviations from Protocol:** | Nil |
| **Comments on Solution Preparation:** | The samples were serially diluted with Sweedish standard medium (SIS) to achieve the test concentrations. A SIS control was tested concurrently with the samples. |
| **Source of Test Organisms:** | ESA Laboratory culture |
| **Test Initiated:** | 27 October 2009 at 1400h |

Sample 3798: *23rd Avenue L.R*

| Concentration (%) | Specific Growth Rate (Mean ± SD) |
|---|---|
| SIS Control | 0.39 ± 0.02 |
| 6.3 | 0.41 ± 0.01 |
| 12.5 | 0.40 ± 0.02 |
| 25 | 0.34 ± 0.02 * |
| 50 | 0.17 ± 0.03 * |
| 100 | 0.0 ± 0.05 * |

**7 day IC10 = 21.6 (16.8-27.8)%**
**7 day IC50 = 45.3 (40.4-50.9)%**
**NOEC = 12.5%**
**LOEC = 25%**

Sample 3798: *23rd Avenue L.R*

| Concentration (%) | Dry Weight, mg (Mean ± SD) |
|---|---|
| SIS Control | 3.2 ± 0.2 |
| 6.3 | 2.7 ± 0.3 |
| 12.5 | 3.6 ± 0.5 |
| 25 | 2.6 ± 1.1 |
| 50 | 1.8 ± 0.5** |
| 100 | 1.7 ± 0.5** |

**7 day IC10 = 17.3 (0.0-39.5)%**
**7 day IC50 =>100%**
**NOEC = 25%**
**LOEC = 50%**

*Significantly lower specific growth rate compared with the SIS Control (Dunnett's Test, 1-tailed, P=0.05)
**Significantly lower dry weight compared with the SIS Control (Dunnett's Test, 1-tailed, P=0.05)

**Table A27 (continue)**

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## Toxicity Test Report: TR0535/5

(page 2 of 3)

Sample 3799: *Isa Street Crossing L.R*

| Concentration (%) | Specific Growth Rate (Mean ± SD) |
|---|---|
| SIS Control | 0.39 ± 0.02 |
| 6.3 | 0.40 ± 0.01 |
| 12.5 | 0.41 ± 0.02 |
| 25 | 0.36 ± 0.01 |
| 50 | 0.29 ± 0.03 * |
| 100 | 0.27 ± 0.02 * |

**7 day IC10 = 25.5 (19.9-31.7)%**
**7 day IC50 = >100%**
**NOEC = 25%**
**LOEC = 50%**

Sample 3799: *Isa Street Crossing L.R*

| Concentration (%) | Dry Weight, mg (Mean ± SD) |
|---|---|
| SIS Control | 3.2 ± 0.2 |
| 6.3 | 3.1 ± 0.6 |
| 12.5 | 3.7 ± 0.9 |
| 25 | 3.2 ± 0.4 |
| 50 | 2.1 ± 0.6** |
| 100 | 2.8 ± 0.5 |

**7 day IC10 = 30.4 (11.3-45.8)%**
**7 day IC50 = >100%**
**NOEC = 100%**
**LOEC = >100%**

*Significantly lower specific growth rate compared with the SIS Control (Dunnett's Test, 1-tailed, P=0.05)
**Significantly lower dry weight compared with the SIS Control (Dunnett's Test, 1-tailed, P=0.05)

Sample 3800: *Alma Street Crossing L.R*

| Concentration (%) | Specific Growth Rate (Mean ± SD) |
|---|---|
| SIS Control | 0.39 ± 0.02 |
| 6.3 | 0.40 ± 0.02 |
| 12.5 | 0.38 ± 0.02 |
| 25 | 0.26 ± 0.03 * |
| 50 | 0.25 ± 0.01 * |
| 100 | 0.20 ± 0.02 * |

**7 day IC10 = 15.0 (11.2-17.5)%**
**7 day IC50 = >100%**
**NOEC = 12.5%**
**LOEC = 25%**

Sample 3800: *Alma Street Crossing L.R*

| Concentration (%) | Dry Weight, mg (Mean ± SD) |
|---|---|
| SIS Control | 3.2 ± 0.2 |
| 6.3 | 4.0 ± 0.3 |
| 12.5 | 3.2 ± 0.5 |
| 25 | 2.2 ± 0.7** |
| 50 | 2.1 ± 0.2** |
| 100 | 1.9 ± 0.4** |

**7 day IC10 = 11.6 (7.9-18.3)%**
**7 day IC50 = >100%**
**NOEC = 12.5%**
**LOEC = 25%**

*Significantly lower specific growth rate compared with the SIS Control (Dunnett's Test, 1 tailed, P=0.05)
**Significantly lower dry weight compared with the SIS Control (Dunnett's Test, 1 tailed, P=0.05)

Sample 3801: *Davis Street Crossing L.R*

| Concentration (%) | Specific Growth Rate (Mean ± SD) |
|---|---|
| SIS Control | 0.39 ± 0.02 |
| 6.3 | 0.40 ± 0.01 |
| 12.5 | 0.40 ± 0.01 |
| 25 | 0.38 ± 0.00 |
| 50 | 0.36 ± 0.02 * |
| 100 | 0.18 ± 0.02 * |

**7 day IC10 = 50.1 (28.6-56.7)%**
**7 day IC50 = 95.3%****
**NOEC = 25%**
**LOEC = 50%**

Sample 3801: *Davis Street Crossing L.R*

| Concentration (%) | Dry Weight, mg (Mean ± SD) |
|---|---|
| SIS Control | 3.2 ± 0.2 |
| 6.3 | 3.5 ± 0.4 |
| 12.5 | 5.0 ± 0.8 |
| 25 | 4.1 ± 0.4 |
| 50 | 4.6 ± 0.8 |
| 100 | 3.0 ± 0.7 |

**7 day IC10 = 68.7%****
**7 day IC50 = >100%**
**NOEC = 100%**
**LOEC = >100%**

*Significantly lower specific growth rate compared with the SIS Control (Dunnett's Test, 1-tailed, P=0.05)

**Table A27 (continue)**

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## Toxicity Test Report: TR0535/5

(page 3 of 3)

| Sample 3802: *Moondarra Crossing L.R* Concentration (%) | Specific Growth Rate (Mean ± SD) | Sample 3802: *Moondarra Crossing L.R* Concentration (%) | Dry Weight, mg (Mean ± SD) |
|---|---|---|---|
| DMW control | 0.39 ± 0.02 | DMW control | 3.2 ± 0.2 |
| 6.3 | 0.41 ± 0.01 | 6.3 | 3.8 ± 0.3 |
| 12.5 | 0.39 ± 0.01 | 12.5 | 4.0 ± 0.8 |
| 25 | 0.36 ± 0.04 | 25 | 3.1 ± 0.4 |
| 50 | 0.25 ± 0.01 * | 50 | 1.9 ± 0.5** |
| 100 | 0.22 ± 0.04 * | 100 | 1.5 ± 0.5** |
| **7 day IC10 = 25.6 (14.6-34.4)%** | | **7 day IC10 = 20.7 (11.5-32.5)%** | |
| **7 day IC50 = >100%** | | **7 day IC50 = 59.3%*** ** | |
| **NOEC = 25%** | | **NOEC = 25%** | |
| **LOEC = 50%** | | **LOEC = 50%** | |

*Significantly lower specific growth rate compared with the SIS Control (Dunnett's Test, 1-tailed, P=0.05)
**Significantly lower dry weight compared with the SIS Control (Dunnett's Test, 1-tailed, P=0.05)
*** 95% confidence limits are not available

| QA/QC Parameter | Criterion | This Test | Criterion met? |
|---|---|---|---|
| Control frond doubling time | <2.5 days | 1.7 days | Yes |
| Reference Toxicant within cusum chart limits | 110.9-796.7µg Cu/L* | 225.0µg Cu/L | Yes |

* Cusum chart limits are calculated using limited amount of data

**Table A28 Toxicity test reports on 96-hr fish Imbalance *Melanotaenia splendida* for water samples collected by CMLR (13 October 2009)**

## Toxicity Test Report: TR0535/6

(page 1 of 2)

This document is issued in accordance with NATA's accreditation requirements

| | | | |
|---|---|---|---|
| **Client:** | University of Queensland<br>Centre for Mined Land Rehabilitation<br>Brisbane QLD 4072 | **ESA Job #:**<br>**Date Sampled:**<br>**Date Received:** | PR0535<br>13 October 2009<br>14 October 2009 |
| **Attention:** | Barry Noller | **Sampled By:** | Client |
| **Client Ref:** | Not supplied | **ESA Quote #:** | PL0535_q01 |

| Lab ID No.: | Sample Name: | Sample Description: |
|---|---|---|
| 3798 | 23rd Avenue L.R | Aqueous sample, pH 8.2, conductivity 1721µS/cm, total ammonia <2.0mg/L*. Sample received at 20.0°C in apparent good condition. |
| 3799 | Isa Street Crossing L.R | Aqueous sample, pH 8.3, conductivity 4190µS/cm, total ammonia <2.0mg/L*. Sample received at 20.0°C in apparent good condition. |
| 3800 | Alma Street Crossing L.R | Aqueous sample, pH 8.6, conductivity 4520µS/cm, total ammonia <2.0mg/L*. Sample received at 20.0°C in apparent good condition. |
| 3801 | Davis Street Crossing L.R | Aqueous sample, pH 8.2, conductivity 5740µS/cm, total ammonia <2.0mg/L*. Sample received at 20.0°C in apparent good condition. |
| 3802 | Moondarra Crossing L.R | Aqueous sample, pH 8.7, conductivity 5760µS/cm, total ammonia <2.0mg/L*. Sample received at 20.0°C in apparent good condition. |

| | |
|---|---|
| **Test Performed:** | 96-hr fish imbalance toxicity test using rainbow fish *Melanotaenia splendida* |
| **Test Protocol:** | ESA SOP 117 (ESA 2009), based on USEPA (2002) |
| **Deviations from Protocol:** | Samples 'Alma Street Crossing L.R' and 'Moondarra Crossing L.R' were tested in triplicate due to a shortage of sample volume. |
| **Comments on Solution Preparation:** | The samples were serially diluted with dilute mineral water (DMW) to achieve the test concentrations. A DMW control was tested concurrently with the samples. |
| **Source of Test Organisms:** | Hatchery reared, Ausyfish QLD |
| **Test Initiated:** | 4 December 2009 at 1300h |

| Sample 3798: *23rd Avenue L.R* | | Sample 3799: *Isa Street Crossing L.R* | | Sample 3800: *Alma Street Crossing L.R* | |
|---|---|---|---|---|---|
| **Control Treatment** | **% Un-affected (Mean ± SD)** | **Concentration (%)** | **% Un-affected (Mean ± SD)** | **Concentration (%)** | **% Un-affected (Mean ± SD)** |
| DMW Control | 100 ± 0.0 | DMW Control | 100 ± 0.0 | DMW Control | 100 ± 0.0 |
| 6.3 | 95.0 ± 10.0 | 6.3 | 100 ± 0.0 | 6.3 | 100 ± 0.0 |
| 12.5 | 100 ± 0.0 | 12.5 | 95.0 ± 10.0 | 12.5 | 100 ± 0.0 |
| 25 | 100 ± 0.0 | 25 | 100 ± 0.0 | 25 | 100 ± 0.0 |
| 50 | 100 ± 0.0 | 50 | 100 ± 0.0 | 50 | 100 ± 0.0 |
| 100 | 100 ± 0.0 | 100 | 100 ± 0.0 | 100 | 100 ± 0.0 |
| **96-hr EC10 = >100%** | | **96-hr EC10 = >100%** | | **96-hr EC10 = >100%** | |
| **96-hr EC50 = >100%** | | **96-hr EC50 = >100%** | | **96-hr EC50 = >100%** | |
| **NOEC = 100%** | | **NOEC = 100%** | | **NOEC = 100%** | |
| **LOEC = >100%** | | **LOEC = >100%** | | **LOEC = >100%** | |

**Table A28 (continue)**

## Toxicity Test Report: TR0535/6 (page 2 of 2)

| Sample 3801: *Davis Street Crossing L.R* | | Sample 3802: *Moondarra Crossing L.R* | | *Vacant* |
|---|---|---|---|---|
| **Concentration (%)** | **% Un-affected (Mean ± SD)** | **Concentration (%)** | **% Un-affected (Mean ± SD)** | |
| DMW Control | 100 ± 0.0 | DMW Control | 100 ± 0.0 | |
| 6.3 | 100 ± 0.0 | 6.3 | 100 ± 0.0 | |
| 12.5 | 100 ± 0.0 | 12.5 | 100 ± 0.0 | |
| 25 | 100 ± 0.0 | 25 | 100 ± 0.0 | |
| 50 | 100 ± 0.0 | 50 | 100 ± 0.0 | |
| 100 | 100 ± 0.0 | 100 | 100 ± 0.0 | |
| **96-hr EC10 = >100%** | | **96-hr EC10 = >100%** | | |
| **96-hr EC50 = >100%** | | **96-hr EC50 = >100%** | | |
| **NOEC = 100%** | | **NOEC = 100%** | | |
| **LOEC = >100%** | | **LOEC = >100%** | | |

| QA/QC Parameter | Criterion | This Test | Criterion met? |
|---|---|---|---|
| Control mean % un-affected | >80.0% | 100% | Yes |
| Reference Toxicant within cusum chart limits | 1.5-917.7µg Cu/L | 44.2µg Cu/L | Yes |

**Table A29 Toxicity test reports on 72-hr *Selenastrum capricornutum* for water samples collected at Riffle Creek (28 July 2010)**

## Toxicity Test Report: TR0631/3

(page 1 of 2)

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| | | | |
|---|---|---|---|
| **Client:** | Centre for Mined Land Rehabilitation<br>University Of Queensland<br>Brisbane QLD 4072 | **ESA Job #:**<br>**Date Sampled:**<br>**Date Received:** | PR0631<br>28 July 2010<br>30 July 2010 |
| **Attention:** | Barry Noller | **Sampled By:** | Client |
| **Client Ref:** | None Supplied | **ESA Quote #:** | PL0631_q01 |

| Lab ID No.: | Sample Name: | Sample Description: |
|---|---|---|
| 4265 | Riffle Creek Dam | Aqueous sample, pH 8.5, conductivity 4370µS/cm, total ammonia <2.0mg/L*. Sample received at 16°C in apparent good condition |

*Ammonia analysis is not covered by Ecotox Services Australasia's scope of accreditation

| | |
|---|---|
| **Test Performed:** | 72-hr microalgal growth inhibition test using the green alga *Selenastrum capricornutum* |
| **Test Protocol:** | ESA SOP 103 (ESA 2010), based on USEPA (2002) |
| **Test Temperature:** | The test was performed at 25±1°C. |
| **Deviations from Protocol:** | Nil |
| **Comments on Solution Preparation:** | The sample was serially diluted with USEPA media. A diluent control (USEPA media) was tested concurrently with the sample. |
| **Source of Test Organisms:** | ESA Laboratory culture, originally sourced from CSIRO Microalgal Supply Service, TAS |
| **Test Initiated:** | 30 July 2010 at 1400h |

| Sample 4265, *Riffle Creek Dam* Concentration (%) | Cell Yield $x10^4$ cells/mL (Mean ± SD) | *Vacant* | *Vacant* |
|---|---|---|---|
| Diluent Control | 93.4 ± 9.3 | | |
| 6.3 | 114.0 ± 19.7 | | |
| 12.5 | 106.5 ± 19.6 | | |
| 25 | 87.3 ± 17.2 | | |
| 50 | 131.6 ± 12.2 | | |
| 100 | 12.2 ± 22.8 * | | |
| **72-hr IC10 = 55.6 (47.9-57.1)%**<br>**72-hr IC50 = 78.2 (71.2-85.6)%**<br>**NOEC = 50%**<br>**LOEC = 100%** | | | |

*Significantly lower cell yield compared with the Diluent Control (Dunnett's Test, 1-tailed, P=0.05)

**Table A30 Toxicity test reports on 48hr Survival *Cerio daphnia* cf *dubia* for water samples collected at Riffle Creek Dam (28 July 2010)**

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## Toxicity Test Report: TR0631/1

(page 1 of 2)

