

Stage 2 Aquatic Assessment - Ecological Risk Assessment, Kurri Kurri Aluminium Smelter

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Hydro Aluminium Kurri Kurri Pty Ltd

Prepared by:
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Contents

Acronyms and Abbreviations

AHD	Australian height datum
Al	aluminium
ANZECC	Australian and New Zealand Environment and Conservation Council
BGL	below ground level
COPC	constituent of potential concern
COPEC	constituent of potential ecological concern
CSM	conceptual site model
DQO	data quality objective
EIL	Ecological Investigation Level
EPA	Environment Protection Authority
ERA	ecological risk assessment
ESA	Environmental Site Assessment
F-	fluoride
ha	Hectare
HQ	hazard quotient
km	kilometer
LOR	limit of reporting
m	metre
mg/kg	milligrams per kilogram
mg/L	milligrams per litre
n	number of samples
NATA	National Association of Testing Authorities
NC	not calculated
ND	not detected
NEPM	National Environment Protection Measure
OH&S	Occupational Health & Safety
PQL	practical quantitation limit
pH	a measure of acidity, hydrogen ion activity
QA/QC	Quality Assurance/Quality Control
USEPA	United States Environmental Protection Agency
-	shown on tables equals "not calculated", "no criteria" or "not applicable”

Executive Summary

ENVIRON Australia Pty Limited (ENVIRON) was commissioned by Hydro Aluminium Kurri Kurri Pty Ltd (Hydro) to undertake additional aquatic sampling and assessment in response to recommendations contained within the Tier 2 Ecological Risk Assessment (ERA) report (*ENVIRON 2013*). The Tier 2 ERA was undertaken to assess ecological risks associated with potential fluoride and aluminium contamination of groundwater, soils and surface water down gradient from a former smelter waste storage area at the Hydro's Kurri Kurri Aluminium Smelter in New South Wales, Australia.

The conclusions of the Tier 2 ERA included recommendations for gathering additional data to strengthen the risk profile, including:

- Sampling and chemical analysis of sediments and surface water from within the semi-permanent dam to provide a more rigorous chemical basis for the assessment of risk to the aquatic community within the dam; and
- Sampling and analysis of aquatic invertebrates from within the semi-permanent dam and at suitable reference locations to assess whether the risk profile calculated for the dam is apparent as community effects.

Surface water, sediment and macroinvertebrate samples were collected at three sites within the semi-permanent dam and at two reference dams within the smelter's buffer zone on 1st and 2nd May, 2013. Sample data successfully characterised the surface water and sediment quality and the complexity of the macroinvertebrate community within each of the three dams, enabling an assessment of aquatic quality within the semi-permanent dam relative to 'natural' background conditions in nearby dams. The results of sample and data analysis indicated the following:

- Surface water quality within the semi-permanent dam was not different from the reference dams except for elevated concentrations of total fluoride;
- Sediment within the semi-permanent dam had elevated concentrations of total and bioavailable aluminium and total and soluble fluoride;
- Concentrations of aluminium in sediments within the semi-permanent dam were well below the available benchmark for impact to benthic species;
- Concentrations of fluoride in sediments within the semi-permanent dam were expected to be strongly bound to clay particles under the existing conditions of pH > 5.5;
- Macroinvertebrate diversity and abundance within the semi-permanent dam was similar if not marginally higher than for the reference dams;
- The differences in water and sediment quality noted above had not caused a noticeable impact on aquatic habitats within the semi-permanent dam;
- Risk profiles that identify potential unacceptable risk to aquatic species from elevated fluoride and aluminium concentrations within the semi-permanent dam were unfounded in terms of ecological measures and were likely to be overly conservative due to the use of limited toxicity information to derive the risk profiles.

In conclusion, the results of the Stage 2 Aquatic Assessment indicated that there is no discernible impact to the aquatic ecology within the semi-permanent dam as a result of elevated concentrations of fluoride in surface water and sediments.

1 Introduction

1.1 General

ENVIRON Australia Pty Limited (ENVIRON) was commissioned by Hydro Aluminium Kurri Kurri Pty Ltd (Hydro) to undertake a Tier 2 ecological risk assessment (ERA) associated with potential fluoride and aluminium contamination of groundwater, soils and surface water down gradient from a former smelter waste storage area at the Kurri Kurri Aluminium Smelter in New South Wales, Australia. During that risk assessment the need for additional data on the relative quality of one of the aquatic features within the investigation area was identified.

1.2 Objectives and Scope of Work

Soil and groundwater investigations at the Kurri Kurri Aluminium Smelter identified elevated fluoride (F-) and aluminium (Al) concentrations at the site and in the surrounding environment. Vegetation down gradient of the Alcan Mound has shown signs of stress and dieback which is believed to be attributed to the surfacing of leachate impacted groundwater in the vicinity of the affected vegetation. The identification of elevated contaminants in groundwater and surface water triggered an evaluation of the potential risk to terrestrial and aquatic ecosystems and livestock on neighbouring farms via a Tier 2 ERA (*ENVIRON 2013*).

The overall objective of the Tier 2 ERA was to review existing information on contaminants of concern for the protection of terrestrial and aquatic flora and fauna specific to the area surrounding the smelter and for livestock on nearby properties. The conclusions of the risk assessment included recommendations for gathering additional data to strengthen the risk profile, including:

- Undertake sampling and chemical analysis of sediments and surface water from within the semi-permanent dam to provide a more rigorous chemical basis for the assessment of risk to the aquatic community within the dam; and

- Undertake sampling and analysis of aquatic invertebrates from within the semi-permanent dam and at suitable reference locations to assess whether the risk profile calculated for the dam is apparent as community effects.

This report presents the additional aquatic data and discusses implications for the assessment of ecological risk associated with potentially elevated aluminium and fluoride concentrations within the semi-permanent dam.

1.3 Structure of Report

This aquatic assessment was undertaken to address the relevant Tier 2 ERA recommendations and the remainder of this report is divided into the following sections:

- Section 2: Assessment Methods
- Section 3: Analysis Results
- Section 4: Discussion
- Section 5: Conclusions

1.4 Data Sources

Environmental data used to conduct this aquatic assessment was derived from samples collected during targeted fieldwork on the 1st and 2nd May 2013.

1.5 Limitations

The scope of this Stage 2 Aquatic Assessment was based on ENVIRON's email proposal dated 15 March 2013.

Specific assumptions and limitations identified by ENVIRON as being relevant are set out in the report. The methodology and sources of information used by ENVIRON are outlined in our scope of work. ENVIRON has made no independent verification of this information beyond the agreed scope of works and assumes no responsibility for any inaccuracies or omissions made by others.

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.

2 Assessment Methods

Detailed information describing the Hydro Aluminium Kurri Kurri Smelter site and the results of previous environmental investigations are described in the Phase 2 ESA report (*ENVIRON 2012*) and the Tier 2 Ecological Risk Assessment (*ENVIRON 2013*). Only details relevant to the current aquatic assessment are included here.

2.1 Background

Location of Investigation Area

The Hydro Aluminium Kurri Kurri Smelter is located approximately 30 km west of the city of Newcastle and 150 km north of Sydney, in New South Wales, Australia. The smelter is located off Hart Road in Loxford and includes a 60 ha plant area and a 2500 ha buffer zone (*Figure 2.1*). The buffer zone consists of areas of remnant native vegetation including wetlands, the Wangara farming property (used for cattle grazing), the Loxford Park Junior Raceway (sealed motorcycle track) and residential areas (leased by Hydro to local residents). The township of Kurri Kurri lies just over 2 km south of the smelter and a mix of cleared and partially cleared agricultural land lies west, east and north of the smelter. Swamp Creek lies approximately 500 m east of the smelter and flows in a northerly direction into Wentworth Swamps.

Aquatic Environment

Surface water features within and adjacent to the investigation area (*Figure 2.2*) include artificial surge ponds within the smelter grounds, ephemeral soaks and overland drainage lines within the buffer zone to the east of the Alcan mound, a small ephemeral dam near the motorcycle track, a semi-permanent dam immediately up gradient of Swamp Creek and Swamp Creek itself. The semi-permanent dam is the only surface water feature identified during the Tier 2 ERA as presenting a potentially unacceptable risk to aquatic ecology from elevated aluminium and fluoride concentrations.

The semi-permanent dam forms an elongated feature that runs roughly north-south along the western bank of Swamp Creek and is perched several metres above the level of the creek. The semi-permanent dam is fed from the ephemeral dam along a meandering gully that runs along the northern boundary of the motorcycle track property. The dam is likely to contain water for most of the year although may dry during extended periods without rainfall. The approximate dimensions of the dam are 150 m x 30 m.

The semi-permanent dam is likely to support a range of aquatic invertebrate species, fish and water plants. Wildlife species such as birds and mammals utilise dam water for drinking, and waterfowl are known to occur on the dam.

Fluoride

Fluorine is highly reactive and does not occur in nature in its elemental state, existing either as inorganic fluorides (including the free anion F^-) or as organic fluoride compounds. Inorganic fluorides are much more abundant than organic fluoride compounds and the main natural sources of inorganic fluorides include weathering of minerals, volcanic emissions and marine aerosols. Major anthropogenic sources of inorganic fluorides include aluminium smelters, phosphate fertilizer plants, plants producing fluoride chemicals, and brick, ceramic and glass manufacturers. Some municipal water treatment plants also actively add fluoride to public drinking water and fluoride often occurs within the effluent of sewerage treatment plants in areas where fluoridation of drinking water occurs.

