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Preliminary Screening Level, Health Risk Assessment for Fluoride and Aluminium

Part of the Kurri Kurri Aluminium Smelter
Hart Road, Loxford

Prepared for:
Hydro Australia Pty Limited

Prepared by:
ENVIRON Australia Pty Ltd

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Prepared by:		**Authorised by:**			
Name:	Emma Struik/Jackie Wright	Name:	Fiona Robinson		
Title:	Manager/EnRiskS Health Risk Assessor	Title:	Manager – Hunter		
Phone:	02 9954 8100	Phone:	02 4962 5444		
Email:	estruik@environcorp.com	Email:	frobinson@environcorp.com		
Email:	jackie@enrisks.com	Signature:		Date:	6/5/16

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Acronyms and Abbreviations

CSM	Conceptual Site Model
DNA	Deoxyribonucleic Acid
g	gram
HRA	Health Risk Assessment
kg	kilogram
L	litre
mg	milligram
MRL	Minimal Risk Level
NOAEL	No Observed Adverse Effect Level
PTDI	Provisional Tolerable Daily Intake
PTWI	Provisional Tolerable Weekly Intake
RfD	Reference Dose
TC	Tolerable Concentration
TDI	Tolerable Daily Intake
TRV	Toxicity Reference Value

Executive Summary

ENVIRON Australia Pty Limited (ENVIRON) was commissioned by Hydro Aluminium Kurri Kurri Pty Ltd (Hydro) to undertake a preliminary screening level human health risk assessment (HRA) 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.

Soil and groundwater investigations identified elevated fluoride (F-) and aluminium (Al) concentrations at the site and in the surrounding environment especially within an area down gradient of the Alcan Mound where impacts to vegetation were apparent. 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 HRA report specifically addressed the third bullet point and is a companion document to the Ecological Risk Assessment being prepared by ENVIRON.

The preliminary screening level human health risk assessment (HRA) has been undertaken by ENVIRON in conjunction with Jackie Wright of EnRiskS. The objective of the HRA was to develop preliminary screening level guidelines that are protective of human health for the compounds of fluoride and aluminium under a range of current and possible future site uses.

The Hydro Kurri Kurri Smelter site comprises a 60 ha plant area and 2,000 ha of surrounding buffer lands. The investigations subject to this health risk assessment relate to an area of approximately 8 ha comprising the Alcan Mound and the down-gradient area of leachate impact as shown in Figure 1. This area is referred to as 'the notified area" in this report.

The preliminary screening level health risk assessment is a companion document to an Ecological Risk Assessment being prepared to evaluate risks to the environment on and off the notified area.

The health risk assessment was qualitative and involved a desktop evaluation of toxicity reference values for the compounds, identified source exposure pathways and mechanisms and development of preliminary screening levels based on the compound's toxicity and the possible exposure routes.

The preliminary screening levels identified are tabulated in Table E1 following.

Table E1 – Preliminary screening levels	
Land Use	**Prelimimary screening level**
Residential - soil	F 440mg/kg, Al 100,000mg/kg
Recreational - soil	F 1,200mg/kg, Al 210,000mg/kg
Industrial - soil	F 17,000mg/kg, Al non-limiting
Recreational – surface water	F 1.5mg/L, Al 9mg/L

The Geochemical Atlas of Australia shows background (naturally occurring) concentrations of total fluoride of between 30mg/kg and 1185mg/kg and aluminium concentrations of between 40 000mg/kg and 150 000 mg/kg occur in this region of Australia.

The evaluation found that the notified area needs no immediate action for the protection of human health under the limited current site use activities.

The preliminary screening levels developed for the notified area show that the most likely end land use comprising recreational or less sensitive uses are likely to be acceptable, subject to further detailed evaluation of the soil concentrations present.

The preliminary screening level of fluoride in surface water was exceeded on one occasion in the limited sampling undertaken. Further evaluation of surface water may be necessary to better evaluate any health risk and assess variability within the system.

