Tier 2 Ecological Risk Assessment, Kurri Kurri Aluminium Smelter

Prepared for:
Hydro Aluminium Kurri Kurri Pty Ltd

Prepared by:
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Contents

Figures

Tables

Acronyms and Abbreviations

AHD	Australian height datum
Al	aluminium
ANZECC	Australian and New Zealand Environment and Conservation Council
AUF	area use factor
BAF	bioaccumulation factor
BGL	below ground level
BW	body weight
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
EPC	exposure point concentration
ERA	ecological risk assessment
ESA	Environmental Site Assessment
F-	fluoride
ha	Hectare
HQ	hazard quotient
IR	ingestion rate
km	kilometre
LOAEL	lowest observed adverse effect level
LOR	limit of reporting
m	metre
mg/kg	milligrams per kilogram
mg/L	milligrams per litre
m BGL	metres below ground level
n	number of samples
NATA	National Association of Testing Authorities
NC	not calculated
ND	not detected
NEPM	National Environment Protection Measure
NOAEL	no observed adverse effect level
OH&S	Occupational Health & Safety
PQL	practical quantitation limit
pH	a measure of acidity, hydrogen ion activity
QA/QC	Quality Assurance/Quality Control
ROI	receptor of interest
RWC	reasonable worst case
SLERA	screening level ecological risk assessment
TDI	total daily intake
TRV	toxicity reference value
µg/L	micrograms per litre
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 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 Hydro's Kurri Kurri Aluminium Smelter in New South Wales, Australia.

In 2012, plant operations were curtailed and production ceased in September of that year. In preparation for curtailment of smelter operations, Hydro engaged ENVIRON to undertake Phase 1 and Phase 2 environmental site assessments (ESA) of the plant and surrounding buffer land. These investigations included review of documentation relating to storage of Spent Pot Liner (SPL) and other smelter waste in an area known as the 'Alcan Mound' on the north-east boundary of the smelter property. The Alcan Mound is a stockpile of mixed smelter waste used during early smelter operations between 1969 and 1992. An estimated 100,000 m3 of mixed wastes, including SPL, were stored in this area and were subsequently capped with clay in 1995.

The Hydro Aluminium Kurri Kurri Smelter site comprises a 60 ha plant area and 2,000 ha of surrounding buffer lands. The investigations subject to this ecological risk assessment relate to an area of approximately 8 ha comprising the Alcan Mound and the down-gradient area of leachate impact. This area is referred to as 'the notified area" in this report.

Soil and groundwater investigations identified elevated fluoride (F-) and aluminium (Al) concentrations within the notified area. The ESA recommended notification of the Alcan Mound and associated leachate impact area to the NSW Environmental Protection Agency (EPA) under Section 60 of the Contaminated Land Management Act 1997. Notification was subsequently made to the EPA on the 11th July 2012 and the EPA requested on 18th October 2012 that further information be provided comprising:

- Site plans and tables of results summarising the concentrations of contaminants for each of the groundwater monitoring wells;
- The nature and extent of groundwater contamination arising from the leaching of contaminants from the waste stockpiles; and
- An assessment of the risks posed to any nearby receptors (including water bodies, livestock and groundwater users) from the potential off-site migration of the contamination.

The first two bullet points were covered by the ESA report completed by ENVIRON and submitted to Hydro in December 2012 (ENVIRON 2012). This current ERA report specifically addressed the third bullet point and is a companion document to the Preliminary Screening Level Health Risk Assessment currently being prepared by ENVIRON.

A Tier 1 (Screening Level) ERA was undertaken as part of the ESA, and compared on-site environmental contamination data with existing generic trigger values for soil and surface water quality (ENVIRON 2012). The Tier 1 ERA identified fluoride and aluminium as the main constituents occurring in excess of the generic threshold criteria and were therefore designated as the contaminants of potential ecological concern (COPECs). Electrical conductivity and pH were also elevated within two vegetation impact areas in the notified area but nowhere else and as such are not considered within this ERA since levels are not outside the expected natural range for the majority of the water features examined.

Tier 2 Risk Assessment

The overall objective of this ERA was to review existing information on contaminants of concern for the protection of terrestrial and aquatic flora and fauna specific to the notified area the lands surrounding the notified area and for livestock on nearby properties. For the purposes of this ERA, the investigation area was defined as the notified area (shown on Figure 1) and down gradient features that may be impacted by off-site migration of contaminants from the notified area. Specifically these features included several surface water features further down gradient comprising a small ephemeral dam, a larger semi-permanent dam and Swamp Creek.

Based on the environmental setting, the feeding guilds potentially exposed to COPECs via complete exposure pathways and their dominant exposure routes were:

- soil microbes (via direct contact with soil);
- terrestrial plants (via direct contact with soil);
- terrestrial fauna (via ingestion of drinking water);
- aquatic plants (via direct contact with surface water and/or sediment);
- aquatic invertebrates (via direct contact with surface water);
- fish (via gill exchange with surface water);
- aquatic birds (via ingestion of drinking water and aquatic species); and
- cattle (via ingestion of drinking water).

The exposure assessment for microbes, terrestrial plants, aquatic plants, invertebrates and fish were based solely on COPEC concentrations within the relevant media (soil or surface water). Exposures for birds and mammals were estimated from concentrations of COPECs in surface water and measurement endpoints focused on the comparison of estimates of dose (in units of mg/kg/day) to published dose-based toxicity reference values (TRVs). TRVs for Australian receptors are lacking and therefore the exposure assessment for birds and mammals was based on published wildlife toxicity benchmarks from the US, using data for species that, as far as possible, were from similar taxonomic groups, trophic levels and body size.

The assessment of risk identified that concentrations of fluoride in surface soils and exfiltrated leachate (when present after significant rainfall) could pose unacceptable risk to shallow-rooted terrestrial plants and soil microbial communities within the upper 0.4 m soil horizon within the southern and northern vegetation impact areas. Aluminium is unlikely to pose an unacceptable risk to terrestrial plants and microbes since it is tightly bound to soil under existing soils conditions where pH is greater than 5.5. Field observations do not indicate any evidence that microbial activity or terrestrial plant health is being impacted by current conditions within the investigation area. Historical conditions within the vegetation impact areas have clearly impacted vegetation but the low level of risk identified and the current health of vegetation within the two areas indicates that conditions are currently suitable for plant growth.

No unacceptable risk from fluoride and aluminium was identified for terrestrial bird and mammal species through their use of surface water for drinking, except under highly conservative and unrealistic scenarios whereby species rely on exfiltrated groundwater within the two investigation areas for 100% of their drinking water.

Results indicated that surface water within the semi-permanent dam could pose an unacceptable risk to aquatic invertebrates and fish species. No reliable benchmark was sourced for aquatic plants but it was assumed that aquatic plants were also potentially at risk from fluoride contamination within the semi-permanent dam. Results also indicated that aluminium concentrations within the surface water of the semi-permanent dam could pose an unacceptable risk to aquatic invertebrates and aquatic plants but are unlikely to pose unacceptable risk to fish species. These risk scenarios were based on low reliability benchmarks for non-Australian species under non-field conditions and the risk rating is unlikely to translate into actual impacts within the investigation area.

Swamp Creek is the ultimate water feature within the investigation area that could potentially receive COPECs from the exfiltrated leachate impacted groundwater. Based on conservative toxicity benchmarks, the concentration of fluoride within the surface water of Swamp Creek is unlikely to pose an unacceptable risk to aquatic invertebrates and fish (Hazard Quotients less than 1) and a broadly similar risk profile was apparent for fluoride concentrations at all other Swamp Creek sites (downstream) as well as the two ‘reference’ locations upstream of the investigation area. These results indicate that there is a low level ‘background’ of fluoride concentrations in the vicinity of the investigation area.

The reference locations, while not representative of the natural background water quality in the region, provided a useful comparison between the quality of surface water in Swamp Creek upstream and downstream of the inflow of surface water within the investigation area. On that basis, there was no significant change in risk from fluoride concentration in Swamp Creek as a result of surface water inflow from the investigation area.

There were no apparent risks from aluminium concentrations within surface water in Swamp Creek except at the location furthest downstream from the investigation area. This isolated result was unrelated to surface water originating from within the investigation area.

Swamp Creek water is also used for watering local livestock. The concentrations of fluoride and aluminium in Swamp Creek surface waters do not pose an unacceptable risk to livestock according to criteria based on the ANZECC (2000) livestock drinking water guidelines.

Conclusions

The evaluation of ecological risk for terrestrial and aquatic plant and animal species indicated that, with limited exceptions, the conditions within the investigation area do not pose an unacceptable risk to these receptors. The exceptions included the following:

- Potential risks to soil microbial communities and shallow-rooted plants from fluoride concentrations in soil and exfiltrate within the two vegetation impact areas.

- Potential risks to aquatic invertebrates, fish and plants from fluoride and aluminium concentrations in surface water within the semi-permanent dam.

On the basis of those results the following actions were recommended:

1. Investigate potential mitigation measures to halt, reduce or capture exfiltrated leachate-contaminated groundwater;
2. Continue to map and monitor the location and quality of the groundwater plume associated with the Alcan Mound in order to document any temporal change that may indicate increasing or decreasing risk to ecological receptors;
3. Further investigate the range of ‘background’ concentrations of aluminium and fluoride in soil and surface water within the buffer zone to better understand variability with respect to potential smelter impacts.
4. 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
5. 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.

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.

ENVIRON had previously completed a Phase 2 Environmental Site Assessment (ESA) at the smelter in May 2012. The ESA recommended notification of the Alcan Mound and associated leachate impact area to the NSW Environmental Protection Agency (EPA) under Section 60 of the Contaminated Land Management Act 1997. Notification was subsequently made to the EPA on the 11th July 2012 and the EPA requested on 18th October 2012 that further information be provided comprising:

- Site plans and tables of results summarising the concentrations of contaminants for each of the groundwater monitoring wells;
- The nature and extent of groundwater contamination arising from the leaching of contaminants from the waste stockpiles; and
- An assessment of the risks posed to any nearby receptors (including water bodies, livestock and groundwater users) from the potential off-site migration of the contamination.

The first two bullet points were covered by an Environmental Site Assessment (ESA) report completed by ENVIRON and submitted to Hydro in December 2012 (*ENVIRON 2012*). This current ERA report specifically addresses the third bullet point and is a companion document to the Preliminary Screening Level Health Risk Assessment currently being prepared by ENVIRON.

1.2 Objectives and Scope of Work

Soil and groundwater investigations at the Kurri Kurri Aluminium Smelter have identified elevated fluoride (F-) and aluminium (Al) concentrations at the site and in the surrounding environment. Initial information included groundwater and soil data and a range of other physical and chemical constituents. ENVIRON subsequently undertook a more detailed investigation including assessment of available F- in soils, pH, ions, electrical conductivity (EC) and soluble F- in water.

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, and the development of guidelines protective of the local environment, if possible.

The overall objective of this 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.

1.3 Ecological Risk Assessment Framework

The 1999 NEPM on Ecological Risk Assessment (NEPC 1999) defines ERA as "a set of formal, scientific methods for defining and estimating the probabilities and magnitudes of adverse impacts on plants, animals and/or the ecology of a specified area posed by a particular stressor(s) and frequency of exposure to the stressor(s)…it is a process which identifies the ecological receptors of concern, estimates the concentration that the ecological receptors are exposed to and, based on the magnitude of this concentration, determines whether the ecological receptors and ecological values may be at risk."

ERA is a useful tool to assist with the management of contamination through the assessment of risk associated with potential impacts from contamination on a range of environmental receptors with respect to known toxicity and levels of exposure. The scope of work undertaken to achieve the project objective follows that recommended in guidance for assessing risk to the environment in Australia as provided in:

- Schedule B(5) Guideline on Ecological Risk Assessment, National Environmental Protection (Assessment of Site Contamination) Measure (NEPM). National Environment Protection Council, Australia (NEPC 1999).

In addition, the following guidelines for the assessment of contamination and environmental quality were also considered within the ERA approach, where relevant:

- *Guidelines for Consultants Reporting on Contaminated Sites*. Office of Environment & Heritage, NSW Government (*OEH 2011*)
- *Guidelines for the Assessment and Management of Groundwater Contamination*. Department of Environment and Conservation NSW (*DEC 2007*)
- *Australian and New Zealand Guidelines for Fresh and Marine Water Quality.* Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand (*ANZECC 2000*)
- *Australian Drinking Water Guidelines*. NHMRC and Natural Resource Management Ministerial Council of Australia and New Zealand (*NHMRC 2004*).

The NEPM establishes a tiered approach to risk assessment consisting of three levels – Tiers 1 to 3 – with each level having a similar approach but with an "increasing degree of data collection and complexity and decreasing uncertainty".

A basic screening level ERA was incorporated in the ESA (ENVIRON 2012) and this current ERA builds on those conclusions. This ERA is defined as a Tier 2 Assessment given that site-specific contamination and ecological data are reviewed and evaluated with respect to the physical, toxicological and biological parameters that affect the exposure and toxicity assessments.

1.4 Structure of Report

This ERA was undertaken to address the project objectives and the remainder of this report is divided into the following sections:

- Section 2: Site Characterisation
- Section 3: Problem Identification, including identification of receptors
- Section 4: Exposure Assessment

- Section 5: Toxicity Assessment
- Section 6: Risk Characterisation, including uncertainty factors
- Section 7: Conclusions

The risk assessment assumptions and results specific to the site are provided in *Sections 3* to *8* of this report. Additional supporting figures and tables that are referenced throughout the text are provided within standalone sections at the end of the report.

1.5 Data Sources

Environmental data used to conduct the ERA was sourced from previous investigation reports associated with the investigation area, specifically the recent ESA (*ENVIRON 2012*).

1.6 Limitations

The scope of this Tier 2 Ecological Risk Assessment was based on ENVIRON's proposal dated 17 August 2012.

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 Site Characterisation

Detailed information describing the Hydro Aluminium Kurri Kurri Smelter site and the results of previous environmental investigations is described in the Phase 2 ESA report (*ENVIRON 2012*). A brief summary of background information considered relevant to the ERA is provided below.

2.1 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.

For the purposes of this ERA, the investigation area was defined as the notified area (shown on Figure 1) and downgradient features that may be impacted by off-site migration of contaminants from the notified area. Specifically these features included several surface water features further down gradient comprising a small ephemeral dam, a larger semi-permanent dam and Swamp Creek.

2.2 Site History

The Hydro Aluminium Kurri Kurri Smelter has operated on previously undeveloped agricultural land since commissioning by Alcan in 1969. Hydro commenced ownership of the facility in 2001 with the purchase of VAW Pty Limited. During production the smelter produced aluminium ingots which were used to produce a large range of aluminium products. The smelting process included the manufacture of carbon anodes, the reduction of alumina to aluminium and the casting of molten metal. The smelter comprised three pot-lines, a carbon plant, a casting plant, and other ancillary and storage areas.

In 2012, plant operations were curtailed and production ceased in September of that year. Site operations will remain in curtailment until a decision is made to re-open or decommission the facility. In preparation for curtailment of smelter operations, Hydro engaged ENVIRON to undertake Phase 1 and Phase 2 environmental site assessments of the plant and buffer land. These investigations included review of documentation relating to storage of Spent Pot Liner (SPL) and other smelter waste in an area known as the 'Alcan Mound' on the north-east boundary of the smelter property (*Figure 2.2*).

The Alcan Mound is a stockpile of mixed smelter waste used during early smelter operations between 1969 and 1992. An estimated 100,000 m^3 of mixed wastes, including SPL, were stored in this area and the stockpile which was subsequently capped with clay in 1995. Investigations commencing in the mid-1980s identified that the original uncapped method of waste storage had resulted in leachate impacts to groundwater down gradient of the site and that a plume of leachate-impacted groundwater extended approximately 250 m into the buffer zone to the north-east of the Alcan Mound. The capping of the Alcan Mound in 1995 was designed to address the leachate issue.

Following the Phase 1 and Phase 2 evaluation process, the area in the vicinity of the Alcan Mound was deemed to meet the duty to report triggers for contaminated land and on 11 July 2012, in accordance with Section 60 of the Contaminated Land Management Act 1997, the area was notified as potentially contaminated land to the EPA. The notified area (*Figure 2.2*) comprises the Alcan Mound and the leachate impact area down gradient of the mound.

In response to the notification the EPA requested provision of further information regarding the contaminant status of the site. A Phase 2 Environmental Site Assessment was subsequently undertaken by ENVIRON for the site to provide information relevant to the history and current status of the notified area. This ERA addresses the EPA's request for an assessment of risk to ecological receptors from the potential off-site migration of contamination. An assessment of human health risk has been completed as a separate stand-alone report (*ENVIRON 2013*).

For the purposes of this ERA, the investigation area was defined as the notified area (shown on Figure 1) and downgradient features that may be impacted by off-site migration of contaminants from the notified area. Specifically these features included several surface water features further down gradient comprising a small ephemeral dam, a larger semi-permanent dam and Swamp Creek. Within the notified area are two areas of potentially impacted vegetation and a leachate impacted groundwater plume. The groundwater plume is understood to have originated from the north-east corner of the Alcan Mound and extends for approximately 250 m into the buffer zone (*Figure 2.2)*.

Vegetation dieback was apparent at two locations – the southern vegetation impact area and the northern vegetation impact area - where groundwater exfiltrates to the surface and surface flow of leachate impacted water occurs after heavy rainfall. Dead vegetation in these two areas was removed by Alcan in 2008 and the areas currently consist of a mosaic of grasses and bare soil. The remainder of the investigation area within the buffer zone comprises undeveloped bushland with thick vegetation crossed by unsealed vehicle tracks used to access monitoring wells and act as firebreaks.

2.3 Environmental Setting

The Hydro smelter includes the smelter facility (60 ha) and a buffer zone of approximately 2500 ha. The buffer zone consists of areas of remnant native vegetation, farmland and wetlands. Information pertaining to the local ecology is based on EIA reports prepared for the various development stages of the smelter (e.g. *Croft & Associates 1980*) supplemented with additional information obtained from online biodiversity databases managed by State and Commonwealth government agencies. Hydro also conducts routine sampling and survey of terrestrial species.

2.3.1 Topography

The local topography ranges from 8 m AHD on the eastern margin adjacent to Swamp Creek to 20 m AHD on the western boundary of the smelter, with typically gentle to moderate slopes across the intervening area (*Croft & Associates 1980*). The investigation area is located on low lying, relatively flat land that straddles the central eastern portion of the smelter site and the eastern buffer zone. The natural gradient slopes down in a north-easterly direction. The Alcan Mound consists of a clay-capped hill approximately 130 m by 160 m, with steep sides and a maximum elevation of 25 m AHD.

2.3.2 Hydrology

Surface water runoff from the smelter site is directed to a number of 'surge ponds'. The East Surge Pond is located to the north of the Alcan Mound on the eastern boundary of the smelter (*Figure 2.2*) and receives surface water runoff from the smelter site via an open channel. Excess water from the East Surge Pond is pumped to the North Surge Pond and/or the North Boundary Dam where water is discharged under licence to an irrigation area within the buffer zone. All of the surface water ponds and dams were constructed by excavation into the residual clay underlying weathered bedrock.

Within the buffer zone, surface water is distributed via infiltration into sandy soils, with some overland flow occurring. In the investigation area, excess surface water flows through natural depressions to Swamp Creek, which is the closest 'natural' surface water receptor to the Alcan Mound. Swamp Creek flows north and discharges into Wentworth Swamp approximately 2 km north of the smelter. Water from the Wentworth Swamp eventually discharges to the Hunter River near Maitland, approximately 15 km north-east of the smelter.