Once dissolved, inorganic fluorides remain in solution (as F-) under conditions of low pH and hardness, and in the presence of ion-exchange material such as bentonite clays and humic acids (CEPA 1994). However, in hard waters inorganic fluorides may be removed from the aquatic phase by precipitation as magnesium or aluminium complexes into the sediment zone. Aquatic organisms living in soft waters may be more affected by fluoride pollution than those living in hard waters because the bioavailability of F- is reduced with increasing water hardness (Camargo 2003).

Levels of fluoride in surface waters vary with geographical location and proximity to fluoride emission sources but natural concentrations are typically less than 1.0 mg/L (*Fleiss 2011*). Uptake and subsequent absorption of inorganic fluorides by aquatic and terrestrial animals appears to be greater from water than from food (*Hemens & Warwick 1972*). Limited available evidence indicates that biomagnification of inorganic fluoride does not occur in aquatic or terrestrial food chains (ATSDR 2003).

Fluoride is known to either inhibit or enhance the population growth of algae depending on fluoride concentration, exposure time and algal species (*Camargo 2003*). Aquatic plants are able to uptake F^- directly from the water and therefore the fluoride content of aquatic plants is known to increase with increasing F^- concentration and exposure time.

Fluoride is taken up directly from the water by aquatic invertebrates and is accumulated in the exoskeleton where it may provide an important role in hardening of supporting tissues. Fluoride toxicity to aquatic invertebrates increases with increasing F^- concentration, exposure time and water temperature (*Camargo 2003*). Evidence to date suggests that caddisfly larvae are more sensitive to F^- concentration than many other invertebrates tested. *Camargo* (*2003*) reports that F^- safe concentrations for a number of different caddisfly species range from 0.2 – 1.8 mg/L (in soft waters of between 15 - 40 mg $CaCO_3$/L).

Fish are able to uptake F^- directly from the water, and to a much lesser extent via food, and F^- tends to be accumulated in the bones. Fluoride uptake increases with increasing fluoride concentration, exposure time and water temperature, but decreases with increasing fish size and increasing water content of calcium and chloride (*Camargo 2003*).

Aluminium

Aluminium (Al) is very common in the natural environment in the form of silicates, oxides and hydroxides, combined with other elements such as sodium and fluorine and as complexes with organic matter. At pH values greater than 5.5, naturally occurring aluminium compounds exist predominantly in an undissolved form, such as gibbsite or as alluminosilicates, except in the presence of high amounts of dissolved organic matter (which binds with aluminium and can lead to increased concentrations of dissolved aluminium in aquatic environments) (*WHO 1997*). Acidification of soils may lead to release of aluminium which can be taken up by plants and/or transported into aquatic environments. Aluminium concentrations in soils and surface water vary widely depending on local geology and other physical aspects of the environment.

Aluminium toxicity to aquatic plants has mainly been reported for acidic conditions. Aquatic unicellular algae showed increased toxic effect of aluminium at low pH, where bioavailability of aluminium was increased.

For aquatic invertebrates and fish, toxicity of aluminium is widely variable ranging from effects at concentrations of less than 1 part per million through to concentrations of more than 60%. Although the wide range of tolerances may in part relate to pH variability in test waters (*WHO 1997*).

2.2 Sampling Locations

The focus for this aquatic assessment is the semi-permanent dam where the potential for unacceptable risk to aquatic species was identified during the Tier 2 ERA. However, in order to provide sufficient local context for water and sediment quality and macroinvertebrate community structure, it was necessary to compare the environmental data from the semi-permanent dam with data obtained from similar environments located outside the area of influence (in this case, areas that are not down gradient of the Alcan Mound and the notification area). Since most environmental data varies in space and time, it was also necessary to use data from at least two reference dams for comparison. This approach enabled the capture of some measure of natural variability between aquatic environments in the immediate vicinity of the Kurri Kurri Smelter, to provide a means to compare data from the semi-permanent dam within the context of any natural variability.

Reference dams should ideally be of similar size, shape and geographical setting as the potentially impacted dam yet fulfill the prime objective of being outside the area of influence of the stressor under investigation. Few options were available for reference dams near the smelter but two dams of relatively similar size and setting were selected. The locations of the two reference dams relative to the semi-permanent dam under investigation are shown in *Figure 2.3.*

Dams were numbered Dam 01 to 03 from north to south (in the order of sampling), with Dam 03 being the semi-permanent dam that is potentially at risk from aluminium and fluoride contamination.

2.3 Aquatic Sampling and Sample Analysis Methodology

Water and Sediment Quality

Surface water and sediments were sampled at three locations (A, B and C) in each of the three dams. The coordinates for each sampling location are provided in *Table 2.1*. The local environmental setting and the approximate locations of each sampling site at each dam are shown in *Figures 2.4 – 2.6.*

Surface water was collected from just below the water's surface into laboratory prepared sampling bottles of appropriate size and type for the intended analyses. Water samples were labelled and temporarily stored under chilled conditions (on ice at ~4°C) in plastic eskies.

Sediment was collected using a PVC push corer (55 mm ID). Sediments were collected by wading into the dam and pushing the corer into the sediment to depth of refusal. Due to the high clay content of sediments, coring refusal typically occurred at a sediment depth between 50 - 100 mm and multiple cores were required to collect sufficient sediment for the intended analyses. Replicate cores were collected within an area of approximately 1 m^2. Sediment from replicate cores at each site was extruded from the core tube into a clean stainless steel bowl where the sediment was homogenised using a stainless steel spoon. Homogenised sediment was transferred to laboratory-prepared containers appropriate for the intended analyses. Sediment samples were labelled and temporarily stored under chilled conditions (on ice at ~4°C) in plastic eskies.

Due to relatively long holding times for the intended analyses, surface water and sediment samples from the first day were held over (under chilled conditions) until the end of the second day of sampling before being hand delivered to the analytical laboratory under chain-of-custody protocols.

Surface water and sediment samples were submitted to ALS Environmental laboratory in Newcastle for analyses. Samples were analysed for a suite of parameters to characterise the surface water and sediment quality with respect to the contaminants of concern – aluminium and fluoride. A list of the parameters and their respective limits of reporting (LORs) using the specified analytical methods are presented in *Table 2.3*.

Macroinvertebrates

Aquatic macroinvertebrates were sampled at three locations (A, B and C) in each of the three dams. The coordinates for each macroinvertebrate sampling location are provided in *Table 2.2*. The local environmental setting and the approximate locations of each sampling site at each dam are shown in *Figures 2.4 – 2.6.*

At each location, a sweep net sample was obtained from the margin of emergent vegetation using a flat bottomed ‘sweep’ net with 250 µm mesh size. Macroinvertebrates were sampled using short, vigorous sweeps of the net amongst the stems of the vegetation, across submerged logs and substrata. A total distance of 5 m along the shore was sampled at each location. Samples were rinsed with clean dam water while still in the collection net and then emptied from the net into a white plastic bucket. Each sample was subsequently ‘live sorted’.

Live sorting involved hand-picking of live macroinvertebrate taxa in white plastic trays, with allocation of sorting effort following the Australian Rivers Assessment System (AUSRIVAS) protocols whereby during an initial period of 30 minutes, effort was made to collect as many taxa as possible. If no new taxa were collected within the final five minutes of the 30 minute period, more individuals of existing taxa were collected. After 30 minutes, a search for new taxa was conducted for a further 10 minutes, if none were found then sorting was ceased. If new taxa were found then sorting continued for a further 10 minutes, with the pattern repeated up to a maximum picking time of 60 minutes.

Hand-picked taxa were preserved in wide-mouthed jars and later identified to the lowest possible taxonomic level (typically Order or Family) using the taxonomic keys contained in *Gooderham & Tsyrlin* (*2005*).

Analysis of macroinvertebrate data was undertaken using the widely recognised water quality classification scheme using the Stream Invertebrate Grade Number – Average Level (SIGNAL) scoring methods established by *Chessman* (*2001*). Within this system, SIGNAL sensitivity grades between 1 and 10 are allocated to each macroinvertebrate Family or Order

(*Chessman, 2003*). Invertebrate families with a grade of 1 are very tolerant of a wide range of aquatic conditions whereas those families with a grade of 10 are very sensitive to aquatic conditions and are likely to be found in habitats that are relatively pristine. The abundance of members from each Family in each sample is also of importance and analysis of macroinvertebrate data includes the use of a weight factor (WF) based on abundance in each sample. A SIGNAL score is calculated for each sampling site by dividing the sum of Family scores by the sum of the WFs.

The SIGNAL score provides an indication of whether the water quality at each sample site is likely to be high quality (ie. invertebrate families with high SIGNAL grades are present) or low quality (ie. only invertebrate families with low SIGNAL grades are present). In reality, macroinvertebrate communities consist of a mixture of sensitive and tolerant taxa but the proportions of each may indicate impacted aquatic environments.