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| | | | |
|---|---|---|---|
| **Client:** | Centre for Mined Land Rehabilitation<br>University Of Queensland<br>Brisbane QLD 4072 | **ESA Job #:**<br>**Date Sampled:**<br>**Date Received:** | PR0631<br>28 July 2010<br>30 July 2010 |
| **Attention:** | Barry Noller | **Sampled By:** | Client |
| **Client Ref:** | None Supplied | **ESA Quote #:** | PL0631_q01 |

| Lab ID No.: | Sample Name: | Sample Description: |
|---|---|---|
| 4265 | Riffle Creek Dam | Aqueous sample; pH 8.5, conductivity 43 70µS/cm, total ammonia <2.0mg/L*. Sample received at 16°C in apparent good condition |

*Ammonia analysis is not covered by Ecotox Services Australasia's scope of accreditation

| | |
|---|---|
| **Test Performed:** | 48-hr acute (survival) toxicity test using the freshwater cladoceran *Ceriodaphnia cf dubia* |
| **Test Protocol:** | ESA SOP 101 (ESA 2009), based on USEPA (2002) and Bailey *et al.* (2000) |
| **Test Temperature:** | The test was performed at 25±1°C. |
| **Deviations from Protocol:** | Nil |
| **Comments on Solution Preparation:** | The sample 4265 'Riffle Creek Dam' was serially diluted with Dilute Mineral Water (DMW) to achieve the test concentrations. A DMW control was tested concurrently with the sample. |
| **Source of Test Organisms:** | ESA Laboratory culture |
| **Test Initiated:** | 30 July 2010 at 1130h |

| Sample 4265: *Riffle Creek Dam* | | *Vacant* | *Vacant* |
|---|---|---|---|
| **Concentration (%)** | **% Survival at 48 h (Mean ± SD)** | | |
| DMW Control | 100 ± 0.0 | | |
| 6.3 | 100 ± 0.0 | | |
| 12.5 | 100 ± 0.0 | | |
| 25 | 100 ± 0.0 | | |
| 50 | 100 ± 0.0 | | |
| 100 | 100 ± 0.0 | | |
| **48-hr IC10 = >100%**<br>**48-hr IC50 = >100%**<br>**NOEC = 100%**<br>**LOEC = >100%** | | | |

**Table A31 Toxicity test reports on 7-day partial life-cycle (chronic) toxicity test using the freshwater cladoceran *Ceriodaphnia cf dubia* for water samples collected at Riffle Creek Dam (28 July 2010)**

## Toxicity Test Report: TR0631/2

(page 1 of 2)

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| | | | |
|---|---|---|---|
| **Client:** | Centre for Mined Land Rehabilitation<br>University Of Queensland<br>Brisbane QLD 4072 | **ESA Job #:**<br>**Date Sampled:**<br>**Date Received:** | PR0631<br>28 July 2010<br>30 July 2010 |
| **Attention:** | Barry Noller | **Sampled By:** | Client |
| **Client Ref:** | None Supplied | **ESA Quote #:** | PL0631_q01 |

| Lab ID No.: | Sample Name: | Sample Description: |
|---|---|---|
| 4265 | Riffle Creek Dam | Aqueous sample, pH 8.5, conductivity 43 70µS/cm, total ammonia <2.0mg/L*. Sample received at 16ºC in apparent good condition |

*Ammonia analysis is not covered by Ecotox Services Australasia's scope of accreditation

| | |
|---|---|
| **Test Performed:** | 7-day par tial l ife-cycle ( chronic) t oxicity t est us ing t he f reshwater cladoceran *Ceriodaphnia cf dubia* |
| **Test Protocol:** | ESA SOP 102 (ESA 2010), based on USEPA (2002) and Bailey *et al.* (2000) |
| **Test Temperature:** | The test was performed at 25±1°C. |
| **Deviations from Protocol:** | Nil |
| **Comments on Solution Preparation:** | The s ample 4265 ' Riffle C reek D am' w as serially d iluted with D ilute Mineral Water (DMW) to achieve the test concentrations. A DMW control was tested concurrently with the sample. |
| **Source of Test Organisms:** | ESA Laboratory culture |
| **Test Initiated:** | 3 August 2010 at 1530h |

Sample 4265: *Riffle Creek Dam*

| Concentration (%) | % Survival at 7 days (Mean ± SD) |
|---|---|
| DMW Control | 90.0 ± 31.6 |
| 6.3 | 90.0 ± 31.6 |
| 12.5 | 100 ± 0.0 |
| 25 | 100 ± 0.0 |
| 50 | 100 ± 0.0 |
| 100 | 100 ± 0.0 |

**7 day EC10 (survival) = >100%**
**7 day EC50 (survival) = >100%**
**NOEC = 100%**
**LOEC = >100%**

Sample 4265: *Riffle Creek Dam*

| Concentration (%) | Number of Young (Mean ± SD) |
|---|---|
| DMW Control | 15.8 ± 6.9 |
| 6.3 | 16.9 ± 6.5 |
| 12.5 | 18.8 ± 2.5 |
| 25 | 23.9 ± 1.9 |
| 50 | 25.0 ± 1.4 |
| 100 | 21.9 ± 4.2 |

**7 day IC10 (reproduction) = >100%**
**7 day IC50 (reproduction) = >100%**
**NOEC = 100%**
**LOEC = >100%**

| QA/QC Parameter | Criterion | This Test | Criterion met? |
|---|---|---|---|
| Control mean % survival | >80.0% | 90.0% | Yes |
| Control mean number of young | >15.0 | 15.8 | Yes |
| Reference Toxicant within cusum chart limits | 234.8mg KCl/L | 85.0-444.0mg KCl/L | Yes |

**Table A32 Toxicity test reports on 7-day Growth inhibition of the freshwater aquatic duckweed *Lemna Disperma* for water samples collected at Riffle Creek (28 July 2010)**

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## Toxicity Test Report: TR0631/4

(page 1 of 3)

| | | | |
|---|---|---|---|
| **Client:** | Centre for Mined Land Rehabilitation<br>University Of Queensland<br>Brisbane QLD 4072 | **ESA Job #:**<br>**Date Sampled:**<br>**Date Received:** | PR0631<br>28 July 2010<br>30 July 2010 |
| **Attention:** | Barry Noller | **Sampled By:** | Client |
| **Client Ref:** | None Supplied | **ESA Quote #:** | PL0631_q01 |

| Lab ID No.: | Sample Name: | Sample Description: |
|---|---|---|
| 4265 | Riffle Creek Dam | Aqueous sample, pH 8.6, conductivity 43 70µS/cm, total ammonia <2.0mg/L. Sample received at 16°C in apparent good condition |

| | |
|---|---|
| **Test Performed:** | 7-day Growth inhibition of the freshwater aquatic duckweed *Lemna disperma* |
| **Test Protocol:** | ESA SOP 112 (ESA 2010), based on OECD method 221 (2006) |
| **Test Temperature:** | The test was performed at 25±2°C. |
| **Deviations from Protocol:** | Nil |
| **Comments on Solution Preparation:** | The sample 4265 'Riffle Creek Dam' was serially diluted with Swedish standard medium (SIS) to achieve the test concentrations. A SIS control was tested concurrently with the sample. |
| **Source of Test Organisms:** | ESA Laboratory culture |
| **Test Initiated:** | 2 August 2010 at 1400h |

| Sample 4265: *Riffle Creek Dam* Concentration (%) | Specific Growth Rate (Mean ± SD) | *Vacant* | *Vacant* |
|---|---|---|---|
| Diluent Control | 0.3 ± 0.0 | | |
| 6.1 | 0.3 ± 0.0 | | |
| 12.1 | 0.2 ± 0.1 | | |
| 24.2 | 0.2 ± 0.1 * | | |
| 48.4 | 0.2 ± 0.0 * | | |
| 96.8 | 0.2 ± 0.0 * | | |
| **7 day IC10 = 8.9 (5.3-19.6)%** | | | |
| **7 day IC50 = >96.8%** | | | |
| **NOEC = 12.1%** | | | |
| **LOEC = 24.2%** | | | |

*Significantly lower specific growth rate compared with the Diluent Control (Dunnett's Test, 1-tailed, P=0.05)

**Table A33 Toxicity test reports on 96-hr fish imbalance toxicity test using the rainbow fish *Melanotaenia splendida* for water samples collected at Riffle Creek Dam (28 July 2010)**

## Toxicity Test Report: TR0631/5 (page 1 of 2)

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| | | | |
|---|---|---|---|
| **Client:** | Centre for Mined Land Rehabilitation<br>University Of Queensland<br>Brisbane QLD 4072 | **ESA Job #:**<br>**Date Sampled:**<br>**Date Received:** | PR0631<br>28 July 2010<br>30 July 2010 |
| **Attention:** | Barry Noller | **Sampled By:** | Client |
| **Client Ref:** | None Supplied | **ESA Quote #:** | PL0631_q01 |

| Lab ID No.: | Sample Name: | Sample Description: |
|---|---|---|
| 4265 | Riffle Creek Dam | Aqueous sample, pH 8.5, conductivity 43 70µS/cm, total ammonia <2.0mg/L*. Sample received at 16°C in apparent good condition |

*Ammonia analysis is not covered by Ecotox Services Australasia's scope of accreditation

| | |
|---|---|
| **Test Performed:** | 96-hr fish imbalance toxicity test using the rainbowfish *Melanotaenia splendida* |
| **Test Protocol:** | ESA SOP 117 (ESA 2009), based on USEPA (2002) |
| **Test Temperature:** | The test was performed at 25±1°C. |
| **Deviations from Protocol:** | Nil |
| **Comments on Solution Preparation:** | The sample was serially diluted with dilute mineral water (DMW) to achieve the test concentrations. A DMW control was tested concurrently with the sample |
| **Source of Test Organisms:** | In-house cultures |
| **Test Initiated:** | 17 August 2010 at 1500h |

| Sample 4265: *Riffle Creek Dam* | | *Vacant* | *Vacant* |
|---|---|---|---|
| **Concentration (%)** | **% Un-affected (Mean ± SD)** | | |
| DMW Control | 100 ± 0.0 | | |
| 6.3 | 100 ± 0.0 | | |
| 12.5 | 75.0 ± 37.9 | | |
| 25 | 85.0 ± 30.0 | | |
| 50 | 100 ± 0.0 | | |
| 100 | 100 ± 0.0 | | |
| **96-hr IC10 = >100%**<br>**96-hr IC50 = >100%**<br>**NOEC = 100%**<br>**LOEC = >100%** | | | |

**Table A34 Summary sampling dates for toxicity test and GPS coordinates for sediment samples**

| Sampling date/team | Toxicity Test | Site description | Site ID | GPS coordinates | |
|---|---|---|---|---|---|
| | | | | x | y |
| 4 September 2007 CMLR | - 48hr Survival *Cerio daphnia* cf dubia elutrial<br>- 10day whole sediment *corophium* sp | LR - upstream (background) | L1 | 343416 | 7700904 |
| | | LR - Between Isa Street Crossing and Grace Street Bridge | L7 | 342523 | 7707217 |
| | | LR - Downstream/East of Velodrome | L9 | 342676 | 7708051 |
| | | LR - Pipe exit | L12 | 342357 | 7707643 |
| | | LR - Fluvial downstream (Moondarra) | L15 | 343454 | 7713760 |
| | | LR - Downstream of Lake Moondarra (Leichhardt River) | L16 | 353578 | 7723640 |
| 7 October 2009 Xstrata | - 48hr Survival *Cerio daphnia* cf *dubia* | Davis Crossing | DC_T_1-36073 | 343003 | 7710027 |
| | | Stinky Creek | SC-J_T_01-36077 | 343106 | 7709719 |
| | | Alma Crossing | AC_T_1-36081 | 342838 | 7708662 |
| 13 October 2009 CMLR | - 48hr Survival *Cerio daphnia* cf *dubia*<br>- 72-hr Inhibition *Selenestrum capricornutum* | 23 Avenue | 23 ave | 348163 | 7720710 |
| | | Isa Crossing | ISA | 347853 | 7720956 |
| | | Alma Crossing | ALM | 344837 | 7716299 |
| | | Davis Crossing | DC | 346299 | 7718882 |
| | | Moondarra Crossing | MC | 344618 | 7715647 |
| **28** July 2010 | -48-hr acute (survival) *Ceriodaphnia cf dubia*<br>-72-hr microalgal growth inhibition test using the green alga *Selenastrum capricornutum* | Riffle creek dam | | 354742 | 7681168 |

**Table A35 Toxicity test reports on 48hr Survival *Cerio daphnia* cf *dubia* elutrial of sediment samples collected on 4 September 2007 by CMLR**

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## Toxicity Test Report: TR0326/1 (page 1 of 2)

| | | | |
|---|---|---|---|
| **Client:** | Centre for Mined Land Rehabilitation of University QLD Brisbane | **ESA Job #:** | PR0326 |
| | | **Date Sampled:** | 4 September 2007 |
| | | **Date Received:** | 28 September 2007 |
| **Attention:** | Dr Barry Noller | **Sampled By:** | Client |
| **Contract #:** | n/a | **Quote #:** | PL0326_q01 |

| Lab ID No.: | Sample Name: Sample | Description: |
|---|---|---|
| 2366 L1 | | Dry sediment |
| 2367 L7 | | Dry sediment |
| 2368 L9 | | Dry sediment |
| 2369 L12 | | Dry sediment |
| 2370 L15 | | Dry sediment |
| 2371 L16 | | Dry sediment |

| | |
|---|---|
| **Test Performed:** | 48-hr acute (survival) toxicity test using the freshwater cladoceran *Ceriodaphnia cf dubia* |
| **Test Protocol:** | ESA SOP 101, based on USEPA (1993) |
| **Deviations from Protocol:** | Tests were conducted on elutriate prepared from the dry sediment according to the US EPA procedure (US EPA 1991), where sediment is mixed with dilution water at a ration of 1:4, stirred and allowed to settle for 2h prior to preparation of dilution series and seeding with test organisms. |
| **Source of Test Organisms:** | ESA Laboratory culture |
| **Test Initiated:** | 24 October 2007 at 1700h |

| Sample 2366: *L1* | | Sample 2367: *L7* | | Sample 2368: *L9* | |
|---|---|---|---|---|---|
| **Concentration (%)** | **% Survival (at 48 hr)** | **Concentration (%)** | **% Survival (at 48 hr)** | **Concentration (%)** | **% Survival (at 48 hr)** |
| 0 (control) | 100 ± 0.0 | 0 (control) | 100 ± 0.0 | 0 (control) | 100 ± 0.0 |
| 6.25 | 100 ± 0.0 | 6.25 | 100 ± 0.0 | 6.25 | 0.0 ± 0.0 |
| 12.5 | 100 ± 0.0 | 12.5 | 100 ± 0.0 | 12.5 | 0.0 ± 0.0 |
| 25 | 100 ± 0.0 | 25 | 100 ± 0.0 | 25 | 0.0 ± 0.0 |
| 50 | 100 ± 0.0 | 50 | 100 ± 0.0 | 50 | 0.0 ± 0.0 |
| 100 | 100 ± 0.0 | 100 | 100 ± 0.0 | 100 | 0.0 ± 0.0 |
| **48 hr EC50 = >100%** | | **48 hr EC50 = >100%** | | **48 hr EC50 = <6.25%** | |
| **NOEC = 100%** | | **NOEC = 100%** | | **NOEC = <6.25%** | |
| **LOEC = >100%** | | **LOEC = >100%** | | **LOEC = 6.25%** | |

**Table A35 (continue)**

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## Toxicity Test Report: TR0326/1