The creek and swamp system are within the Fishery Creek Catchment, where declining stream water quality and a reduction in diversity of native plants and animals has occurred due to human population growth and development pressures within the catchment over the last ten years.

2.3.3 Geology

According to the Geological Series Sheet 9312 (*DMR 1993*), the regional geology at the site comprises alluvial sediments of Quaternary age associated with the erosional and depositional environments of the Hunter River. The sediments include point bar, levee, overbank and alluvial terrace deposits, which are highly variable both horizontally and vertically and show extensive inter-fingering and inter-lensing. The alluvial sediments are underlain by siltstone, marl and minor sandstone from the Permian aged Rutherford Formation (Dalwood Group) in the Sydney Basin.

The smelter is located within the Hexham and Hunter land systems, which are characterized by freshwater swamps and underlain by dark sandy and sandy-clay soils that can be high in organic matter. Soils vary greatly in texture and consistency from sands to clayey soils of medium to high plasticity. Profiles are generally indicative of high water tables and water logged ground conditions (*Croft & Associates 1980*). The variable and complex nature of the sedimentary layers is a result of the deposition of the sediments in an alluvial environment with a meandering river system migrating across the historical flood plain.

2.3.4 Hydrogeology

Regional groundwater follows topography flowing north-east towards Swamp Creek although the complexity of the system likely results in discontinuities occurring within the flow pathways. Groundwater aquifers are present within both bedrock and unconsolidated sediments. The topography and the presence of surface water bodies such as Swamp Creek and Wentworth Swamp are expected to influence the regional groundwater flow regime.

Seventeen licensed groundwater abstractions (bores) are located within the smelter's buffer zone (Office of Industry and Investment, NSW), although there are no licensed groundwater bores within 2 km of the investigation area. It is understood that the bores were installed for monitoring purposes, not for stock watering or domestic water use.

Groundwater aquifers in the immediate vicinity of the notified area comprise near-surface aquifers within a complex system of relict braided alluvial channels. One such channel is present beneath the Alcan Mound and trends north-east extending to depths of between 0.6 and 3.2 m below ground surface (bgs). The presence of local topographical changes and lenses of lower permeability strata within the geological sequence results in the discharge of shallow groundwater from this aquifer to surface water in areas along the channel path. These seep zones form localised areas of overland surface water flow, such as those found in the two vegetation impact areas.

The presence of a semi-continuous clay aquitard has been identified in most locations where investigation drilling has continued to depth. Sand lenses are identified beneath the clay aquitard extending to at least 15 m bgs and it is likely that these sand lenses also form part of a relict braided alluvial system and that the clay aquitard is remnant of a period of floodplain or swamp environment. The clay aquitard acts to mitigate the vertical and horizontal movement of groundwater from the shallow relict channel systems.

2.3.5 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 surge ponds are not included in this assessment as their main purpose is for the on-site management of storm water. The surface water features of interest in this risk assessment include:

- Ephemeral soaks that occur in areas where the water table intersects the ground surface. The most notable areas within the investigation area correlate with the two vegetation impact areas where leachate contaminated groundwater surfaces. Surface water within these soaks is only apparent after significant rainfall.
- Overland drainage lines drain surface water down gradient from the soaks towards the dams and Swamp Creek. The main flow line aligns with a vehicle access track that divides the northern and southern vegetation areas, with ephemeral water flow occurring in an easterly direction towards the small ephemeral dam. Surface water within these drainage lines is only apparent after significant rainfall.
- A small ephemeral dam is located near the motorcycle track property boundary where a fence line runs north-south beside a vehicle track. The track is raised above the level of the dam (thus creating the dam wall) and a culvert (pipe) runs in an easterly direction under the track to drain water from the ephemeral dam into a gully and towards the semi-permanent dam. The approximate maximal dimensions of the ephemeral dam are 10 m x 5 m. Surface water is only apparent within this dam after significant rainfall.
- A 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.

- Swamp Creek runs roughly north-south along the boundary between the vegetated buffer zone to the west and the predominantly cleared agricultural land to the east. In its natural state the creek would be considered ephemeral; however, treated effluent is discharged directly into Swamp Creek from the Kurri Kurri Wastewater Treatment Works located 2.5 km upstream from the investigation area and diffuse runoff occurs from surrounding agricultural and urban areas. Swamp Creek varies in width but is up to 10 m wide within the investigation area. Water depth is unknown. In addition to the sampling locations at and downstream of the likely locations for the inflow of leachate impacted surface water into Swamp Creek, two 'Reference" locations were sampled upstream of the potential impact area.

Due to the highly ephemeral nature of the soaks, overland drainage lines and the small dam near the motorcycle track, these features are not expected to support aquatic invertebrates or fish species, and are unlikely to provide a reliable source of water for other wildlife species. In contrast, the semi-permanent dam perched above Swamp Creek is likely to support a range of aquatic invertebrate species, fish and water plants. Furthermore, wildlife species such as birds and mammals are likely to utilise dam water for drinking, and waterfowl are known to occur on the dam.

Similarly, Swamp Creek would provide a reliable source of water for a range of terrestrial species (including livestock) and is known to support aquatic plant species, invertebrates, fish and waterfowl.

2.3.6 Terrestrial Environment

Vegetation

Various vegetation assemblages have been described for the smelter's buffer zone (*Croft & Associates 1980*, *Hydro 2007*). There is no evidence of old growth vegetation within the buffer zone and most areas have been highly disturbed in the past through clearing, easements for overhead power lines, vehicle access tracks, and regular fires. Blocks of native vegetation, mainly north and west of the smelter, are reported to be in good condition with relatively few introduced species, and retaining a large proportion of their natural biodiversity (*Hydro 2007*).

The main remnant vegetation community potentially occurring within the investigation area is the *Kurri Sand Swamp Woodland* which is listed as an Endangered Ecological Community (EEC) in Schedule 3 of the *Threatened Species Conservation Act, 1995* (TSC Act). This community consists of a highly variable vegetation type mostly occurring on sandy soils and comprising a number of combinations of canopy and understorey species (*Bell 2004*). Canopy species include *Angophora bakeri, Corymbia gummifera, Eucalyptus agglomerata, Eucalyptus resinifera, Eucalyptus parramattensis subsp. decadens, Eucalyptus fibrosa, Eucalyptus punctata, Eucalyptus racemosa,* and *Eucalyptus capitellata*. Scrub and heath variants are also present, where a stunted and widely spaced canopy of trees occurs (*Bell 2004*).

A second EEC - *River-flat Eucalypt Forest on Coastal Floodplains* – may occur as a thin strip of vegetation along the banks of Swamp Creek. River-flat eucalypt forest is a tall mixed open forest to woodland occurring on river flats and terraces in the central to upper parts of coastal floodplains and is distinguished from other floodplain EECs by its dominance of either a mixed or single species eucalypt tree layer (including *Angophoras*), with few she-oak (*Casuarina*) or swamp mahogany (*Eucalyptus robusta*) trees, and a prominent groundcover of soft leaved herbs and grasses (*DECC 2007*).

A third EEC – *Freshwater Wetlands on Costal Floodplains* – includes the Wentworth Swamp area. This EEC is associated with periodic, semi-permanent or permanent inundation by freshwater, although there may be minor saline influence in some wetlands. Meadows of grasses, sedges and rushes occur where submersion is not prolonged, while aquatic herbs dominate where semi-permanent or permanent standing water is present. Under the influence of saline water tall reeds and rushes dominate. The boundaries of this EEC are dynamic, and vary greatly depending on rain and other climatic factors (*DECC 2008*).

Fire access vehicle tracks run throughout the buffer zone and the Loxford Park Junior Raceway (a sealed motorcycle racing track), which is located approximately 350 m east of the Alcan Mound and directly south of the semi-permanent dam adjacent to Swamp Creek. An ephemeral creek meanders along the northern boundary of the racing track and feeds into the southern end of the semi-permanent dam.

The area east of Swamp Creek and east of the Wentworth Swamp consists of cleared farmland for cattle grazing (Wangara Property). Woodland/forest vegetation and areas of Wentworth Swamp on Hydro-owned land have been fenced to prevent livestock from accessing these areas. This fencing aims to promote natural regeneration of native plant species.

Wildlife

The most recent comprehensive fauna survey conducted within the Hydro buffer area was conducted in 2004 (*Hydro 2004*). Fish, amphibians, reptiles, birds and mammals were reported.

The Hydro property is located within the Hunter River drainage basin. Fish species which have been recorded from the Hunter River Drainage Basin (*Harris and Gerhke 1997*) include: long-finned eel (*Anguilla reinhardtii*), striped mullet (*Mugil cephalus*), freshwater mullet (*Myxus petardi*), bullrout (*Notesthes robusta*), mountain galaxias (*Galaxias olidus*), flathead gudgeon (*Philypnodon grandiceps*), dwarf flathead gudgeon (*Philypnodon sp. 1*), striped gudgeon (*Gobiomorphus australis*), freshwater herring (*Potamalosa richmondia*), Cox's gudgeon (*Gobiomorphus coxii*), Australian smelt (*Retropinna semoni*), sprat (*Herklotsichthys castelnaui*), freshwater catfish (*Tandanus tandanus*), Australian bass (*Macquaria novemaculeata*). Three introduced fish species - goldfish (*Carassius auratus*), mosquito fish (*Gambusia holbrooki*) and common carp (*Cyprinus carpio*) - are also known to occur within the Hunter River drainage basin.

There is no current information regarding the presence of specific fish species within the investigation area.

Fourteen amphibians were recorded during surveys (*Hydro 2004*), namely the common eastern froglet (*Crinia signifera*), eastern banjo frog (*Limnodynastes dumerilii*), brown-striped frog (*Limnodynastes peronii*), spotted grass frog (*Limnodynastes tasmaniensis*), ornate burrowing frog (*Limnodynastes ornatus*), bleating tree frog (*Litoria dentata*), green reed frog (*Litoria fallax*), brown toadlet (*Pseudophryne bibronii*), smooth toadlet (*Uperoleia laevigata*), eastern dwarf tree frog (*Litoria caerulea*), greenthighed frog (*Litoria brevipalmata*), broad-palmed frog (*Litoria latopalmata*), Peron's tree frog (*Litoria peronii*) and the leaf-green tree frog (*Litoria phyllochroa*). Many of the amphibian species were recorded in a variety of habitat types. Some of these species are expected to occur within the investigation area due to the presence of permanent or semi-permanent surface water features.

Ten reptile species were recorded during surveys in 2004 (*Hydro 2004*), namely the eastern snake-necked turtle (*Chelodina longicollis*), lace monitor (*Varanus varius*), jacky lizard (*Amphibolurus muricatus*), eastern water dragon (*Physignathus lesueurii ssp. lesueurii*), southern rainbow skink (*Carlia tetradactyla*), heath monitor (*Varanus rosenbergi*), copper-tailed skink (*Ctenotus taeniolatus*), blackish blind snake (*Ramphotylphlops nigrescens*), red-bellied black snake (*Pseudechis porphyriacus*) and yellow-faced whip snake (*Demansia psammophis*). All reptiles recorded were either uncommon or recorded on one occasion only. Some of these species may occur within the investigation area.

Twenty-six native mammal species were recorded during fauna surveys (*Hydro 2004*). Many of the mammals recorded were bats, comprising 11 of the 26 mammal species recorded. A number of the bat species roost in caves (eg. little bentwing bat [*Miniopterus australis*] and southern myotis [*Myotis macropus*]), while others roost in tree hollows (eg. Gould's wattled bat [*Chalinolobus gouldii*], chocolate wattled bat [*Chalinolobus morio*] and little forest bat [*Vespadelus vulturnus*]).

Other native mammal species recorded include the common brushtail possum (*Trichosurus vulpecular*), eastern grey kangaroo (*Macropus giganteus*), rednecked wallaby (*Macropus rufogriseus*), swamp wallaby (*Wallabia bicolour*), short-beaked echidna (*Tachyglossus aculeatus*), common ringtail possum (*Pseudocheirus peregrinus*), brown antechinus (*Antechinus stuartii*), common dunnart (*Sminthopsis murina*), common wombat (*Vombatus ursinus*), sugar glider (*Petaurus breviceps*) and feathertail glider (*Acrobates pygmaeus*) (*Hydro 2004*). Some of these species are expected to occur within the investigation area at times.

A total of 68 to 95 bird species have been reported for the buffer zone during annual avifauna surveys conducted between 2006 and 2009. During November 2009, 92 native bird species – 25 waterbirds, three raptors and 64 woodland or forest birds – and three introduced species were recorded. None of the observed species were listed as threatened under the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999*, and only one species – the Grey-crowned Babbler (*Pomatostomus temporalis temporalis*) – is listed under the NSW TSC Act.

2.3.7 Introduced Pests

Hydro's current Property Management Plan (PMP) for the smelter includes management of introduced pests on Hydro property. Survey records for introduced pests include eleven terrestrial weed species (eg. lantana, blackberry, pampas grass), two aquatic weed species (eg. *Salvinia* and water hyacinth) and feral animals (eg. wild dogs, foxes, cats, pigs, rabbits). European carp (*Cyprinus carpio*) have also been recorded in the permanent waterways such as Wentworth Swamp and Swamp Creek. Some of these introduced species have the potential to cause degradation of habitats through intensive grazing and foraging, and by predation of and competition with native species.

Hydro has implemented a variety of pest management measures to help mitigate the effects of pest species, including a poison bait program for wild dogs and foxes, and herbicide spraying for the control of terrestrial and aquatic plants.

2.4 Tier 1 (Screening Level) ERA Findings

A Tier 1 (Screening Level) ERA was undertaken as part of the ESA, and compared on-site environmental contamination data with existing generic trigger values for soil and surface water quality (*ENVIRON 2012*). A summary of those findings are provided below.

A leachate-impacted plume was identified within a sand lens approximately 50 m to 100 m wide and extending approximately 250 m to the north-east of the Alcan Mound. Exfiltration of the plume has resulted in visible impacts to vegetation in two areas – south and north vegetation impact areas. Historical data indicated that fluoride concentrations in the leachate plume have been reducing since capping of the Alcan Mound in 1995. Consistent with this trend, fluoride concentrations in the leachate plume from the two rounds of sampling completed by ENVIRON (*2012*) were less than concentrations reported in July 2010.

The investigations indicated that exfiltration of the plume to the ground surface has not resulted in cyanide contamination in shallow soils. Fluoride concentrations within soil exceeded the preliminary screening criteria for agricultural use and the semi-permanent dam located down gradient of the plume (up gradient of Swamp Creek) appears to be collecting and containing water with an elevated fluoride concentration. Fluoride concentrations within Swamp Creek are at ‘background levels’ upstream of the smelter and are slightly elevated downstream.

An evaluation of potential ecological receptors identified that exposure pathways are likely to exist for some populations although the risk to receptors from fluoride was unknown. Other contaminants of potential concern (COPCs) that could present a risk to ecological receptors were identified as aluminium, cyanide and the high electrical conductivity of the leachate. Concentrations of other metals, VOCs, SVOCs and phenols were generally not elevated.

2.4.1 Soil

2.4.1.1 Soil Assessment Criteria

For the purposes of the Tier 1 (Screening Level) ERA (SLERA), the criteria proposed for the assessment of soil contamination were sourced from the following references:

- NSW DEC (*2006*) Guidelines for the NSW Site Auditor Scheme (Second Edition); and
- NEPC (*1999*) National Environmental Protection (Assessment of Site Contamination) Measure (NEPM).

These references provide ecological-based investigation levels (EILs) for various land uses, including:

- ‘Standard’ residential with gardens and accessible soil (home-grown produce contributing 10% of fruit and vegetable intake; no poultry);
- Residential with minimal access to soil including high rise apartments and flats;
- Parks, recreational open space, playing fields including secondary schools;
- Commercial or industrial.

Because the two vegetation impact areas are located within the buffer zone amongst remnant native vegetation and in an area where there is no active human or agricultural use, the NEPC (1999) or NSWDEC (2006) guidelines for the protection of plant communities were considered the most representative and were adopted for those COPECs where guidelines were available.

Neither the NEPM nor NSW DEC provide soil criteria for fluoride, aluminium or sodium and no phototoxic based criteria were available for cyanide. Consequently, international guidelines were reviewed to provide preliminary screening criteria for the notified area. Where available, agricultural criteria were used and where agricultural criteria were not provided, the next most appropriate criteria were selected.

Tables 2.1, 2.2 and *2.3* present available soil assessment criteria for fluoride, aluminium and cyanide, respectively. Soil criteria were selected from relevant US, Dutch, Canadian and Australian guidelines. No Australian or international guidelines were identified for sodium in soil.

A summary of the adopted preliminary screening criteria for COPECs in soil within the investigation area is presented in *Table 2.4*. Australian guideline criteria were used as a preference (where available) and in their absence, the most conservative international criteria were used.

2.4.1.2 Soil Screening Results

Soil analysis results from the southern and northern vegetation impact areas are presented in *Table 2.5*. The soil results indicate the following:

- pH range between 9.6 and 10.8 pH units and is consistent throughout the top 0.4 m of the soil profile;
- Total cyanide concentrations did not exceed the Australian preliminary health screening criteria of 500 mg/kg, concentrations decreased with depth;
- Soluble fluoride concentrations marginally exceeded the Canadian preliminary screening criteria for agricultural use of 200 mg/kg in four of the ten samples. These four samples were all from 0.0-0.1 m bgs. Soluble fluoride concentrations decrease with depth and were between 50 and 66% of the total fluoride concentration;
- Preliminary evaluation of the vertical distribution of fluoride in the soil profile found that total and soluble fluoride concentrations decreased with by 65% to 80% with increasing depth at three of the five sample locations. The results indicate that fluoride is likely to be concentrated near the surface.

2.4.2 Groundwater and Surface Water

2.4.2.1 Groundwater and Surface Water Assessment Criteria

For the purposes of the Tier 1 (Screening Level) ERA, the criteria proposed for the assessment of groundwater and surface water contamination were sourced from the following references:

- Guidelines for the Assessment and Management of Groundwater Contamination, NSW (*DEC 2007*); and

- Australian and New Zealand Guidelines for Fresh and Marine Water Quality (*ANZECC 2000*)

In accordance with DEC (*2007*), the assessment of groundwater quality included a review of beneficial uses of groundwater and surface water down gradient of the notified area. The closest surface water receptors to the groundwater exfiltration zone are a small ephemeral dam near the motorcycle track and the large semi-permanent dam further down gradient on the west bank of Swamp Creek, approximately 400 m and 500 m to the north-east of the Alcan Mound, respectively. Under peak flow conditions, water would drain from the ephemeral dam into the semi-permanent dam and then into Swamp Creek. Surface water within Swamp Creek was measured as neutral, ranging between pH 7.0 and 7.8 with a conductivity range of 626 to 1520 µS/cm, which is indicative of a freshwater system.

Water level gauging confirmed the groundwater flow follows the topography in a north-east direction towards the ephemeral dam, the semi-permanent dam and Swamp Creek. The only potential beneficial uses of groundwater down gradient of the investigation area are for the support of aquatic ecology within the semi-permanent dam, Swamp Creek and Wentworth Swamp, and for water extraction from Swamp Creek which may be used for stock watering and/ or irrigation. Based on the review of potential beneficial uses of groundwater and surface water, the criteria for protection of aquatic ecosystems, irrigation and stock watering were used during the Tier 1 (Screening Level) ERA.