1 Introduction

The Kurri Kurri Aluminium Smelter has operated at Hart Road Loxford, New South Wales since commissioning by Alcan in 1969. The Smelter includes a 60 hectare plant area and a 2,000 hectare buffer zone. Hydro Australia Kurri Kurri Pty Limited (Hydro) commenced ownership of the facility in 2001. In 2012, plant operations were curtailed and production ceased in September 2012. The site operations will remain in curtailment until a decision is made to re-open or decommission the facility.

In preparation for curtailment of the smelter operations, Hydro engaged ENVIRON Australia Pty Limited (ENVIRON) to undertake Phase 1 and Phase 2 environmental site assessment (ESA) of the plant and surrounding buffer land. Specifically, an area of the plant known as the Alcan Mound and a down-gradient area affected by leachate impact from the Alcan Mound (together referred to as ‘the notified area’) was identified to contain concentrations of fluoride and aluminium in soil and groundwater. The location of the notified area is shown on **Figure 1, Attachment A**.

A Tier 1 (Screening Level) HRA 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 range of contaminants were assessed that were considered contaminants of concern from the operations of the aluminium smelter. The Tier 1 HRA identified fluoride and aluminium as the main constituents occurring in excess of the generic threshold criteria and therefore required further assessment. ENVIRON, with the assistance of Jackie Wright from EnRiskS, have now conducted a preliminary level Human Health Risk Assessment (HRA) specific to fluoride and aluminium. The objective of the assessment was to derive preliminary screening levels for these compounds that are protective of the range of human receptors within the notified area and the potential receptors in surrounding areas.

This letter report outlines the background site conditions being evaluated including an identification of receptors; the methodology adopted for the assessment of preliminary screening levels including an assessment of conservatism and adequacy; the risk assessment process; and evaluation of measured concentrations against preliminary screening levels.

2 Scope of Work

The scope of work comprised:

- A desk top review of the existing international human health guidelines for fluoride and aluminium in soil and groundwater.
- Review of the basis and applicability of the identified guidelines.
- The development of a Conceptual Site Model (CSM). The CSM clearly defined the source, media contaminated, mechanism for transport / exposure, pathways of exposure and receptors.
- Selection of soil and groundwater preliminary screening levels considered most applicable for the notified area based on the available criteria and the CSM.
- A review the available soil and groundwater data against the selected criteria.

- Preparation of a report presenting the results of the desk top review, data assessment and preliminary screening level health risk assessment.

3 Conceptual Site Model

A conceptual site model was developed during site investigations (ENVIRON 2012). The notified area is zoned rural and is currently unused comprising a fenced closed landfill area and part of a fenced buffer zone. Access to the site is by maintenance workers only. Down-gradient land is used for rural purposes and recreational use of the waterway may occur.

Future use of the notified area is not known at this time but could include a combination of recreational, rural, industrial and commercial development. Future down-gradient land use could comprise recreational, rural and residential use, although residential use is considered to have a low likelihood. Recreational use of the downstream waterway is also possible. The health risk assessment has considered all possible future uses for the notified area and the down-gradient land.

Contaminants within the notified area are present in shallow accessible soils, shallow groundwater and surface water.

Exposure pathways considered as part of this health risk assessment are ingestion of soil and home-grown produce, inhalation of dust and dermal contact with soils. Chemical specific exposure assessment is included in the following sections.

4 Health effects of Key Chemicals

4.1 General

The potential for risks to human health from any chemical requires consideration of the human health response to the chemical, i.e. the health end point. The health end point can be non-carcinogenic, where a safe chemical dose exists (threshold value) and no adverse health risk occurs, or carcinogenic. Carcinogenic chemicals can be genotoxic, where no safe dose exists (non-threshold value), or non-genotoxic where a safe dose can exist. In all cases the dose-response relationship needs to be understood to assess the impacts of the chemical on human health.

Dose-response values (threshold or non-threshold) that are considered relevant to the characterisation of potential health effects associated with exposure to fluoride and aluminium have been selected from credible peer-reviewed sources as per Australian guidance (enHealth 2012, NEPC 1999).