(page 2 of 2)

| Sample 2369: *L12* | | Sample 2370: *L15* | | Sample 2371: *L16* | |
|---|---|---|---|---|---|
| Concentration (%) | % Survival (at 48 hr) | Concentration (%) | % Survival (at 48 hr) | Concentration (%) | % Survival (at 48 hr) |
| 0 (control) | 100 ± 0.0 | 0 (control) | 100 ± 0.0 | 0 (control) | 100 ± 0.0 |
| 6.25 | 0.0 ± 0.0 | 6.25 | 100 ± 0.0 | 6.25 | 100 ± 0.0 |
| 12.5 | 0.0 ± 0.0 | 12.5 | 100 ± 0.0 | 12.5 | 100 ± 0.0 |
| 25 | 0.0 ± 0.0 | 25 | 100 ± 0.0 | 25 | 100 ± 0.0 |
| 50 | 0.0 ± 0.0 | 50 | 100 ± 0.0 | 50 | 100 ± 0.0 |
| 100 | 0.0 ± 0.0 | 100 | 100 ± 0.0 | 100 | 100 ± 0.0 |
| 48 hr EC50 = <6.25% | | 48 hr EC50 = >100% | | 48 hr EC50 = >100% | |
| NOEC = <6.25% | | NOEC = 100% | | NOEC = 100% | |
| LOEC = 6.25% | | LOEC = >100% | | LOEC = >100% | |

| QA/QC Parameter | Criterion | This Test | Criterion met? |
|---|---|---|---|
| Control minimum % survival | >70 % | 100% | Yes |
| Test Temperature limits | 25.0 ± 1 °C | 25.0°C Yes | |
| Reference Toxicant within cusum chart limits | 137.0-252.7mg/L | 212.1mg/L | Yes |

Test Report Authorised by: Dr Rick Krassoi, Director on 29 November 2007

Results are based on the samples in the condition as received by ESA

**NATA Accredited Laboratory Number: 14709**

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**Table A36 Toxicity test reports on 10day whole sediment survival toxicity test using estuarine amphipod C*orophium spp* of sediment samples collected on 4 September 2007 by CMLR**

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## Toxicity Test Report: TR0326/2

(page 1 of 1)

| | | | |
|---|---|---|---|
| **Client:** | Centre for Mined Land Rehabilitation of University QLD Brisbane | **ESA Job #:** | PR0326 |
| | | **Date Sampled:** | 4 September 2007 |
| | | **Date Received:** | 28 September 2007 |
| **Attention:** | Dr Barry Noller | **Sampled By:** | Client |
| **Contract #:** | n/a | **Quote #:** | PL0326_q01 |

| Lab ID No.: | Sample Name: Sample | Description: |
|---|---|---|
| 2366 L1 | | Dry sediment |
| 2367 L7 | | Dry sediment |
| 2368 L9 | | Dry sediment |
| 2369 L12 | | Dry sediment |
| 2370 L15 | | Dry sediment |
| 2371 L16 | | Dry sediment |

| | |
|---|---|
| **Test Performed:** | 10-day whole sediment survival toxicity test using the estuarine amphipod *Corophium spp.* |
| **Test Protocol:** | ESA SOP 109, based on USEPA (1996) |
| **Deviations from Protocol:** | Nil |
| **Source of Test Organisms:** | Field collected from Wisemans Ferry on 22 October 2007 |
| **Test Initiated:** | 30 October 2007 at 1300h |

| *Sample 2366-2371* Sample | % Survival (at 10 Days) | *Vacant* | *Vacant* |
|---|---|---|---|
| Control | 92.5 ± 5.0 | | |
| L1 | 75.0 ± 12.9 | | |
| L7 | 90.0 ± 8.2 | | |
| L9 | 0.0 ± 0.0 | | |
| L12 | 0.0 ± 0.0 | | |
| L15 | 82.5 ± 15.0 | | |
| L16 | 90.0 ± 0.0 | | |

The concentration of total ammonia and sulphide in the overlying water in all sample treatments at Day 0 was <2.0 and <0.10 mg/L, respectively.

| QA/QC Parameter | Criterion | This Test | Criterion met? |
|---|---|---|---|
| Control minimum % survival | >70 % | 92.5% | Yes |
| Test Temperature limits | 20.0 ± 1 °C | 19.5-20.5°C | Yes |
| Reference Toxicant within cusum chart limits | 125-3189µg/L | 488µg/L | Yes |

Test Report Authorised by: Dr Rick Krassoi, Director on 29 November 2007

Results are based on the samples in the condition as received by ESA
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**Table A37 Toxicity test reports on 48-hr *Survival Cerio daphnia cf dubia* sediment samples collected on 7 October 2009 by CMLR**

## Toxicity Test Report: TR0505/2

(page 1 of 2)

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| | | | |
|---|---|---|---|
| **Client:** | Xstrata Copper Ltd | **ESA Job #:** | PR0505 |
| | PMB6 | **Date Sampled:** | 7 October 2009 |
| | Mt Isa QLD 4825 | **Date Received:** | 8 October 2009 |
| **Attention:** | Alex Sexton | **Sampled By:** | Client |
| **Client Ref:** | Not supplied | **ESA Quote #:** | PL0505_q03 |

| Lab ID No.: | Sample Name: | Sample Description: |
|---|---|---|
| 3785 | DC_T_1S_36074 | Sediment grab. Sample received chilled in apparent good condition. |
| 3786 | SC_J_T_1S-36078 | Sediment grab. Sample received chilled in apparent good condition. |
| 3787 | AC_T_1S-36082 | Sediment grab. Sample received chilled in apparent good condition. |

*Ammonia analysis is not covered by Ecotox Services Australasia's scope of accreditation

| | |
|---|---|
| **Test Performed:** | 48-hr acute (survival) toxicity test using the freshwater cladoceran *Ceriodaphnia cf dubia* |
| **Test Protocol:** | ESA SOP 101 (ESA 2008), based on USEPA (2002) and Bailey *et al.* (2000) |
| **Deviations from Protocol:** | Nil |
| **Comments on Solution Preparation:** | Sediment elutriates were prepared according to USEPA (1991). One hundred millilitres of sediment was mixed with 400 mL dilute mineral water (DMW) and manually shaken vigorously for 1 minute. The mixture was left to settle for 10 minutes and then shaken again for 1 minute. This process was repeated to achieve a total of 3 shaking times. The mixture was allowed to settle for 1 h before the supernatant was carefully siphoned off without disturbing the sediment. Total ammonia and sulphide concentrations for all of the prepared elutriates were below the detection limits of 2.0mg/L and 0.10mg/L, respectively. The sediment elutriates were serially diluted with DMW to achieve the test concentrations. A DMW control was tested concurrently with the samples. |
| **Source of Test Organisms:** | ESA Laboratory culture |
| **Test Initiated:** | 20 October 2009 at 1730h |

| Sample 3785: *DC_T_1S_36074* | | Sample 3786: *SC_J_T_1S-36078* | | Sample 3787: *AC_T_1S-36082* | |
|---|---|---|---|---|---|
| **Concentration (%)** | **% Survival at 48 hr (Mean ± SD)** | **Concentration (%)** | **% Survival at 48 hr (Mean ± SD)** | **Concentration (%)** | **% Survival at 48 hr (Mean ± SD)** |
| DMW Control | 100 ± 0.0 | DMW Control | 100 ± 0.0 | DMW Control | 100 ± 0.0 |
| 6.3 | 100 ± 0.0 | 6.3 | 100 ± 0.0 | 6.3 | 100 ± 0.0 |
| 12.5 | 100 ± 0.0 | 12.5 | 100 ± 0.0 | 12.5 | 100 ± 0.0 |
| 25 | 100 ± 0.0 | 25 | 95.0 ± 10.0 | 25 | 100 ± 0.0 |
| 50 | 100 ± 0.0 | 50 | 100 ± 0.0 | 50 | 100 ± 0.0 |
| 100 | 100 ± 0.0 | 100 | 100 ± 0.0 | 100 | 100 ± 0.0 |
| **48 hr EC10 = >100%** | | **48 hr EC10 = >100%** | | **48 hr EC10 = >100%** | |
| **48 hr EC50 = 100%** | | **48 hr EC50 = >100%** | | **48 hr EC50 = >100%** | |
| **NOEC = 100%** | | **NOEC = 100%** | | **NOEC = 100%** | |
| **LOEC = >100%** | | **LOEC = >100%** | | **LOEC = >100%** | |

**Table A38 Toxicity test reports on 48-hr Survival Cerio daphnia cf dubia sediment samples collected on 13 October 2009 by CMLR**

## Toxicity Test Report: TR0535/8 (page 1 of 2)

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| | | | |
|---|---|---|---|
| **Client:** | University of Queensland<br>Centre for Mined Land Rehabilitation<br>Brisbane QLD 4072 | **ESA Job #:**<br>**Date Sampled:**<br>**Date Received:** | PR0535<br>19 October 2009<br>20 October 2009 |
| **Attention:** | Barry Noller | **Sampled By:** | Client |
| **Client Ref:** | Not supplied | **ESA Quote #:** | PL0535_q01 |

| Lab ID No.: | Sample Name: | Sample Description: |
|---|---|---|
| 3828 | 23rd Avenue L.R | Sediment grab received in apparent good condition. |
| 3829 | Isa Street Crossing L.R | Sediment grab received in apparent good condition. |
| 3830 | Alma Street Crossing L.R | Sediment grab received in apparent good condition. |
| 3831 | Davis Street Crossing L.R | Sediment grab received in apparent good condition. |
| 3832 | Moondarra Crossing L.R | Sediment grab received in apparent good condition. |

| | |
|---|---|
| **Test Performed:** | 48-hr acute (survival) toxicity test using the freshwater cladoceran *Ceriodaphnia cf dubia* |
| **Test Protocol:** | ESA SOP 101 (ESA 2008), based on USEPA (2002) and Bailey *et al.* (2000) |
| **Deviations from Protocol:** | Nil |
| **Comments on Solution Preparation:** | Sediment elutriates were prepared according to USEPA (1991). One hundred millilitres of sediment was mixed with 400 mL dilute mineral water (DMW) and manually shaken vigorously for 1 minute. The mixture was left to settle for 10 minutes and then shaken again for 1 minute. This process was repeated to achieve a total of 3 shaking times. The mixture was allowed to settle for 1 h before the supernatant was carefully siphoned off without disturbing the sediment. The 'Alma Street Crossing L.R' sample was centrifuged prior to testing to remove suspended particles.<br>The sediment elutriates were serially diluted with DMW to achieve the test concentrations. A DMW control was tested concurrently with the samples. |
| **Source of Test Organisms:** | ESA Laboratory culture |
| **Test Initiated:** | 28 October 2009 at 1700h |

| Sample 3828: *23rd Avenue L.R* | | Sample 3829: *Isa Street Crossing L.R* | | Sample 3830: *Alma Street Crossing L.R* | |
|---|---|---|---|---|---|
| **Concentration (%)** | **% Survival at 48 h (Mean ± SD)** | **Concentration (%)** | **% Survival at 48 h (Mean ± SD)** | **Concentration (%)** | **% Survival at 48 h (Mean ± SD)** |
| DMW Control | 100 ± 0.0 | DMW Control | 100 ± 0.0 | DMW Control | 100 ± 0.0 |
| 6.3 | 100 ± 0.0 | 6.3 | 100 ± 0.0 | 6.3 | 100 ± 0.0 |
| 12.5 | 95.0 ± 10.0 | 12.5 | 100 ± 0.0 | 12.5 | 100 ± 0.0 |
| 25 | 100 ± 0.0 | 25 | 95.0 ± 10.0 | 25 | 100 ± 0.0 |
| 50 | 100 ± 0.0 | 50 | 100 ± 0.0 | 50 | 100 ± 0.0 |
| 100 | 95.0 ± 10.0 | 100 | 100 ± 0.0 | 100 | 100 ± 0.0 |
| **48-hr EC10 = >100%** | | **48-hr EC10 = >100%** | | **48-hr EC10 = >100%** | |
| **48-hr EC50 = >100%** | | **48-hr EC50 = >100%** | | **48-hr EC50 = >100%** | |
| **NOEC = 100%** | | **NOEC = 100%** | | **NOEC = 100%** | |
| **LOEC = >100%** | | **LOEC = >100%** | | **LOEC = >100%** | |

**Table A38 (continue)**

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## Toxicity Test Report: TR0535/8

(page 2 of 2)

| Sample 3831: *Davis Street Crossing L.R* Concentration (%) | % Survival at 48 h (Mean ± SD) | Sample 3832: *Moondarra Crossing L.R* Concentration (%) | % Survival at 48 h (Mean ± SD) | *Vacant* |
|---|---|---|---|---|
| DMW Control | 100 ± 0.0 | DMW Control | 100 ± 0.0 | |
| 6.3 | 100 ± 0.0 | 6.3 | 100 ± 0.0 | |
| 12.5 | 100 ± 0.0 | 12.5 | 100 ± 0.0 | |
| 25 | 100 ± 0.0 | 25 | 100 ± 0.0 | |
| 50 | 100 ± 0.0 | 50 | 100 ± 0.0 | |
| 100 | 100 ± 0.0 | 100 | 100 ± 0.0 | |
| **48-hr EC10 = >100%** | | **48-hr EC10 = >100%** | | |
| **48-hr EC50 = >100%** | | **48-hr EC50 = >100%** | | |
| **NOEC = 100%** | | **NOEC = 100%** | | |
| **LOEC = >100%** | | **LOEC = >100%** | | |

| QA/QC Parameter | Criterion | This Test | Criterion met? |
|---|---|---|---|
| Control mean % survival | >90.0% | 100% | Yes |
| Reference Toxicant within cusum chart limits | 178.5-277.2mg KCl/L | 252.3mg KCl/L | Yes |

Test Report Authorised by: Dr Rick Krassoi, Director on 4 January 2010

Results are based on the samples in the condition as received by ESA

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**Citations:**

Bailey, H.C., Krassoi, R., Elphick, J.R., Mulhall, A., Hunt, P., Tedmanson, L. and Lovell, A. (2000) Application of *Ceriodaphnia cf. dubia* for whole effluent toxicity tests in the Hawkesbury-Nepean watershed, New South Wales, Australia: method development and validation. *Environmental Toxicology and Chemistry* 19:88-93.

ESA (2008) *SOP 101 – Acute toxicity test using Ceriodaphnia dubia*. Issue No. 7. Ecotox Services Australasia. Sydney, New South Wales.

USEPA (2002) *Short-term Methods for Estimating the Chronic Toxicity of Effluents and Receiving Waters to Freshwater Organisms.4th Ed.* United States Environmental Protection Agency, Office of Water, Washington DC.