The ANZECC (*2000*) investigation levels are considered applicable for the protection of aquatic ecosystems on receiving waters. ANZECC (*2000*) advocates a site-specific approach to developing guideline trigger values based on such factors as local biological effects data and the current levels of disturbance of the ecosystem. The guidelines present ‘low risk trigger values’ which are defined as concentrations of key performance parameters below which there is a low risk of adverse biological effects. If these trigger values are exceeded, then further action is required which may include further site-specific investigations to assess potential contamination or management and remedial actions. Low risk trigger values are presented in Table 3.4.1 of ANZECC (*2000*) for the protection of 80-99% of species in fresh and marine waters, with trigger values depending on the health of the receiving waters. Results were compared against trigger values for the protection of 95% of freshwater species since this level of protection was deemed acceptable considering the existing impact of human activities within the catchment.

A guideline for fluoride that is protective of the environment has not been developed for Australia. Anecdotal information indicates that 5 mg/L has been ‘regulator-approved’ and adopted as a trigger concentration for fluoride in groundwater at a nearby aluminium smelter. This guideline value was adopted in the screening level evaluation; however, its applicability for the investigation area requires further consideration.

A summary of the assessment criteria for surface water is provided in *Table 2.6* and a summary of the adopted preliminary screening criteria for COPECs in surface water within the investigation area is presented in *Table 2.7*. The most conservative criteria for the protection of aquatic ecosystems, irrigation or stock watering were used.

2.4.2.2 Surface Water Results

Surface water samples were collected from the southern and northern vegetation impact areas after rainfall, from two dams down gradient of the impact areas and from five locations in Swamp Creek (*Figure 2.3*). Two of the five Swamp Creek locations were upstream from the investigation area and outside the influence of the Alcan Mound run-off. These two locations (SW1 and SW2) were designated as Reference locations for the purpose of assessing potential water quality impacts associated with the leachate contaminated run-off. Surface water results are presented in *Table 2.8*.

The surface water results indicated the following:

- (DZ2, 48 mg/L), with the next highest concentration in water collected from the ephemeral dam (SW8, 9.5 mg/L) and the semi-permanent dam (SW6, 1.7 – 2 mg/L). Aluminium concentrations in all samples from all sites, including those upstream of the investigation area, exceeded the criteria for the protection of 95% of aquatic ecosystems of 0.055 mg/L (*ANZECC 2000*) indicating a high natural background of aluminium.
- Fluoride concentrations varied across the sampling area with the highest concentration measured in surface water collected from the southern vegetation impact area (DZ1, 350 mg/L). The next highest F- concentrations were measured in samples from the ephemeral dam (SW8, 91 mg/L), the northern vegetation impact area (DZ2, 45 mg/L) and the semi-permanent dam (SW3, 18 – 21 mg/L). Fluoride concentrations were significantly less within Swamp Creek immediately below the semi-permanent dam (SW4, 1.5 – 1.6 mg/L) but, interestingly, were between 0.59 and 1.2 mg/L at the notified area.
- Fluoride concentrations exceed the most conservative guideline (irrigation) of 1 mg/L at both vegetation impact areas and at both the ephemeral dam (SW8) and the semi-permanent dam (SW3) and in Swamp Creek at SW4 and SW6.
- Free cyanide concentrations are also highest in the southern vegetation impact area (DZ1, 6.1 mg/L), with next highest concentration was evident at the ephemeral dam (SW8, 0.034 mg/L). Free cyanide was not detected in water samples from any of the other sites. The reported free cyanide concentrations at DZ1 and SW8 exceed the screening criteria for the protection of 95% of aquatic ecosystems.
- pH was highest within water samples from the southern vegetation impact area (DZ1, 9.7), with the next highest readings in samples from the ephemeral dam (SW8, pH9.1) and the northern vegetation impact area (DZ2, pH8.8). pH values for all other sites were between 5.9 and 8.1, which are typically within the expected range for lowland river pH values (6.5 to 8 pH units, *ANZECC 2000*).
- The pH and colour of the exfiltrated groundwater in the two vegetation impact areas was similar to that of the leachate impacted groundwater, which was brown in colour with a pH of between 8.8 and 9.7.
- Electrical conductivity was also highest in the water sample from the southern vegetation impact area (DZ1, 15,000 µS/cm), with the next highest recordings in the samples from the ephemeral dam (SW8, 5400 µS/cm), one of the upstream sites in Swamp Creek (SW2, 5300 µS/cm) and the sample from the northern vegetation impact area (DZ2, 1900 µS/cm). Electrical conductivity readings from all other sites were below 1500 µS/cm) which is indicative of freshwater.
- Water hardness (derived from Ca2+ and Mg2+ concentrations) was classified as high (between 120 and 180 mg CaCO3/L) for all samples from Swamp Creek, including the two upstream reference samples. Water hardness was classified as soft (<60 mg

CaCO3/L) to moderately soft (between 60 and 120 mg CaCO3/L) for all samples from the vegetation impacts areas, the ephemeral dam and the semi-permanent dam. Ecotoxicity of fluoride is dependent on the degree of water hardness with harder water providing a buffer from fluoride toxicity due to formation of calcium and magnesium precipitates.

2.4.3 Conceptual Site Model – Tier 1 (Screening Level) ERA

The shallow nature of the semi-continuous sand aquifer results in the exfiltration of leachate impacted groundwater within topographically low areas of the notified area and following high rainfall events. The impacts of exfiltration are observed on the eastern edge of the plume where dieback of vegetation has occurred (in the southern and northern vegetation impact areas). Brown coloured seepage was observed and evaporation of exfiltrated groundwater has left a white salt crust on surface soils in this area. The high electrical conductivity of the exfiltrated groundwater (up to 15,000 µs/cm) exceeds the limit (12,200 µs/cm) at which conditions are generally too saline for plant growth according to irrigation guidelines (*ANZECC 2000*).

Fluoride, cyanide and aluminium concentrations in the impacted aquifer exceed guidelines. ENVIRON notes there are no guidelines in Australia for fluoride for the protection of aquatic ecosystems, the environment or human health. As fluoride is the main COPEC at the notified area, the lack of applicable guidelines for fluoride is a major data gap. Soil sampling within the vegetation impact areas found soluble fluoride concentrations in surface soils (0-0.1 m bgs) above the preliminary screening criteria for agricultural use of 200 mg/kg. Concentrations of cyanide within the groundwater do not appear to have impacted surface soils, with cyanide concentrations in both vegetation impact areas well below the preliminary screening criteria.

Elevated fluoride concentration (18 mg/L) was detected in the semi-permanent dam located between the fluoride plume and Swamp Creek. Elevated fluoride concentrations in the dam are potentially due to overland flow of exfiltrated groundwater from the source near the southern and northern vegetation impact areas.

Ecological receptors with the potential to be impacted by the leachate plume within the investigation area were identified as fauna (via ingestion and dermal contact with surface water and via dermal contact with soils). Livestock were also identified as potential receptors via ingestion of surface water from Swamp Creek.

The main conclusions from the Tier 1 (Screening Level) ERA were:

1. Fluoride is considered to be the main COPEC due to high concentrations in some surface water features within the investigation area, especially the ephemeral and semi-permanent dams up gradient of Swamp Creek. Fluoride concentrations within Swamp Creek immediately down gradient of the semi-permanent dam were slightly elevated above the irrigation criterion but were below the criteria for stock watering and the criterion adopted by a neighbouring aluminium smelter for protection of aquatic ecology.
2. Aluminium was detected at concentrations above the adopted screening criterion at all locations, including the reference sites upstream of the investigation area, and therefore it was concluded that the background levels of aluminium within the region are naturally high. However, aluminium concentrations in surface water samples from

within the investigation area were higher than the mean aluminium concentration in samples from the reference areas.

3. Free cyanide concentrations in surface water samples other than in ephemeral areas, were below the adopted screening criteria. Cyanide is not considered as a COPEC.
4. Electrical conductivity was below screening criteria within all freshwater features within the investigation area and is therefore not considered to be of concern.
5. The exposure pathway of surface water to terrestrial fauna is potentially complete although species may not drink contaminated surface water when other water sources are available.
6. The exposure pathway to off-site agriculture (farming downstream) is potentially complete due to stock watering from Swamp Creek. However, the concentration of fluoride in surface waters within Swamp Creek did not exceed the stock watering criterion of 2 mg/L.

3 Problem Formulation

3.1 Introduction

The overall objective of this Tier 2 ERA is to investigate the potential risk to ecological receptors within the investigation area from leachate contaminated groundwater, soil and / or surface water.

Groundwater is only available to plant species that have root systems extending into the water table. However, contaminants of potential ecological concern (COPECs) may become available to other species (flora and fauna) in areas where the groundwater table intersects the ground surface and groundwater becomes surface water. COPECs in surface waters may become an issue for ecological receptors that are dependent on water for survival, such as aquatic species or terrestrial species that utilise water sources for drinking and/or species that consume aquatic plants and animals.

The investigation area is related to two areas of vegetation dieback – the *north vegetation impact area* and *south vegetation impact area* - where contaminated groundwater exfiltrates to the ground surface and surface flow of leachate-impacted water occurs. Surface water features down gradient of those vegetation impact areas are potentially affected.

3.2 Conceptual Site Model

A conceptual site model (CSM) is a written description and visual representation of predicted relationships between ecological receptors and the stressors to which they may be exposed. This subsection provides a narrative description of the ecological CSM for the investigation area, and *Figure 3.1* provides a visual depiction of the ecological CSM. This CSM builds upon the information presented in the Tier 1 (Screening Level) ERA by providing discussion of the source, ecological receptors and exposure pathways.

Potential exposure pathways are evaluated for completeness based on whether the linkage between the source of the COPECs and each receptor is complete. A complete linkage must include a contaminant source, a transport mechanism, a receptor and an exposure mechanism (such as ingestion). If one or more of these elements is missing, the exposure pathway is incomplete and there is therefore no risk to the identified receptor. An exposure pathway can be either 'direct', where the receptor comes into direct contact with the affected environmental media (e.g. soil ingestion) or 'indirect', where exposure occurs at a different location or in a different medium than the source (e.g. aquatic sediments).

3.3 Contaminants of Potential Ecological Concern

Based on the information presented in ***Section 2*** and the conceptual site model (*Figure 2.1*), the following contaminants have been identified in excess of the threshold criteria and are considered to represent the COPECs within the investigation area:

- Fluoride (F^-)
- Aluminium (Al)

Other constituents within surface water and soils that may influence the local ecology are electrical conductivity and pH, which are elevated within the two vegetation impact areas but nowhere else and as such are almost certainly a direct reflection of the characteristics of the leachate contaminated groundwater in the immediate area where groundwater exfiltrates to ground surface. Electrical conductivity and pH are not considered within this ERA since levels are not outside the expected natural range for the majority of the water features examined but it is acknowledged that elevated electrical conductivity and/or pH may have influenced the declining health of vegetation within the two vegetation impact areas.

3.3.1 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*).

Numerous studies have indicated that soils rich in calcium carbonate or amorphous aluminium-hydroxides may bind inorganic fluoride by forming insoluble calcium fluoride or aluminium-fluoro-hydroxide complexes, thus limiting leaching from the soil and uptake by plants (CEPA 1994). The fate of inorganic fluorides released to soil also depends on their chemical form, rate of deposition, soil chemistry, and climate with some terrestrial plants accumulating inorganic fluorides following airborne deposition and uptake from the soil. Inorganic fluorides tend to accumulate preferentially in the skeletal tissues of vertebrates, exoskeletons of invertebrates, and cell walls of plants (*WHO 2002*).

Terrestrial Flora

Fluoride is strongly adsorbed by soils and occurs mostly in an insoluble form that is less available to plants and animals. Plant uptake of F^- via the roots is therefore relatively low and if uptake occurs, the F^- concentrations are often higher in the roots than in the shoots because of low mobility within the plant (*WHO 2002*). The transport and transformation of F^- in soil is driven by low pH and the formation of predominantly aluminium and calcium complexes.

Signs of inorganic F phytotoxicity (fluorosis) appear as chlorosis, necrosis and decreased growth rates (most noticeable in young plants), expanding tissues of broadleaf plants and elongating needles of conifers (*WHO 2002*).

Terrestrial Fauna

The effects of fluoride on wildlife are the same as those for people and livestock but the problem is more severe for predators with their greater need for unimpaired mobility and good dentition (*BCMoE 1995*). Wildlife exposed to high fluoride concentrations could suffer skeletal deformation and/or mottled teeth although slightly higher levels of fluoride could be tolerated by wildlife (and livestock) since the aesthetics of mottled teeth is not as important as function. Effects of F- on wildlife are focused on structural integrity of teeth and bone in terms of ability to forage and risk of broken bones. Lameness, dental disfigurement and tooth damage have been found in the vicinity of smelters.

Aquatic Flora

Fluoride is known to either inhibit or enhance the population growth of algae depending on fluoride concentration, exposure time and algal species (*Camargo 2003*). Hekman *et al.* (*1985*) examined the toxic effects of inorganic fluoride on six species of freshwater phytoplankton and found that five species showed no significant effects to 175 hours of exposure to fluoride concentrations of up to 50 mg/L. The sixth species exhibited growth and photosynthesis inhibition at fluoride concentrations between 25 and 50 mg/L. Rai *et al.* (*1998*) estimated a15 day EC_{50} value for the freshwater green alga, *Chlorella vulgaris*, as 380 mg/L at pH 6.8 and LeBlanc (1984) estimated 96 hour EC_{50} values based on growth inhibition as 123 mg/L for the freshwater blue-green alga, *Selenastrum capricornutum*.

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. Wang (1986) estimated a 96 hour EC_{50} value for common duckweed, *Lemna minor*, to be at least 60 mg/L. In terms of bioaccumulation, the fronds of the duckweed, *Spirodela polyrrhiza*, contained up to 918 µg F /g dry weight after exposure over seven days to 20 mg/L F^- but with no significant effect on chlorophyll and protein content (*Shirke & Chandra 1991*).

Aquatic Fauna

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*).

Fleiss (*2011*) plotted species sensitivity distributions (SSDs) for invertebrate acute and chronic F^- toxicity (LC_{50}). The lowest acute LC_{50} concentration was 10.5 mg/L (for a Mysid shrimp in seawater) and acute LC_{50} concentrations of between 11 and 100 mg/L were apparent for a variety of caddisfly larvae. For chronic exposures, the lowest LC_{50} concentration was 11.5 mg/L for a species of caddisfly in water with hardness of 40.2 mg $CaCO_3$/L at a temperature of 18°C (Fleiss 2011).

LeBlanc (*1980*) reported a 48h no observed effect concentration (NOEC) of 50 mg/L (at 23.2°C and 173 mg $CaCO_3$/L) and Kuhn *et al.* (1989) reported a 24h NOEC of 231 mg/L (at 20°C and 160 mg $CaCO_3$/L) for the water flea, *Daphnia magna*. In terms of chronic exposures, Dave (*1984*) calculated a fluoride safe concentration (for reproduction) of 4.40 mg/L in *D.magna* (at 20°C and 250 mg $CaCO_3$/L).

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*).

Fluoride toxicity varies with fish species but results from testing indicate that the rainbow trout, *Oncorhyncus mykiss*, is more sensitive to F^- than other freshwater fish species tested (*Camargo 2003*). The range of reported 96h LC_{50} for *O.mykiss* (acute exposures) is between 51 and 200 mg/L (at 12 - 15°C and 17 – 385 mg $CaCO_3$/L). On the basis of LC_{50} test results Pimental & Bulkley (*1983*) proposed fluoride safe concentrations for maximum chronic exposure levels for *O.mykiss* fry as 2.5 mg/L (at 17 mg $CaCO_3$/L) and 9.6 mg/L (at 385 mg $CaCO_3$/L).

Wild fish population are able to adapt physiologically and genetically to localised high fluoride concentrations, with healthy, growing populations of *O.mykiss* occurring in streams in Yellowstone National Park that have up to 14 mg/L of F^-.

Livestock

The majority of research into fluoride toxicity in vertebrates is based on captive sheep, cattle and deer. Dairy cattle appear to be the most sensitive livestock to fluoride toxicity since they have high food and water uptake rates and long productive lives which lead to maximal opportunity for fluoride to accumulate to harmful levels in the bones and teeth. Fluoride uptake is possible via vegetation, soil and drinking water, with tolerance levels for dairy cattle at 30 mg/kg of feed or 2.5 mg/L in drinking water (*BCMoE 1995*). Fluorosis has been observed in sheep and cattle and mottling of teeth in deer observed at 35 mg/kg diet dose. Symptoms of F- toxicity include emaciation, stiffness of joints, abnormal teeth and bones, lowered milk production and detrimental effects on reproductive capacity.

3.3.2 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*). The USEPA have adopted a policy whereby aluminium is identified as a COPEC only for those soils with a pH less than 5.5 (*USEPA 2003*).

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.

Terrestrial Flora

Plants differ in their ability to take up aluminium with some species able to immobilise aluminium at the root surface. Aluminium taken into the roots is not translocated to any great extent to the shoots (*Roy et al. 2000*). However, aluminium is considered to be available to plants only under conditions of low pH (<5.5).

Terrestrial Fauna

There have been few reliable studies that conclusively identify aluminium as a toxicant to terrestrial species. WHO (*1997*) states that no information has been reported regarding field effects of aluminium on terrestrial invertebrates and mentions just two studies of potential toxicity to birds with conflicting results for defective eggshell formation.

Aquatic Flora

Aluminium toxicity 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 example, the majority of 19 lake species exhibited complete growth inhibition at 200 µg/L at pH 5.5 (*WHO 1997*).

Aquatic Fauna

For aquatic invertebrates, LC50 values ranged from 480 µg/L (polychaete worm) to 59,600 mg/L (daphnia). Fish species exhibited 96 h LC50 values that ranged from 95 to 235,000 µg/L. Although the wide range of tolerances may in part relate to pH variability in test waters (*WHO 1997*).

Livestock

Very little information on toxicity of aluminium to livestock is reported although guideline criteria for water used for stock watering have been established in some countries, including Australia (*ANZECC 2000, BCMoE 2001*). Soil acidity accentuates the toxicity of aluminium to livestock and aluminium toxicity is reported as the main cause of low yields in agriculture as a result of rising soil acidity (*DAF 2013*).

3.4 Receptors and Exposure Pathways

Once COPECs are present in soil, surface water and sediment, a variety of organisms may be exposed to them via different exposure pathways. Exposed organisms are commonly referred to as receptors. A viable (complete) exposure pathway has five parts:

- a source of contaminants (e.g. the Alcan Mound);
- an environmental medium and transport mechanism (e.g. leachate contaminated surface water flowing down gradient);
- a point of exposure (e.g. the semi-permanent dam);
- a route of exposure (e.g. drinking contaminated water); and
- a population of receptors (e.g. kangaroos).

The exposure pathway is viable and potentially capable of causing unacceptable risks only when all five parts are present. Identification of receptors initially relies on the identification of functional groups or feeding ‘guilds’ that are representative of, or essential to, habitat function. Based on the environmental setting, the feeding guilds potentially exposed to COPECs via complete exposure pathways and their dominant exposure routes are:

- soil microbes (via direct contact with soil);
- terrestrial plants (via direct contact with soil);

- terrestrial fauna (via ingestion of drinking water);
- aquatic plants (via direct contact with surface water and/or sediment);
- aquatic invertebrates (via direct contact with surface water);
- fish (via gill exchange with surface water);
- aquatic birds (via ingestion of drinking water and aquatic species); and
- cattle (via ingestion of drinking water).