Note that the SIGNAL method of aquatic assessment was developed for the assessment of natural waterways within Australia and categorisation of the artificial dam environments using this method has acknowledged limitations. However, since the same methodology has been used for each of the three dams, direct comparison between aquatic environments in each dam is possible.

3 Assessment Results

3.1 Water Quality

The analysis results for surface water quality in each of the three dams are provided in *Table 3.1*. Summary graphs showing the relative concentration of each water quality parameter between each dam are provided in *Figure 3.1*.

A narrow range of pH was evident for each dam, as shown by small standard deviations about each mean for the three individual samples per dam. Surface water from each dam has relatively similar pH (6.0 – 7.5) but Dam 02 has slightly lower pH than the other two dams. Importantly, the pH of surface water in Dam 03 is well within the background range evident at the two reference dams (but most similar to Dam 01).

Total hardness (as $CaCO_3$) shows a similar trend to pH, with surface water from Dam 02 having lower hardness than the other two dams. These differences indicate the natural variability in environments at each dam. Importantly, total hardness of surface water in Dam 03 is well within the background range evident at the two reference dams (but most similar to Dam 01). Water with hardness levels less than 60 mg/L are categorised as soft water.

Total aluminium concentrations in surface water within the three dams are more variable than the physical characteristics of pH and hardness. Mean total aluminium is different for each dam and surface water from Dam 02 exhibits very high variability. Surface water from Dam 01 has the lowest mean aluminium concentration (mean = 0.12 mg/L) followed by Dam 02 (mean = 0.96 mg/L) and Dam 03 (mean = 1.27 mg/L). However, the maximum aluminium concentration in Dam 02 (1.6 mg/L) exceeds the maximum aluminium concentration in Dam 03 (1.3 mg/L). Importantly, the total aluminium concentrations in surface water in Dam 03 is within the background range evident at the other two dams (but most similar to Dam 02).

Mean total fluoride concentrations in surface water from Dams 01 and 02 are both 0.40 mg/L. Total fluoride concentrations in Dam 03 are higher than the reference dams, with a mean of 12.90 mg/L. These results indicate that the surface water in Dam 03 is elevated above the natural background concentration expected within dams in the buffer zone, and suggests that water quality in the semi-permanent dam may have been impacted by previous events that have occurred up gradient in the notification area.

3.2 Sediment Quality

The analysis results for sediment quality in each of the three dams are provided in *Table 3.1*. Summary graphs showing the relative concentration of sediment parameters between each dam are provided in *Figure 3.2*.

Moisture content of sediments from the three dams is relatively similar which is to be expected considering the broadly similar sediment type.

Total aluminium concentrations are similar in sediments from Dams 01 and 02, with mean concentrations of 4,746.7 mg/kg and 4,320.0 mg/kg, respectively. The concentration of total aluminium in sediment from Dam 03 (mean = 24,366.7 mg/kg) is higher than concentrations in the reference dams. These results indicate that sediments in the semi-permanent dam are likely to have been impacted by contamination of total aluminium in the past.

The concentrations of aluminium analysed via 1M HCl digest of sediments (which are used as an indicator of bioavailability) show that sediments from Dams 01 and 02 are quite similar with means of 696.7 mg/kg and 953.3 mg/kg, respectively. However, the mean 1M HCl aluminium concentration for sediments from Dam 03 (mean = 2016.7 mg/kg) is higher than the means from the other two dams. These results indicate that sediments in the semi-permanent dam are likely to have concentrations of bioavailable aluminium that are elevated above the expected background ranges for dams within the buffer zone.

Total fluoride concentrations in sediments from each of the three dams are different. Dam 02 has the lowest total fluoride concentration (mean = 113.3 mg/kg) followed by Dam 01 (mean = 240.0 mg/kg) and Dam 03 (mean = 616.7 mg/kg). The higher total fluoride concentration in sediments from Dam 03 is a likely indication of fluoride enrichment of sediment from past contamination from the notification area up gradient from the dam.

Soluble fluoride concentrations are relatively similar in sediments from Dams 01 and 02, with means of 3.0 mg/kg and 1.3 mg/kg, respectively. In comparison, soluble fluoride is higher in sediment from Dam 03 (mean = 115.0 mg/kg). The higher soluble fluoride concentration in sediments from Dam 03 is a likely indicator of fluoride enrichment of the sediment from past contamination from the notification area.

3.3 Macroinvertebrate Community

A total of 488 macroinvertebrates were collected from the three dams: 173 individuals from Dam 01, 120 individuals from Dam 02 and 195 individuals from Dam 03 (*Table 3.2*). The mean number of individuals per dam varies between 40 (Dam 02) and 65 (Dam 03). Each dam has a different suite of macroinvertebrates which likely reflects the subtle differences in environmental conditions within and adjacent to each dam.

Twenty-seven different macroinvertebrate taxa were identified within fourteen Classes / Orders in the samples from the three dams (*Table 3.2*). Higher level taxonomy identified nineteen distinct Families within nine of those Classes/Orders. The Atyid shrimp (*Paratya australiensis*) was the most common native species found across all samples from all three dams. The next most common species were nematodes, waterboatmen, aquatic mites and dragonfly larvae. Only Atyid shrimp and nematodes were found in all nine samples.

The most ‘speciose’ taxonomic groups sampled were the beetles (O. Coleoptera) and the damselfly / dragonfly larvae (O. Odonata) with four families observed in each group. Most non-crustacean taxa were typically represented by less than five individuals per sample.

Twenty-three of the total of 27 taxa identified in the samples are regarded as being tolerant or very tolerant of environmental stress (such as poor water quality) and two taxa are regarded as sensitive to environmental stress (and the remaining two taxa do not have tolerance ratings). The two taxa that are sensitive to environmental stress are the mites (O. Acarina) and caddisfly larvae (O. Trichoptera). Mites were found to be reasonably abundant in all samples from Dam 01 and Dam 03 but absent from Dam 02, and caddisfly larvae were only found in two samples from Dam 01.

Classification of water quality at each location was undertaken using the SIGNAL scores for each macroinvertebrate Family (*Tables 3.3 – 3.5*). Weight factors (WFs) based on abundances within each Family were sourced from *Chessman* (*2003*).

SIGNAL scores were within a narrow range between 2.8 and 3.6 for all sites within each of the three dams. The mean SIGNAL score for each dam indicates that although there are only slight differences between the dams, the highest SIGNAL score (and therefore potentially higher water quality) is associated with Dam 03.

Plotting of the SIGNAL score for each site against the number of taxa in each sample provides a measure of the extent of disturbance of the aquatic environments at each site (*Figure 3.3*). Each site is plotted within the bottom left quadrant of the graph which indicates that all sites are likely to be impacted by “urban, industrial or agricultural pollution, or downstream effects of dams”. This result is not surprising considering that all three dams are artificial water features located within disturbed woodlands and/or agricultural land.

3.4 Aquatic Vertebrates

Neither fish nor amphibians were targeted during the aquatic sampling but individuals were counted as incidental by-catch in each sample.

Frogs were not captured in the aquatic samples but a single tadpole was found in one sample from Dam 01, one sample from Dam 02 and two samples from Dam 03. Tadpoles (and frogs) are very sensitive to water quality and their presence usually indicates that water quality is reasonably good.

Fish were captured in all samples from each dam with numbers varying between dams: between 50 and >100 fish per sample (Dam 01), >10 fish per sample (Dam 02) and between 10 and >20 fish per sample (Dam03). Only one species of fish was captured – *Gambusia holbrooki* (Girard, 1859) - which is commonly known as the mosquito fish, and is regarded as a very common introduced pest species in waterways of NSW. Both male and female fish were captured in aquatic samples. This fish species is tolerant of a wide range of water quality.

4 Discussion

The main focus for this Stage 2 aquatic assessment was to further characterise the water and sediment quality within the semi-permanent dam in relation to the ‘typical’ background conditions in similar dam environments within the smelter’s buffer zone. Macroinvertebrate community data was collected to assess whether the environmental conditions within the semi-permanent dam were potentially affecting the suitability of aquatic habitat.

The water quality data indicates that surface water within the semi-permanent dam is not different from the reference dams except for total fluoride. The mean total fluoride concentration within the semi-permanent dam (Dam 03, 12.90 mg/L) was higher than concentrations found in both reference dams (0.40 mg/L). However, the ‘new’ mean fluoride concentration in the semi-permanent dam was less than the previously reported concentration of 20 mg/L used for the Tier 2 ERA but is still above the adopted fluoride guideline value of 3.706 mg/L (*Suter & Tsao 1996*). The revised hazard quotients (HQs) for toxicity to aquatic invertebrates and fish from fluoride in surface water within the semi-permanent dam are 3.63 and 2.51, respectively. These HQs are low but do indicate that there is still potentially unacceptable risk to aquatic species from elevated fluoride concentrations within the surface water.

However, the assessment of the macroinvertebrate community within the semi-permanent dam indicates that there is no difference in the range and abundance of aquatic species found in the dam compared to two reference dams. In fact, the mean abundance of macroinvertebrates and the associated SIGNAL scores were marginally higher in samples collected from the semi-permanent dam. Taxa such as aquatic mites and tadpoles that are considered sensitive to degraded water quality were present within the semi-permanent dam, and a range of healthy aquatic plants were also observed within the dam.