**Table A39 Toxicity test reports on 72-hr microalgal growth inhibition test using the green alga *Selenastrum capricornutum* of sediment samples collected on 7 October 2009 by CMLR**

## Toxicity Test Report: TR0535/7 (page 1 of 2)

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| | | | |
|---|---|---|---|
| **Client:** | University of Queensland<br>Centre for Mined Land Rehabilitation<br>Brisbane QLD 4072 | **ESA Job #:**<br>**Date Sampled:**<br>**Date Received:** | PR0535<br>19 October 2009<br>20 October 2009 |
| **Attention:** | Barry Noller | **Sampled By:** | Client |
| **Client Ref:** | Not supplied | **ESA Quote #:** | PL0535_q01 |

| Lab ID No.: | Sample Name: | Sample Description: |
|---|---|---|
| 3828 | 23rd Avenue L.R | Sediment grab received in apparent good condition. |
| 3829 | Isa Street Crossing L.R | Sediment grab received in apparent good condition. |
| 3830 | Alma Street Crossing L.R | Sediment grab received in apparent good condition. |
| 3831 | Davis Street Crossing L.R | Sediment grab received in apparent good condition. |
| 3832 | Moondarra Crossing L.R | Sediment grab received in apparent good condition. |

| | |
|---|---|
| **Test Performed:** | 72-hr microalgal growth inhibition test using the green alga *Selenastrum capricornutum* |
| **Test Protocol:** | ESA SOP 103 (ESA 2009), based on USEPA (2002) |
| **Deviations from Protocol:** | Nil |
| **Comments on Solution Preparation:** | Sediment elutriates were prepared according to USEPA (1991). One hundred millilitres of sediment was mixed with 400 mL USEPA media and manually shaken vigorously for 1 minute. The mixture was left to settle for 10 minutes and then shaken again for 1 minute. This process was repeated to achieve a total of 3 shaking times. The mixture was allowed to settle for 1 h before the supernatant was carefully siphoned off without disturbing the sediment. Sediment elutriates were centrifuged prior to testing to remove suspended particles. The sediment elutriates were serially diluted with USEPA media to achieve the test concentrations. A Diluent control (USEPA media) was tested concurrently with the samples. |
| **Source of Test Organisms:** | ESA Laboratory culture, originally sourced from CSIRO Microalgal Supply Service, TAS |
| **Test Initiated:** | 13 November 2009 at 1600h |

| Sample 3828: *23rd Avenue L.R* | | Sample 3829: *Isa Street Crossing L.R* | | Sample 3830: *Alma Street Crossing L.R* | |
|---|---|---|---|---|---|
| **Concentration (%)** | **Cell Yield x10⁴ cells/mL (Mean ± SD)** | **Concentration (%)** | **Cell Yield x10⁴ cells/mL (Mean ± SD)** | **Concentration (%)** | **Cell Yield x10⁴ cells/mL (Mean ± SD)** |
| Diluent Control | 132.2 ± 18.9 | Diluent Control | 132.2 ± 18.9 | Diluent Control | 132.2 ± 18.9 |
| Colour Control | 72.4 ± 8.2** | Colour Control | 65.6 ± 9.6** | Colour Control | 74.7 ± 23.0** |
| 6.3 | 97.5 ± 23.4 | 6.3 | 119.0 ± 18.5 | 6.3 | 96.7 ± 22.8 * |
| 12.5 | 95.3 ± 17.2 | 12.5 | 118.3 ± 16.1 | 12.5 | 89.0 ± 17.4 * |
| 25 | 92.0 ± 27.0 * | 25 | 49.8 ± 9.3 * | 25 | 61.5 ± 9.9 * |
| 50 | 102.7 ± 29.2 | 50 | 8.0 ± 5.7 * | 50 | 19.2 ± 8.0 * |
| 100 | 76.3 ± 18.0 * | 100 | 4.2 ± 4.0 * | 100 | 8.4 ± 9.2 * |
| **72-hr IC10 = 2.4 (1.4-8.0)%** | | **72-hr IC10 = 6.5 (1.3-19.6)%** | | **72-hr IC10 = 2.3 (1.2-10.2)%** | |
| **72-hr IC50 = >100%** | | **72-hr IC50 = 22.0 (18.9-25.1)%** | | **72-hr IC50 = 22.9 (14.4-32.8)%** | |
| **NOEC = 50%** | | **NOEC = 12.5%** | | **NOEC = <6.3%** | |
| **LOEC = 100%** | | **LOEC = 25%** | | **LOEC = 6.3%** | |

*Significantly lower cell yield compared with the Diluent Control (Dunnett's Test, 1-tailed, P=0.05)
**Significantly lower cell yield compared with the Diluent Control (Bonferroni t Test, 1-tailed, P=0.05)

**Table A39 (continue)**

## Toxicity Test Report: TR0535/7 (page 2 of 2)

| Sample 3831: *Davis Street Crossing L.R* | | Sample 3832: *Moondarra Crossing L.R* | | *Vacant* |
|---|---|---|---|---|
| **Concentration (%)** | **Cell Yield x10$^4$ cells/mL (Mean ± SD)** | **Concentration (%)** | **Cell Yield x10$^4$ cells/mL (Mean ± SD)** | |
| Diluent Control | 132.2 ± 18.9 | Diluent Control | 132.2 ± 18.9 | |
| Colour Control | 81.6 ± 6.8** | Colour Control | 82.2 ± 18.4** | |
| 6.3 | 139.2 ± 10.2 | 6.3 | 96.0 ± 7.5 * | |
| 12.5 | 138.3 ± 17.6 | 12.5 | 100.3 ± 16.7 * | |
| 25 | 162.5 ± 13.6 | 25 | 113.4 ± 30.4 | |
| 50 | 161.6 ± 7.2 | 50 | 91.7 ± 20.1 * | |
| 100 | 210.0 ± 18.4 | 100 | 44.4 ± 4.6 * | |
| **72-hr IC10 = >100%** | | **72-hr IC10 = 2.9 (1.4-38.8)%** | | |
| **72-hr IC50 = >100%** | | **72-hr IC50 = 77.1 (50.8-93.7)%** | | |
| **NOEC = 100%** | | **NOEC = 25%** | | |
| **LOEC = >100%** | | **LOEC = 50%** | | |

*Significantly lower cell yield compared with the Diluent Control (Dunnett's Test, 1-tailed, P=0.05)
**Significantly lower cell yield compared with the Diluent Control (Bonferroni t Test, 1-tailed, P=0.05)

| QA/QC Parameter | Criterion | This Test | Criterion met? |
|---|---|---|---|
| Control mean cell density | >16.0x10$^4$ cells/mL | 133.2x10$^4$ cells/mL | Yes |
| Control coefficient of variation | <20% | 14.3% | Yes |
| Reference Toxicant within cusum chart limits | 0.9-4.3g KCl/L | 1.5g KCl/L | Yes |

Test Report Authorised by: Dr Rick Krassoi, Director on 4 January 2010

Results are based on the samples in the condition as received by ESA

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**Citations:**

ESA (2009) *ESA SOP 103 – Green Alga, Selenastrum capricornutum, Growth Test*. Issue No 4, Ecotox Services Australasia, Sydney, NSW.

USEPA (2002) *Short-term methods for estimating the chronic toxicity of effluents and receiving waters to freshwater organisms*. Fourth Edition, EPA-821-R-02-013, United States Environmental Protection Agency, Office of Research and Development, Washington DC, USA.

**Table A40 Toxicity test reports 48hr Survival *Cerio daphnia* cf *dubia* elutrial of sediment samples collected at Riffle Creek Dam(28 July 2010)**

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## Toxicity Test Report: TR0631/6

(page 1 of 2)

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| | | | |
|---|---|---|---|
| **Client:** | Centre for Mined Land Rehabilitation<br>University Of Queensland<br>Brisbane QLD 4072 | **ESA Job #:**<br>**Date Sampled:**<br>**Date Received:** | PR0631<br>28 July 2010<br>3 August 2010 |
| **Attention:** | Barry Noller | **Sampled By:** | Client |
| **Client Ref:** | None Supplied | **ESA Quote #:** | PL0631_q01 |

| Lab ID No.: | Sample Name: | Sample Description: |
|---|---|---|
| 4272 | Riffle Creek Dam | Sediment received chilled in apparent good condition |

| | |
|---|---|
| **Test Performed:** | 48-hr acute (survival) toxicity test using the freshwater cladoceran *Ceriodaphnia cf dubia* |
| **Test Protocol:** | ESA SOP 101 (ESA 2009), based on USEPA (2002) and Bailey *et al.* (2000) |
| **Test Temperature:** | The test was performed at 25±1°C. |
| **Deviations from Protocol:** | Nil |
| **Comments on Solution Preparation:** | The elutriate was prepared by adding one part sample to four parts dilute mineral water (DMW). The mixture was shaken vigorously every 10 min, for a period of 1 min, over a 30 min mixing period. After the 30 min mixing period, the mixture was allowed to settle for 1 h before the supernatant was siphoned off. The elutriate was serially diluted with DMW to achieve the test concentrations. A DMW control was tested concurrently with the elutriate. |
| **Source of Test Organisms:** | ESA Laboratory culture |
| **Test Initiated:** | 3 August 2010 at 1600h |

| Sample 4272: *Riffle Creek Dam* Concentration (%) | % Survival at 48 h (Mean ± SD) | *Vacant* | *Vacant* |
|---|---|---|---|
| DMW Control | 100 ± 0.0 | | |
| 6.3 | 100 ± 0.0 | | |
| 12.5 | 100 ± 0.0 | | |
| 25 | 100 ± 0.0 | | |
| 50 | 100 ± 0.0 | | |
| 100 | 100 ± 0.0 | | |
| **48-hr IC10 = >100%**<br>**48-hr IC50 = >100%**<br>**NOEC = 100%**<br>**LOEC = >100%** | | | |

**Table A41 Toxicity test reports on 72-hr microalgal growth inhibition test using the green alga *Selenastrum capricornutum* of sediment samples collected at Riffle Creek Dam (28 July 2010)**

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## Toxicity Test Report: TR0631/7

(page 1 of 2)

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| | | | |
|---|---|---|---|
| **Client:** | Centre for Mined Land Rehabilitation<br>University Of Queensland<br>Brisbane QLD 4072 | **ESA Job #:**<br>**Date Sampled:**<br>**Date Received:** | PR0631<br>28 July 2010<br>3 August 2010 |
| **Attention:** | Barry Noller | **Sampled By:** | Client |
| **Client Ref:** | None Supplied | **ESA Quote #:** | PL0631_g01 |

| Lab ID No.: | Sample Name: | Sample Description: |
|---|---|---|
| 4272 | Riffle Creek Dam | Sediment received chilled in apparent good condition |

| | |
|---|---|
| **Test Performed:** | 72-hr microalgal growth inhibition test using the green alga *Selenastrum capricornutum* |
| **Test Protocol:** | ESA SOP 103 (ESA 2010), based on USEPA (2002) |
| **Test Temperature:** | The test was performed at 25±1°C. |
| **Deviations from Protocol:** | Nil |
| **Comments on Solution Preparation:** | The elutriate was prepared by adding one part sample to four parts USEPA media. The mixture was shaken vigorously every 10 min. for a period of 1 min. over a 30 min mixing period. After the 30 min mixing period, the mixture was allowed to settle for 1 h before the supernatant was siphoned off. The elutriate was centrifuged prior to testing. The elutriate was serially diluted with USEPA media to achieve the test concentrations. A diluent control (USEPA media) and a colour control were tested concurrently with the elutriate. |
| **Source of Test Organisms:** | ESA Laboratory culture, originally sourced from CSIRO Microalgal Supply Service, TAS |
| **Test Initiated:** | 3 August 2010 at 1600h |

| Sample 4272: *Riffle Creek Dam* Concentration (%) | Cell Yield x10$^4$ cells/mL (Mean ± SD) | *Vacant* | *Vacant* |
|---|---|---|---|
| Diluent Control | 142.2 ± 16.4 | | |
| Colour Control | 94.7 ± 14.1 * | | |
| 6.3 | 136.9 ± 11.5 | | |
| 12.5 | 145.2 ± 14.4 | | |
| 25 | 125.7 ± 4.4 | | |
| 50 | 105.5 ± 4.8** | | |
| 100 | 97.9 ± 27.4** | | |
| **72-hr IC10 = 23.1 (0.0-36.2)%**<br>**72-hr IC50 = >100%**<br>**NOEC = 25%**<br>**LOEC = 50%** | | | |

*Significantly lower cell yield compared with the Diluent Control (Homoscedastic t, 1-tailed, P=0.05)
**Significantly lower cell yield compared with the Diluent Control (Dunnett's Test, 1-tailed, P=0.05)

**Appendix 8.Summary toxicity assessment and metal and metalloid concentrations in water and sediment at 5 sites at Leichhardt River. Samples were collected on 13-16 October 2009 by CMLR**

| Toxicity test species | Unit | Test results |
|---|---|---|
| 72-h Inhibition *Selenastrum capricornutum* | 72-h IC50 | 91.8% |
| 48h Survival *Ceriodaphnia cf dubia* | 48-h EC50 | >100% |
| 7-d partial life-cycle (chronic) toxicity *cladoceran Ceriodaphnia* cf *dubia* (survival) | 8-d EC50 | >100% |
| 7-d partial life-cycle (chronic) toxicity cladoceran *Ceriodaphia* cf *dubia* | 8-d IC50 (reproduction) | >100% |
| 7-d Growth Inhibition *Lemna minor* | 7-d IC50 (growth rate) | 45.3% |
| 7-d Growth Inhibition *Lemna minor* | 7-d IC50 (dry weight) | >100% |
| 96-h fish Imbalance *Melanotaenia splendida* | 96-h EC50 | >100% |

**Table A42.2 Chemical properties and metal concentrations in water quality**

| | | | |
|---|---|---|---|
| pH | | 8.6 | Trigger values for 95% fresh water species protection level (µg/L)* |
| EC | (µS/cm) | 1500 | |
| Alkalinity | $CaCO_3$(mg/L) | 277 | |
| Sulfate | (mg/L) | 152 | |
| Nitrate | (mg/L) | <0.5 | |
| Chloride | (mg/L) | 281 | |
| DOC | (mg/L) | 6.8 | |
| Hardness | (mg/L) | 318 | |
| Cadmium (µg/L) | Total | 0.1 | 1.1 |
| | 0.45µm | 0.1 | |
| Copper (µg/L) | Total | 8.6 | 7.3 |
| | 0.45µm | 5.1 | |
| Lead (µg/L) | Total | 3.3 | 40 |
| | 0.45µm | 0.06 | |
| Zinc (µg/L) | Total | 16.8 | 42 |
| | 0.45µm | 13.6 | |

* Trigger value have been adjusted to site-specific water hardness

**Table A42.3 Toxicity Assessment of Sediment**

| Toxicity test species | Unit | Test results |
|---|---|---|
| 48-h Survival *Ceriodaphnia* cf *dubia* | 48-h EC50 | 100% |
| 72-h Inhibition *Selenastrum capricornutum* | 72-h IC50 | 100% |

**Table A42.4 Chemical properties and metal or metalloid concentration in sediment**

| Metal or Metalloid | Fractions | (mg/kg) | ISQG Low | ISQG high |
|---|---|---|---|---|
| Antimony (Sb) | 1MHCl | <1 | 2 | 25 |
| | Total | | | |
| Arsenic (As) | 1MHCl | 3 | 20 | 70 |
| | Total | | | |
| Cadmium (Cd) | 1MHCl | 0.5 | 1.5 | 10 |
| | Total | | | |
| Cobalt (Co) | 1MHCl | 8.2 | NA | NA |
| | Total | | | |
| Copper (Cu) | 1MHCl | 194 | 65 | 270 |
| | Total | | | |
| Lead (Pb) | 1MHCl | 50 | 50 | 220 |
| | Total | | | |
| Nickel (Ni) | 1MHCl | 1.9 | 21 | 52 |
| | Total | | | |
| Zinc (Zn) | 1MHCl | 42 | 200 | 410 |
| | Total | | | |

**Table A42.5 *In situ* deployment of DGT units in sediment results**

| Metal | $C_{DGT}$ (± SE) | $R_{diff}$ | $C_E$ (± SE) | $C_{SOL}$ |
|---|---|---|---|---|
| | (µg/L) | | (µg/L) | |
| Cadmium (Cd) | 0.005 ± 0.001 | 0.03 | 0.2 ± 0.03 | 0.4 |
| Copper (Cu) | 0.15 ± 0.09 | 0.06 | 2.5 ± 1.5 | 3.3 |
| Lead (Pb) | 0.025 ± 0.01 | 0.05 | 0.5 ± 0.2 | 0.01 |
| Nickel (Ni) | 0.18 ± 0.04 | 0.06 | 2.9 ± 0.7 | 1.6 |
| Zinc (Zn) | 3.2 ± 0.9 | 0.07 | 47 ± 14 | 20 |

-$C_{SOL}$: The concentrations of metals in 0.45µm filtered pore water. Sediment samples were centrifuged at 1509 g for five min and the pore water was filtered through 0.45µm filter.
-$C_E$: Effective concentration of metals. $C_E = C_{DGT}/R_{diff}$ where $R_{diff}$ is calculated using the 2D DIFS model (Section 2.5.6)
- $C_{DGT}$: Concentration of metals measured by DGT
- SE: Standard Error

Location 2: Isa Crossing, Leichhardt River

**Table A43.1 Toxicity Assessment of Water**

| Toxicity test species | Unit | Test results |
|---|---|---|
| 72-h Inhibition *Selenastrum capricornutum* | 72-h IC50 | >100% |
| 48-h Survival *Ceriodaphnia* cf *dubia* | 48-h EC50 | >100% |
| 7-d partial life-cycle (chronic) toxicity cladoceran *Ceriodaphia* cf *dubia* (survival) | 8-d EC 50 | >100% |
| 7-d partial life-cycle (chronic) toxicity cladoceran *Ceriodaphia* cf *dubia* | 8-d IC 50 (reproduction) | >100% |
| 7-d Growth Inhibition *Lemna minor* | 7-d IC50 (growth rate) | >100% |
| 7-d Growth Inhibition *Lemna minor* | 7-d IC50 (dry weight) | >100% |
| 96-h fish Imbalance *Melanotaenia splendida* | 96-h EC 50 | >100% |