Although populations of herpetofauna (reptiles and amphibians) are valued ecological entities, the current state of the art techniques for risk assessment are insufficient to adequately incorporate herpetofauna in risk analysis with acceptable levels of uncertainty. Generalizations from fish (and aquatic invertebrates) are somewhat applicable to the herpetofauna receptor group, so that the risks to herpetofauna are estimated by using other receptors as surrogates.

Most healthy ecosystems support a large number of individual species representing a variety of feeding guilds. However, it is not feasible to complete risk calculations for all potentially exposed species. Moreover, such an effort would be duplicative because of the similarity of exposure patterns among closely related species and among those with similar feeding habits. For these reasons, a range of receptors of interest (ROIs) are selected to represent the different feeding guilds and their selection was primarily based on ecological relevance, potential for high exposure, toxicological sensitivity and expected presence in the investigation area.

Based on the CSM (*Figure 3.1*) and using the list of available flora and fauna species for the investigation area, either confirmed or expected, the main groups identified as potential ecological receptors of interest (ROIs) are:

- Soil microbes
- Terrestrial plants
- Aquatic plants
- Aquatic invertebrates
- Fish
- Birds
  - Forest species – eastern yellow robin (*Eopsaltria australis*)
  - Raptor – nankeen kestrel (*Falco cenchroides*)
  - Aquatic herbivore – Pacific black duck (*Anas superciliosa*)
  - Aquatic carnivore – white-faced heron (*Ardea novaehollandiae*)
- Terrestrial Mammals
  - small insectivorous bat - little forest bat (*V.vulturnus*)
  - small insectivore - brown antechinus (*A.stuartii*)
  - arboreal herbivore – brush-tailed possum (*T.vulpecula*)
  - large herbivore - eastern grey kangaroo (*M.giganteus*)

- Cattle

These ROIs are considered to be among the most highly exposed and ecotoxicologically sensitive (i.e. susceptible) of the species likely to inhabit or forage within the investigation area, so extrapolation of conclusions regarding these ROIs is assumed to be protective of other, less susceptible species.

The exposure pathways for fauna typically include oral exposure (eating and drinking), dermal exposure (absorption through the skin) and exposure through inhalation (breathing). However, dermal exposure is assumed to be negligible for birds and mammals since feathers and fur limit the contact of skin and contaminated media (*Sample & Suter 1994*). Furthermore, the focus for this risk assessment is on risks from contaminated surface water and therefore the main exposure pathway investigated for birds and mammals is via consumption of drinking water.

3.5 Endpoints

3.5.1 Assessment Endpoints

Assessment endpoints are the explicit expression of ecological entities (e.g., mammal populations) and attributes (e.g. reproductive ability) to be protected (*USEPA 1992, 1997*). The selection of assessment endpoints depends on knowledge about the receiving environment, chemicals released (including ecotoxicological properties and concentrations that cause adverse impacts), and the values that will drive risk management decision making. Assessment endpoints selected for evaluation in this ERA are:

- survival and reproduction of terrestrial plant and soil microbes;
- survival and reproduction of aquatic plants;
- aquatic invertebrate survival and growth;
- survival and reproduction of fish populations;
- survival and reproduction of bird populations; and
- survival and reproduction of terrestrial mammal populations.

As described by Barnthouse *et al.* (*2008*), “regulations, policies, directives, and guidance documents frequently discuss the need for ecological risk assessments to consider risks to populations, not simply to individual organisms or organism-level attributes. The reason for this is that, from a management perspective, the population-level attributes such as abundance, persistence, age composition, and genetic diversity are usually more relevant than are the health or persistence of individual organisms.”

The assessment endpoints listed above consider attributes that are tied to the population level attributes of abundance and persistence, in that they consider both survival and reproduction. Decreased survival will result in smaller numbers of individuals, decreasing the population of that receptor. Similarly, decreased reproduction can result in smaller numbers of individuals over time, also decreasing the population of that receptor. Decreased growth of individuals, on the other hand, is not directly related to population-level effects. Consequently, ecotoxicological studies on growth endpoints cannot be tied to population-level impacts.

3.5.2 Measurement Endpoints

Measurement endpoints are measurable ecological characteristics that are related to the valued characteristics chosen as the assessment endpoints and are measures of biological effects. The measurement endpoints become lines of evidence (LOE) that indicate the potential for risk to the ROIs. The selected measurement endpoints associated with each assessment endpoint are listed below.

- Terrestrial plants and soil microbes are evaluated based on one measurement endpoint, the measured concentrations of COPECs in surface soil in relation to effects-based benchmarks and concentrations reported in the literature for plants and microbes.
- Aquatic plants are evaluated based on one measurement endpoint, measured concentrations of COPECs in surface water in relation to effects-based benchmarks and concentrations reported in the literature for aquatic plants.
- Aquatic invertebrates are evaluated based on one measurement endpoint, measured concentrations of COPECs in surface water and sediment in relation to appropriate benchmarks and concentrations reported in the literature to be protective of invertebrates.
- Fish populations are evaluated based on one measurement endpoint, measured concentrations of dissolved COPECs in surface water in relation to appropriate surface water benchmarks and concentrations reported in literature to be protective of aquatic life.
- Bird populations are evaluated based on one measurement endpoint, comparison of modelled dietary intake of COPECs by four representative avian species to doses reported in the literature as toxicity reference value (TRV) thresholds for adverse effects on survival or reproduction ('bird hazard quotients').
- Mammal populations are evaluated based on one measurement endpoint, comparison of modelled dietary intake of COPECs by four representative mammalian species to doses reported in the literature as TRV thresholds for adverse effects on survival or reproduction ('mammal dose-based hazard quotients').
- Cattle are evaluated based on one measurement endpoint, comparison of modelled dietary intake of COPECs to doses reported in the literature as TRV thresholds for adverse effects on survival or reproduction ('cattle dose-based hazard quotients').

4 Exposure Assessment

Exposure assessment is the process of measuring or estimating the magnitude, frequency, and duration of ROI exposures to COPECs (*USEPA 2003*). The exposure assessment builds upon qualitative descriptions presented in the CSM in order to quantitatively estimate COPEC exposures for each ROI. The exposure assessment reflects the exposures likely to occur in the ROIs evaluated, exposure routes specific to the investigation area and the selected measurement endpoints.

In all cases, the exposures are based on calculation of hazard quotients (HQs) which are defined as the ratio of the estimated exposure of a receptor at the site to a "benchmark" exposure that is believed to be without significant risk of unacceptable adverse effect:

HQ = Exposure / Benchmark

If the HQ value is less than or equal to 1, the risk of adverse effects in the exposed ROI is deemed to be low and acceptable. If the HQ is greater than 1, the risk of adverse effects in the ROI is of potential concern, and the probability and/or severity of effect increases with increasing HQ values.

Exposure is based on the COPEC concentration in an environmental medium (water, sediment, soil) with respect to exposure routes such as direct contact with contaminated media, or ingestion of COPECs in food or drinking water. Other forms of exposure, such as inhalation and dermal absorption are possible but, in this instance, have not been investigated since exposure via these routes is expected to be minimal due to the nature of the contaminants and the ROIs.

Concentration values in soil, sediment and water are measured directly, while exposure to COPECs in dietary items (including drinking water) are predicted using calculations of dose for each ROI based on a variety of factors, including daily ingestion rates, body size, home ranges, etc. These criteria are sourced from available literature for the specific ROI or for species that are similar in size, habitat and trophic level (proxy species). Food chain input variables and receptor parameters are provided in *Table 4.1* for birds, mammals and cattle.

When a receptor is exposed by more than one pathway (e.g. drinking water and food), the HQs for each exposure pathway are added to provide a “Total HQ” for each COPEC. In accordance with USEPA guidance, HQs for different chemicals are not added unless reliable data are available to indicate that the two (or more) chemicals act on the same target tissue by the same mode of action.

4.1 Exposure Assessment for Terrestrial Plants and Soil Microbes

Exposures for the terrestrial plant and soil microbe community are evaluated based on concentrations of COPECs in soil and surface water (for plants only). Within the investigation area, exposure of terrestrial plant and soil microbe species is restricted to the two vegetation investigation areas where groundwater exfiltrates to surface during periods of high rainfall and soil may retain COPECs. Measurements at each sampling station are evaluated individually whereby each soil sampling station is treated as a discrete exposure area or exposure unit. This practice reflects the relative immobility of soil microbes and facilitates the spatial analysis of soil and water exposures.

4.2 Exposure Assessment for Aquatic Plants

Exposures for the aquatic plants are evaluated based on concentrations of COPECs in surface water. Within the investigation area, aquatic plants are likely to occur only in the semi-permanent dam and Swamp Creek. The COPEC concentrations within these two surface water features were used for individual exposure assessments for aquatic plants at each location.

4.3 Exposure Assessment for Aquatic Invertebrates

Exposures for the aquatic invertebrates are evaluated based on concentrations of COPECs in surface water. Within the investigation area, aquatic invertebrates are likely to occur only in the semi-permanent dam and Swamp Creek. The COPEC concentrations within these two surface water features were used for individual exposure assessments for aquatic invertebrates at each location.

4.4 Exposure Assessment for Fish Populations

Exposures for the fish populations are evaluated based on concentrations of COPECs in surface water. Within the investigation area, fish are likely to occur only in the semi-permanent dam and Swamp Creek. The COPEC concentrations within these two surface water features were used for individual exposure assessments for fish at each location.

4.5 Exposure Assessment for Birds and Mammal Populations

Exposures for birds and mammals are estimated from concentrations of COPECs in surface water. For most wildlife ROIs, measurement endpoints focus on the comparison of estimates of dose (in units of mg/kg/day) to published dose-based toxicity reference values (TRVs).

TRVs for Australian ROIs are lacking and therefore the exposure assessment for birds and mammals is based on published wildlife toxicity benchmarks from the US, using data for species that, as far as possible, are from similar taxonomic groups, trophic levels and body size. The selection of suitable proxy species is restricted by the availability of benchmark data and it is acknowledged that much of the “species-specific” US data are extrapolated from laboratory test animals. *Table 4.2* lists the species identified as ROIs for the investigation area and the proxy US species used for wildlife toxicity benchmarks.

Where appropriate, the total exposures for species are based on calculated COPEC doses in drinking water and food. Average daily food consumption rates are based on the proxy US species, as derived from published literature (*Sample et al. 1996*). Note however, that species-specific data for mean body sizes and daily water consumption rates are used for the Australian marsupial ROIs (antechinus, possum and kangaroo) since it has been suggested that marsupial water consumption is lower than for equivalent sized placental mammals (*Hume 1999*).

4.5.1 Exposure Scenarios

The exposure point concentrations (EPCs) reflect the long-term concentration of COPECs that the populations of wildlife ROIs contact throughout their lives as they live and forage within the study area.

The usual approach for calculating exposure scenarios is to define a realistic exposure scenario, and a reasonable worst case (RWC) exposure scenario. The realistic exposure scenario is based on mean COPEC concentrations and describes the more population-focused perspective for risk management decision making, whereas the RWC exposure scenario is based on maximum COPEC concentrations or the 95% upper confidence limit (UCL) of the mean (whichever is lower), and helps characterize the uncertainty in the overall analysis and risks posed to the most highly exposed individual organisms. In this instance, considering that there are typically only one or two analysis points for each of the exposure units, the maximum COPEC concentrations were routinely used to provide RWC exposure scenarios, and mean COPEC concentrations were used to define realistic exposure scenarios only where RWC risk was deemed to be unacceptable and where the mean COPEC concentration differed significantly from the maximum.

4.5.2 Exposure Units

Two main exposure units for drinking water are considered for birds and mammals – exposure from surface water contained within the semi-permanent dam and exposure from surface water within Swamp Creek. The ephemeral runoff from the vegetation impact areas and the small dam are not considered to be reliable water sources for terrestrial (or aquatic) species and, although exposure assessments are provided for these water sources, the reality is that species could not reliably obtain drinking water from those ephemeral sources throughout the year.

4.5.3 Dose Estimates

Oral exposure to COPECs occurs from a number of sources, including consumption of contaminated drinking water, consumption of contaminated food and ingestion of contaminated soil while foraging, eating or grooming. Soil ingestion is considered to be insignificant for the range of species being investigated and is not considered further. Furthermore, with the current curtailment of smelter operations, fallout of atmospheric fluoride onto plants in the investigation area is assumed to be zero and therefore fluoride content in the diet of herbivores (who generally consume new shoots and leaves) is expected to be negligible, and this pathway is not considered in the exposure assessment. The main food items within the investigation area that could potentially influence the daily dose of fluoride for the selected ROIs are fish which are considered in the exposure assessment for the white-faced heron only.

The total oral exposure experienced by white-faced heron in the investigation area therefore equals the sum of exposures from drinking water and fish in the diet.

$$Exposure\ = AUF\ \times \left[\frac{IR\ water\ x\ C\ water + IR\ food\ \times \sum(FIR\ food\ item\ \times C\ food\ item)}{BW}\right]$$

Where:

Exposure = Oral intake of COPEC in diet (mg/kg body weight/day)

AUF = Area Use Factor (percentage) (literature)

IR water = Ingestion rate of water (L of water/individual/day) (literature)

C water = Concentration of COPEC in water (mg/L water) (measured)

IR food = Ingestion rate of food (kg fresh weight of food/individual/day) (literature)

FIR food item = Fractional ingestion rate of food item (percentage) (literature)

C food item = Concentration of COPEC in a food item (mg/kg fresh weight) (calculated)

BW = Body Weight (kg) (literature)

For all other ROIs where the food-based intake of fluoride has not been assessed, the calculation of exposure is based on the following simplified formula:

$$Exposure = AUF \times \left[\frac{IR\ water\ x\ C\ water}{BW}\right]$$

Where:

Exposure = Oral intake of COPEC (mg/kg body weight/day)

AUF = Area Use Factor (percentage) (literature)

IR water = Ingestion rate of water (L of water/individual/day) (literature)

C water = Concentration of COPEC in water (mg/L water) (measured)

BW = Body Weight (kg) (literature)

The total daily intake (TDI) of COPECs for the wildlife ROIs via ingestion of drinking water is calculated by multiplying the constituent concentration in drinking water by the specie's daily water ingestion rate and dividing by the body weight of the animal. The assessment of food-based dose for the white-faced heron provides an estimated intake of constituents via food to the constituent concentration in fish consumed. The dietary component of fish is weighted by its relative contribution to the total diet (as a percentage). The concentration of COPECs in fish is estimated using COPEC concentrations in surface water and literature-derived bioaccumulation factors (BAFs). Species-specific water ingestion rates and body weights were obtained from published literature.

Absorption factors and area use factors (AUFs) are also a component of the TDI. A conservative default value of 1.0 is used as the absorption factor (the fraction of chemical ingested that is absorbed into the system). This assumption likely overestimates the TDIs, as laboratory toxicity tests often use highly available forms of the test chemical, whereas actual bioavailability under natural conditions is considerably lower. AUFs are the estimation of dose to account for the possibility that some wildlife ROIs may obtain some drinking water from outside of the investigation area. An AUF is the ratio of the area of potential exposure (e.g. pond area) divided by the species' home range.

4.6 Exposure Assessment for Cattle

The exposure assessment for cattle was based on a similar approach to that used for mammals and birds, whereby the TDI of COPECs was calculated for ingestion via drinking water. Cattle water ingestion rates and body weights were obtained from published literature. The only water body within the investigation area that is accessible to cattle is Swamp Creek.

5 Toxicity Assessment

The assessment of toxicity evaluates the potential for COPECs to cause adverse effects in ROIs and estimates the relationship between the extent of exposure and severity of effects. The effects assessment is the review and selection of toxicity reference values (TRVs) that are used to interpret the potential for adverse effects. TRVs are the literature-derived concentrations or doses, below which adverse effects are unlikely.

Described below are the methods used to characterize effects for each receptor group, as well as the outcomes of those analyses.

5.1 Terrestrial Plants and Soil Microbes

The effects assessment for terrestrial plants and soil microbes was focused on screening benchmarks that are specific for plants and microbes in relation to contaminated soils. Soil data for the investigation area do not include analytical results for aluminium. However, the USEPA have adopted a policy whereby aluminium is identified as a COPEC only for soils with a pH less than 5.5 (*USEPA 2003*) and since the pH of surface water samples collected within the vegetation impact areas had pH ranging from 8.8 to 9.7, the conditions are clearly unsuitable for mobilisation of aluminium from soil. Therefore, aluminium is not considered to be a COPEC in soils within the investigation area (*Table 5.3*).

In the absence of Australian benchmarks for soil toxicity, an alternative source of criteria is the USEPA's Eco-SSL data (*USEPA 2013*). However, Eco-SSL data is available for a limited number of contaminants only and no data are available for fluoride. The only available benchmark located for fluoride toxicity to terrestrial plants (200 mg/kg in soil is considered to be of low reliability since it is based on a single study (*Efroymson et al.1997a*). However, in the absence of reliable alternatives, this benchmark has been adopted for this assessment (*Table 5.3*).

Fluoride toxicity to US native soil microbial flora is provided by the Efroymson *et al.* (*1997b*) but with only two reported studies, there is very high variation between the results (LOEC values of 32 ppm and 5000 ppm). No data were located for fluoride toxicity to earthworms or other terrestrial invertebrates. The low reliability benchmark of 30 ppm was adopted for soil microbes in this assessment (*Table 5.3*).

5.2 Terrestrial Fauna – Birds and Mammals

Toxicity benchmarks are unavailable for most Australian species but are available for a range of North American terrestrial bird and mammal species (*Sample et al. 1996*). However, reliance on these benchmarks is deemed acceptable if using data for species that are taxonomically similar, with similar body size, habits and trophic levels to Australian species. In this assessment, toxicity data for appropriate US species were used for calculation of risk to a selection of Australian species known to occur within the investigation area. US-based toxicity data were supplemented with specific data on body sizes, home ranges and ingestion rates wherever Australian data were available.

No observed apparent effect level (NOAEL) TRVs are indicative of doses of constituents that have had no deleterious effects on a wildlife receptor. Lowest observed apparent effect level (LOAEL) TRVs are the minimum doses of constituents where deleterious effects are apparent. The LOAEL TRVs were used in this assessment as a realistic measure of effect. The TRVs for fluoride were all based on data derived from experimental research using fluoride as sodium fluoride (NaF) and TRVs for aluminium were all based on experimental data for aluminium chloride ($AlCl_3$). The adopted TRVs are provided in *Table 5.1*.

5.3 Aquatic Flora & Fauna – Plants, Invertebrates and Fish

Toxicity data for Australian aquatic species is limited for aluminium (one listed study in Markich *et al.* 2002) and non-existent for fluoride. However, 'conventional' US-based benchmarks are available for aluminium in relation to chronic toxicity to fish, daphnid invertebrates and aquatic plants (Suter & Tsao 1996). In addition, 'alternative benchmarks' are available for aluminium and fluoride in relation to chronic toxicity to fish and daphnid invertebrates (Suter & Tsao 1996). These benchmarks are invariably based on EC20 test data which indicate the highest tested concentration causing less than 20% reduction in the measured endpoint. Where multiple benchmarks are available, the most conservative benchmark was adopted, as shown in *Table 5.2*.