4.2 Fluoride

4.2.1 General

Under standard conditions of temperature and pressure, fluorine is a halogen that exists as a light yellow-green, pungent, acrid gas of F_2 molecules. Fluoride has a molecular weight of 19.0 g/mol and it is the most electronegative element and has the highest chemical reactivity of all elements in the Periodic Table. Due to its high reactivity, fluorine is not present naturally in its elemental state; rather, it exists either as inorganic fluoride (i.e., ionic fluoride, [F^-], which is either free or matrix-bound in minerals or covalently bound in inorganic compounds such as hydrogen fluoride), or as organic fluoride (covalently bound in organic compounds). The assessment of whether inorganic fluorides are “toxic” is principally evaluated on the basis of hydrogen fluoride, calcium fluoride, sodium fluoride, and sulphur hexafluoride (CEPA 1993).

Inorganic and organic fluorides are present in all soils and water, as well as in the plants and animals consumed by humans for food. Except for industrial emissions, the largest environmental source of fluorides is fluoridated water supplies; fluorine is added deliberately with the aim of preventing dental caries. Fluoride is found in all natural waters at some concentration. In some parts of the world, deposits of rocks containing a high level of fluoride cause a large increase in the fluoride content of water or food and, consequently, the exposure to fluoride is sufficiently high (usually more than 6 mg/day) to cause endemic fluorosis, which is characterized by stiff joints, weight loss, brittle bones, anemia and weakness. Fluoride is also present in insecticides, rodenticides, floor polishes, in the petroleum and aluminium industries, glass etching and timber preservation and in dietary supplementation and toothpastes (up to 1 mg/g of toothpaste), and is added to water supplies (WHO 2000).

In relation to exposure, air is responsible for only a small fraction of total fluoride exposure. In addition vegetables and fruits normally have low levels of fluoride, however higher levels have been found in barley and rice and tea. In general fluoride levels are low in most food products including meat and fish products, however as fluoride accumulates in bone, products that include bones of fish such as salmon and sardines may contain higher levels of fluorine. Higher levels of exposure occur through the use of dental products (with child exposure from swallowing toothpaste estimated to be up to 0.75 mg per child per day). Intakes of fluoride by adults (from all sources including drinking water) has been estimated in Canada (CEPA 1993) to be approximately 2.2-4.1 mg/day (or 0.03-0.06 mg/kg/day), and for young children (aged 7 months to 4 years) approximately 0.6-2.1 mg/day (or 0.05-0.16 mg/kg/day). These intakes exceed the toxicity reference values (TRVs) identified for consideration in this assessment.

In fluoridated water supplies in Australia, the target fluoride levels are typically between 0.6 and 1 mg/L with the lower value typically adopted in hot climates, allowing for a higher intake of water (NHMRC 2011).

4.2.2 Health Effects

Fluoride has beneficial effects on teeth at low concentrations in drinking-water, but excessive exposure to fluoride in drinking-water, or in combination with exposure to fluoride from other sources, can give rise to a number of adverse effects. These range from mild dental fluorosis to crippling skeletal fluorosis as the level and period of exposure increases.

Approximately 75–90% of ingested fluoride is absorbed. Once absorbed into the blood, fluoride readily distributes throughout the body, with approximately 99% of the body burden of fluoride retained in calcium rich areas such as bone and teeth (dentine and enamel) where it is incorporated into the crystal lattice. In infants about 80 to 90% of the absorbed fluoride is retained but in adults this level falls to about 60%. Fluoride crosses the placenta and is found in mother's milk at low levels essentially equal to those in blood.

A large number of mutagenicity and genotoxic studies have been conducted with inorganic fluoride ion. While the results of these studies have been mixed, in general fluoride is not considered mutagenic or genotoxic. In addition, although there is some evidence for the carcinogenicity of inorganic fluoride, available data are inconclusive (WHO 2006, CEPA 1993).

In humans, acute (oral) exposure to fluoride may produce effects that include nausea, vomiting, abdominal pain, diarrhoea, fatigue, drowsiness, coma, convulsions, cardiac arrest, and death.