**Table A43.2 Chemical properties and metal concentrations in water quality**

| | | | |
|---|---|---|---|
| pH | | 9.0 | Trigger values for 95% fresh water species protection level (µg/L)* |
| EC | (µS/cm) | 3700 | |
| Alkalinity | $CaCO_3$(mg/L) | 292 | |
| Sulfate | (mg/L) | 710 | |
| Nitrate | (mg/L) | <0.5 | |
| Chloride | (mg/L) | 793 | |
| DOC | (mg/L) | 7.3 | |
| Hardness | (mg/L) | 569 | |
| Cadmium (µg/L) | Total | 0.4 | 2 |
| | 0.45µm | 0.2 | |
| Copper (µg/L) | Total | 9.2 | 13 |
| | 0.45µm | 6.5 | |
| Lead (µg/L) | Total | 2.3 | 91 |
| | 0.45µm | 0.4 | |
| Zinc (µg/L) | Total | 34.5 | 72 |
| | 0.45µm | 18.0 | |

* Trigger value have been adjusted to site-specific water hardness

**Table A43.3 Toxicity Assessment of Sediment**

| Toxicity test species | Unit | Test results |
|---|---|---|
| 48-h Survival *Ceriodaphnia* cf dubia | 48-h EC50 | 22% |
| 72-h Inhibition *Selenastrum capricornutum* | 72-h IC50 | 100% |

**Table A43.4 Chemical properties and metal or metalloid concentration in sediment**

| Metal or Metalloid | Fractions | (mg/kg) | ISQG Low | ISQG high |
|---|---|---|---|---|
| Antimony (Sb) | 1MHCl | <1 | 2 | 25 |
| | Total | <5 | | |
| Arsenic (As) | 1MHCl | 4.3 | 20 | 70 |
| | Total | 10 | | |
| Cadmium (Cd) | 1MHCl | 4.7 | 1.5 | 10 |
| | Total | 4 | | |
| Cobalt (Co) | 1MHCl | 8.7 | NA | NA |
| | Total | 16 | | |
| Copper (Cu) | 1MHCl | 218 | 65 | 270 |
| | Total | 390 | | |
| Lead (Pb) | 1MHCl | 82.1 | 50 | 220 |
| | Total | 89 | | |
| Nickel (Ni) | 1MHCl | 3.6 | 21 | 52 |
| | Total | 19 | | |
| Zinc (Zn) | 1MHCl | 932 | 200 | 410 |
| | Total | 947 | | |

**Table A43.5: In situ deployment of DGT units in sediment results**

| Metal | $C_{DGT}$ (± SE) | $R_{diff}$ | $C_E$ (± SE) | $C_{SOL}$ |
|---|---|---|---|---|
| | (µg/L) | | (µg/L) | |
| Cadmium (Cd) | 0.002 ± 0.001 | 0.03 | 0.07 ± 0.03 | 0.7 |
| Copper (Cu) | 0.27 ± 0.2 | 0.07 | 4.2 ± 3.1 | 11.3 |
| Lead (Pb) | 0.008 ± 0.001 | 0.05 | 0.2 ± 0.02 | 0.4 |
| Nickel (Ni) | 0.29 ± 0.02 | 0.07 | 4.5 ± 0.3 | 5.0 |
| Zinc (Zn) | 4.1 ± 0.4 | 0.05 | 67.2 ± 0.4 | 51 |

-$C_{SOL}$: The concentrations of metals in 0.45µm filtered pore water. Sediment samples were centrifuged at 1509 g for five min and the pore water was filtered through 0.45µm filter.
-$C_E$: Effective concentration of metals. $C_E = C_{DGT}/R_{diff}$ where $R_{diff}$ is calculated using the 2D DIFS model (Section 2.5.6)
- $C_{DGT}$: Concentration of metals measured by DGT
- SE: Standard Error

Location 3: Alma St Crossing, Leichhardt River

**Table A44.1 Toxicity Assessment of Water**

| Toxicity test species | Unit | Test results |
|---|---|---|
| 72-h Inhibition *Selenastrum capricornutum* | 72-h IC50 | >100% |
| 48-h Survival *Ceriodaphnia* cf *dubia* | 48-h EC50 | >100% |
| 7-d partial life-cycle (chronic) toxicity cladoceran *Ceriodaphia* cf *dubia* (survival) | 8-d EC 50 | >100% |
| 7-d partial life-cycle (chronic) toxicity cladoceran *Ceriodaphia* cf *dubia* | 8-d IC 50 (reproduction) | >100% |
| 7-d Growth Inhibition *Lemna minor* | 7-d IC50 (growth rate) | >100% |
| 7-d Growth Inhibition *Lemna minor* | 7-d IC50 (dry weight) | >100% |
| 96-h fish Imbalance *Melanotaenia splendida* | 96-h EC 50 | >100% |

**Table A44.2 Chemical properties and metal concentrations in water quality**

| | | | |
|---|---|---|---|
| pH | | 9 | Trigger values for 95% fresh water species protection level (µg/L)* |
| EC | (µS/cm) | 4230 | |
| Alkalinity | $CaCO_3$(mg/L) | 541 | |
| Sulfate | (mg/L) | 429 | |
| Nitrate | (mg/L) | <0.5 | |
| Chloride | (mg/L) | 1130 | |
| DOC | (mg/L) | 58 | |
| Hardness | (mg/L) | 845 | |
| Cadmium (µg/L) | Total | 1.0 | 2 |
| | 0.45µm | 0.4 | |
| Copper (µg/L) | Total | 28 | 13 |
| | 0.45µm | 14 | |
| Lead (µg/L) | Total | 19.4 | 91 |
| | 0.45µm | 1.6 | |
| Zinc (µg/L) | Total | 36.2 | 72 |
| | 0.45µm | 18.1 | |

* Trigger value have been adjusted to site-specific water hardness

**Table A44.3. Toxicity Assessment of Sediment**

| Toxicity test species | Unit | Test results |
|---|---|---|
| 48-h Survival *Ceriodaphnia* cf *dubia* | 48-h EC50 | 100% |
| 72-h Inhibition *Selenastrum capricornutum* | 72-h IC50 | 100% |

**Table A44.4 Chemical properties and metal or metalloid concentration in sediment**

| Metal or Metalloid | Fractions | (mg/kg) | ISQG Low | ISQG high |
|---|---|---|---|---|
| Antimony (Sb) | 1MHCl | <1 | 2 | 25 |
| | Total | | | |
| Arsenic (As) | 1MHCl | 4.2 | 20 | 70 |
| | Total | | | |
| Cadmium (Cd) | 1MHCl | 7 | 1.5 | 10 |
| | Total | | | |
| Cobalt (Co) | 1MHCl | 8.5 | NA | NA |
| | Total | | | |
| Copper (Cu) | 1MHCl | 190 | 65 | 270 |
| | Total | | | |
| Lead (Pb) | 1MHCl | 144 | 50 | 220 |
| | Total | | | |
| Nickel (Ni) | 1MHCl | 2.7 | 21 | 52 |
| | Total | | | |
| Zinc (Zn) | 1MHCl | 274 | 200 | 410 |
| | Total | | | |

**Table A44.5 *In situ* deployment of DGT units in sediment results**

| Metal | $C_{DGT}$ (± SE) | $R_{diff}$ | $C_E$ (± SE) | $C_{SOL}$ |
|---|---|---|---|---|
| | (µg/L) | | (µg/L) | |
| Cadmium (Cd) | 0.015 ± 0.001 | 0.05 | 0.33 ± 0.02 | 0.7 |
| Copper (Cu) | 0.3 ± 0.2 | 0.06 | 4.5 ± 3.8 | 8.6 |
| Lead (Pb) | 0.19 ± 0.001 | 0.06 | 3.06 ± 0.02 | 0.6 |
| Nickel (Ni) | 0.21 ± 0.01 | 0.06 | 3.3 ± 0.2 | 5.0 |
| Zinc (Zn) | 1.3 ± 0.2 | 0.07 | 20 ± 3 | 32.0 |

-$C_{SOL}$: The concentrations of metals in 0.45µm filtered pore water. Sediment samples were centrifuged at 1509 g for five min and the pore water was filtered through 0.45µm filter.
-$C_E$: Effective concentration of metals. $C_E = C_{DGT}/R_{diff}$ where $R_{diff}$ is calculated using the 2D DIFS model (Section 2.5.6)
- $C_{DGT}$: Concentration of metals measured by DGT
- SE: Standard Error

Location 4: Davis Crossing, Leichhardt River

**Table A45.1 Toxicity Assessment of Water**

| Toxicity test species | Unit | Test results |
|---|---|---|
| 72-h Inhibition *Selenastrum capricornutum* | 72-h IC50 | >100% |
| 48-h Survival *Cerio daphnia* cf *dubia* | 48-h EC50 | >100% |
| 7-d partial life-cycle (chronic) toxicity cladoceran *Ceriodaphia* cf *dubia* (survival) | 8-d EC 50 | >100% |
| 7-d partial life-cycle (chronic) toxicity cladoceran *Ceriodaphia* cf *dubia* | 8-d IC 50 (reproduction) | 66.1% |
| 7-d Growth Inhibition *Lemna minor* | 7-d IC50 (growth rate) | 95.3% |
| 7-d Growth Inhibition *Lemna minor* | 7-d IC50 (dry weight) | >100% |
| 96-h fish Imbalance *Melanotaenia splendida* | 96-h EC 50 | >100% |

**Table A45.2 Chemical properties and metal concentrations in water quality**

| | | | |
|---|---|---|---|
| pH | | 8.14 | Trigger values for 95% fresh water species protection level (µg/L)* |
| EC | (µS/cm) | 5900 | |
| Alkalinity | $CaCO_3$(mg/L) | 451 | |
| Sulfate | (mg/L) | 726 | |
| Nitrate | (mg/L) | <0.5 | |
| Chloride | (mg/L) | 1220 | |
| DOC | (mg/L) | 4.4 | |
| Hardness | (mg/L) | 741 | |
| Cadmium (µg/L) | Total | 2.8 | 2 |
| | 0.45µm | 1.09 | |
| Copper (µg/L) | Total | 4.24 | 13 |
| | 0.45µm | 2.67 | |
| Lead (µg/L) | Total | 2.69 | 91 |
| | 0.45µm | 0.27 | |
| Zinc (µg/L) | Total | 15.59 | 72 |
| | 0.45µm | 10.6 | |

* Trigger value have been adjusted to site-specific water hardness

**Table A45.3 Toxicity Assessment of Sediment**

| Toxicity test species | Unit | Test results |
|---|---|---|
| 48-h Survival *Ceriodaphnia* cf *dubia* | 48-h EC50 | 100% |
| 72-h Inhibition *Selenastrum capricornutum* | 72-h IC50 | 100% |

**Table A45.4 Chemical properties and metal or metalloid concentration in sediment**

| Metal or Metalloid | Fractions | (mg/kg) | ISQG Low | ISQG high |
|---|---|---|---|---|
| Antimony (Sb) | 1MHCl | <1 | 2 | 25 |
| | Total | <5 | | |
| Arsenic (As) | 1MHCl | 7.4 | 20 | 70 |
| | Total | 16 | | |
| Cadmium (Cd) | 1MHCl | 59.1 | 1.5 | 10 |
| | Total | 58 | | |
| Cobalt (Co) | 1MHCl | 12 | NA | NA |
| | Total | 21 | | |
| Copper (Cu) | 1MHCl | 148 | 65 | 270 |
| | Total | 264 | | |
| Lead (Pb) | 1MHCl | 225 | 50 | 220 |
| | Total | 281 | | |
| Nickel (Ni) | 1MHCl | 2.9 | 21 | 52 |
| | Total | 19 | | |
| Zinc (Zn) | 1MHCl | 578 | 200 | 410 |
| | Total | 699 | | |

**Table A45.5 *In situ* deployment of DGT units in sediment results**

| Metal | $C_{DGT}$ (± SE) | $R_{diff}$ | $C_E$ (± SE) | $C_{SOL}$ |
|---|---|---|---|---|
| | (µg/L) | | (µg/L) | |
| Cadmium (Cd) | 0.01 ± 0.005 | 0.06 | 0.2 ± 0.1 | 1.1 |
| Copper (Cu) | 0.27 | 0.07 | 4.0 | 6.0 |
| Lead (Pb) | 0.09 ± 0.05 | 0.06 | 1.5 ± 0.8 | 0.6 |
| Nickel (Ni) | 0.12 ± 0.01 | 0.06 | 2.0 ± 0.2 | 2.7 |
| Zinc (Zn) | 0.3 ± 0.2 | 0.06 | 5 ± 3 | 19 |

-$C_{SOL}$: The concentrations of metals in 0.45µm filtered pore water. Sediment samples were centrifuged at 1509 g for five min and the pore water was filtered through 0.45µm filter.
-$C_E$: Effective concentration of metals. $C_E = C_{DGT}/R_{diff}$ where $R_{diff}$ is calculated using the 2D DIFS model (Section 2.5.6)
- $C_{DGT}$: Concentration of metals measured by DGT
- SE: Standard Error

Location 5: Moondarra Crossing, Leichhardt River

**Table A46.1 Toxicity Assessment of Water**

| Toxicity test species | Unit | Test results |
|---|---|---|
| 72-h Inhibition *Selenastrum capricornutum* | 72-h IC50 | 41.8% |
| 48-h Survival *Cerio daphnia* cf *dubia* | 48-h EC50 | >100% |
| 7-d partial life-cycle (chronic) toxicity cladoceran *Ceriodaphia* cf *dubia* (survival) | 8-d EC 50 | >100% |
| 7-d partial life-cycle (chronic) toxicity cladoceran *Ceriodaphia* cf *dubia* | 8-d IC 50 (reproduction) | 74.2% |
| 7-d Growth Inhibition *Lemna minor* | 7-d IC50 (growth rate) | >100% |
| 7-d Growth Inhibition *Lemna minor* | 7-d IC50 (dry weight) | 59.3% |
| 96-h fish Imbalance *Melanotaenia splendida* | 96-h EC 50 | >100% |

**Table A46.2 Chemical properties and metal concentrations in water quality**

| | | | |
|---|---|---|---|
| pH | | 8.24 | Trigger values for 95% fresh water species protection level (µg/L)* |
| EC | (µS/cm) | 333 | |
| Alkalinity | $CaCO_3$(mg/L) | 258 | |
| Sulfate | (mg/L) | 824 | |
| Nitrate | (mg/L) | <0.5 | |
| Chloride | (mg/L) | 1340 | |
| DOC | (mg/L) | 11 | |
| Hardness | (mg/L) | 748 | |
| Cadmium (µg/L) | Total | 0.36 | 2 |
| | 0.45µm | 0.31 | |
| Copper (µg/L) | Total | 16.26 | 13 |
| | 0.45µm | 15.41 | |
| Lead (µg/L) | Total | 5.58 | 91 |
| | 0.45µm | 1.36 | |
| Zinc (µg/L) | Total | 10.22 | 72 |
| | 0.45µm | 7.86 | |

* Trigger value have been adjusted to site-specific water hardness

**Table A46.3 Toxicity Assessment of Sediment**

| Toxicity test species | Unit | Test results |
|---|---|---|
| 48-h Survival *Ceriodaphnia* cf *dubia* | 48-h EC50 | 77.1% |
| 72-h Inhibition *Selenastrum capricornutum* | 72-h IC50 | 100% |

**Table A46.4 Chemical properties and metal or metalloid concentration in sediment**

| Metal or Metalloid | Fractions | (mg/kg) | ISQG Low | ISQG high |
|---|---|---|---|---|
| Antimony (Sb) | 1MHCl | <1 | 2 | 25 |
| | Total | <11 | | |
| Arsenic (As) | 1MHCl | 4.7 | 20 | 70 |
| | Total | 19 | | |
| Cadmium (Cd) | 1MHCl | 6.9 | 1.5 | 10 |
| | Total | 8 | | |
| Cobalt (Co) | 1MHCl | 9.2 | NA | NA |
| | Total | 18 | | |
| Copper (Cu) | 1MHCl | 155 | 65 | 270 |
| | Total | 252 | | |
| Lead (Pb) | 1MHCl | 282 | 50 | 220 |
| | Total | 348 | | |
| Nickel (Ni) | 1MHCl | 3.2 | 21 | 52 |
| | Total | 23 | | |
| Zinc (Zn) | 1MHCl | 294 | 200 | 410 |
| | Total | 500 | | |