Differences between the dams are subtle but importantly, the macroinvertebrate community within the semi-permanent dam does not indicate a degraded aquatic environment compared to the reference dams located elsewhere within the smelter’s buffer zone, despite elevated fluoride concentrations in surface water and elevated concentrations of fluoride and aluminium in sediments in the semi-permanent dam.

Interestingly, the background concentration of total aluminium at some of the reference sites in Dam 02 exceeded the available aluminium guideline value of 0.54 mg/L adopted within the ERA. These results indicate that the guideline values derived from elsewhere do not necessarily reflect actual risk to ecological receptors that are adapted to living in environments with naturally ‘elevated’ concentrations of contaminants of interest.

The sediment quality data indicates that sediments within the semi-permanent dam contain higher concentrations of total aluminium and bioavailable aluminium (1M HCl digest), total fluoride and soluble fluoride than sediment within the reference dams. Sediment quality guidelines for fluoride are not available but fluoride is expected to be strongly bound to clay particles under the non-acidic (pH > 5.5) conditions present within the dam. Reported natural concentrations of aluminium in freshwater sediments indicate that concentrations in US and Canada are often at percentage values (i.e. greater than 10,000 mg/kg), as reported in ATSDR (2008). Concentrations of aluminium in sediments from the semi-permanent dam are less than 33,000 mg/kg (total) and 2,320 mg/kg (bioavailable) and therefore aluminium concentrations in the sediments are unlikely to cause unacceptable risk to aquatic species.

5 Conclusions

Collection of environmental samples during the Stage 2 Aquatic Assessment successfully characterised the surface water quality, the sediment quality and the complexity of the macroinvertebrate community within the semi-permanent dam and two appropriate reference dams within the Hydro Kurri Kurri smelter's buffer zone. The results of sample and data analysis indicate the following:

- Surface water quality within the semi-permanent dam is not different from the reference dams except for elevated concentrations of total fluoride;
- Sediment within the semi-permanent dam has elevated concentrations of total and bioavailable aluminium and total and soluble fluoride;
- Concentrations of aluminium in sediments within the semi-permanent dam are well below the available benchmark for impact to benthic species;
- Concentrations of fluoride in sediments within the semi-permanent dam are expected to be strongly bound to clay particles under the existing conditions of pH > 5.5;
- Macroinvertebrate diversity and abundance within the semi-permanent dam is similar if not marginally higher than for the reference dams;
- The differences in water and sediment quality noted above have not caused a noticeable impact on aquatic habitats within the semi-permanent dam;
- Risk profiles that identify potential unacceptable risk to aquatic species from elevated fluoride and aluminium concentrations within the semi-permanent dam are unfounded in terms of ecological measures and are likely to be overly conservative due to the use of limited toxicity information to derive the risk profiles.

In conclusion, the results of the Stage 2 Aquatic Assessment indicate that there is no discernible impact to the aquatic ecology within the semi-permanent dam as a result of elevated concentrations of the fluoride in surface water and sediments reported herein.

We acknowledge however, that these conclusions are based on a limited temporal and spatial investigation that was focused on identifying potential impacts from the current concentrations of COPEC reported for water bodies within the investigation area. The collection of the additional lines-of-evidence as discussed in this report was undertaken to expand and strengthen the evidence base for discerning ecological risk. The uncertainties and limitations associated with the distinct lack of high reliability guidance criteria on aquatic ecotoxicity of aluminium and fluoride is acknowledged. Nonetheless, due to the limited availability of published guidance on the ecotoxicology of the specific COPEC (aluminium and fluoride), we are confident that the results are indicative of the low levels of risk to aquatic species in the water bodies investigated.

6 References

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7 Limitations

ENVIRON Australia prepared this report in accordance with the scope of work as outlined in our proposal to Hydro Aluminium Kurri Kurri Pty Ltd dated 17 August 2012 and in accordance with our understanding and interpretation of current regulatory standards.

A representative program of sampling and laboratory analyses was undertaken as part of this investigation, based on past and present known uses of the site. While every care has been taken, concentrations of contaminants measured may not be representative of conditions between the locations sampled and investigated. We cannot therefore preclude the presence of materials that may be hazardous.

Site conditions may change over time. This report is based on conditions encountered at the site at the time of the report and ENVIRON disclaims responsibility for any changes that may have occurred after this time.

The conclusions presented in this report represent ENVIRON's professional judgment based on information made available during the course of this assignment and are true and correct to the best of ENVIRON's knowledge as at the date of the assessment.

ENVIRON did not independently verify all of the written or oral information provided to ENVIRON during the course of this investigation. While ENVIRON has no reason to doubt the accuracy of the information provided to it, the report is complete and accurate only to the extent that the information provided to ENVIRON was itself complete and accurate.

This report does not purport to give legal advice. This advice can only be given by qualified legal advisors.

7.1 User Reliance

This report has been prepared exclusively for Hydro Aluminium Kurri Kurri Pty Ltd and may not be relied upon by any other person or entity without ENVIRON's express written permission.

Figures

Figure 2.1 Hydro Australia's Kurri Kurri Aluminium Smelter (red boundary) and Buffer Zone (blue) showing the ERA Investigation Area (circled). More detail on the Investigation Area is shown on *Figure 2.2*.

Figure 2.2 North-east Corner of the Kurri Kurri Smelter Site, showing the Notification Area (blue shading) Relative to the Alcan Mound, Northern and Southern Vegetation Impact Areas and Other Features Mentioned in the Text. The semi-permanent dam is shown in red.

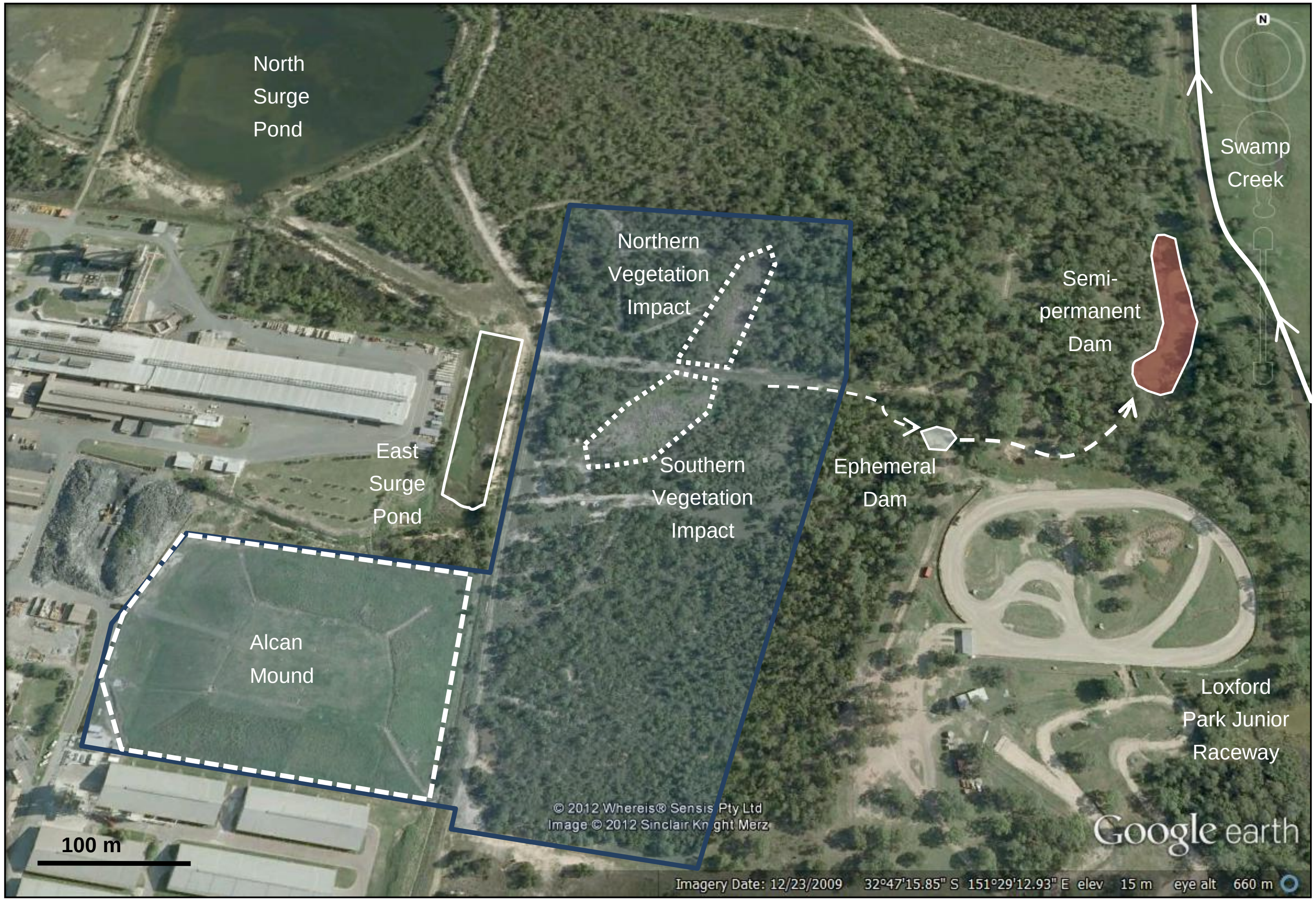


Figure 2.3 The relative location of the three dams sampled during the Stage 2 aquatic assessment. More detail for each dam is shown in subsequent figures.