5.4 Livestock – Cattle

Toxicity benchmarks for cattle were derived using the Australian livestock drinking water criteria (ANZECC 2000). The livestock drinking water criteria (2 mg/L for fluoride and 5 mg/L for aluminium) were used as the upper limit to back calculate the acceptable contaminant dose for cows based on average weight and water consumption figures. The adopted benchmark doses were 1 mg/kg/day for aluminium and 0.4 mg/kg/day for fluoride. These benchmarks are considered to be conservative due to the criteria used for their derivation.

6 Risk Characterisation

Risk characterisation involves the integration of the exposure assessment and toxicity assessment to evaluate the likelihood, severity, and spatial distribution of predicted or observed effects. Risk characterisation is conducted for each of the measurement endpoints identified in *Section 3.5*.

Risk characterisation for all measurement endpoints involves mathematical comparison of exposure and effects estimates for each measurement endpoint. Exposure estimates that are below the relevant effects metric (i.e. surface water quality benchmark or TRV) indicate that adverse effects to a given ROI are unlikely. Exposure estimates that exceed the relevant effects metric indicate that further investigation is warranted to define the potential for adverse effects at the population level, as well as the spatial extent and severity of any such adverse effects (Barnthouse *et al.* 2008).

Evaluation of key uncertainties is an important element of the risk characterisation. Therefore, risk characterisation includes a discussion of the sources of uncertainty in the ERA and the effects of that uncertainty on the risk conclusions (i.e. whether each source of uncertainty is likely to lead to an overestimation or underestimation of the HQ). In many cases, unavoidable uncertainty in an ERA is balanced by purposefully conservative assumptions. Therefore, sources of conservatism in the ERA are also discussed.

Note that all assessment calculations are based on maximum COPEC concentrations rather than median values, therefore representing realistic worst case scenarios based on existing knowledge of COPECs within the investigation area.

6.1 Risk Characterisation for Terrestrial Plant and Microbial Communities

The evaluation of potential risks for terrestrial plants and soil microbes relies on a single line of evidence: comparison of COPEC concentrations in soils and exfiltrated groundwater to effects based benchmarks for plants and soil microbes. Location specific HQs are provided in *Table 6.1* for fluoride in soil and surface water in relation to soil microbes and terrestrial plants.

The only exposure units assessed for contaminated soils within the investigation area are the two vegetation impact areas (northern and southern) where leachate impacted groundwater periodically exfiltrates to the ground surface. These two areas were also assessed for potential exposure of receptors to contaminated surface water during exfiltration events. Due to the highly ephemeral nature of surface water in these exposure units, exposure of aquatic receptors was not assessed. In alignment with the current USEPA approach, aluminium was not included as a COPEC since soil pH was greater than 5.5.

HQ values for toxicity to terrestrial plants from fluoride in soil within the southern vegetation impact area varied between 0.29 and 1.48. Surface soil (less than 0.1 m deep) had the highest HQ values (1.13 and 1.48) whereas the two sub-surface soil samples from between 0.3 and 0.4 m depth had HQ values equal to or less than 1.

HQ values for toxicity to terrestrial plants from fluoride in soil within the northern vegetation impact area varied between 0.2 and 1.77. Surface soil (less than 0.1 m) in two of the three sampling locations had HQ values greater than 1 (1.30 and 1.77) whereas the third surface sample and all three sub-surface samples had HQ values less than 1.

These results indicate that the top 0.1 m of soil at sampling locations within the southern vegetation impact area (Locations DZ1-HA1 and DZ1-HA2) and within the southern half of the northern vegetation impact area (Locations DZ2-HA1 and DZ2-HA2) represent a potential risk to terrestrial plants from fluoride toxicity. However, the upper 0.1 m of soil is unlikely to be of significant value to large terrestrial plant species that have root systems extending down into the soil profile towards the water table and therefore fluoride would only be available in potentially toxic concentrations to shallow rooted species such as small shrubs and/or grasses.

HQ values for toxicity to soil microbes from fluoride in soil within the southern vegetation impact area varied between 1.93 and 9.87. Surface soil (less than 0.1 m deep) had the highest HQ values (7.53 and 9.87) compared to HQ values between 1.93 and 6.67 for sub-surface soils.

HQ values for toxicity to soil microbes from fluoride in soil within the northern vegetation impact area varied between 1.33 and 11.80. At two of the three sampling locations (DZ2-HA1 and DZ2-HA3) the surface soil samples had higher HQ values than the sub-surface soil samples. The reverse trend was apparent at DZ2-HA2.

Note however, that the toxicity benchmark for soil microbes is considered to be of low reliability due to the limited data underpinning its calculation (*Efroymson et al. 1997b*). The benchmark used in this assessment (NOEC of 30 mg/kg) was based on the lower of two toxicity results and therefore is considered to be the most conservative approach. Use of the higher benchmark value (NOEC of 3000 mg/L) would not have returned positive HQ values for fluoride toxicity in any of the soil samples.

HQ values for toxicity to terrestrial plants from fluoride in the exfiltrated groundwater were 7 in the southern vegetation impact area and 3.26 in the northern vegetation impact area. Both HQ values indicate potential risk to terrestrial plant species from fluoride within the exfiltrated groundwater. Note however, that the toxicity benchmark is considered to be of low reliability due its basis on a single toxicity NOEC value (*Efroymson et al. 1997a*).

No appropriate benchmark was located for toxicity to soil microbes from fluoride in the exfiltrated groundwater although the benchmark used for soils was based on data from experiments where soils were ‘wetted’ with solutions containing fluoride. Therefore this benchmark may also be appropriate for the exfiltrated groundwater. Using data from the wetted soils, HQ values were 11.7 and 5.43 for the southern and northern vegetation impact areas, respectively.

The conclusion that can be drawn from this assessment endpoint is that the surface soils within the southern vegetation impact area and within the southern part of the northern vegetation impact area may pose marginal risk to shallow-rooted terrestrial vegetation from fluoride toxicity. In addition, surface soils and sub-surface soils in both vegetation impact areas may pose unacceptable risk to soil microbes from fluoride toxicity on the basis of a low reliability, potentially overly conservative benchmark. Exfiltrated groundwater within the two vegetation impact areas is also likely to pose unacceptable risk to soil microbes from fluoride toxicity although surface water is only present for a short period following significant rainfall events.

6.2 Risk Characterisation for Terrestrial Fauna - Birds and Mammals

The evaluation of potential risks for terrestrial fauna involves food web modeling using surface water chemistry results, calculation of daily drinking water doses and comparison to protective TRVs. Location specific HQs are provided in *Tables 6.2* and *6.3* for each of the eight ROIs within each of the five main exposure units for fluoride and aluminium, respectively.

6.2.1 Southern Vegetation Impact Area

HQ values for toxicity to birds and mammals from fluoride in exfiltrated groundwater within the southern vegetation impact area varied between <1 and 48.3. Only one bird species – eastern yellow robin – and two mammal species – little forest bat and brown antechinus - had HQ values greater than 1.

These three species are the smallest species assessed and they have correspondingly small home ranges. The risk assessment is based on the assumption that individuals obtain their entire drinking water ration from contaminated surface water within the southern vegetation impact area. This assumption is overly conservative due to surface water within the southern vegetation impact area being highly ephemeral since it is only present for a short period of time after major rainfall events and would not provide a reliable drinking water source throughout the year. Therefore it is highly unlikely that any species would use the exfiltrated groundwater as a drinking source for more than a few days at a time and only periodically throughout the year. The HQ values greater than 1 are therefore not considered to be truly representative of the actual utilization of exfiltrated groundwater within the southern vegetation impact area and the fluoride concentrations are not expected to pose unacceptable risk to terrestrial fauna species.

HQ values for toxicity to birds and mammals from aluminium in surface water within the southern vegetation impact area were all less than 1, indicating that surface water within the southern investigation area is not expected to pose unacceptable risks to bird and mammal species from aluminium.

6.2.2 Northern Vegetation Impact Area

HQ values for toxicity to birds and mammals from fluoride in exfiltrated groundwater within the northern vegetation impact area varied between less than 1 and 3.98. Only one bird species – eastern yellow robin – and one mammal species – brown antechinus - had HQ values greater than 1, which indicate potential unacceptable risk from fluoride toxicity for these species.

HQ values for toxicity to birds and mammals from aluminium in exfiltrated groundwater within the northern vegetation impact area varied between <1 and 2.86. Only one bird species – eastern yellow robin – and one mammal species – brown antechinus - had HQ values greater than 1, which indicate potential unacceptable risk from aluminium toxicity for these species.

Similar to the discussion above for the southern vegetation impact area, the assumption that these species obtain their entire drinking water ration from within the northern vegetation impact area is overly conservative. In reality, the ephemeral nature of the water source means that it is highly unlikely that any species would use the exfiltrated groundwater as a drinking source for more than a few days at a time and only after significant rainfall events during the year. The HQ values greater than 1 are therefore not considered to be representative of the true utilisation of exfiltrated groundwater within the northern vegetation impact area and the fluoride and aluminium concentrations are not expected to pose unacceptable risk to terrestrial fauna species.

6.2.3 Ephemeral Dam

HQ values for toxicity to birds and mammals from fluoride and aluminium in surface water within the ephemeral dam were all less than 1, indicating that surface water within the dam is not expected to pose unacceptable risks to bird and mammal species. This conclusion is based on the conservative assumption that water within the dam is available to species throughout the year but this is clearly not the case given the ephemeral nature of the water body.

6.2.4 Semi-permanent Dam

HQ values for toxicity to birds and mammals from fluoride and aluminium in surface water within the semi-permanent dam were all less than 1, indicating that surface water within the dam is not expected to pose unacceptable risks to bird and mammal species. Water within this dam is likely to be available to species throughout most years and therefore the conclusion of no unacceptable risk is based on realistic assumptions associated with the drinking water source.

Note that in addition to the risk assessment based on consumption of drinking water described above, the potential dose of fluoride obtained from prey items was assessed for the white-faced heron since this species relies heavily on fish for food. The resultant HQ based on potential fluoride intake in food and water was less than 1 (*Table 6.2b*), indicating no unacceptable risk. Risk calculations are believed to be conservative considering that calculations were based on consumption of 90% of their daily food requirement from the dam alone, and in reality, the dam is unlikely to support sufficient fish numbers to support continuous feeding throughout the year.

6.2.5 Swamp Creek

HQ values for toxicity to birds and mammals from fluoride and aluminium in surface water within Swamp Creek were all less than 1, indicating that surface water within the creek is not expected to pose unacceptable risks to bird and mammal species. Water within the creek is likely to be available to species throughout most years and therefore the conclusion of no unacceptable risk is based on realistic assumptions associated with the drinking water source.

Note that in addition to the risk assessment based on consumption of drinking water described above, the potential dose of fluoride obtained from prey items was assessed for the white-faced heron since this species relies heavily on fish for food. The resultant HQ based on potential fluoride intake in food and water was less than 1 (*Table 6.2b*), indicating no unacceptable risk. Risk calculations are believed to be conservative considering that calculations were based on consumption of 90% of their daily food requirement from the same reach of the creek (where fish are exposed to the specified fluoride concentrations), and in reality, the birds would also forage in other reaches of the river where the concentration of fluoride in fish is likely to be lower.

6.3 Risk Characterisation for Aquatic Flora & Fauna

In the absence of invertebrate community data and sediment quality data, the evaluation of potential risks for aquatic flora and fauna relied on a single line of evidence: comparison of COPEC concentrations in surface water to effects based benchmarks for aquatic species. Two exposure units within the investigation area potentially include aquatic receptors – the semi-permanent dam and Swamp Creek. All other exposure units are ephemeral in nature and unlikely to support aquatic receptors. Location specific HQs are provided in *Tables 6.4* and *6.5* for surface water in relation to aquatic flora and fauna for fluoride and aluminium, respectively.

6.3.1 Semi-permanent Dam

HQ values for toxicity to aquatic invertebrates and fish from fluoride in surface water within the semi-permanent dam were 5.66 and 3.94, respectively. These results indicate that surface water within the dam could be expected to pose an unacceptable risk to aquatic invertebrates and fish species. No reliable benchmark was sourced for aquatic plants but it is noted that aquatic invertebrates are likely to be more sensitive to fluoride contamination than aquatic plants and fish (*Camargo 2003*). The assumption is that aquatic plants are also potentially at risk from fluoride contamination within the semi-permanent dam.

HQ values for toxicity to aquatic invertebrates, fish and aquatic plants from aluminium in surface water within the semi-permanent dam were 3.7, 0.61 and 4.35, respectively. These results indicate that aluminium concentrations within the surface water of the dam could pose an unacceptable risk to aquatic invertebrates and aquatic plants but are unlikely to pose unacceptable risk to fish species.

6.3.2 Swamp Creek

HQ values for toxicity to aquatic invertebrates and fish from fluoride in surface water within Swamp Creek (SW4) were 0.43 and 0.30, respectively. These results indicate that fluoride concentrations within the surface water of Swamp Creek are unlikely to pose unacceptable risk to invertebrates or fish species. No benchmark criteria are available for fluoride toxicity to aquatic plants. Not however, similar risk profiles were calculated for fluoride contamination at sampling locations further downstream (SW5 and SW6), and also for upstream locations designated as Reference locations (SW1 and SW2). At all locations, fluoride concentrations in surface waters at the time of sampling were not deemed to pose unacceptable risk to aquatic invertebrates or fish species.

These trends suggest that leachate contaminated surface waters from the vegetation impact areas that potentially run down gradient to Swamp Creek do not significantly increase the risk profile for aquatic species in Swamp Creek compared to conditions at the upstream Reference locations. Note that the upstream sampling locations are downstream of the discharge point for the treated effluent from the Kurri Kurri Wastewater Treatment Works which may be contributing to ‘elevated background’ fluoride concentrations in Swamp Creek. The Reference locations are not representative of natural background water quality but rather are deemed to be representative of surface water quality prior to input of the potentially leachate impacted surface water from the investigation area. The Reference locations do provide a valid means of comparison to assess potential increases in COPEC concentrations as a result of the processes under investigation.

HQ values for toxicity to aquatic invertebrates, fish and aquatic plants from aluminium in surface water within Swamp Creek (SW4) were all less than 1, which indicates that aluminium concentrations do not pose an unacceptable risk to aquatic flora and fauna.

Similar risk profiles were calculated for aluminium contamination at one sampling location further downstream (SW5), and also for upstream locations designated as Reference locations (SW1 and SW2). However, the risk profile for the sampling location furthest downstream (SW6) indicates that the aluminium concentration at the time of sampling could pose an unacceptable risk to aquatic invertebrates. This isolated result suggests that the higher aluminium concentration in surface water at SW6 is from a local source within the agricultural land, and which is unrelated to potentially contaminated surface water within the investigation area.

6.4 Risk Characterisation for Livestock – Cattle

The assessment of risk from fluoride and aluminium in drinking water for cattle was assessed using calculated daily dose based on intake rates and the COPEC concentrations in surface water in Swamp Creek. Swamp Creek is the only exposure unit within the investigation area where cattle have access to water. The HQs for fluoride and aluminium were both below 1, which indicates that fluoride and aluminium concentrations in Swamp Creek do not pose an unacceptable risk to cattle.

6.5 Summary of Risk Profiles for All Exposure Units and Receptors of Interest

Summaries of identified risks for the ROIs within each of the potential exposure units for fluoride and aluminium are provided in *Tables 6.6* and *6.7* for fluoride and aluminium, respectively.

6.6 Uncertainties

Uncertainty can be introduced into an ERA at every step in the process, as information of varying quality is gathered from diverse sources in order to be integrated into a complex framework. The analytical data collection effort for this ERA was designed to minimize uncertainties related to COPEC bioaccumulation and bioavailability. However, some uncertainty in the ERA process is unavoidable. Conservative assumptions are generally employed to compensate for that uncertainty, to ensure the protectiveness of the overall assessment. The primary sources of uncertainty in this ERA include:

Uncertainty associated with the aquatic assessment:

- Incomplete availability of benchmarks for all constituents (e.g. fluoride for aquatic plants).
- Lack of dissolved-water concentrations for aluminium.
- Reliance on North American benchmarks due to absence of suitable Australian data.
- Benchmarks that do not reflect the bioavailability of constituents in media, that do not account for the effects of cumulative exposure to all constituents in the investigation area simultaneously, and that were estimated using laboratory model organisms in controlled laboratory conditions and not the ROIs under site-specific conditions.
- Limited number of sampling locations within each exposure unit.

- Limited repeat sampling to identify temporal variability in constituent concentrations.

Uncertainty associated with terrestrial plant and microbial assessment:

- Incomplete availability of appropriate plant and microbial benchmarks for all constituents.
- Reliance on North American benchmarks due to absence of suitable Australian data.
- Reliance on benchmarks with acknowledged low confidence.
- Uncertainty about the benchmarks (as above).
- Limited number of sampling locations within each exposure unit.
- Limited repeat sampling to identify temporal variability in constituent concentrations.

Uncertainty associated with the wildlife assessment:

- Examination of high-end reasonable worst case exposure estimates that are unlikely to be reflective of population or community level effects.
- Use of standardized receptor parameters that may not be reflective of the actual body weights, intakes, or dietary preferences of species in the investigation area.
- Area use factors that may not reflect actual species use of the investigation area, particularly given human disturbances in the area.
- Uncertainty about the TRVs.

Additional sources of uncertainty are:

- Chemicals that are unlikely to contribute significant ecological risk because they are common minerals were retained in the risk assessment (for example, aluminium).
- Appropriateness of background locations.
- Unknown bioavailability of COPECs.
- Uncertainty about the effects of multiple stressors on the ROIs.
- The links between effects on individuals and populations or communities of those species are unknown.

6.6.1 Refinement of COPECs

The refinement of COPECs serves to concentrate the ERA on the constituents likely to contribute the most to risk, which introduces some uncertainty into the ERA. Constituents are eliminated due to consideration of background concentrations, their role as essential nutrients and electrolytes, and the frequency of detection. This process slightly underestimates risks; however, this underestimate of risk is likely of little biological importance compared to the risks from the most frequently detected COPECs.

6.6.2 Site Chemistry

The base data set for chemistry of surface water and soil is biased in a way that meaningfully overestimates risk. The samples collected to assess and demarcate site-related constituents are collected to target and define “hot spots” so that the assessment process can result in appropriate site management. Taken as a whole, these samples often show the worst case scenario because they are biased to include more samples in the most contaminated areas, and fewer samples in the less contaminated areas. This sampling approach is not appropriate for characterizing the average exposure of wildlife receptors throughout the study area and leads to a considerable overestimation of the concentrations in the environment in which wildlife exposure occurs.

6.6.3 Benchmarks

The benchmarks for terrestrial plants, soil microbes, aquatic invertebrates, aquatic plants, fish and the TRVs used for terrestrial bird and mammal species are a source of substantial uncertainty that overestimates risk. Available benchmarks for most COPECS are often a function of studies conducted on common laboratory species that tend to be more sensitive due to inbreeding and a lack of adaptation so that these studies overestimate risk to site species which may exhibit tolerance of and adaption to the constituents that have been in-place for many generations. These benchmarks also do not reflect the bioavailability of constituents in site media. Often laboratory studies use highly bioavailable forms of the constituents which also serve to overestimate risk compared to site conditions where the presence of high organic carbon or competing chemical species will limit the bioavailability of many constituents.