Skeletal fluorosis (including dental fluorosis) is a pathological condition that may arise following long-term exposure (either by inhalation or ingestion) to elevated levels of fluoride, and is considered to be the most relevant (and sensitive) effects in assessing long-term exposure to inorganic fluorides (and establishing public health guidelines). Although the incorporation of fluoride into bone may increase the stability of the crystal lattice, and render the bone less soluble, bone mineralization is delayed or inhibited, and consequently the bones may become brittle and their tensile strength reduced. In the preclinical phase, the "fluorotic" patient may be relatively asymptomatic, with only a slight increase in bone mass (detected radiographically). Sporadic pain and stiffness of the joints, chronic joint pain, osteosclerosis of cancellous bone, and calcification of ligaments are associated with the first and second clinical stages of skeletal fluorosis. Crippling skeletal fluorosis (clinical phase III) may be associated with limited movement of the joints, skeletal deformities, intense calcification of ligaments, muscle wasting, and neurological effects. Osteomalacia may be observed in fluorotic individuals with a reduced or suboptimal intake of calcium; secondary hyperparathyroidism may also be observed in a subset of patients.

Other effects identified in relation to long-term exposures to fluoride include endocrine effects (pineal function, thyroid function and diabetes) and neurological effects (IQ).

People with kidney impairment have a lower margin of safety for fluoride intake. Limited data indicates that their fluoride retention may be up to three times normal.

4.2.3 Identification of Quantitative Toxicity Reference Values

For the quantification of risks associated with exposure to fluoride in the environment (soil and water) an appropriate toxicity reference value relevant to ingestion (in particular) needs to be identified. Based on the available information in relation to adverse health effects associated with exposures to fluorides (where fluoride has not been identified as a genotoxic carcinogen), it is appropriate that a threshold dose-response approach is adopted.

It is noted that a number of soil guidelines are currently available for fluoride in soil. Many of these are not derived on a risk-based approach, utilising a published peer reviewed toxicity reference value. Rather a number of the available guidelines are based on background concentrations in a particular area (region) and are not specifically relevant for this evaluation.

The following table presents a summary of the currently available toxicity reference values for fluoride, based on published peer-reviewed sources as outlined in enHealth 2012.

Table 1: Available Toxicity Reference Values for Fluoride

Source	Toxicity Reference Value/Guideline	Basis/Comments
NHMRC (NHMRC 2011)	Guideline value (maximum) of 1.5 mg/L in drinking water Equivalent to TDI = 0.04 mg/kg/day	Guideline value adopted is consistent with the WHO guideline as noted below. The guidelines note that there is a narrow margin between concentrations producing beneficial effects to teeth and those producing objectionable fluorosis. The minimum concentration required for a protective effect against detail caries is 0.5 mg/L.
NHMRC (NHMRC 2006)	Upper limit = 0.7 mg/day for infants 0-6 months, 1.3 mg/day for children 1-3 years and 10 mg/day for ages 9 years and older (including pregnant and lactating women).	Upper limit of intake set at a level associated with moderate tooth fluorosis, based on a LOAEL of 0.1 mg/kg/day from community studies for infants and children up to 8 years of age and an uncertainty factor of 1. For older children and adults the upper limit is based on a NOAEL of 10 mg/day based on the relationship between fluoride intake and fluorosis and an uncertainty factor of 1. No data exists that shows increased susceptibility for pregnant or lactating women.
RIVM (1991)	TDI = 0.07 mg/kg/day	Limited information is available in relation to the basis for the TDI derived, however it is understood to be based on a human study.
WHO (WHO 2006)	1.5 mg/L in drinking water Equivalent to TDI = 0.04 mg/kg/day	Guideline derived on the basis of a level at which dental fluorosis (a mottling of the teeth that can occur occasionally) should be minimal. Concentrations of greater than 4 mg/L have been associated with skeletal fluorosis. The WHO guidance also notes that local conditions (diet, water consumption etc.) should also be taken into account and the guideline should not be considered to be a fixed value.
ATSDR (ATSDR 2003)	Chronic oral MRL = 0.05 mg/kg/day	MRL for fluorine (soluble fluoride) derived on the basis of a NOAEL of 1.5 mg/kg/day associated with musculoskeletal effects in a human study and application of a 3 fold uncertainty factor.
Health Canada (CEPA 1993)	Provisional TDI = 0.2 mg/kg/day	Provisional TDI based on a NOAEL of 0.2 mg/kg/day associated with skeletal effects in a number of human studies and an uncertainty factor of 1. It is noted that this provisional guideline has been recently reviewed by the