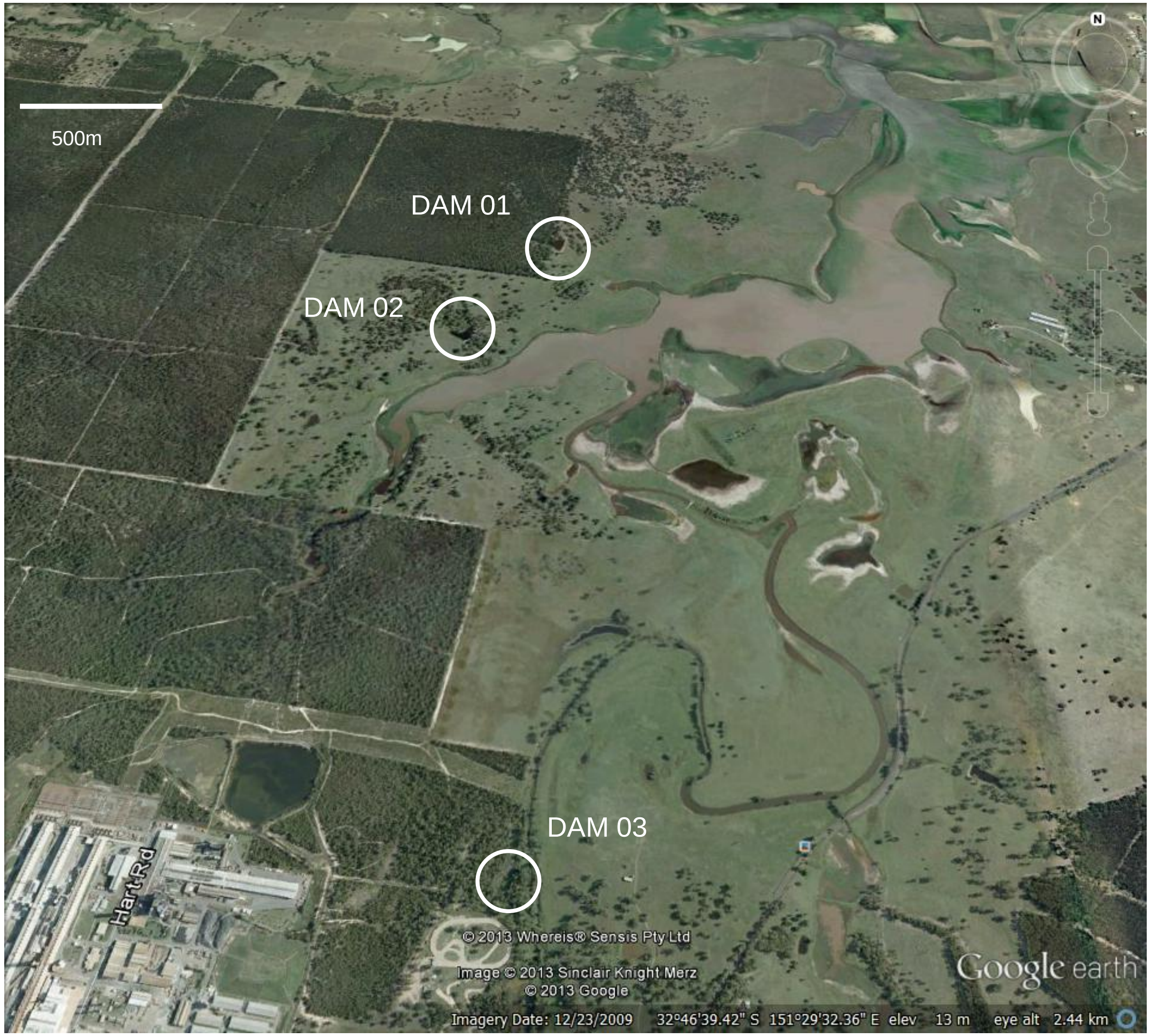


Figure 2.4 Dam 01: Environmental Setting and Approximate Location of Sampling Sites.

Figure 2.5 Dam 02: Environmental Setting and Approximate Location of Sampling Sites.

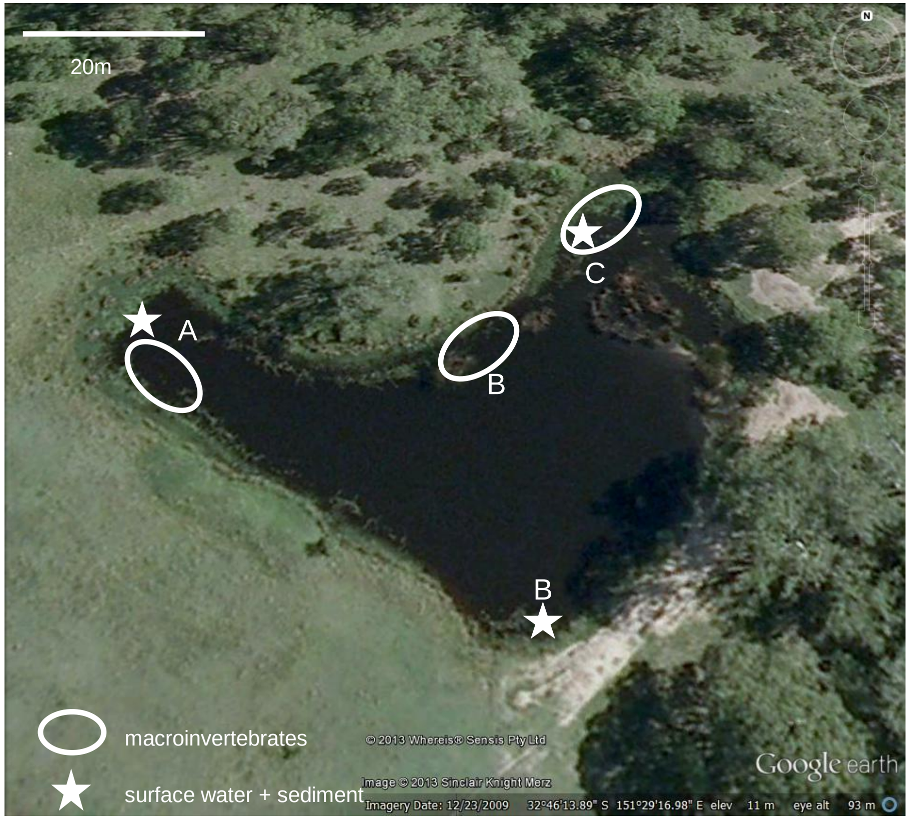


Figure 2.6 Dam 03: Environmental Setting and Approximate Location of Sampling Sites.

Figure 3.1 Surface Water Quality – Comparison between Dams (mean ± standard deviation, n=3).