**Table A46.5 *In situ* deployment of DGT units in sediment results**

| Metal | $C_{DGT}$ | $R_{diff}$ | $C_E$ (± SE) | $C_{SOL}$ |
|---|---|---|---|---|
| | (µg/L) | | (µg/L) | |
| Cadmium (Cd) | 0.05 ± 0.005 | 0.06 | 0.8 ± 0.1 | 0.9 |
| Copper (Cu) | 1.2 | 0.06 | 18.8 | 11.6 |
| Lead (Pb) | 0.2 ± 0.05 | 0.06 | 3.1 ± 0.8 | 2.3 |
| Nickel (Ni) | 0.24 ± 0.01 | 0.06 | 3.8 ± 0.2 | 4.8 |
| Zinc (Zn) | 0.9 ± 0.2 | 0.07 | 14 ± 3 | 25.8 |

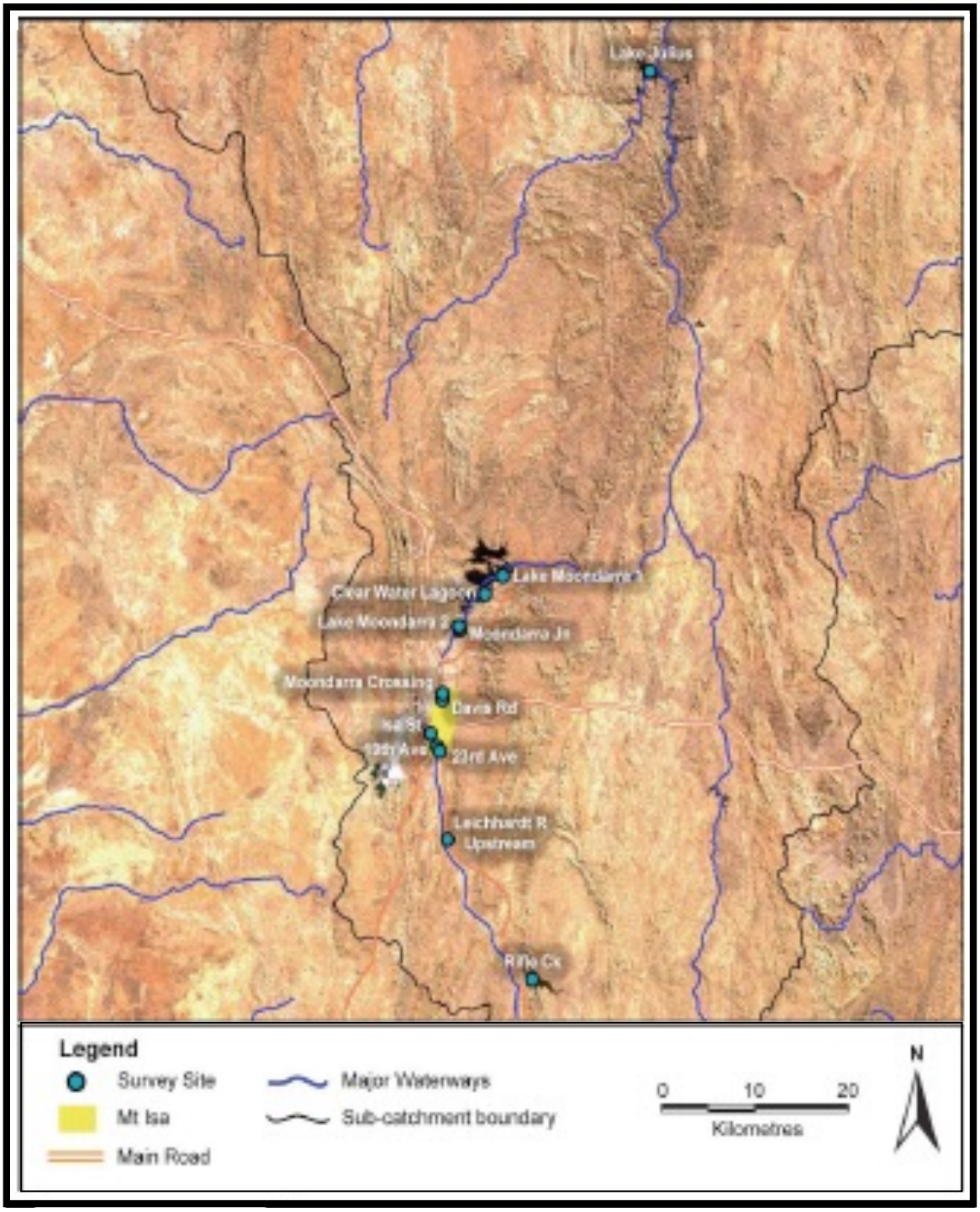
-$C_{SOL}$: The concentrations of metals in 0.45µm filtered pore water. Sediment samples were centrifuged at 1509 g for five min and the pore water was filtered through 0.45µm filter.
-$C_E$: Effective concentration of metals. $C_E = C_{DGT}/R_{diff}$ where $R_{diff}$ is calculated using the 2D DIFS model (Section 2.5.6)
- $C_{DGT}$: Concentration of metals measured by DGT
- SE: Standard Error

**Appendix 9. Results for heavy metals in fish and aquatic macroinvertebrates**

## Table A47: Location of survey sites (FRC Environmental 2010)

| Site Code | Description | Location (UTM MGA Zone 54) | |
|---|---|---|---|
| | | Easting | Northing |
| **Background Sites** | | | |
| K | Lake Julius | 365 690 | 7 773 617 |
| D | Rifle Creek Dam | 353 463 | 7 682 051 |
| **Test Sites** | | | |
| H | Leichardt River upstream of Mount Isa | 343 938 | 7 696 970 |
| B | Leichardt River at 23rd Avenue | 343 200 | 7 705 374 |
| A | Leichardt River at 19th Avenue | 343 132 | 7 705 608 |
| C | Leichardt River at Isa Street | 342 631 | 7 706 933 |
| E | Leichardt River at Davis Road | 343 163 | 7 710 364 |
| J | Leichardt River at Moondarra Crossing | 343 178 | 7 711 474 |
| F | Leichardt River at Moondarra Junction | 345 850 | 7 717 359 |
| I | Clear Water Lagoon | 348 053 | 7 720 779 |
| G | Lake Moondarra 1 (near Clear Water Lagoon) | 349 826 | 7 722 454 |
| LM | Lake Moondarra 2 (between Clear Water Lagoon and Moondarra Junction) | 346 100 | 7 718 090 |

**Location of sites for heavy metals in fish and aquatic macro invertebrates (FRC Environmental 2010)**



**Data for metal concentrations in aquatic biota (FRC Environmental 2010)**

**A. Cadmium**

| Species | | Site Abbreviation | Site name | Cadmium mg/kg (LOR =0.02) | N | Mean | SD | SE | Median | 75th Percentile |
|---|---|---|---|---|---|---|---|---|---|---|
| **Spangled Perch** | (muscle or whole fish) | B1-4 | | 0.14 | | | | | | |
| | | | | 0.7 | | | | | | |
| | | | | 0.11 | | | | | | |
| | | | | 0.11 | 4 | 0.265 | 0.290345 | 0.145172 | 0.125 | 0.28 |
| | (muscle or whole fish) | C1-8 | | 0.39 | | | | | | |
| | | | | 0.43 | | | | | | |
| | | | | 0.49 | | | | | | |
| | | | | 0.35 | | | | | | |
| | | | | 0.43 | | | | | | |
| | | | | 0.38 | | | | | | |
| | | | | 0.32 | | | | | | |
| | | | | 0.51 | 8 | 0.4125 | 0.065629 | 0.023203 | 0.41 | 0.445 |
| | (muscle or whole fish) | D15-18 | | 0.01 | | | | | | |
| | | | | 0.36 | | | | | | |
| | | | | 0.34 | | | | | | |
| | | | | 0.01 | 4 | 0.18 | 0.196469 | 0.098234 | 0.175 | 0.345 |
| | (muscle or whole fish) | K-14 | | 0.01 | 1 | | | | | |
| | (muscle or whole fish) | A1-8 (No. 6) | | 0.026 | | | | | | |
| | | | | 0.025 | | | | | | |
| | | | | 0.036 | | | | | | |
| | | | | 0.033 | | | | | | |
| | | | | 0.024 | | | | | | |
| | | | | 0.036 | | | | | | |
| | | | | 0.039 | 7 | 0.031286 | 0.006157 | 0.002327 | 0.033 | 0.036 |
| | (muscle) | ML19 | | 0.01 | | | | | | |

| Species | | Site Abbreviation | Site name | Cadmium mg/kg (LOR =0.02) | N | Mean | SD | SE | Median | 75th Percentile |
|---|---|---|---|---|---|---|---|---|---|---|
| | (whole fish) | ML19 | | 45 | 2 | 22.505 | 31.81273 | 22.495 | 22.505 | 33.7525 |
| | | | | | ALL | 1.935346 | 8.785882 | 1.723053 | 0.125 | 0.3875 |
| | (Liver) | D15-18 | | 0.11 | | | | | | |
| | | | | 4.7 | | | | | | |
| | | | | 0.18 | 3 | 1.663333 | 2.630063 | 1.518468 | 0.18 | 2.44 |
| | (Liver) | K-14 | | 0.18 | | | | | | |
| | | | | 0.12 | 2 | 0.15 | 0.042426 | 0.03 | 0.15 | 0.165 |
| | | | | | ALL | 1.058 | 2.036202 | 0.910617 | 0.18 | 0.18 |
| **Catfish** | (muscle or whole fish) | B9-12 | | 0.057 | | | | | | |
| | | | | 0.095 | | | | | | |
| | | | | 0.041 | | | | | | |
| | | | | 0.1 | 4 | 0.07325 | 0.028826 | 0.014413 | 0.076 | 0.09625 |
| | | | | | ALL | 0.07325 | 0.028826 | 0.014413 | 0.076 | 0.09625 |
| **Sleepy Cod** | (muscle) | C9 | | 0.01 | | | | | | |
| | (muscle) | C10 | | 0.01 | 2 | 0.01 | 0 | 0 | 0.01 | 0.01 |
| | (muscle or whole fish) | D9 | | 0.01 | | | | | | |
| | (muscle or whole fish) | D10 | | 0.01 | | | | | | |
| | (muscle or whole fish) | D11 | | 0.01 | | | | | | |
| | (muscle or whole fish) | D12 | | 0.01 | 4 | 0.01 | 0 | 0 | 0.01 | 0.01 |
| | (muscle or whole fish) | E1 | | 0.4 | | | | | | |
| | (muscle or whole fish) | E2 | | 0.18 | | | | | | |
| | (muscle or whole fish) | E3 | | 0.39 | | | | | | |
| | (muscle or whole fish) | E4 | | 0.28 | | | | | | |
| | (muscle or whole fish) | E13 | | 0.29 | | | | | | |
| | (muscle or whole fish) | E14 | | 0.31 | | | | | | |
| | (muscle or whole fish) | E15 | | 0.72 | 7 | 0.367143 | 0.172212 | 0.06509 | 0.31 | 0.395 |
| | (muscle or whole fish) | F1 | | 0.34 | | | | | | |
| | (muscle or whole fish) | F2 | | 0.53 | | | | | | |

| Species | | Site Abbreviation | Site name | Cadmium mg/kg (LOR =0.02) | N | Mean | SD | SE | Median | 75th Percentile |
|---|---|---|---|---|---|---|---|---|---|---|
| | (muscle or whole fish) | F3 | | 0.33 | | | | | | |
| | (muscle or whole fish) | F4 | | 0.41 | | | | | | |
| | (muscle or whole fish) | F5 | | 0.32 | | | | | | |
| | (muscle or whole fish) | F6 | | 0.29 | | | | | | |
| | (muscle or whole fish) | F7 | | 0.47 | | | | | | |
| | (muscle or whole fish) | F8 | | 0.25 | | | | | | |
| | (muscle or whole fish) | F9 | | 0.042 | | | | | | |
| | (muscle or whole fish) | F10 | | 0.01 | | | | | | |
| | (muscle or whole fish) | F11 | | 0.023 | | | | | | |
| | (muscle or whole fish) | F12 | | 0.034 | 12 | 0.254083 | 0.183959 | 0.053104 | 0.305 | 0.3575 |
| | (muscle or whole fish) | I9 | | 0.01 | | | | | | |
| | (muscle or whole fish) | I10 | | 0.01 | | | | | | |
| | (muscle or whole fish) | I11 | | 0.01 | | | | | | |
| | (muscle or whole fish) | I12 | | 0.01 | 4 | 0.01 | 0 | 0 | 0.01 | 0.01 |
| | (muscle or whole fish) | J1 | | 0.24 | | | | | | |
| | (muscle or whole fish) | J2 | | 0.42 | | | | | | |
| | (muscle or whole fish) | J3 | | 0.24 | | | | | | |
| | (muscle or whole fish) | J4 | | 0.32 | 4 | 0.305 | 0.08544 | 0.04272 | 0.28 | 0.345 |
| | (muscle or whole fish) | K7 | | 0.01 | | | | | | |
| | (muscle or whole fish) | K8 | | 0.01 | | | | | | |
| | (muscle or whole fish) | K9 | | 0.01 | | | | | | |
| | (muscle or whole fish) | K10 | | 0.01 | 4 | 0.01 | 0 | 0 | 0.01 | 0.01 |
| | (muscle) | LM1 | | 0.01 | | | | | | |
| | (muscle) | LM2 | | 0.01 | | | | | | |
| | (muscle) | LM3 | | 0.01 | | | | | | |
| | (muscle) | LM4 | | 0.01 | 4 | 0.01 | 0 | 0 | 0.01 | 0.01 |
| | | | | | ALL | 0.171195 | 0.191222 | 0.029864 | 0.034 | 0.32 |
| | (liver) | C9 | | 0.95 | | | | | | |

| Species | | Site Abbreviation | Site name | Cadmium mg/kg (LOR =0.02) | N | Mean | SD | SE | Median | 75th Percentile |
|---|---|---|---|---|---|---|---|---|---|---|
| | (liver) | C10 | | 2.8 | 2 | 1.875 | 1.308148 | 0.925 | 1.875 | 2.3375 |
| | (liver) | D9 | | 0.074 | | | | | | |
| | (liver) | D10 | | 0.045 | | | | | | |
| | (liver) | D11 | | 0.063 | | | | | | |
| | (liver) | D12 | | 0.11 | 4 | 0.073 | 0.02741 | 0.013705 | 0.073 | 0.083 |
| | (liver) | K7 | | 0.32 | | | | | | |
| | (liver) | K8 | | 0.32 | | | | | | |
| | (liver) | K9 | | 0.2 | | | | | | |
| | (liver) | K10 | | 0.1 | 4 | 0.235 | 0.106301 | 0.053151 | 0.26 | 0.32 |
| | (liver) | I9 | | 0.17 | | | | | | |
| | (liver) | I10 | | 0.01 | | | | | | |
| | (liver) | I11 | | 0.099 | | | | | | |
| | (liver) | I12 | | 0.095 | 4 | 0.0935 | 0.065465 | 0.032733 | 0.097 | 0.11675 |
| | (liver) | LM1 | | 0.32 | | | | | | |
| | (liver) | LM2 | | 0.61 | | | | | | |
| | (liver) | LM3 | | 1.1 | | | | | | |
| | (liver) | LM4 | | 0.37 | 4 | 0.6 | 0.356558 | 0.178279 | 0.49 | 0.7325 |
| | | | | | ALL | 0.430889 | 0.666339 | 0.157058 | 0.185 | 0.3575 |
| **Barramundi** | (muscle or whole fish) | G17 | | 0.01 | 1 | | | | | |
| | (liver) | G17 | | 0.88 | 1 | | | | | |
| **Barred Grunter** | (muscle or whole fish) | D1 | | 0.01 | | | | | | |
| | (muscle or whole fish) | D2 | | 0.01 | | | | | | |
| | (muscle or whole fish) | D3 | | 0.01 | | | | | | |
| | (muscle or whole fish) | D4 | | 0.01 | | | | | | |
| | (muscle or whole fish) | D5 | | 0.01 | | | | | | |
| | (muscle or whole fish) | D6 | | 0.01 | | | | | | |
| | (muscle or whole fish) | D7 | | 0.01 | | | | | | |
| | (muscle or whole fish) | D8 | | 0.01 | 8 | 0.01 | 0 | 0 | 0.01 | 0.01 |