The effects assessment benchmarks do not account for some factors that may underestimate risk. The studies used to generate these benchmarks often only test one constituent at a time, so the cumulative effects of multiple constituents simultaneously acting on a species at the site are unknown and may be greater than are estimated by single-chemical studies. Additionally, the laboratory studies do not account for multiple stressors, such as normal seasonal changes in dissolved oxygen, pH, and temperature. Given the circumstances that may lead to an underestimation of risk, many benchmarks are multiplied by an uncertainty factor to make them more conservative – so the end product is a benchmark that still likely overestimates risk.

6.6.4 Population Effects

The benchmarks are designed to assess risks to individual organisms rather than populations or communities of organisms. One of the greatest uncertainties associated with evaluating risks to wildlife is the assumption that, as the doses and HQs increase, an increasing number of individuals could experience adverse effects, and that the higher the number of individuals affected, the greater the risk to the population. By considering mean exposures, we estimate exposures (and risks) to average individuals within the population. It is assumed that, if the average individual within the population is not adversely affected, then the population as a whole also is not likely to be adversely affected. Density-dependent biological processes, such as competition for limited food resources, can at least partially offset reductions in the reproductive output of individual organisms. For instance, extensive long-term monitoring of striped bass populations in the Hudson River revealed no PCB-related effects, despite the documentation of adverse effects on individual organisms in laboratory tests (*Barnthouse et al. 2003*). Site-specific community-level data are unavailable for most species. The relationship between individual and population-level effects is thus a significant source of uncertainty and may lead to overestimation of risks.

6.6.5 Bioavailability of COPECs

This ERA assumes that all constituents are completely bioavailable which substantially overestimates risks. The bioavailability of COPECs in environmental media is generally lower than in the exposure media employed in invertebrate, fish, avian, and mammalian toxicity tests. COPECs are generally administered as soluble salts added to the diet or exposure media in toxicity tests, resulting in relatively high bioavailability to the test organisms. In contrast, wildlife within the investigation area is exposed to COPECs that are incorporated in soil, sediment, or organic residues, which are expected to exhibit lower bioavailability. This uncertainty leads to overestimation of potential risks.

6.6.6 Uncertainty in Aquatic Invertebrate Assessment

In addition to the uncertainty in the chemistry dataset and the benchmarks described above that potentially overestimate risk, the aquatic invertebrate assessment is subject to uncertainty due to the lack of multiple lines-of-evidence (LOE). Invertebrate community assessment and sediment quality analysis would strengthen conclusions regarding potential risk to aquatic environments. Toxicity is only one LOE but when combined with statistical comparison of community structure (diversity and abundance) at impacted and reference locations, data on COPEC concentrations and toxicity in aquatic sediments, the potential for actual community effects can be more readily assessed.

6.6.7 Uncertainty in Terrestrial Plant and Soil Microbial Assessment

In addition to the uncertainty in the chemistry dataset, the terrestrial plant and soil microbial assessment is subject to uncertainty in the process of deriving effects-based benchmarks. The EcoSSL and US benchmark criteria are conservative criteria that are based on values that demonstrate no effects. The benchmarks used in the plant and terrestrial invertebrate assessment were generated from both no-effect and low-effect studies. This ultimately reduces the overestimation of risk in comparison to using overly-conservative benchmarks.

6.6.8 Uncertainty in Terrestrial Plant and Soil Microbial Assessment

The use of standardized receptor parameters that may not be reflective of the actual body weights, intakes, or dietary preferences of species within the investigation area overestimates risk. The receptor parameters were taken from USEPA guidance and these values are derived from conservative estimates that tend to increase the calculated daily dose and may not reflect the wildlife that is actually present at the notified area.

7 Conclusions

The assessment of potential risk to ecological receptors within the investigation area from leachate contaminated soil and surface water was undertaken using available data on concentrations of COPECs within each medium and toxicity benchmarks obtained from international literature. The assessment has identified variable risk for the range of receptors within each of the exposure units investigated. A summary of risk identified for each exposure unit is provided below.

7.1 Southern Vegetation Impact Area

The southern vegetation impact area is closest to the zone where leachate contaminated groundwater exfiltrates and is therefore expected to have the greatest risk of impacts from COPECs. The assessment of risk identified that concentrations of fluoride in surface soils and exfiltrated leachate (when present after significant rainfall) could pose unacceptable risk to shallow-rooted terrestrial plants and soil microbial communities within the upper 0.1 m soil horizon within the southern vegetation impact area.

The conclusion that only shallow-rooted plant species are at risk is based on the comparison of the risk profile between surface soils (0 – 0.1 m depth) and sub-surface soils (0.3 – 0.4 m depth). Surface soils provide the greatest risk; possibly as a result of residue from the exfiltrate accumulating at the ground surface after surface water evaporates. Deep-rooted plant species would have their active roots within soil where fluoride concentrations do not pose an unacceptable risk to plant health. Some deep-rooted species would utilise water directly from the water table and could be at risk from COPECs contained within groundwater; however, mapping of the groundwater plume relative to the Alcan Mound and the two vegetation impact areas indicates that the plume of leachate contaminated groundwater is located to the west of the vegetation impact areas beneath areas of healthy vegetation. The absence of visible health impacts to the vegetation that is growing directly above the plume (which presumably has roots within the water table) may indicate that the concentrations of F- in the larger leachate impacted groundwater plume are non-toxic to the deep-rooted plant species

In the absence of current risk to deep-rooted plants growing above the groundwater plume, the reason for the initial vegetation dieback within the two vegetation impact areas is unclear. The historical impacts to vegetation could have occurred as a result of contact with more concentrated leachate during the period prior to capping of the Alcan Mound.

Note that the risk profiles to plants and soil microbes is based on the use of low reliability, conservative toxicity benchmarks derived from a very limited number of laboratory tests and does not include consideration of cumulative or antagonistic effects of physico-chemical conditions present within the immediate area. For example, the high conductivity and pH of leachate may itself cause unacceptable risk to vegetation and/or soil microbial communities which may outweigh the risk from fluoride. However, the presence of healthy vegetation above the groundwater plume and the presence of a heavy cover of grasses across the two vegetation impact areas suggest that there is, at most, a low level risk to plant species in these two vegetation impact areas.

The assessment of risk from fluoride in exfiltrated groundwater within the southern vegetation impact area identified that there may be an unacceptable risk to one species of bird – the eastern yellow robin – and two species of mammal – the little forest bat and the brown antechinus. However, the level of risk is based on an unrealistic scenario whereby these small animals (with small home ranges) obtain 100% of their drinking water from the exfiltrated groundwater. The highly ephemeral nature of the exfiltrate means that it is only available for a few days after significant rainfall and therefore the risk assessment significantly overestimates the dose of fluoride to these animals. In reality, animals are unlikely to derive much of their drinking water from the exfiltrate and consequently there is not expected to be an unacceptable risk from fluoride toxicity to any terrestrial fauna.

The concentration of aluminium in soils (surface and sub-surface) and in exfiltrate within the southern vegetation impact area is not expected to pose an unacceptable risk to plants, soil microbes, birds or mammals since aluminium would be strongly bound in the soil matrix due to pH conditions being above 5.5.

7.2 Northern Vegetation Impact Area

Soil and surface water within the northern vegetation impact area has lower fluoride concentrations and higher aluminium concentrations than found in the southern vegetation impact area. The assessment of risk identified that concentrations of fluoride and aluminium are unlikely to pose unacceptable risk to terrestrial plants within the upper 0.4 m soil horizon except in surface soils (0.0 to 0.1 m) at DZ2-HA1 and DZ2-HA2 (the two southernmost sampling locations). In contrast, the risk profiles for soil microbes indicate potential unacceptable risk at all three sampling locations from fluoride concentrations in surface and sub-surface soils.

Concentrations of fluoride in exfiltrated leachate (when present after significant rainfall) could also pose unacceptable risk to plants and soil microbes.

However, the risk assessment is based on a low reliability benchmark derived from a single experiment, and the presence of a healthy groundcover community in the absence of abundant organic matter lying on the ground do indicate that microbial processes are currently functioning well. Historical impacts to vegetation are known but conditions within the vegetation impact areas are clearly suitable for the growth of vegetation. The risk assessment is considered to be highly conservative and the translation of the risk profile into observable impacts in the field is not apparent under the current environmental conditions.

The assessment of risk from fluoride and aluminium in exfiltrated groundwater within the northern vegetation impact area identified that there may be an unacceptable risk to one species of bird – the eastern yellow robin – and one species of mammal – the brown antechinus. However, as discussed above for the southern vegetation impact area, the level of risk is based on an unrealistic scenario whereby these small species (with small home ranges) obtain 100% of their drinking water from the exfiltrated groundwater. In reality, these species are unlikely to derive much of their drinking water from the exfiltrate and there is not expected to be an unacceptable risk from fluoride or aluminium toxicity to any terrestrial fauna species.

7.3 Ephemeral Dam

The small ephemeral dam that lies down gradient from the two vegetation impact areas accumulates surface water flow immediately after significant rainfall events. The ephemeral nature of the dam prevents the development of aquatic communities and therefore risk was only calculated for bird and mammal species that might utilize the dam for drinking water. The concentrations of fluoride and aluminium in the dam water do not pose an unacceptable risk to bird and animal species, even if they were to utilize the dam for 100% of their drinking water. The risk scenario significantly overestimates the dose of COPECs since the dam does not provide a reliable source of drinking water throughout the year.

7.4 Semi-permanent Dam

The semi-permanent dam lies down gradient of the ephemeral dam and is likely to contain reliable water supply throughout the year for most years but could dry during extended periods without rainfall. The concentrations of fluoride and aluminium within the dam water do not pose unacceptable risk to bird and mammal species, even if they utilize water within the dam for 100% of their drinking water.

The assessment of risk from fluoride in water within the semi-permanent dam did identify potentially unacceptable risk to aquatic invertebrates, fish and potentially aquatic plants. Concentration of aluminium within the dam water may also pose an unacceptable risk to aquatic invertebrates and aquatic plants but not to fish. These conclusions of risk are based on COPEC concentrations within the dam water only, and do not include an assessment of invertebrate and aquatic plant communities nor sediment quality. A single line-of-evidence should not be relied on as a true indication of potential risk in aquatic systems but rather provides a trigger to consider further assessment to build a picture of actual aquatic condition. The calculation of risk based on toxicity benchmarks for non-Australian species under non-field conditions does not imply that the risk is actually present within the dam and an assessment of aquatic communities within the dam would strengthen the risk profile considerably.

Note also that the semi-permanent dam is a totally artificial feature that was presumably built to collect and store excess storm water run-off by capturing overland flow. The purpose of the dam is unclear but it may have been used as a secondary source of water for local agriculture during periods of extended drought. The artificial nature of the dam means that it has limited value as native aquatic habitat and is likely to support a community of the most adaptable aquatic species only. Currently, the complexity and condition of aquatic ecology within the dam is unknown.

7.5 Swamp Creek

Swamp Creek is the ultimate water feature within the investigation area that could potentially receive COPECs from the exfiltrated leachate impacted groundwater. Based on conservative toxicity benchmarks, the concentration of fluoride within the surface water of Swamp Creek is unlikely to pose an unacceptable risk to aquatic invertebrates and fish (HQ values less than 1). A broadly similar risk profile was apparent for fluoride concentrations at all three Swamp Creek sites and at the two reference locations upstream of the investigation area. This result indicates that fluoride is detectable throughout the 'background' in the vicinity of the investigation area but there is no detectable change in risk to aquatic species within the 'natural' receiving environment adjacent to the smelter. It is noted that the discharge of treated effluent from the Kurri Kurri Wastewater Treatment Works may be contributing to the reported 'background' fluoride concentrations in Swamp Creek.

The Reference locations, while not representative of the 'natural' background water quality in the region, do provide a useful comparison between the quality of surface water in Swamp Creek upstream and downstream of the inflow of surface water from the investigation area. On that basis, there does not appear to be any significant change in fluoride concentration in Swamp Creek as a result of surface water inflow from the investigation area. There are also no apparent risks from aluminium concentrations in surface water in the sections of Swamp Creek within the investigation area.

Swamp Creek water is also used for watering local livestock. The concentrations of fluoride and aluminium in Swamp Creek surface waters do not pose an unacceptable risk to livestock according to criteria based on the ANZECC (*2000*) livestock drinking water guidelines.

8 Risk Management Decisions

The evaluation of ecological risk for terrestrial and aquatic plant and animal species indicates that, with limited exceptions, the conditions within the investigation area do not pose an unacceptable risk to ecological receptors. The exceptions include the following:

- Potential risks to soil microbial communities and shallow-rooted plants from fluoride concentrations in soil and exfiltrate within the two vegetation impact areas.
- Potential risks to aquatic invertebrates, fish and plants from fluoride and aluminium concentrations in surface water within the artificial semi-permanent dam.

On the basis of these results the following actions are recommended:

1. Investigate potential mitigation measures to halt, reduce or capture exfiltrated leachate-contaminated groundwater;
2. Continue to map and monitor the location and quality of the groundwater plume associated with the Alcan Mound in order to document any temporal change that may indicate increasing or decreasing risk to ecological receptors;
3. Further investigate the range of ‘background’ concentrations of aluminium and fluoride in soil and surface water within the buffer zone to better understand variability with respect to potential smelter impacts.
4. 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
5. 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.

9 References

ANZECC (2000) *Australian and New Zealand Guidelines for Fresh and Marine Water Quality.* Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand

ATSDR (2003) *Toxicological Profile for Fluorides, Hydrogen Fluoride, and Fluorine*, U.S. Department of Health and Human Services, Public Health Service.

ATSDR (2008) *Toxicological Profile for Aluminum*, Agency for Toxic Substances and Disease Registry, U.S. Department of Health and Human Services.

Barnthouse LW, Munns WR & Sorensen MT (2008). *Population-level Ecological Risk Assessment.* CRC Taylor & Francis

BCMoE (1995) Ambient Water Quality Criteria for Fluoride. Ministry of Environment, Province of British Columbia. http://www.env.gov.bc.ca/wat/wq/BCguidelines/fluoride/index.html (accessed January 2013)

BCMoE (2001) Water Quality Criteria for Aluminium. Ministry of Environment, Province of British Columbia. http://www.env.gov.bc.ca/wat/wq/BCguidelines/aluminum/aluminum.html (accessed January 2013)

Bell SAJ (2004) *The vegetation of the Hunter Economic Zone (HEZ), Cessnock LGA, New South Wales.* Report to Harper Somers O'Sullivan, Broadmeadow, NSW. 71pp

Camargo JA (2003) Fluoride toxicity to aquatic organisms: a review. *Chemosphere* 50:251-264

Canadian Council of Ministers of the Environment. 2002. Canadian water quality guidelines for the protection of aquatic life: Inorganic fluorides. In: Canadian environmental quality guidelines, 1999, Canadian Council of Ministers of the Environment, Winnipeg.

CCME (1999) *Canadian Soil Quality Guidelines for the Protection of Environmental and Human Health.* Canadian Council of Ministers of the Environment.

CEPA (1994) *Priority Substances List Supporting Document for Inorganic Fluorides.* Prepared by the Eco_Health Branch & Environment Canada for Canadian Environmental Protection Agency, Ottawa

Croft & Associates (1980) *Environmental Impact Statement for Expansion of an Aluminium Smelter. Line III Kurri Kurri, NSW*. Prepared by James B Croft & Associates, Newcastle

CSIRO (2009) *The Australian Methodology to Derive Ecological Investigation Levels in Contaminated Soils*. Prepared for the National Environmental Protection Council by D Heemsbergen, M Warne, M McLaughlin and R Kookana. 74pp

DAF (2013) Effect of boron, soil acidity and aluminium toxicity on barley. Department of Agriculture, Government of Western Australia. http://www.agric.wa.gov.au/PC_92014.html?s=1001 (accessed January 2013)

Dave G (1984) Effects of fluoride on growth, reproduction and survival in *Daphnia magna. Comp. Biochem. Physiol. 78:425-431*

DEC (2007) *Guidelines for the Assessment and Management of Groundwater Contamination.* Department of Environment and Conservation NSW, Australia

DECC (2007) *Eucalypt Forest on Coastal Floodplain - Identification Guidelines for Endangered Ecological Communities Information Brochure.* Department of Environment and Climate Change. 4pp

DECC (2008) *Freshwater Wetlands on Coastal Floodplains (Freshwater Wetlands) - Identification Guidelines for Endangered Ecological Communities Information Brochure.* Department of Environment and Climate Change. 2pp

DMR (1993) *Geological Series Sheet 9312*. Department of Mineral Resources, Australia

Efroymson RA, Will ME, Suter GW and Wooten AC (1997a) *Toxicological Benchmarks for Screening Contaminants of Potential Concern for Effects on Terrestrial Plants: 1997 Revision.* Prepared for the US Department of Energy, Office of Environmental Management. ES/ER/TM-85/R3

Efroymson RA, Will ME, Suter GW and Wooten AC (1997b) *Toxicological Benchmarks for Screening Contaminants of Potential Concern for Effects on Soil and Litter Invertebrates and Heterotrophic Process: 1997 Revision.* Prepared for the US Department of Energy, Office of Environmental Management. ES/ER/TM-126/R2

ENVIRON (2012) *Environmental Site Assessment, Alcan Mound, Kurri Kurri Aluminium Smelter*. Report prepared for Hydro Aluminium Kurri Kurri Australia. 290pp.

ENVIRON (2013) *Preliminary Screening Level Health Risk Assessment for Fluoride and Aluminium Part of the Kurri Kurri Aluminium Smelter Hart Road, Loxford.* Report prepared for Hydro Aluminium Kurri Kurri Australia. 23pp.

Fleiss S (2011) *Review of fluoride toxicity to aquatic organisms and its toxicity contribution in Volvo wastewater.* Master of Science, University of Gothenburg

Harper MJ (2005) Home range and den use of common brushtail possums (*Trichosurus vulpecula*) in urban forest remnants. *Wildlife Research 32(8) 681–687*

Harris JH & Gehrke PC (1997) *Fish and rivers in stress – The NSW rivers survey*. NSW Fisheries Office of Conservation, Cronulla, and the Cooperative Research Centre for Freshwater Ecology, Canberra. 298 pp.

Hekman WE, Budd K, Palmer GR & MacArthur JD (1984). Responses of certain freshwater planktonic algae to fluoride. *J. Phycol 20:243-249*

Hemens J & Warwick RJ (1972) The effects of fluoride on estuarine organisms. *Water Res. 6:1301-1308*

Hume ID (1999) *Marsupial Nutrition.* Cambridge University Press. 450pp

Kuhn R, Pattard M, Pernak KD & Winter A (1989) Results of the harmful effects of water pollutants to *Daphnia magna* in the 21 day reproduction test. *Water Re. 23:501-510*

LeBlanc GA (1980) Acute toxicity of priority pollutants to water flea (*Daphnia magna*). *Bull. Environ. Contam. Toxicol. 24:684-691*

Lindenmeyer D (2010) Forest Pattern and Ecological Process: A Synthesis of 25 Years of Research. CSIRO Publishing. 308pp

Markich SJ, Warne MStJ, Westbury AM and Roberts CJ (2002) A compilation of data on the toxicity of chemicals to species in Australasia. Part 3: Metals. *Aust. J Ecotox*. 8:1-72.

NEPC (1999) *Guideline on Ecological Risk Assessment, Schedule B (5), National Environmental Protection (Assessment of Site Contamination) Measure.* National Environmental Protection Council, Australia. 188pp.