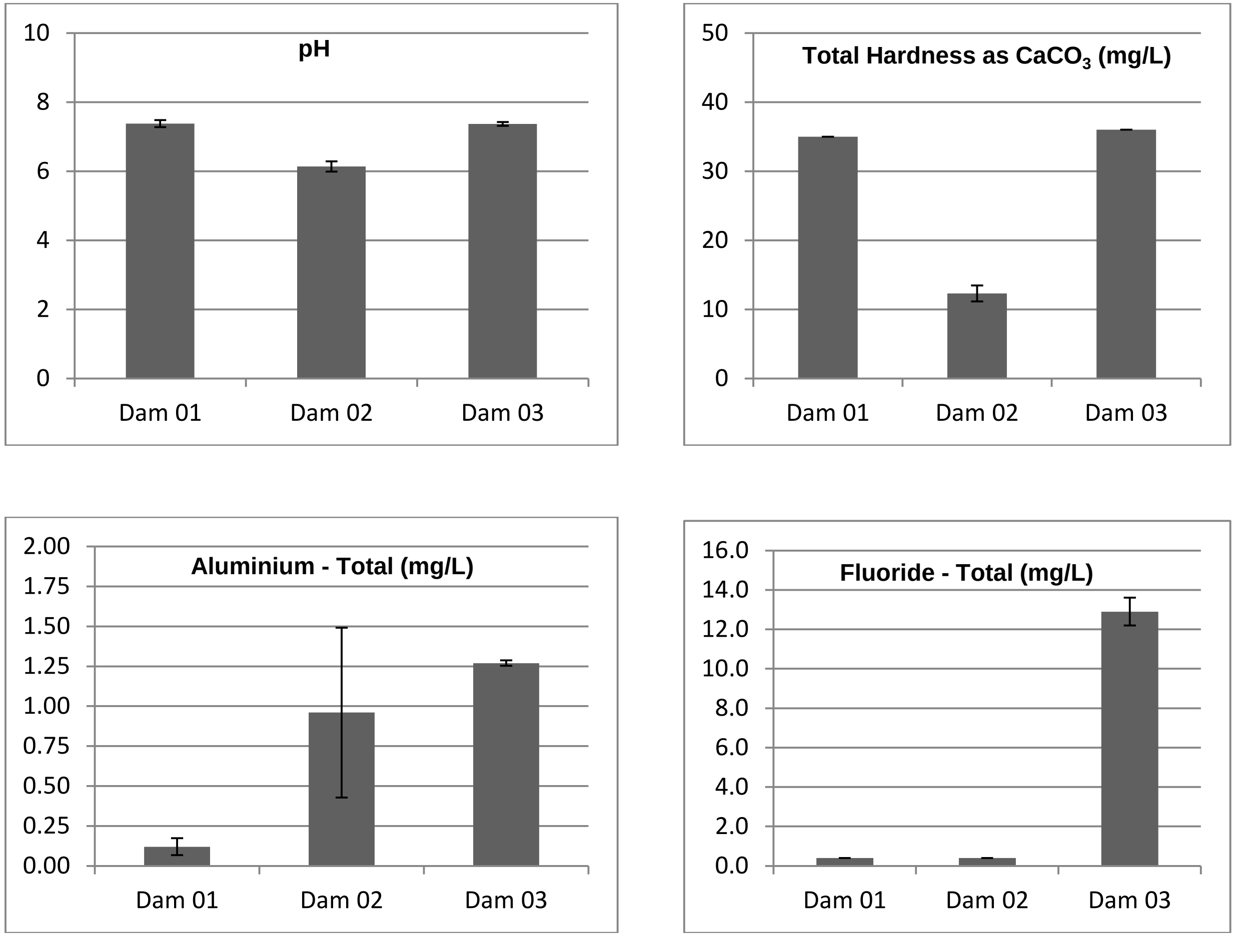


Figure 3.2 Sediment Quality – Comparison between Dams (mean ± standard deviation, n=3).

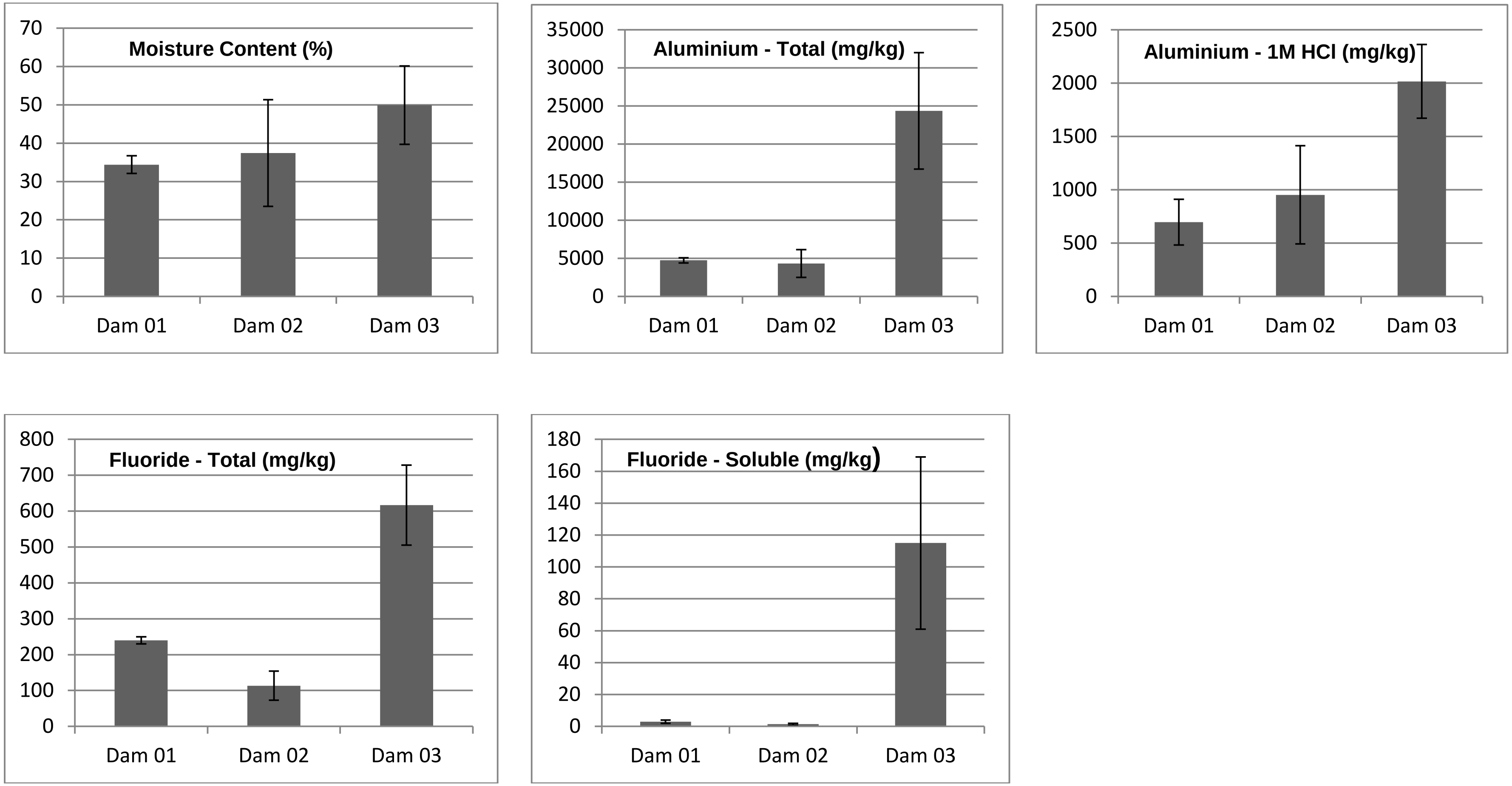
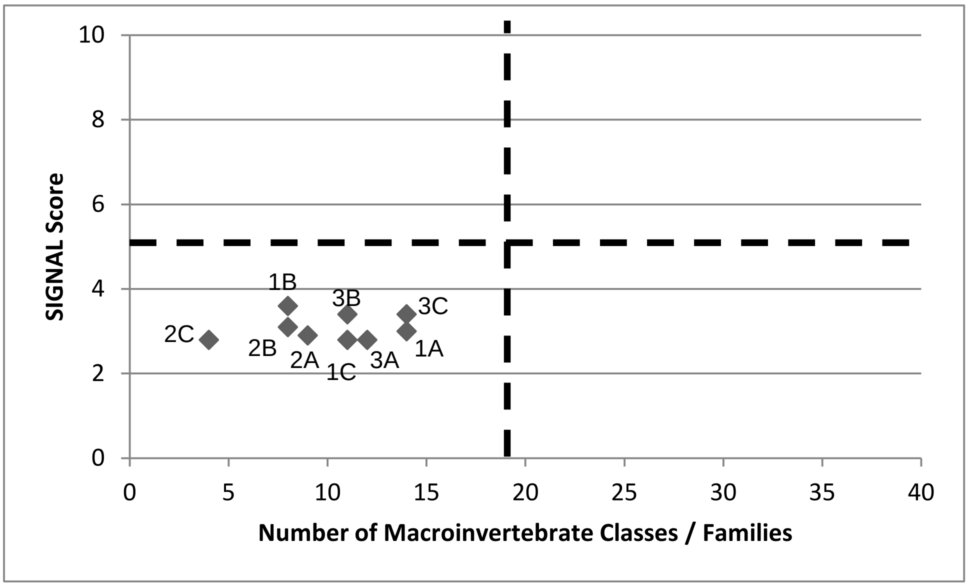


Figure 3.3 Plot of the SIGNAL Score Versus Number of Macroinvertebrate Taxa at each Site (Data labels refer to Dam and Site numbers)



Tables

Table 2.1: Coordinates for Water and Sediment Quality Sampling Locations					
Location		**Latitude**	**Longitude**	**Easting ***	**Northing ***
Dam 01	A	32° 45' 59.46" S	151° 29' 29.38" E	358704.891	6373589.732
	B	32° 45' 58.09" S	151° 29' 29.44" E	358705.851	6373631.947
	C	32° 45' 58.58" S	151° 29' 28.03" E	358669.377	6373616.333
Dam 02	A	32° 46' 13.83" S	151° 29' 15.57" E	358351.869	6373142.039
	B	32° 46' 13.69" S	151°29' 17.10" E	358391.617	6373146.920
	C	32° 46' 13.00" S	151° 29' 17.66" E	358405.885	6373168.378
Dam 03	A	32° 47' 13.92" S	151° 29'26.07" E	358651.476	6371295.297
	B	32° 47' 10.30" S	151° 29' 26.27" E	358655.088	6371406.860
	C	32° 47' 12.36" S	151° 29' 25.93" E	358647.148	6371343.290

** UTM Zone 56*

Table 2.2: Coordinates for Macroinvertebrate Sampling Locations					
Location		**Latitude**	**Longitude**	**Easting ***	**Northing ***
Dam 01	A	32° 45' 59.46" S	151° 29' 29.38" E	358704.891	6373589.732
	B	32° 45' 58.09" S	151° 29' 29.44" E	358705.851	6373631.947
	C	32° 45' 58.58" S	151° 29' 28.03" E	358669.377	6373616.333
Dam 02	A	32° 46' 13.83" S	151° 29' 15.57" E	358351.869	6373142.039
	B	32° 46' 13.69" S	151°29' 17.10" E	358391.617	6373146.920
	C	32° 46' 13.00" S	151° 29' 17.66" E	358405.885	6373168.378
Dam 03	A	32° 47' 13.92" S	151° 29'26.07" E	358651.476	6371295.297
	B	32° 47' 10.30" S	151° 29' 26.27" E	358655.088	6371406.860
	C	32° 47' 12.36" S	151° 29' 25.93" E	358647.148	6371343.290