| Species | | Site Abbreviation | Site name | Cadmium mg/kg (LOR =0.02) | N | Mean | SD | SE | Median | 75th Percentile |
|---|---|---|---|---|---|---|---|---|---|---|
| | (muscle or whole fish) | G1 | | 0.11 | | | | | | |
| | (muscle or whole fish) | G2 | | 0.1 | | | | | | |
| | (muscle or whole fish) | G3 | | 0.039 | | | | | | |
| | (muscle or whole fish) | G4 | | 0.13 | | | | | | |
| | (muscle or whole fish) | G5 | | 0.15 | | | | | | |
| | (muscle or whole fish) | G6 | | 0.12 | | | | | | |
| | (muscle or whole fish) | G7 | | 0.056 | | | | | | |
| | (muscle or whole fish) | G8 | | 0.061 | 8 | 0.09575 | 0.039521 | 0.013973 | 0.105 | 0.1225 |
| | (muscle or whole fish) | I1 | | 0.01 | | | | | | |
| | (muscle or whole fish) | I2 | | 0.01 | | | | | | |
| | (muscle or whole fish) | I3 | | 0.01 | | | | | | |
| | (muscle or whole fish) | I4 | | 0.034 | | | | | | |
| | (muscle or whole fish) | I5 | | 0.01 | | | | | | |
| | (muscle or whole fish) | I6 | | 0.01 | | | | | | |
| | (muscle or whole fish) | I7 | | 0.01 | | | | | | |
| | (muscle or whole fish) | I8 | | 0.01 | 8 | 0.013 | 0.008485 | 0.003 | 0.01 | 0.01 |
| | (muscle or whole fish) | J5 | | 0.4 | | | | | | |
| | (muscle or whole fish) | J6 | | 0.57 | | | | | | |
| | (muscle or whole fish) | J7 | | 0.45 | | | | | | |
| | (muscle or whole fish) | J8 | | 0.62 | | | | | | |
| | (muscle or whole fish) | J11 | | 0.68 | | | | | | |
| | (muscle or whole fish) | J12 | | 0.71 | | | | | | |
| | (muscle or whole fish) | J13 | | 0.5 | | | | | | |
| | (muscle or whole fish) | J14 | | 0.64 | 7 | 0.57125 | 0.111668 | 0.042206 | 0.595 | 0.65 |
| | (muscle or whole fish) | K1 | | 0.01 | | | | | | |
| | (muscle or whole fish) | K2 | | 0.01 | | | | | | |
| | (muscle or whole fish) | K3 | | 0.01 | | | | | | |
| | (muscle or whole fish) | K4 | | 0.01 | 4 | 0.01 | 0 | 0 | 0.01 | 0.01 |

| Species | | Site Abbreviation | Site name | Cadmium mg/kg (LOR =0.02) | N | Mean | SD | SE | Median | 75th Percentile |
|---|---|---|---|---|---|---|---|---|---|---|
| | (muscle or whole fish) | LM8 | | 0.01 | | | | | | |
| | (muscle or whole fish) | LM9 | | 0.01 | | | | | | |
| | (muscle or whole fish) | LM10 | | 0.01 | | | | | | |
| | (muscle or whole fish) | LM11 | | 0.01 | 4 | 0.01 | 0 | 0 | 0.01 | 0.01 |
| | | | | | ALL | 0.154524 | 0.249745 | 0.038536 | 0.01 | 0.1275 |
| | (liver) | K1 | | 0.27 | | | | | | |
| | (liver) | K2 | | 0.35 | | | | | | |
| | (liver) | K3 | | 0.22 | | | | | | |
| | (liver) | K4 | | 0.45 | 4 | 0.718 | 0.100457 | 0.050229 | 0.31 | 0.375 |
| | (liver) | LM8 | | 2.3 | 1 | | | | | |
| | | | | | ALL | 0.718 | 0.888634 | 0.397409 | 0.35 | 0.45 |
| **Rainbow** | (muscle or whole fish) | E5 | | 0.26 | | | | | | |
| | (muscle or whole fish) | E6 | | 0.36 | | | | | | |
| | (muscle or whole fish) | E7 | | 0.45 | | | | | | |
| | (muscle or whole fish) | E8 | | 0.36 | | | | | | |
| | (muscle or whole fish) | E9 | | 0.63 | | | | | | |
| | (muscle or whole fish) | E10 | | 0.31 | | | | | | |
| | (muscle or whole fish) | E11 | | 0.18 | | | | | | |
| | (muscle or whole fish) | E12 | | 0.56 | 8 | 0.38875 | 0.150849 | 0.053333 | 0.36 | 0.4775 |
| | | | | | ALL | 0.38875 | 0.150849 | 0.053333 | 0.36 | 0.4775 |
| **Tandan** | (muscle or whole fish) | F9 | | 0.023 | 1 | | | | | |
| | (muscle or whole fish) | K19 | | 0.01 | 1 | | | | | |
| | | | | | ALL | 0.0165 | 0.009192 | 0.0065 | 0.0165 | 0.01975 |
| | (liver) | F9 | | 1.8 | 1 | | | | | |
| | (liver?) | K19 | | 0.077 | 1 | | | | | |
| | | | | | ALL | 0.9385 | 1.218345 | 0.8615 | 0.9385 | 1.36925 |
| **Bony Bream** | (muscle or whole fish) | G13 | | 0.023 | | | | | | |
| | (muscle or whole fish) | G14 | | 0.01 | | | | | | |

| Species | | Site Abbreviation | Site name | Cadmium mg/kg (LOR =0.02) | N | Mean | SD | SE | Median | 75th Percentile |
|---|---|---|---|---|---|---|---|---|---|---|
| | (muscle or whole fish) | G15 | | 0.01 | | | | | | |
| | (muscle or whole fish) | G16 | | 0.01 | 4 | 0.01325 | 0.0065 | 0.00325 | 0.01 | 0.01325 |
| | (muscle or whole fish) | I15 | | 0.01 | | | | | | |
| | (muscle or whole fish) | I17 | | 0.029 | | | | | | |
| | (muscle or whole fish) | I19 | | 0.01 | | | | | | |
| | (muscle or whole fish) | I20 | | 0.01 | 4 | 0.01475 | 0.0095 | 0.00475 | 0.01 | 0.01475 |
| | (muscle or whole fish) | K15 | | 0.01 | | | | | | |
| | (muscle or whole fish) | K16 | | 0.01 | | | | | | |
| | (muscle or whole fish) | K17 | | 0.01 | | | | | | |
| | (muscle or whole fish) | K18 | | 0.01 | 4 | 0.01 | 0 | 0 | 0.01 | 0.01 |
| | (muscle or whole fish) | LM24 | | 0.01 | | | | | | |
| | (muscle or whole fish) | LM25 | | 0.01 | | | | | | |
| | (muscle or whole fish) | LM26 | | 0.01 | | | | | | |
| | (muscle or whole fish) | LM27 | | 0.01 | 4 | 0.01 | 0 | 0 | 0.01 | 0.01 |
| | | | | | ALL | 0.012 | 0.005574 | 0.001393 | 0.01 | 0.01 |
| | (liver) | G13 | | 4.8 | | | | | | |
| | (liver) | G14 | | 2.2 | | | | | | |
| | (liver) | G15 | | 1.3 | | | | | | |
| | (liver) | G16 | | 1.2 | 4 | 2.375 | 1.678044 | 0.839022 | 1.75 | 2.85 |
| | (liver) | I16 | | 0.01 | | | | | | |
| | (liver) | I18 | | 0.01 | | | | | | |
| | (liver) | I19 | | 0.038 | | | | | | |
| | (liver) | I20 | | 0.43 | 4 | 0.122 | 0.205757 | 0.102879 | 0.024 | 0.136 |
| | (liver) | K15 | | 0.11 | | | | | | |
| | (liver) | K16 | | 0.17 | | | | | | |
| | (liver) | K17 | | 0.22 | | | | | | |
| | (liver) | K18 | | 0.21 | 4 | 0.1775 | 0.049917 | 0.024958 | 0.19 | 0.2125 |
| | (liver) | LM24 | | 12 | | | | | | |

| Species | | Site Abbreviation | Site name | Cadmium mg/kg (LOR =0.02) | N | Mean | SD | SE | Median | 75th Percentile |
|---|---|---|---|---|---|---|---|---|---|---|
| | (liver) | LM25 | | 24 | | | | | | |
| | (liver) | LM26 | | 7.6 | | | | | | |
| | (liver) | LM27 | | 0.66 | 4 | 11.065 | 9.805759 | 4.902879 | 9.8 | 15 |
| | | | | | ALL | 3.434875 | 6.432997 | 1.608249 | 0.545 | 2.85 |
| **Forked Tail Catfish** | (muscle or whole fish) | LM13 | | 0.01 | | | | | | |
| | (muscle or whole fish) | LM14 | | 0.01 | | | | | | |
| | (muscle or whole fish) | LM15 | | 0.01 | | | | | | |
| | | | | | ALL | 0.01 | 0 | 0 | 0.01 | 0.01 |
| | (liver) | LM13 | | 3.2 | | | | | | |
| | (liver) | LM14 | | 1.7 | | | | | | |
| | (liver) | LM15 | | 0.88 | | | | | | |
| | | | | | ALL | 1.926667 | 1.176492 | 0.679248 | 1.7 | 2.45 |
| **Eel Tail Catfish** | (muscle or whole fish) | LM17 | | 0.16 | | | | | | |
| | (muscle or whole fish) | LM18 | | 0.19 | | | | | | |
| | (muscle or whole fish) | LM30 | | 0.01 | | | | | | |
| | | | | | ALL | 0.12 | 0.096437 | 0.055678 | 0.16 | 0.175 |
| | (liver) | LM30 | | 0.64 | 14 | | | | | |
| **Red Claw** | | B5 | | 0.047 | | | | | | |
| | | B6 | | 0.11 | | | | | | |
| | | B7 | | 0.11 | 3 | 0.089 | 0.036373 | 0.021 | 0.11 | 0.11 |
| | | F10 | | 0.35 | 1 | | | | | |
| | | I22 | | 0.01 | 1 | | | | | |
| | | K21 | | 0.01 | | | | | | |
| | | K22 | | 0.01 | 2 | 0.01 | 0 | 0 | 0.01 | 0.01 |
| | | LM20 | | 0.041 | | | | | | |
| | | LM21 | | 0.01 | | | | | | |
| | (muscle) | LM22 | | 0.01 | 3 | 0.020333 | 0.017898 | 0.010333 | 0.01 | 0.0255 |

| Species | | Site Abbreviation | Site name | Cadmium mg/kg (LOR =0.02) | N | Mean | SD | SE | Median | 75th Percentile |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | ALL | 0.0708 | 0.105916 | 0.033494 | 0.0255 | 0.09425 |
| **Shrimp** | | F11 | | 0.056 | 1 | | | | | |
| | | I23 | | 0.01 | | | | | | |
| | | I24 | | 0.01 | | | | | | |
| | | I25 | | 0.01 | | | | | | |
| | | I26 | | 0.01 | 4 | 0.01 | 0 | 0 | 0.01 | 0.01 |
| | | | | | ALL | 0.0192 | 0.020572 | 0.0092 | 0.01 | 0.01 |
| **Mussel** | | K20 | | 0.051 | 1 | | | | | |
| | | | | | | | | | | |

## B. Lead

| Species | | Site Abbreviation | Site name | Lead mg/kg (LOR = 0.1) | N | Mean | SD | SE | Median | 75th Percentile |
|---|---|---|---|---|---|---|---|---|---|---|
| **Spangled Perch** | (muscle or whole fish) | B1-4 | | 0.63 | | | | | | |
| | | | | 1.7 | | | | | | |
| | | | | 1.1 | | | | | | |
| | | | | 0.48 | 4 | 0.9775 | 0.549325 | 0.274663 | 0.865 | 1.25 |
| | (muscle or whole fish) | C1-8 | | 2.6 | | | | | | |
| | | | | 3.1 | | | | | | |
| | | | | 4.7 | | | | | | |
| | | | | 3 | | | | | | |
| | | | | 3.5 | 5 | 3.38 | 0.804363 | 0.359722 | 3.1 | 3.5 |
| | (muscle or whole fish) | D15-18 | | 0.05 | | | | | | |
| | | | | 0.05 | | | | | | |
| | | | | 0.05 | | | | | | |
| | | | | 0.05 | 4 | 0.05 | 0 | 0 | 0.05 | 0.05 |
| | (muscle or whole fish) | K-14 | | 0.05 | 1 | 0.05 | 0 | 0 | 0.05 | 0.05 |
| | (muscle or whole fish) | A1-8 (No. 6) | | 0.05 | | | | | | |
| | | | | 0.05 | | | | | | |
| | | | | 0.05 | | | | | | |
| | | | | 0.05 | | | | | | |
| | | | | 0.05 | | | | | | |
| | | | | 0.05 | | | | | | |
| | | | | 0.11 | 7 | 0.058571 | 0.022678 | 0.008571 | 0.05 | 0.05 |
| | (muscle) | ML19 | | 0.05 | | | | | | |
| | (whole fish) | ML19 | | 0.78 | 2 | 0.415 | 0.516188 | 0.365 | 0.415 | 0.5975 |
| | | | | | ALL | 0.969565 | 1.405614 | 0.293091 | 0.05 | 1.4 |
| | (Liver) | D15-18 | | 0.05 | | | | | | |
| | | | | 0.05 | | | | | | |
| | | | | 0.11 | 3 | 0.07 | 0.034641 | 0.02 | 0.05 | 0.08 |

| Species | | Site Abbreviation | Site name | Lead mg/kg (LOR = 0.1) | N | Mean | SD | SE | Median | 75th Percentile |
|---|---|---|---|---|---|---|---|---|---|---|
| | (Liver) | K-14 | | 0.05 | | | | | | |
| | | | | 0.05 | 2 | 0.05 | 0 | 0 | 0.05 | 0.05 |
| | | | | | ALL | 0.062 | 0.026833 | 0.012 | 0.05 | 0.05 |
| **Catfish** | (muscle or whole fish) | B9-12 | | 0.18 | | | | | | |
| | | | | 0.24 | | | | | | |
| | | | | 0.2 | | | | | | |
| | | | | 0.19 | 4 | | | | | |
| | | | | | ALL | 0.2025 | 0.0263 | 0.01315 | 0.195 | 0.21 |
| **Sleepy Cod** | (muscle) | C9 | | 0.05 | | | | | | |
| | (muscle) | C10 | | 0.05 | 2 | 0.05 | 0 | 0 | 0.05 | 0.05 |
| | (muscle or whole fish) | D9 | | 0.05 | | | | | | |
| | (muscle or whole fish) | D10 | | 0.05 | | | | | | |
| | (muscle or whole fish) | D11 | | 0.05 | | | | | | |
| | (muscle or whole fish) | D12 | | 0.05 | 4 | 0.05 | 0 | 0 | 0.05 | 0.05 |
| | (muscle or whole fish) | E1 | | 0.31 | | | | | | |
| | (muscle or whole fish) | E2 | | 0.11 | | | | | | |
| | (muscle or whole fish) | E3 | | 0.29 | | | | | | |
| | (muscle or whole fish) | E4 | | 0.38 | | | | | | |
| | (muscle or whole fish) | E13 | | 0.14 | | | | | | |
| | (muscle or whole fish) | E14 | | 0.32 | | | | | | |
| | (muscle or whole fish) | E15 | | 0.69 | 7 | 0.32 | 0.190613 | 0.072045 | 0.31 | 0.35 |
| | (muscle or whole fish) | F1 | | 0.81 | | | | | | |
| | (muscle or whole fish) | F2 | | 0.9 | | | | | | |
| | (muscle or whole fish) | F3 | | 0.57 | | | | | | |
| | (muscle or whole fish) | F4 | | 0.86 | | | | | | |
| | (muscle or whole fish) | F5 | | 0.55 | | | | | | |
| | (muscle or whole fish) | F6 | | 0.41 | | | | | | |
| | (muscle or whole fish) | F7 | | 0.53 | | | | | | |