NHMRC (2004) *Australian Drinking Water Guidelines.* NHMRC and Natural Resource Management Ministerial Council of Australia and New Zealand

NY DEC (New York State Department of Environmental Conservation), Division of Water. 1993. Technical and Operational Guidance Series (1.1.1). Ambient Water Quality Standards and Guidance Values and Groundwater Effluent Limitations. http://www.dec.ny.gov/docs/water_pdf/togs111.pdf (accessed December 2012)

NYCRR (New York Compilation of Codes, Rules, and Regulations). 1999. Title 6, Part 706. http://www.dec.state.ny.us/website/regs/part706.html (accessed December 2012)

OEH, (2011) *Guidelines for Consultants Reporting on Contaminated Sites.* Office of Environment & Heritage, NSW Government, Australia

Pimental R & Bulkley RV (1983) Influence of water hardness on fluoride toxicity to rainbow trout. *Environ. Toxicol. Chem 2:381-386*

Rai LC, Husaini Y & Mallick N (1998) ph-altered interaction of aluminium and fluoride on nutrient uptake, photosynthesis and other variables of *Chlorella vulgaris*. *Aquatic Toxicology 42:67-84*

RIVM (2000) Dutch Target and Intervention Values (the New Dutch List) Rijksinstituut Voor Volksgezondheid en Milieu (National Institute of Public Health and the Environment). ANNEX A: Target Values, Soil Remediation Intervention Values and Indicative Levels For Serious Contamination.

Roy RL, Campbell PGC, Premont S & Labrie J (2000) Geochemisrty and toxicology of Aluminium in the Saguenay River, Quebec, Canada, in relation to discharges from an aluminium smelter. *Environ. Toxicol. Chem. 19(10):2457-2466*

Sample BE and Suter GW (1994) Estimating Exposure of Terrestrial Wildlife to Contaminants. Oak Ridge National Laboratory ES/ER/TM-125 49pp.

Sample BE, Opresko DM and Suter GW (1996). Toxicological Benchmarks for Wildlife: 1996 Revision. Prepared for the US Department of Energy, Office of Environmental Management. ES/ER/TM-86/R3

Shirke PA & Chandra P (1991) Fluoride uptake by duckweed *Spirodela polyrrhiza. Fluoride 24:109-112*

Suter GW & Tsao CL (1996) Toxicological Benchmarks for Screening Potential Contaminants of Concern for Effects on Aquatic Biota: 1996 Revision. ES/ER/TM-96/R2

USEPA (1992) Framework for Ecological Risk Assessment. EPA/630/R-92/001.

USEPA (1997) Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessments. EPA/540/R-97/006.

USEPA (1998) Guidelines for Ecological Risk Assessment. U.S. Environmental Protection Agency, Risk Assessment Forum, Washington, DC, EPA/630/R095/002F

USEPA (2003) *Ecological Soil Screening Level for Aluminium – Interim Final* (OSWER Directive 9285.7-60). US Environmental Protection Agency, Washington

USEPA (2004) National Recommended Water Quality Criteria: 2004. Available at: http://www.epa.gov/waterscience/criteria/wqcriteria.html

USEPA (2012) Freshwater Screening Benchmarks (http://www.epa.gov/reg3hwmd/risk/eco/btag/sbv/fw/screenbench.htm)

USEPA (2012) Regional Screening Levels (Region 9 – Pacific Southwest) http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/Generic_Tables/pdf/master_sl_table_run_NOV2012.pdf (accessed November 2012)

USEPA (2013) Ecological Soil Screening Levels Guidance and Documents. http://www.epa.gov/oswer/riskassessment/ecorisk/ecossl.htm (accessed January 2013)

Wang W (1986) Toxicity tests of aquatic pollutants by using common duckweed. *Environ. Pollut (Series B) 11:1-14*

WHO (1997) Aluminium. Environmental Health Criteria 194, World Health Organisation, Geneva

WHO (2002) *Fluorides.* Environmental Health Criteria 227. World Health Organisation, Geneva

10 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.

10.1 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.

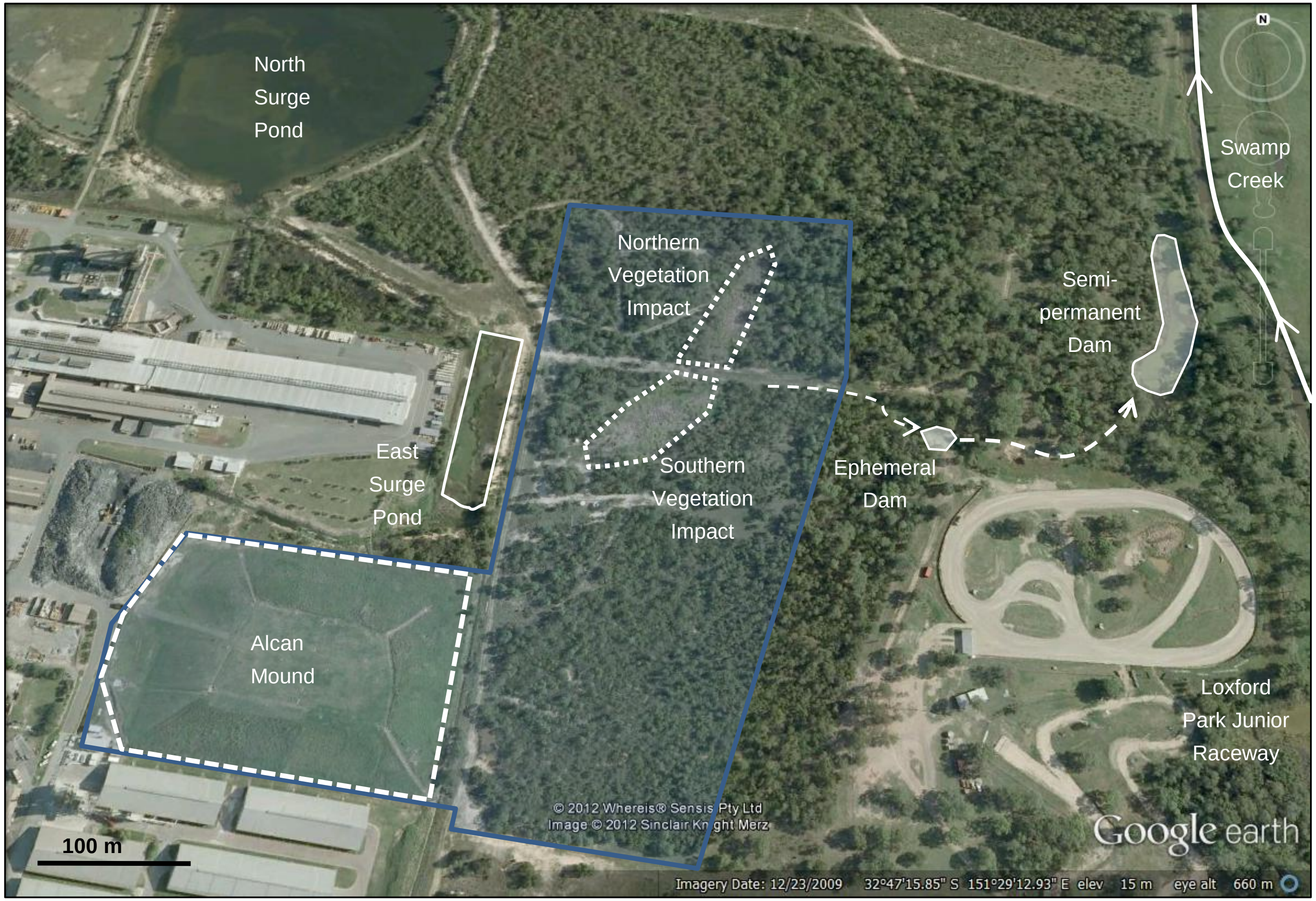
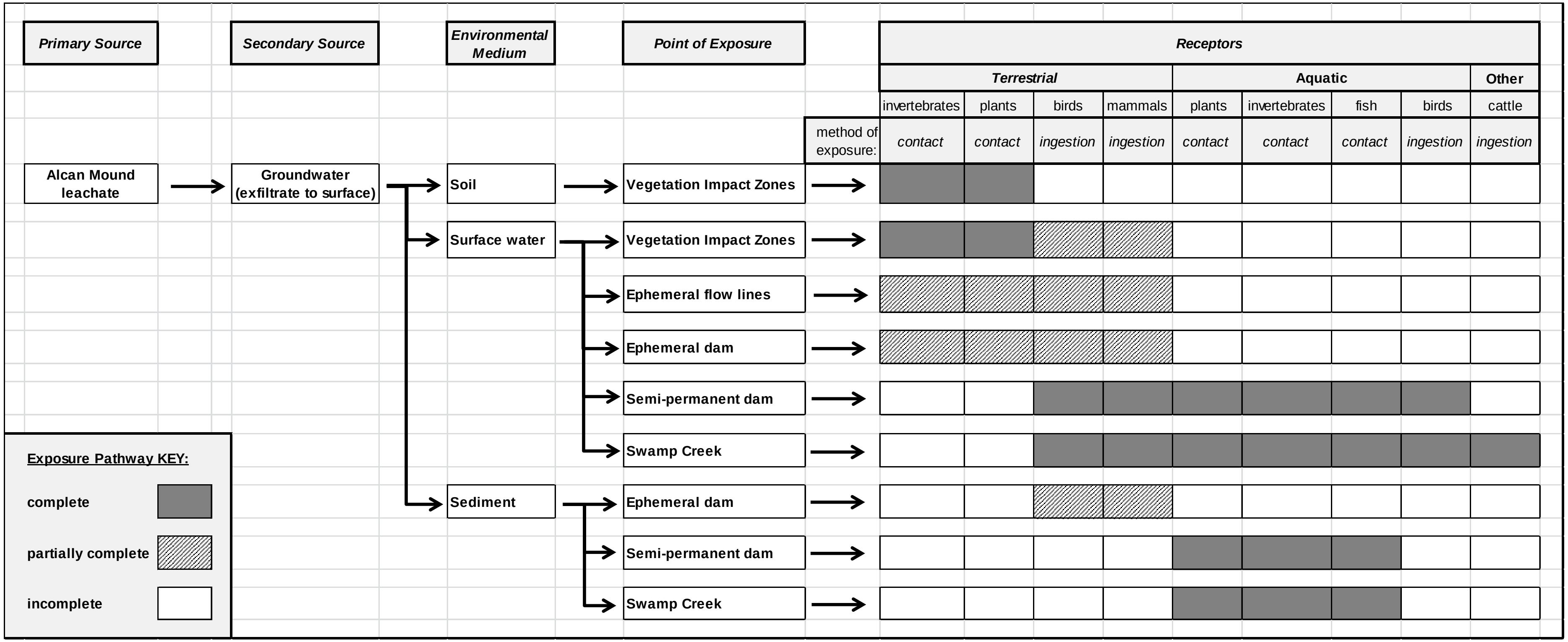


Figure 2.3 Soil and Surface Water Sampling Locations within the ERA Investigation Area, Kurri Kurri Aluminium Smelter.

Figure 3.1: Tier 2 Conceptual Site Model for Alcan Mound Leachate, Kurri Kurri Smelter ERA Investigation Area



Tables

Table 2.1: Soil Assessment Criteria for Fluoride				
	US Region 9 (*USEPA 2012*)	**Netherlands (*RIVM 2000*)**	**Canada (*CCME 1999*)***	**Australia (*NEPM 1999*)**
Soil (target)	-	500	-	-
Soil (fauna)	-	-	-	-
Soil (agricultural)	-	-	200	-
Soil (residential)	3100	-	400	-
Soil (playgrounds)	-	-	-	-
Soil (industrial/ commercial)	41,000	-	2000	-

Table 2.2: Soil Assessment Criteria for Aluminium	
	US - Region 9 (*USEPA 2012*)
Soil (target)	-
Soil (fauna)	-
Soil (agricultural)	-
Soil (residential)	77,000
Soil (playgrounds)	-
Soil (industrial/ commercial)	990,000

Table 2.3: Soil Assessment Criteria for Cyanide				
	US Region 9 (*USEPA 2012*)	**Netherlands (*RIVM 2000*)**	**Canada (*CCME 1999*)***	**Australia (*NEPM 1999*)**
Soil (unspecified)	-	20	-	-
Soil (fauna)	-	-	-	-
Soil (agricultural)	-	-	0.9	-
Soil (residential)	22	-	0.9	500
Soil (playgrounds)	-	-	-	-
Soil (industrial/ commercial)	140	-	8	-

*Free cyanide

Table 2.4: Soil Preliminary Screening Criteria	
Contaminant	**Screening Criteria (mg/kg)**
Fluoride	200*
Aluminium	77,000**
Cyanides (complex)	500**
Sodium	-

* Agricultural criteria

**Residential criteria, as no agricultural criteria available

Table 2.5 Soil Analysis Results, Kurri Kurri Aluminium Smelter (ENVIRON 2012)

DZ1 Southern Vegetation Impact Area

	Site	HA1		HA2	
	Depth (m)	**0.0-0.1**	**0.3-0.4**	**0.0-0.1**	**0.3-0.4**
Constituent	Units				
pH	-	10.8	10.8	10.5	10.7
Total Fluoride	mg/kg	440	100	300	350
Soluble Fluoride	mg/kg	296	58	226	200
Total Cyanide	mg/kg	11.0	3.7	10.0	6.9

DZ2 Northern Vegetation Impact Area

	Site	HA1		HA2		HA3	
	Depth (m)	**0.0-0.1**	**0.3-0.4**	**0.0-0.1**	**0.3-0.4**	**0.0-0.1**	**0.3-0.4**
Constituent	Units						
pH	pH	10.8	10.8	10.5	10.7	10.8	10.8
Total Fluoride	mg/kg	440	100	300	350	440	100
Soluble Fluoride	mg/kg	296	58	226	200	296	58
Total Cyanide	mg/kg	11	3.7	10	6.9	11	3.7

Table 2.6: Australian Surface Water Assessment Criteria

Contaminant	Units	ANZECC (2000)			Other
		Aquatic (95%)	**Stock**	**Irrigation**	
pH	-	6.5 - 8**	-	6.0 – 9.0	-
Aluminium	mg/L	0.055	5	5	-
Fluoride	mg/L	-	2	1	5*
Free Cyanide	mg/L	0.007	-	-	-
Electrical conductivity	µS/cm	-	-	12,200***	-

* Trigger concentration for fluoride at a nearby aluminium smelter

** Values for lowland rivers from Table 3.3.2 in ANZECC (2000)

*** From Table 4.2.4 ANZECC (2000), where electrical conductivity is 'generally too saline' for plant growth

Table 2.7: Soil Preliminary Screening Criteria

Constituent	Screening Criteria
pH	6.5 - 8
Aluminium (mg/L).	0.055
Fluoride (mg/L).	1
Free Cyanide (mg/L).	0.007
Electrical conductivity (µS/cm)	12,200

Table 2.8 Surface Water Analysis Results, Kurri Kurri Aluminium Smelter (ENVIRON 2012)

	PQL	Units	ESB*	SW1 and SW2 Swamp Creek (Reference) (n=4)		DZ1 Southern Veg (n=1)		DZ2 Northern Veg (n=1)		SW8 Ephemeral Dam (n=1)	
				mean	max	mean	max	mean	max	mean	max
pH		pH	6.5-8.0 (a)	7.4	7.9	9.7	9.7	8.8	8.8	9.1	9.1
Electrical Conductivity		µS/cm	300 (a,b)	1,250	5,300	15,000	15,000	1,900	1,900	5,400	5,400
Soluble Fluoride	0.1	mg/L		0.49	0.66	350	350	45	45	91	91
Free Cyanide	0.004	mg/L	0.007 (c)	nd	nd	6.1	6.1	nd	nd	0.034	0.034
Total Aluminium	0.01	mg/L	0.055 (c)	0.155	0.31	0.8	0.8	48.0	48.0	9.5	9.5
Hardness (f)		mg/L		145	166	37	37	22	22	66	66
Total Alkalinity (g)	5	mg/L		125	140	6,900	6,900	840	840	2,200	2,200

	PQL*	Units	ESB**	SW3 Swamp Creek (n=2)		SW4 Swamp Creek (n=2)		SW5 Swamp Creek (n=2)		SW6 Swamp Creek (n=2)	
				mean	max	mean	max	mean	max	mean	max
pH		pH	6.5-8.0 (a)	7.6	7.9	7.65	8.1	7.65	8	7.6	8
Electrical Conductivity		µS/cm	300 (a,b)	560	620	1,200	1,300	1,300	1,400	1,250	1,300
Soluble Fluoride	0.1	mg/L		20	21	1.55	1.60	0.79	0.89	0.90	1.20
Free Cyanide	0.004	mg/L	0.007 (c)	nd	nd	nd	nd	nd	nd	nd	nd
Total Aluminium	0.01	mg/L	0.055 (c)	1.85	2	0.32	0.37	0.22	0.24	1.1	1.7
Hardness (f)		mg/L		52	59	154	169	161	191	169	177
Total Alkalinity (g)	5	mg/L		72.5	81	125	130	115	120	110	120

See Notes below

* - PQL refers to practical quantitation limits, or detection limit of analyses

** - ESB refers to Ecological Screening Benchmark

(a) - Lowland Rivers in Slightly Disturbed Ecosystems, South-East Australia (*ANZECC 2000*)

(b) - higher conductivity may occur in areas with saline influence (*ANZECC 2000*)

(c) - fresh waters in Slightly Disturbed Ecosystems - Protection of 95% of species (*ANZECC 2000*)

(d) - essential nutrients are not typically retained as COPECs and no ecological screening benchmarks are available. However, results greater than 50% above the reference values are highlighted for further comment

(e) - no ecological screening benchmarks are available for sulphate and chloride. However, results greater than 50% above the reference values are highlighted for further comment

(f) - total hardness was calculated from total calcium and total magnesium concentrations - results greater than 50% above or below reference values are highlighted for further comment

(g) - results greater than 50% above reference values are highlighted for further comment

Table 4.1 Food Chain Input Variables and Receptor Parameters for Birds, Mammals and Cattle (sources of data discussed in Section 4.5)

					Southern Vegetation Area		Northern Vegetation Area			
Receptor of Interest (ROI)		Body Weight (kg)	Intake Rate (L/day)	Home Range (ha)	Exposure area (ha)	Area Use Factor (AUF) (%)	Exposure area (ha)	Area Use Factor (AUF) (%)		
Birds	Eastern Yellow Robin	0.02	0.0106	0.42	3.5	8.33E+00	2.1	5.00E+00		
	Nankeen Kestrel	0.172	0.064	233	3.5	1.50E-02	2.1	9.01E-03		
	Pacific Black Duck	1.02	0.058	28,260	3.5	1.24E-04	2.1	7.43E-05		
	White-faced Heron	0.55	0.1058	28,260	3.5	1.24E-04	2.1	7.43E-05		
Mammals	Little Forest Bat	0.0043	0.0012	0.9	3.5	3.89E+00	2.1	2.33E+00		
	Brown Antechinus	0.029	0.0249	0.4	3.5	8.75E+00	2.1	5.25E+00		
	Brushtail Possum	1.59	0.0163	1.2	3.5	2.92E+00	2.1	1.75E+00		
	Eastern Grey Kangaroo	43.9	2.6	8	3.5	4.38E-01	2.1	2.63E-01		