Table 1: Available Toxicity Reference Values for Fluoride		
Source	**Toxicity Reference Value/Guideline**	**Basis/Comments**
		Office of the Auditor General of Canada and found to be inadequately protective of potential adverse effects.
USEPA (USEPA)	RfD = 0.06 mg/kg/day	RfD (last review in 1987) for fluorine (soluble fluoride) based on a NOAEL of 0.06 mg/kg/day associated with dental fluorosis in a human study and application of an uncertainty factor of 1. This RfD has been adopted by the USEPA in the derivation of the tap water and soil Regional Screening Levels (RSLs). In addition the same RfD has been adopted in the derivation of the Italian soil guideline.

Based on Table 1, there is reasonable consistency between the TRV adopted by NHMRC, WHO, ATSDR and USEPA. These are all generally based on the protection of the most sensitive effects of dental/skeletal fluorosis and are based on human studies. The TRV derived from the NHMRC guideline value (maximum) has therefore been adopted in this assessment.

For the purpose of deriving a soil or recreational water quality guidelines the following has been considered:

- An oral TRV = 0.04 mg/kg/day has been adopted. This is based on the maximum water quality guideline of 1.5 mg/L;
- In Australia, drinking water supplies are fluoridated. Based on information presented by NHMRC (NHMRC 2011, NHMRC 2007), target levels of fluoride in drinking water in most states (excluding Queensland where drinking water is not fluoridated) range from 0.6 to 1 mg/L, which comprise up to 66% of the maximum concentration allowable. As drinking water in NSW is fluoridated these intakes need to be accounted for when considering guidelines for both soil and recreational water as these will be in addition to normal daily water intakes.
- Intakes from sources other than drinking water (such as food and dental hygiene practices) are variable and less well evaluated. Based on the available information these intakes have been conservatively estimated to comprise approximately 20% of the adopted TRV.
- Based on the above, 10% of the adopted TRV may be considered in the derivation of intakes from other sources that include soil and recreational water. This assumption is conservative as it is based on generic information regarding intakes of fluoride from drinking water in the area as well as other sources.

4.2.4 Additional Consideration of Uptake Pathways

Dermal absorption of fluoride is considered to be negligible as fluoride is an ion and expected to have low membrane permeability.

The potential for uptake of fluoride into home-grown produce is considered to be limited as most fluoride salts are strongly sorbed to soil. The low solubility of many fluoride salts, and the root endodermis acting as a barrier means that transport of fluoride from the roots to shoots is limited. The most significant uptakes of fluoride into plants relates to soluble fluoride salts, particularly on plant leaf surfaces. Review of fluorides by OEHHA (2012) derived a range of soil to plant uptake factors, where the higher uptake factors related to the uptake of fluoride from deposited soluble salts on the leaf surface. In the assessment presented this mechanism is not expected to be significant (as smelter emissions have ceased and the fluorides are bound with soil and dust generation is not expected to be significant). Hence for the purpose of deriving a soil guideline, the plant uptake factor for root crops of 0.009 (mg/kg plant per mg/kg soil) and protected (from dust deposition) aboveground crops of 0.004 (mg/kg plant per mg/kg soil) has been considered.

4.2.5 Derived Soil Criteria

For the range of land-use scenarios evaluated the following preliminary screening levels are derived (on the basis of the equations and assumptions adopted in enHealth 2012 and the NEPM revision, refer to attached tables for assumptions and calculations):

- **Residential = 440 mg/kg**. This is based on the most sensitive receptor being a young child resident, and the potential for intakes via ingestion, dust inhalation and ingestion of home-grown produce (10% of diet);
- **Recreational = 1200 mg/kg**;
- **Commercial/industrial = 17000 mg/kg**.