| Species | | Site Abbreviation | Site name | Lead mg/kg (LOR = 0.1) | N | Mean | SD | SE | Median | 75th Percentile |
|---|---|---|---|---|---|---|---|---|---|---|
| | (muscle or whole fish) | F8 | | 0.29 | | | | | | |
| | (muscle or whole fish) | F9 | | 0.27 | | | | | | |
| | (muscle or whole fish) | F10 | | 0.13 | | | | | | |
| | (muscle or whole fish) | F11 | | 0.13 | | | | | | |
| | (muscle or whole fish) | F12 | | 0.15 | 12 | 0.466667 | 0.283175 | 0.081745 | 0.47 | 0.63 |
| | (muscle or whole fish) | I9 | | 0.05 | | | | | | |
| | (muscle or whole fish) | I10 | | 0.05 | | | | | | |
| | (muscle or whole fish) | I11 | | 0.05 | | | | | | |
| | (muscle or whole fish) | I12 | | 0.05 | 4 | 0.05 | 0 | 0 | 0.05 | 0.05 |
| | (muscle or whole fish) | J1 | | 0.28 | | | | | | |
| | (muscle or whole fish) | J2 | | 0.57 | | | | | | |
| | (muscle or whole fish) | J3 | | 0.64 | | | | | | |
| | (muscle or whole fish) | J4 | | 0.37 | 4 | 0.465 | 0.168226 | 0.084113 | 0.47 | 0.5875 |
| | (muscle or whole fish) | K7 | | 0.05 | | | | | | |
| | (muscle or whole fish) | K8 | | 0.05 | | | | | | |
| | (muscle or whole fish) | K9 | | 0.05 | | | | | | |
| | (muscle or whole fish) | K10 | | 0.05 | 4 | 0.05 | 0 | 0 | 0.05 | 0.05 |
| | (muscle) | LM1 | | 0.05 | | | | | | |
| | (muscle) | LM2 | | 0.05 | | | | | | |
| | (muscle) | LM3 | | 0.05 | | | | | | |
| | (muscle) | LM4 | | 0.05 | 4 | 0.05 | 0 | 0 | 0.05 | 0.05 |
| | | | | | ALL | 0.258537 | 0.259061 | 0.040459 | 0.13 | 0.38 |
| | (liver) | C9 | | 0.15 | | | | | | |
| | (liver) | C10 | | 0.29 | 2 | 0.22 | 0.098995 | 0.07 | 0.22 | 0.255 |
| | (liver) | D9 | | 0.05 | | | | | | |
| | (liver) | D10 | | 0.05 | | | | | | |
| | (liver) | D11 | | 0.05 | | | | | | |
| | (liver) | D12 | | 0.05 | 4 | 0.05 | 0 | 0 | 0.05 | 0.05 |

| Species | | Site Abbreviation | Site name | Lead mg/kg (LOR = 0.1) | N | Mean | SD | SE | Median | 75th Percentile |
|---|---|---|---|---|---|---|---|---|---|---|
| | (liver) | K7 | | 0.05 | | | | | | |
| | (liver) | K8 | | 0.05 | | | | | | |
| | (liver) | K9 | | 0.05 | | | | | | |
| | (liver) | K10 | | 0.05 | 4 | 0.05 | 0 | 0 | 0.05 | 0.05 |
| | (liver) | I9 | | 0.05 | | | | | | |
| | (liver) | I10 | | 0.05 | | | | | | |
| | (liver) | I11 | | 0.05 | | | | | | |
| | (liver) | I12 | | 0.05 | 4 | 0.05 | 0 | 0 | 0.05 | 0.05 |
| | (liver) | LM1 | | 0.05 | | | | | | |
| | (liver) | LM2 | | 0.05 | | | | | | |
| | (liver) | LM3 | | 0.05 | | | | | | |
| | (liver) | LM4 | | 0.05 | 4 | 0.05 | 0 | 0 | 0.05 | 0.05 |
| | | | | | ALL | 0.068889 | 0.059989 | 0.01414 | 0.05 | 0.05 |
| **Barramundi** | (muscle or whole fish) | G17 | | 0.05 | 1 | | | | | |
| | (liver) | G17 | | 0.1 | 1 | | | | | |
| **Barred Grunter** | (muscle or whole fish) | D1 | | 0.05 | | | | | | |
| | (muscle or whole fish) | D2 | | 0.1 | | | | | | |
| | (muscle or whole fish) | D3 | | 0.05 | | | | | | |
| | (muscle or whole fish) | D4 | | 0.05 | | | | | | |
| | (muscle or whole fish) | D5 | | 0.05 | | | | | | |
| | (muscle or whole fish) | D6 | | 0.05 | | | | | | |
| | (muscle or whole fish) | D7 | | 0.05 | | | | | | |
| | (muscle or whole fish) | D8 | | 0.05 | 8 | 0.05625 | 0.017678 | 0.00625 | 0.05 | 0.05 |
| | (muscle or whole fish) | G1 | | 0.36 | | | | | | |
| | (muscle or whole fish) | G2 | | 0.41 | | | | | | |
| | (muscle or whole fish) | G3 | | 0.12 | | | | | | |
| | (muscle or whole fish) | G4 | | 0.61 | | | | | | |
| | (muscle or whole fish) | G5 | | 0.32 | | | | | | |

| Species | | Site Abbreviation | Site name | Lead mg/kg (LOR = 0.1) | N | Mean | SD | SE | Median | 75th Percentile |
|---|---|---|---|---|---|---|---|---|---|---|
| | (muscle or whole fish) | G6 | | 0.52 | | | | | | |
| | (muscle or whole fish) | G7 | | 0.55 | | | | | | |
| | (muscle or whole fish) | G8 | | 0.3 | 8 | 0.39875 | 0.159234 | 0.056298 | 0.385 | 0.5275 |
| | (muscle or whole fish) | I1 | | 0.05 | | | | | | |
| | (muscle or whole fish) | I2 | | 0.14 | | | | | | |
| | (muscle or whole fish) | I3 | | 0.2 | | | | | | |
| | (muscle or whole fish) | I4 | | 0.13 | | | | | | |
| | (muscle or whole fish) | I5 | | 0.05 | | | | | | |
| | (muscle or whole fish) | I6 | | 0.05 | | | | | | |
| | (muscle or whole fish) | I7 | | 0.05 | | | | | | |
| | (muscle or whole fish) | I8 | | 0.11 | 8 | 0.0975 | 0.056758 | 0.020067 | 0.08 | 0.1325 |
| | (muscle or whole fish) | J5 | | 0.43 | | | | | | |
| | (muscle or whole fish) | J6 | | 0.57 | | | | | | |
| | (muscle or whole fish) | J7 | | 0.4 | | | | | | |
| | (muscle or whole fish) | J8 | | 1.1 | | | | | | |
| | (muscle or whole fish) | J11 | | 1.2 | | | | | | |
| | (muscle or whole fish) | J12 | | 0.62 | | | | | | |
| | (muscle or whole fish) | J13 | | 0.7 | | | | | | |
| | (muscle or whole fish) | J14 | | 0.6 | 8 | 0.7025 | 0.294267 | 0.104039 | 0.61 | 0.8 |
| | (muscle or whole fish) | K1 | | 0.05 | | | | | | |
| | (muscle or whole fish) | K2 | | 0.05 | | | | | | |
| | (muscle or whole fish) | K3 | | 0.05 | | | | | | |
| | (muscle or whole fish) | K4 | | 0.1 | 4 | 0.0625 | 0.025 | 0.0125 | 0.05 | 0.0625 |
| | (muscle or whole fish) | LM8 | | 0.05 | | | | | | |
| | (muscle or whole fish) | LM9 | | 0.05 | | | | | | |
| | (muscle or whole fish) | LM10 | | 0.05 | | | | | | |
| | (muscle or whole fish) | LM11 | | 0.05 | 4 | 0.05 | 0 | 0 | 0.05 | 0.05 |
| | | | | | ALL | 0.26225 | 0.295535 | 0.046728 | 0.105 | 0.415 |

| Species | | Site Abbreviation | Site name | Lead mg/kg (LOR = 0.1) | N | Mean | SD | SE | Median | 75th Percentile |
|---|---|---|---|---|---|---|---|---|---|---|
| | (liver) | K1 | | 0.05 | | | | | | |
| | (liver) | K2 | | 0.05 | | | | | | |
| | (liver) | K3 | | 0.05 | | | | | | |
| | (liver) | K4 | | 0.49 | 4 | 0.16 | 0.22 | 0.11 | 0.05 | 0.16 |
| | (liver) | LM8 | | 0.14 | 1 | | | | | |
| | | | | | ALL | 0.156 | 0.190735 | 0.085299 | 0.05 | 0.14 |
| **Rainbow** | (muscle or whole fish) | E5 | | 0.26 | | | | | | |
| | (muscle or whole fish) | E6 | | 0.8 | | | | | | |
| | (muscle or whole fish) | E7 | | 0.85 | | | | | | |
| | (muscle or whole fish) | E8 | | 0.73 | | | | | | |
| | (muscle or whole fish) | E9 | | 0.37 | | | | | | |
| | (muscle or whole fish) | E10 | | 0.18 | | | | | | |
| | (muscle or whole fish) | E11 | | 0.05 | | | | | | |
| | (muscle or whole fish) | E12 | | 0.2 | 8 | 0.43 | 0.315232 | 0.111451 | 0.315 | 0.7475 |
| | | | | | ALL | | | | | |
| **Tandan** | (muscle or whole fish) | F9 | | 0.05 | 1 | | | | | |
| | (muscle or whole fish) | K19 | | 0.05 | 1 | | | | | |
| | | | | | ALL | 0.05 | 0 | 0 | 0.05 | 0.05 |
| | (liver) | F9 | | 1.1 | 1 | | | | | |
| | (liver?) | K19 | | 0.05 | 1 | | | | | |
| | | | | | ALL | 0.575 | 0.742462 | 0.525 | 0.575 | 0.8375 |
| **Bony Bream** | (muscle or whole fish) | G13 | | 0.17 | | | | | | |
| | (muscle or whole fish) | G14 | | 0.05 | | | | | | |
| | (muscle or whole fish) | G15 | | 0.05 | | | | | | |
| | (muscle or whole fish) | G16 | | 0.05 | 4 | 0.08 | 0.06 | 0.03 | 0.05 | 0.08 |
| | (muscle or whole fish) | I15 | | 0.29 | | | | | | |
| | (muscle or whole fish) | I17 | | 0.18 | | | | | | |
| | (muscle or whole fish) | I19 | | 0.05 | | | | | | |

| Species | | Site Abbreviation | Site name | Lead mg/kg (LOR = 0.1) | N | Mean | SD | SE | Median | 75th Percentile |
|---|---|---|---|---|---|---|---|---|---|---|
| | (muscle or whole fish) | I20 | | 0.05 | 4 | 0.1425 | 0.115866 | 0.057933 | 0.115 | 0.2075 |
| | (muscle or whole fish) | K15 | | 0.05 | | | | | | |
| | (muscle or whole fish) | K16 | | 0.05 | | | | | | |
| | (muscle or whole fish) | K17 | | 0.05 | | | | | | |
| | (muscle or whole fish) | K18 | | 0.05 | 4 | 0.05 | 0 | 0 | 0.05 | 0.05 |
| | (muscle or whole fish) | LM24 | | 0.05 | | | | | | |
| | (muscle or whole fish) | LM25 | | 0.15 | | | | | | |
| | (muscle or whole fish) | LM26 | | 0.67 | | | | | | |
| | (muscle or whole fish) | LM27 | | 0.12 | 4 | 0.2475 | 0.284766 | 0.142383 | 0.135 | 0.28 |
| | | | | | ALL | 0.13 | 0.160375 | 0.040094 | 0.05 | 0.155 |
| | (liver) | G13 | | 3.2 | | | | | | |
| | (liver) | G14 | | 0.24 | | | | | | |
| | (liver) | G15 | | 0.1 | | | | | | |
| | (liver) | G16 | | 0.33 | 4 | 0.9675 | 1.491339 | 0.745669 | 0.285 | 1.0475 |
| | (liver) | I16 | | 0.18 | | | | | | |
| | (liver) | I18 | | 0.18 | | | | | | |
| | (liver) | I19 | | 0.05 | | | | | | |
| | (liver) | I20 | | 0.05 | 4 | 0.115 | 0.075056 | 0.037528 | 0.115 | 0.18 |
| | (liver) | K15 | | 0.05 | | | | | | |
| | (liver) | K16 | | 0.05 | | | | | | |
| | (liver) | K17 | | 0.05 | | | | | | |
| | (liver) | K18 | | 0.05 | 4 | 0.05 | 0 | 0 | 0.05 | 0.05 |
| | (liver) | LM24 | | 0.31 | | | | | | |
| | (liver) | LM25 | | 2.8 | | | | | | |
| | (liver) | LM26 | | 2.4 | | | | | | |
| | (liver) | LM27 | | 0.72 | 4 | 1.5575 | 1.226278 | 0.613139 | 1.56 | 2.5 |
| | | | | | ALL | 0.6725 | 1.079342 | 0.269836 | 0.18 | 0.4275 |
| | | | | | | | | | | |

| Species | | Site Abbreviation | Site name | Lead mg/kg (LOR = 0.1) | N | Mean | SD | SE | Median | 75th Percentile |
|---|---|---|---|---|---|---|---|---|---|---|
| **Forked Tail Catfish** | (muscle or whole fish) | LM13 | | 0.05 | | | | | | |
| | (muscle or whole fish) | LM14 | | 0.05 | | | | | | |
| | (muscle or whole fish) | LM15 | | 0.05 | 3 | 0.05 | 0 | 0 | 0.05 | 0.05 |
| | | | | | ALL | | | | | |
| | (liver) | LM13 | | n/a | | | | | | |
| | (liver) | LM14 | | 2.7 | | | | | | |
| | (liver) | LM15 | | 0.96 | 2 | 1.83 | 1.230366 | 0.87 | 1.83 | 2.265 |
| | | | | | ALL | | | | | |
| **Eel Tail Catfish** | (muscle or whole fish) | LM17 | | 0.21 | | | | | | |
| | (muscle or whole fish) | LM18 | | 0.31 | | | | | | |
| | (muscle or whole fish) | LM30 | | 0.05 | 3 | 0.19 | 0.131149 | 0.075719 | 0.21 | 0.26 |
| | | | | | ALL | | | | | |
| | (liver) | LM30 | | 0.17 | 1 | | | | | |
| **Red Claw** | | B5 | | 0.05 | | | | | | |
| | | B6 | | 0.05 | | | | | | |
| | | B7 | | 0.15 | 3 | 0.083333 | 0.057735 | 0.033333 | 0.05 | 0.1 |
| | | F10 | | 0.22 | 1 | | | | | |
| | | I22 | | 0.12 | 1 | | | | | |
| | | K21 | | 0.05 | | | | | | |
| | | K22 | | 0.05 | 2 | 0.05 | 0 | 0 | 0.05 | 0.05 |
| | | LM20 | | 0.21 | | | | | | |
| | | LM21 | | 0.1 | | | | | | |
| | (muscle) | LM22 | | 0.05 | 3 | 0.12 | 0.081854 | 0.047258 | 0.1 | 0.155 |
| | | | | | ALL | 0.105 | 0.068028 | 0.021512 | 0.075 | 0.1425 |
| **Shrimp** | | F11 | | 0.05 | 1 | | | | | |
| | | I23 | | 0.05 | | | | | | |
| | | I24 | | 0.05 | | | | | | |

| Species | | Site Abbreviation | Site name | Lead mg/kg (LOR = 0.1) | N | Mean | SD | SE | Median | 75th Percentile |
|---|---|---|---|---|---|---|---|---|---|---|
| | | I25 | | 0.05 | | | | | | |
| | | I26 | | 0.05 | 4 | 0.05 | 0 | 0 | 0.05 | 0.05 |
| | | | | | ALL | 0.05 | 0 | 0 | 0.05 | 0.05 |
| **Mussel** | | K20 | | 0.43 | 1 | | | | | |
| | | | | | | | | | | |