** UTM Zone 56*

Table 2.3: Sample Analyses – Parameters, Methods and Limits of Reporting (LOR)			
Parameter	**Sample Type**	**Analytical Method**	**LOR**
pH	Water	PC titrator	0.01
Total Hardness	Water	APHA 2340 B	1 mg/L
Fluoride	Water	APHA 4500 F - C	0.1 mg/L
Total Aluminium	Water	USEPA 6020 ICP/MS	0.01 mg/L
Moisture	Sediment	In-house	1%
Total Fluoride	Sediment	In-house - fusion	40 mg/kg
Soluble Fluoride	Sediment	In-house – fusion	1 mg/kg
Total Aluminium	Sediment	USEPA 6010 ICP/MS	50 mg/kg
1M HCl Aluminium	Sediment	In-house / NADG	50 mg/kg

Table 3.1: Water and Sediment Quality Analytical Results

		Sample:	DAM01-A	DAM01-B	DAM01-C	DAM02-A	DAM02-B	DAM02-C
		Date:	2/05/2013	2/05/2013	2/05/2013	2/05/2013	2/05/2013	2/05/2013
Parameter	**Units**	**LOR**						
Surface Water								
pH Value	pH Unit	0.01	7.3	7.4	7.5	6.3	6.0	6.2
Total Hardness	mg/L	1	35	35	35	13	11	13
Aluminium - Total	mg/L	0.01	0.2	0.1	0.1	1.6	0.8	0.5
Fluoride - Total	mg/L	0.1	0.4	0.4	0.4	0.4	0.4	0.4
Sediment								
Moisture Content	%	1	33.9	32.4	36.9	25.7	52.8	33.8
Aluminium - 1M HCl	mg/kg	50	820	450	820	620	1,480	760
Aluminium - Total	mg/kg	50	5,140	4,470	4,630	3,040	6,400	3,520
Fluoride - Soluble	mg/kg	1	3	4	2	1	2	1
Fluoride - Total	mg/kg	40	230	240	250	90	160	90

		Sample:	DAM03-A	DAM03-B	DAM03-C	QC01
		Date:	3/05/2013	3/05/2013	3/05/2013	3/05/2013
Parameter	**Units**	**LOR**				
Surface Water						
pH Value	pH Unit	0.01	7.3	7.4	7.4	7.4
Total Hardness	mg/L	1	36	36	36	36
Aluminium - Total	mg/L	0.01	1.3	1.3	1.3	1.2
Fluoride - Total	mg/L	0.1	12.1	13.2	13.4	13.3
Sediment						
Moisture Content	%	1	38.2	54.6	57.0	48.3
Aluminium - 1M HCl	mg/kg	50	1,640	2,090	2,320	2,050
Aluminium - Total	mg/kg	50	18,500	33,000	21,600	16,600
Fluoride - Soluble	mg/kg	1	53	140	152	119
Fluoride - Total	mg/kg	40	490	700	660	570

Table 3.2: Number of Individuals per Site in Each Macroinvertebrate Taxa											
CLASS / ORDER	**FAMILY**	**Common Name**	**DAM 01**			**DAM 02**			**DAM 03**		
			A	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**
Nematoda		nematode	>10	>10	>10	>10	>10	>10	>10	>10	>10
Hirudinea		leech	0	1	0	1	0	0	0	0	0
Oligochaeta		worm	1	0	0	0	0	0	0	0	0
Gastropoda	Lymnaeidae	pond snail	0	0	0	2	1	0	0	0	0
	Physidae	snail	0	0	0	0	0	0	0	0	1
Acarina	Hydracarina	mite	>5	>5	>5	0	0	0	>6	>5	>10
Araneae		spider	1	0	0	1	0	0	1	0	0
Cladocera		water flea	3	0	6	0	0	0	0	0	0
Decapoda	Atyidae	shrimp	>20	>30	>30	>10	>10	>10	>10	>10	>10
Coleoptera	Dytiscidae	diving beetle	0	0	0	8	1	6	4	2	1
	Haliplidae	crawling water beetle	2	1	1	4	3	0	0	0	1
	Hydrophilidae	water beetle	0	0	0	0	0	0	1	0	0
		unidentified beetle	0	0	0	0	0	0	0	1	1
Diptera	Chironomidae	non-biting midge	0	0	0	0	0	0	0	1	2
	Culicidae	mosquito wriggler	0	0	0	0	0	0	0	0	2
	Culicidae	mosquito pupae	0	0	0	0	0	0	0	0	2
	Tabanidae	march fly	0	0	0	0	1	0	0	0	0
		unidentified larva	1	0	0	0	0	0	1	3	0
Ephemeroptera	Baetidae	mayfly	1	0	0	0	0	0	1	15	14
Hemiptera	Corixidae	waterboatmen	3	1	1	0	0	0	3	26	6
	Notonectidae	backswimmer	3	0	3	0	0	0	7	0	0
		unidentified bug	0	0	2	0	0	0	0	0	0
Odonata	Coenagrionidae	damselfly	0	0	0	0	0	0	0	0	0
	Protoneuridae	damselfly	3	5	3	4	2	1	0	7	5
	Lestidae	damselfly	0	0	1	0	0	0	1	0	0
	Gomphidae	dragonfly	1	0	1	17	8	0	1	2	2
Trichoptera	Leptoceridae	caddisfly	1	2	0	0	0	0	0	0	0
	TOTAL Number of Individuals		**55**	**55**	**63**	**57**	**36**	**27**	**46**	**82**	**67**
	TOTAL Number of Taxa		**14**	**8**	**11**	**9**	**8**	**4**	**12**	**11**	**14**

Table 3.3: Abundance and SIGNAL Scores for Each Macroinvertebrate Taxa - Dam 01

				Dam 01 - A			Dam 01 - B			Dam 01 - C		
CLASS / ORDER	FAMILY	Common Name	SIGNAL 2 sensitivity grade	Number of Specimens	Weight Factor	Grade x Weight Factor	Number of Specimens	Weight Factor	Grade x Weight Factor	Number of Specimens	Weight Factor	Grade x Weight Factor
Nematoda		nematode	3	>10	4	12	>10	4	12	>10	4	12
Hirudinea		leech	1	0	0	0	1	1	1	0	0	0
Oligochaeta		worm	2	1	1	2	0	0	0	0	0	0
Gastropoda	Lymnaeidae	pond snail	1	0	0	0	0	0	0	0	0	0
	Physidae	snail	1	0	0	0	0	0	0	0	0	0
Acarina	Hydracarina	mite	6	>5	3	18	>5	3	18	>5	3	18
Araneae		spider		1	1	0	0	0	0	0	0	0
Cladocera		water flea		3	2	0	0	0	0	6	3	0
Decapoda	Atyidae	shrimp	3	>20	5	15	>30	5	15	>30	5	15
Coleoptera	Dytiscidae	diving beetle	2	0	0	0	0	0	0	0	0	0
	Haliplidae	crawling water beetle	2	2	1	2	1	1	2	1	1	2
	Hydrophilidae	water beetle	2	0	0	0	0	0	0	0	0	0
		unidentified beetle	2	0	0	0	0	0	0	0	0	0
Diptera	Chironomidae	non-biting midge	3	0	0	0	0	0	0	0	0	0
	Culicidae	mosquito wriggler	1	0	0	0	0	0	0	0	0	0
	Culicidae	mosquito pupae	1	0	0	0	0	0	0	0	0	0
	Tabanidae	march fly	3	0	0	0	0	0	0	0	0	0
		unidentified larva	1	1	1	1	0	0	0	0	0	0
Ephemeroptera	Baetidae	mayfly	5	1	1	5	0	0	0	0	0	0
Hemiptera	Corixidae	waterboatmen	2	3	2	4	1	1	2	1	1	2
	Notonectidae	backswimmer	1	3	2	2	0	0	0	3	2	2
		unidentified bug	1	0	0	0	0	0	0	2	1	1
Odonata	Coenagrionidae	damselfly	2	0	0	0	0	0	0	0	0	0
	Protoneuridae	damselfly	4	3	2	8	5	2	8	3	2	8
	Lestidae	damselfly	1	0	0	0	0	0	0	1	1	1
	Gomphidae	dragonfly	5	1	1	5	0	0	0	1	1	5
Trichoptera	Leptoceridae	caddisfly	6	1	1	6	2	1	6	0	0	0
			Total		***27***	***80***		***18***	***64***		***24***	***66***
			SIGNAL Score			***3.0***			***3.6***			***2.8***