					Ephemeral Dam		Semi-permanent Dam		Swamp Creek (SW4)	
Receptor of Interest (ROI)		Body Weight (kg)	Water Intake Rate (L/day)	Home Range (ha)	Exposure area (ha)	Area Use Factor (AUF) (%)	Exposure area (ha)	Area Use Factor (AUF) (%)	Exposure area (ha)	Area Use Factor (AUF) (%)
Birds	Eastern Yellow Robin	0.02	0.0106	0.42	0.03	7.14E-02	0.36	8.57E-01	1	2.38E+00
	Nankeen Kestrel	0.172	0.064	233	0.03	1.29E-04	0.36	1.55E-03	1	4.29E-03
	Pacific Black Duck	1.02	0.058	28,260	0.05	1.77E-06	4.5	1.59E-04	5	1.77E-04
	White-faced Heron	0.55	0.1058	28,260	0.05	1.77E-06	4.5	1.59E-04	5	1.77E-04
Mammals	Little Forest Bat	0.0043	0.0012	0.9	0.05	5.56E-02	4.5	5.00E+00	5	5.56E+00
	Brown Antechinus	0.029	0.0249	0.4	0.03	7.50E-02	0.36	9.00E-01	1	2.50E+00
	Brushtail Possum	1.59	0.0163	1.2	0.03	2.50E-02	0.36	3.00E-01	1	8.33E-01
	Eastern Grey Kangaroo	43.9	2.6	8	0.03	3.75E-03	0.36	4.50E-02	1	1.25E-01
Cattle		600	120	78,500	-	-	-	-	1	1.27E-05

Table 4.2: Australian Wildlife Receptors and Adopted US Proxy Species					
	Trophic Level, Habitat (Size)	Australian Receptor of Interest (ROI)		US Benchmark Species (*Sample et al. 1996*)	
		Name (species)	Mean Body weight (kg)	Name (species)	Mean Body weight (kg)
Birds:	O, Fo	Eastern Yellow Robin (*E.australis*)	0.020	American Robin (*Turdus migratorius*)	0.077
	C, A	Nankeen Kestrel (*F.cenchroides*)	0.172	Red-tailed Hawk (*Buteo jamaciencis*)	1.126
	H, Aq	Pacific Black Duck (*A.superciliosa*)	1.02	Mallard (*A.platyrhynchos*)	1.1
	C, Aq	White-faced Heron (*A. novaehollandiae*)	0.550	Great Blue Heron (*Ardea herodius*)	2.39
Mammals:	I, A	Little Forest Bat (*V.vulturnus*)	0.0043	Little Brown Bat (*Myotis luciugus*)	0.0075
	I, F (s)	Brown Antechinus (*A.stuartii*)	0.029	Short-tailed Shrew (*Blarina brevicauda*)	0.015
	H, (m)	Brushtail Possum (*T.vulpecula*)	1.59	Cottontail Rabbit (*Sylvilagus floridanus*)	1.2
	H, (l)	Eastern Grey Kangaroo (*M.giganteus*)	43.9	Whitetail Deer (*Odocoileus virginianus*)	56.5

Trophic Level: H – herbivore, I – insectivore, C – carnivore, O – omnivore,

Habitat: Fo – forest, A – aerial, Aq – aquatic

Size: (s) – small, (m) – medium, (l) large

Table 5.1 Wildlife Toxicity Reference Values Adopted for Australian Receptors, sourced from Sample et al. (1996)		
Receptor	Fluoride LOAEL TRV (mg/kg/day)	Aluminium LOAEL TRV (mg/kg/day)
Eastern Yellow Robin	32.0	44.5
Nankeen Kestrel	32.0	44.5
Pacific Black Duck	32.0	44.5
White-faced Heron	32.0	44.5
Little Forest Bat	179.0	27.3
Brown Antechinus	151.0	22.3
Brushtail Possum	50.4	7.7
Eastern Grey Kangaroo	19.2	2.9

Table 5.2: Aquatic Toxicity Benchmarks Adopted for Australian Receptors, sourced from Suter & Tsao 1996 (shaded cells indicate values adopted for the current risk assessment)

Receptor	Fluoride (mg/L)		Aluminium (mg/L)	
	Conventional	Alternative	Conventional	Alternative
Aquatic plants	-	-	0.460	-
Aquatic invertebrates	-	3.706	1.900	0.540
Fish	-	5.336	3.288	4.700

Table 5.3: Adopted Terrestrial Toxicity Benchmarks

	Fluoride (mg/L)	Aluminium (mg/L)
Terrestrial Plants	200	n/a **
Soil microbes	30	n/a **

*** Aluminium not classified as COPC due to soil pH >5.5*

Table 6.1 Location Specific Hazard Quotients (HQs) for Fluoride in Soil and Surface Water with respect to Soil Microbes and Terrestrial Plants

					Southern Vegetation Impact Area				**Northern Vegetation Impact Area**					
				Area	**DZ1**	**DZ1**	**DZ1**	**DZ1**	**DZ2**	**DZ2**	**DZ2**	**DZ2**	**DZ2**	**DZ2**
				Location	**HA1**	**HA1**	**HA2**	**HA2**	**HA1**	**HA1**	**HA2**	**HA2**	**HA3**	**HA3**
COPEC	**ROI**	**Medium**	**Criterion**	**Soil Depth**	**0.0-0.1m**	**0.3-0.4m**	**0.0-0.1m**	**0.3-0.4m**	**0.0-0.1m**	**0.3-0.4m**	**0.0-0.1m**	**0.3-0.4m**	**0.0-0.1m**	**0.3-0.4m**
Fluoride	**microbes**	soil	30	mg/kg	296	58	226	200	259	163	354	97	141	40
		water	30	mg/L	350	-	-	-	163	-	-	-	-	-
	plants	soil	200	mg/kg	296	58	226	200	259	163	354	97	141	40
		water	5	mg/L	350	-	-	-	163	-	-	-	-	-

					HQ	HQ	HQ	HQ	HQ	HQ	HQ	HQ	HQ	HQ
Fluoride	**microbes**	soil	30	mg/kg	9.87	1.93	7.53	6.67	8.63	5.43	11.80	3.23	4.70	1.33
		water	30	mg/L	11.67	-	-	-	5.43	-	-	-	-	-
	plants	soil	200	mg/kg	1.48	0.29	1.13	1.00	1.30	0.82	1.77	0.49	0.71	0.20
		water	5	mg/L	70.00	-	-	-	32.60	-	-	-	-	-

Table 6.2 Location Specific Hazard Quotients (HQs) for Fluoride in Surface Water for Birds and Mammals

Location	Receptor of Interest (ROI)	Toxicity Reference Value (mg/kg/day)	Exposure Point Concentration (mg/L)	Dose (mg/kg/day)	Hazard Quotient
Southern Vegetation Area	Eastern Yellow Robin	3.20E+01	350	1.55E+03	4.83E+01
	Nankeen Kestrel	3.20E+01	350	1.96E+00	6.11E-02
	Pacific Black Duck	3.20E+01	350	2.46E-03	7.70E-05
	White-faced Heron	3.20E+01	350	8.34E-03	2.61E-04
	Little Forest Bat	1.79E+02	350	3.80E+02	2.12E+00
	Brown Antechinus	1.51E+02	350	2.63E+03	1.74E+01
	Brushtail Possum	5.04E+01	350	1.05E+01	2.08E-01
	Eastern Grey Kangaroo	1.92E+01	350	9.07E+00	4.72E-01
Northern Vegetation Area	Eastern Yellow Robin	3.20E+01	45	1.19E+02	3.73E+00
	Nankeen Kestrel	3.20E+01	45	1.51E-01	4.72E-03
	Pacific Black Duck	3.20E+01	45	1.90E-04	5.94E-06
	White-faced Heron	3.20E+01	45	6.43E-04	2.01E-05
	Little Forest Bat	1.79E+02	45	2.93E+01	1.64E-01
	Brown Antechinus	1.51E+02	45	2.03E+02	1.35E+00
	Brushtail Possum	5.04E+01	45	8.07E-01	1.60E-02
	Eastern Grey Kangaroo	1.92E+01	45	7.00E-01	3.64E-02
Ephemeral Dam	Eastern Yellow Robin	3.20E+01	91	3.45E+00	1.08E-01
	Nankeen Kestrel	3.20E+01	91	4.36E-03	1.36E-04
	Pacific Black Duck	3.20E+01	91	9.16E-06	2.86E-07
	White-faced Heron	3.20E+01	91	3.10E-05	9.68E-07
	Little Forest Bat	1.79E+02	91	1.41E+00	7.87E-03
	Brown Antechinus	1.51E+02	91	5.86E+00	3.89E-02
	Brushtail Possum	5.04E+01	91	2.33E-02	4.63E-04
	Eastern Grey Kangaroo	1.92E+01	91	2.02E-02	1.05E-03
Semi-permanent Dam	Eastern Yellow Robin	3.20E+01	21	9.54E+00	2.98E-01
	Nankeen Kestrel	3.20E+01	21	1.21E-02	3.77E-04
	Pacific Black Duck	3.20E+01	21	1.90E-04	5.94E-06
	White-faced Heron	3.20E+01	21	6.43E-04	2.01E-05
	Little Forest Bat	1.79E+02	21	2.93E+01	1.64E-01
	Brown Antechinus	1.51E+02	21	1.62E+01	1.08E-01
	Brushtail Possum	5.04E+01	21	6.46E-02	1.28E-03
	Eastern Grey Kangaroo	1.92E+01	21	5.60E-02	2.92E-03
Swamp Creek (SW4)	Eastern Yellow Robin	3.20E+01	1.6	2.02E+00	6.31E-02
	Nankeen Kestrel	3.20E+01	1.6	2.56E-03	7.98E-05
	Pacific Black Duck	3.20E+01	1.6	1.61E-05	5.03E-07
	White-faced Heron	3.20E+01	1.6	5.45E-05	1.70E-06
	Little Forest Bat	1.79E+02	1.6	2.48E+00	1.38E-02
	Brown Antechinus	1.51E+02	1.6	3.43E+00	2.28E-02
	Brushtail Possum	5.04E+01	1.6	1.37E-02	2.71E-04
	Eastern Grey Kangaroo	1.92E+01	1.6	1.18E-02	6.17E-04
	Cattle	4.00E-01	1.6	4.08E-06	1.02E-05

Table 6.2b Hazard Quotient Data for Total Fluoride Intake (Water + Food) for White-faced Heron			
	Units	Semi-permanent Dam	Swamp Creek
Body Weight	(kg)	0.55	
Intake Rate (IR) - water	(L/day)	0.1058	
Intake Rate (IR) - food	(kg/day)	0.0322425	
Home Range	(ha)	28,260	
Exposure Area	(ha)	4.5	5.0
Area Use Factor (AUF)	(%)	0.00016	0.00018
Exposure Point Concentration (EPC)	(mg/L)	21	1.6
Bioaccumulation Factor (BAF)	-	3.162	
Concentration in food	(mg/kg)	66.402	5.0592
Dose from food	(mg/kg/day)	6.20E-04	5.25E-05
Dose from water	(mg/kg/day)	6.43E-04	5.45E-05
Toxicity Reference Value	(mg/kg/day)	3.20E+01	
Hazard Quotient (HQ) - water	-	2.01E-05	1.70E-06
Hazard Quotient (HQ) - food	-	1.94E-05	1.64E-06
HQ water + HQ food	-	3.95E-05	3.34E-06

Table 6.3 Location Specific Hazard Quotients (HQs) for Aluminium in Surface Water for Birds and Mammals

Location	Receptor of Interest (ROI)	Toxicity Reference Value (mg/kg/day)	Exposure Point Concentration (mg/L)	Dose (mg/kg/day)	Hazard Quotient
Southern Vegetation Area	Eastern Yellow Robin	4.45E+01	0.8	3.53E+00	7.94E-02
	Nankeen Kestrel	4.45E+01	0.8	4.47E-03	1.00E-04
	Pacific Black Duck	4.45E+01	0.8	5.63E-06	1.27E-07
	White-faced Heron	4.45E+01	0.8	1.91E-05	4.28E-07
	Little Forest Bat	2.73E+01	0.8	8.68E-01	3.18E-02
	Brown Antechinus	2.30E+01	0.8	6.01E+00	2.62E-01
	Brushtail Possum	7.67E+00	0.8	2.39E-02	3.12E-03
	Eastern Grey Kangaroo	2.93E+00	0.8	2.07E-02	7.07E-03
Northern Vegetation Area	Eastern Yellow Robin	4.45E+01	48	1.27E+02	2.86E+00
	Nankeen Kestrel	4.45E+01	48	1.61E-01	3.62E-03
	Pacific Black Duck	4.45E+01	48	2.03E-04	4.56E-06
	White-faced Heron	4.45E+01	48	6.86E-04	1.54E-05
	Little Forest Bat	2.73E+01	48	3.13E+01	1.15E+00
	Brown Antechinus	2.30E+01	48	2.16E+02	9.43E+00
	Brushtail Possum	7.67E+00	48	8.61E-01	1.12E-01
	Eastern Grey Kangaroo	2.93E+00	48	7.46E-01	2.55E-01
Ephemeral Dam	Eastern Yellow Robin	4.45E+01	9.5	3.60E-01	8.08E-03
	Nankeen Kestrel	4.45E+01	9.5	4.55E-04	1.02E-05
	Pacific Black Duck	4.45E+01	9.5	9.56E-07	2.15E-08
	White-faced Heron	4.45E+01	9.5	3.23E-06	7.27E-08
	Little Forest Bat	2.73E+01	9.5	8.84E-02	3.24E-03
	Brown Antechinus	2.30E+01	9.5	6.12E-01	2.67E-02
	Brushtail Possum	7.67E+00	9.5	2.43E-03	3.17E-04
	Eastern Grey Kangaroo	2.93E+00	9.5	2.11E-03	7.20E-04
Semi-permanent Dam	Eastern Yellow Robin	4.45E+01	2	9.09E-01	2.04E-02
	Nankeen Kestrel	4.45E+01	2	1.15E-03	2.58E-05
	Pacific Black Duck	4.45E+01	2	1.81E-05	4.07E-07
	White-faced Heron	4.45E+01	2	6.13E-05	1.38E-06
	Little Forest Bat	2.73E+01	2	2.79E+00	1.02E-01
	Brown Antechinus	2.30E+01	2	1.55E+00	6.73E-02
	Brushtail Possum	7.67E+00	2	6.15E-03	8.02E-04
	Eastern Grey Kangaroo	2.93E+00	2	5.33E-03	1.82E-03
Swamp Creek (SW4)	Eastern Yellow Robin	4.45E+01	0.37	4.67E-01	1.05E-02
	Nankeen Kestrel	4.45E+01	0.37	5.91E-04	1.33E-05
	Pacific Black Duck	4.45E+01	0.37	3.72E-06	8.37E-08
	White-faced Heron	4.45E+01	0.37	1.26E-05	2.83E-07
	Little Forest Bat	2.73E+01	0.37	5.74E-01	2.10E-02
	Brown Antechinus	2.30E+01	0.37	7.94E-01	3.46E-02
	Brushtail Possum	7.67E+00	0.37	3.16E-03	4.12E-04
	Eastern Grey Kangaroo	2.93E+00	0.37	2.74E-03	9.35E-04
	Cattle	1.00E+00	0.37	3.93E-07	3.93E-07

Table 6.4 Location Specific Hazard Quotients (HQs) for Fluoride in Surface Water for Aquatic Flora and Fauna

COPEC	ROI	Criterion (mg/L)	Semi-permanent Dam (mg/L)	Swamp Creek (SW4) (mg/L)	Swamp Creek (SW5) (mg/L)	Swamp Creek (SW6) (mg/L)	Swamp Creek Reference (SW1 and SW2) (mg/L)
Fluoride	invertebrates	3.706	21	1.6	0.89	1.2	0.66
	fish	5.336	21	1.6	0.89	1.2	0.66
	plants	-	21	1.6	0.89	1.2	0.66
			HQ	HQ	HQ	HQ	HQ
Fluoride	invertebrates	3.706	5.66E+00	4.32E-01	2.40E-01	3.24E-01	1.78E-01
	fish	5.336	3.94E+00	3.00E-01	1.67E-01	2.25E-01	1.24E-01
	plants	-	-	-	-	-	-

Table 6.5 Location Specific Hazard Quotients (HQs) for Aluminium in Surface Water for Aquatic Flora and Fauna

COPEC	ROI	Criterion (mg/L)	Semi-permanent Dam (mg/L)	Swamp Creek (SW4) (mg/L)	Swamp Creek (SW5) (mg/L)	Swamp Creek (SW6) (mg/L)	Swamp Creek Reference (SW1 and SW2) (mg/L)
Aluminium	invertebrates	0.54	2	0.37	0.24	1.7	0.31
	fish	3.288	2	0.37	0.24	1.7	0.31
	plants	0.46	2	0.37	0.24	1.7	0.31

			HQ	**HQ**	**HQ**	**HQ**	**HQ**
Aluminium	invertebrates	0.54	3.70E+00	6.85E-01	4.44E-01	3.15E+00	5.74E-01
	fish	3.288	6.08E-01	7.87E-02	7.30E-02	5.17E-01	9.43E-02
	plants	0.46	4.35E+00	8.04E-01	5.22E-01	3.70E+00	6.74E-01

Table 6.6: Summary of Risk Profiles for Fluoride within the Investigation Area

Media	Receptor	Southern Vegetation Impact Area	Northern Vegetation Impact Area	Ephemeral Dam	Semi-Permanent Dam	Swamp Creek (SW4)
Surface Soils	Terrestrial Plants			n/a	n/a	n/a
	Soil Microbes			n/a	n/a	n/a
Sub-surface	Terrestrial Plants			n/a	n/a	n/a
	Soil Microbes			n/a	n/a	n/a
Surface Water	Terrestrial Plants			n/a	n/a	n/a
	Soil Microbes			n/a	n/a	n/a
	Eastern Yellow Robin					
	Nankeen Kestrel					
	Pacific Black Duck					
	White-faced Heron					
	Little Forest Bat					
	Brown Antechinus					
	Brushtail Possum					
	Eastern Grey Kangaroo					
	Aquatic invertebrates	n/a	n/a	n/a		
	Fish	n/a	n/a	n/a		
	Aquatic plants	n/a	n/a	n/a		
	Livestock –Cattle	n/a	n/a	n/a	n/a	

n/a	not assessed
	no unacceptable risk identified
	unacceptable risk identified but unlikely due to underlying assumptions
	potential unacceptable risk identified

Table 6.7: Summary of Risk Profiles for Aluminium within the Investigation Area

Media	Receptor	Southern Vegetation Impact Area	Northern Vegetation Impact Area	Ephemeral Dam	Semi-Permanent Dam	Swamp Creek (SW4)
Surface Soils	Terrestrial Plants			n/a	n/a	n/a
	Soil Microbes			n/a	n/a	n/a
Sub-surface Soils	Terrestrial Plants			n/a	n/a	n/a
	Soil Microbes			n/a	n/a	n/a
Surface Water	Terrestrial Plants			n/a	n/a	n/a
	Soil Microbes			n/a	n/a	n/a
	Eastern Yellow Robin					
	Nankeen Kestrel					
	Pacific Black Duck					
	White-faced Heron					
	Little Forest Bat					
	Brown Antechinus					
	Brushtail Possum					
	Eastern Grey Kangaroo					
	Aquatic invertebrates	n/a	n/a	n/a		
	Fish	n/a	n/a	n/a		
	Aquatic plants	n/a	n/a	n/a		
	Livestock – Cattle	n/a	n/a	n/a	n/a	

n/a	not assessed
	no unacceptable risk identified
	unacceptable risk identified but unlikely due to underlying assumptions
	potential unacceptable risk identified