CLASS / ORDER | FAMILY | Common

		Name
Nematoda		nematode
Hirudinea		leech
Oligochaeta		worm
Gastropoda	Lymnaeidae	pond snail
	Physidae	snail
Acarina	Hydracarina	mite
Araneae		spider
Cladocera		water flea
Decapoda	Atyidae	shrimp
Coleoptera	Dytiscidae	diving beetle
	Haliplidae	crawling water beetle
	Hydrophilidae	water beetle
		unidentified beetle
Diptera	Chironomidae	non-biting midge
	Culicidae	mosquito wriggler
	Culicidae	mosquito pupae

	Tabanidae	march fly
		unidentified larva
Ephemeroptera	Baetidae	mayfly

Hemiptera	Corixidae	waterboatmen
	Notonectidae	backswimmer
		unidentified bug
Odonata	Coenagrionidae	damselfly
	Protoneuridae	damselfly
	Lestidae	damselfly
	Gomphidae	dragonfly
Trichoptera	Leptoceridae	caddisfly

very tolerant species (Grades 1 - 3) ***tolerant species (Grades 4 - 5)*** ***sensitive species (Grades 6 - 7)***

very tolerant species (Grades 1 - 3) tolerant species (Grades 4 - 5) sensitive species (Grades 6 - 7)

Table 3.4: Abundance and SIGNAL Scores for Each Macroinvertebrate Taxa - Dam 02

CLASS / ORDER	FAMILY	Common Name	SIGNAL 2 sensitivity grade	Dam 02 - A Number of Specimens	Dam 02 - A Weight Factor	Dam 02 - A Grade x Weight Factor	Dam 02 - B Number of Specimens	Dam 02 - B Weight Factor	Dam 02 - B Grade x Weight Factor	Dam 02 - C Number of Specimens	Dam 02 - C Weight Factor	Dam 02 - C Grade x Weight Factor
Nematoda		nematode	3	>10	4	12	>10	4	12	>10	4	12
Hirudinea		leech	1	1	1	1	0	0	0	0	0	0
Oligochaeta		worm	2	0	0	0	0	0	0	0	0	0
Gastropoda	Lymnaeidae	pond snail	1	2	1	1	1	1	1	0	0	0
	Physidae	snail	1	0	0	0	0	0	0	0	0	0
Acarina	Hydracarina	mite	6	0	0	0	0	0	0	0	0	0
Araneae		spider		1	1	0	0	0	0	0	0	0
Cladocera		water flea		0	0	0	0	0	0	0	0	0
Decapoda	Atyidae	shrimp	3	>10	4	12	>10	4	12	>10	4	12
Coleoptera	Dytiscidae	diving beetle	2	8	3	6	1	1	2	6	3	6
	Haliplidae	crawling water beetle	2	4	2	4	3	2	4	0	0	0
	Hydrophilidae	water beetle	2	0	0	0	0	0	0	0	0	0
		unidentified beetle	2	0	0	0	0	0	0	0	0	0
Diptera	Chironomidae	non-biting midge	3	0	0	0	0	0	0	0	0	0
	Culicidae	mosquito wriggler	1	0	0	0	0	0	0	0	0	0
	Culicidae	mosquito pupae	1	0	0	0	0	0	0	0	0	0
	Tabanidae	march fly	3	0	0	0	1	1	3	0	0	0
		unidentified larva	1	0	0	0	0	0	0	0	0	0
Ephemeroptera	Baetidae	mayfly	5	0	0	0	0	0	0	0	0	0
Hemiptera	Corixidae	waterboatmen	2	0	0	0	0	0	0	0	0	0
	Notonectidae	backswimmer	1	0	0	0	0	0	0	0	0	0
		unidentified bug	1	0	0	0	0	0	0	0	0	0
Odonata	Coenagrionidae	damselfly	2	0	0	0	0	0	0	0	0	0
	Protoneuridae	damselfly	4	4	2	8	2	1	4	1	1	4
	Lestidae	damselfly	1	0	0	0	0	0	0	0	0	0
	Gomphidae	dragonfly	5	17	4	20	8	3	15	0	0	0
Trichoptera	Leptoceridae	caddisfly	6	0	0	0	0	0	0	0	0	0
			Total		***22***	***64***		***17***	***53***		***12***	***34***
			SIGNAL Score			***2.9***			***3.1***			***2.8***

CLASS / ORDER	FAMILY	Common

		Name
Nematoda		nematode
Hirudinea		leech
Oligochaeta		worm
Gastropoda	Lymnaeidae	pond snail
	Physidae	snail
Acarina	Hydracarina	mite
Araneae		spider
Cladocera		water flea
Decapoda	Atyidae	shrimp
Coleoptera	Dytiscidae	diving beetle
	Haliplidae	crawling water beetle
	Hydrophilidae	water beetle
		unidentified beetle
Diptera	Chironomidae	non-biting midge
	Culicidae	mosquito wriggler
	Culicidae	mosquito pupae
	Tabanidae	march fly
		unidentified larva
Ephemeroptera	Baetidae	mayfly
Hemiptera	Corixidae	waterboatmen
	Notonectidae	backswimmer
		unidentified bug
Odonata	Coenagrionidae	damselfly

	Protoneuridae	damselfly
	Lestidae	damselfly
	Gomphidae	dragonfly
Trichoptera	Leptoceridae	caddisfly

very tolerant species (Grades 1 - 3)

tolerant species (Grades 4 - 5)

sensitive species (Grades 6 - 7)

Table 3.5: Abundance and SIGNAL Scores for Each Macroinvertebrate Taxa - Dam 03												
				Dam 03 - A			Dam 03 - B			Dam 03 - C		
CLASS / ORDER	FAMILY	Common Name	SIGNAL 2 sensitivity grade	Number of Specimens	Weight Factor	Grade x Weight Factor	Number of Specimens	Weight Factor	Grade x Weight Factor	Number of Specimens	Weight Factor	Grade x Weight Factor
Nematoda		nematode	3	>10	4	12	>10	4	12	>10	4	12
Hirudinea		leech	1	0	0	0	0	0	0	0	0	0
Oligochaeta		worm	2	0	0	0	0	0	0	0	0	0
Gastropoda	Lymnaeidae	pond snail	1	0	0	0	0	0	0	0	0	0
	Physidae	snail	1	0	0	0	0	0	0	1	1	1
Acarina	Hydracarina	mite	6	>5	3	18	>5	3	18	>10	4	24
Araneae		spider		1	1	0	0	0	0	0	0	0
Cladocera		water flea		0	0	0	0	0	0	0	0	0
Decapoda	Atyidae	shrimp	3	>10	4	12	>10	4	12	>10	4	12
Coleoptera	Dytiscidae	diving beetle	2	4	2	4	2	1	2	1	1	2
	Haliplidae	crawling water beetle	2	0	0	0	0	0	0	1	1	2
	Hydrophilidae	water beetle	2	1	1	2	0	0	0	0	0	0
		unidentified beetle	2	0	0	0	1	1	2	1	1	2
Diptera	Chironomidae	non-biting midge	3	0	0	0	1	1	3	2	1	3
	Culicidae	mosquito wriggler	1	0	0	0	0	0	0	2	1	1
	Culicidae	mosquito pupae	1	0	0	0	0	0	0	2	1	1
	Tabanidae	march fly	3	0	0	0	0	0	0	0	0	0
		unidentified larva	1	1	1	1	3	2	2	0	0	0
Ephemeroptera	Baetidae	mayfly	5	1	1	5	15	4	20	14	4	20
Hemiptera	Corixidae	waterboatmen	2	3	2	4	26	5	10	6	3	6
	Notonectidae	backswimmer	1	7	3	3	0	0	0	0	0	0
		unidentified bug	1	0	0	0	0	0	0	0	0	0
Odonata	Coenagrionidae	damselfly	2	0	0	0	0	0	0	0	0	0
	Protoneuridae	damselfly	4	0	0	0	7	3	12	5	2	8
	Lestidae	damselfly	1	1	1	1	0	0	0	0	0	0
	Gomphidae	dragonfly	5	1	1	5	2	1	5	2	1	5
Trichoptera	Leptoceridae	caddisfly	6	0	0	0	0	0	0	0	0	0
			Total		***24***	***67***		***29***	***98***		***29***	***99***
			SIGNAL Score			***2.8***			***3.4***			***3.4***

CLASS / ORDER	FAMILY	Common

		Name
Nematoda		nematode
Hirudinea		leech
Oligochaeta		worm
Gastropoda	Lymnaeidae	pond snail
	Physidae	snail
Acarina	Hydracarina	mite
Araneae		spider
Cladocera		water flea
Decapoda	Atyidae	shrimp
Coleoptera	Dytiscidae	diving beetle
	Haliplidae	crawling water beetle
	Hydrophilidae	water beetle
		unidentified beetle
Diptera	Chironomidae	non-biting midge
	Culicidae	mosquito wriggler
	Culicidae	mosquito pupae
	Tabanidae	march fly
		unidentified larva
Ephemeroptera	Baetidae	mayfly
Hemiptera	Corixidae	waterboatmen
	Notonectidae	backswimmer
		unidentified bug
Odonata	Coenagrionidae	damselfly

	Protoneuridae	damselfly
	Lestidae	damselfly
	Gomphidae	dragonfly
Trichoptera	Leptoceridae	caddisfly

very tolerant species (Grades 1 - 3)

tolerant species (Grades 4 - 5)

sensitive species (Grades 6 - 7)