The above criteria are dominated by the soil ingestion pathway. For the residential scenario it has been assumed that young children ingest 100 mg of soil and dust every day of the year, 100% of the soluble fluoride reported in soil is bioavailable, and 90% of the allowable fluoride intake is already accounted for via drinking water and other (non-soil) sources. These assumptions are highly conservative and relevant for the derivation of screening level or preliminary criteria. However they can be further refined with the collection of additional data. These refinements may include the following:

- Characterising the concentration of fluoride in drinking water in the area. The preliminary criteria have been based on an assumption that fluoride levels in drinking water are at the maximum target levels. The actual concentration will vary in different areas. Lower levels of background fluoride intakes will enable a higher contribution from soil intakes to be considered in deriving the fluoride soil concentration. If the background intakes were lowered from 90% (considered in the above values) to 80%, the residential soil criteria would increase from 440 mg/kg to 890 mg/kg.
- Characterising the bioavailability of fluoride in soil. In the preliminary criteria it has been conservatively assumed that soluble fluoride in soil is 100% bioavailable. However fluoride is present in soil as inorganic or organic complexes which will bind in different ways to the soil particles. As fluoride will be bound to the soil particles (to varying degrees) the bioavailability of fluoride, once ingested, will be lower than 100%. There are a range of factors that affect the bioavailability of fluoride in soil however site-specific

bioavailability testing could be undertaken in soil where the concentrations exceed the preliminary criteria. This could be used to further refine the calculation of risk or provide a revised, more site-specific, soil criteria. For example if the bioavailabilty of fluoride in soil were 70%, the preliminary criteria would be increased to 570 mg/kg. If the bioavailability were even lower at 40%, the criteria would increase to 800 mg/kg.

4.2.6 Recreational Water Quality Criteria

For most contaminants, a recreational water quality guideline can be derived from the drinking water guideline using a factor that accounts for the difference in water intakes during swimming (taken to be up to 200 mL/day) compared with drinking water (2000 mL/day), consistent with guidance available from NHMRC (2008) for establishing recreational water quality guidelines. This then allows a 10 fold factor to be applied to the drinking water criteria. This approach is suitable where the compound being evaluated is not commonly found in drinking water.

In the case of fluoride, where intakes comprising a significant proportion of the TRV are derived from fluoridated water and other dietary sources, only 10% of the TRV can be permitted from other sources that include recreational water. If the factors noted above are both considered, they essentially cancel each other out and a conservative approach would be that a preliminary recreational water quality guideline be set equal to the drinking water guideline of **1.5 mg/L**.

As mentioned this is a conservative approach to the derivation of a recreational water quality guideline, and the guideline is considered to be preliminary only. It assumes that there is direct contact with fluoride in surface water every day of the year and that 10% of the daily water intake occurs during recreational uses of this water. Once more specific recreational water uses are understood in the area it is expected that the preliminary guideline could be adjusted to account for more appropriate exposure scenarios. For example if recreational water were accessed and used for only 2 days per week in the warmer 6 months of the year (which is likely to be more reasonable, yet still conservative), the recreational water guideline would increase from 1.5 mg/L to 10.5 mg/L. Further, if intakes of water during recreational activities were not 0.2 L/day, but 0.02 mL/day (equivalent to 4 teaspoons of water) the guideline would further increase to 105 mg/L. In addition, the assumption that 90% of fluoride intakes occurs via drinking water and other sources is conservative. As noted above, if this were modified, the recreational water guideline would be higher still.

4.3 Aluminium

4.3.1 General

Aluminium is the most abundant metallic element. It is widely distributed and constitutes approximately 8% of the earth's surface layer. Since aluminium is a very reactive element, it is never found as the free metal (i.e., the metallic state) in nature, but exists in only one oxidation state (+3). As such, it is found combined with other elements, most commonly with oxygen, silicon, and fluorine. Generally, these compounds are found in soil, minerals, (igneous) rocks, and clays, and are the natural forms of aluminium rather than the silvery metal. The metal is obtained from aluminium-containing minerals, primarily bauxite.

Aluminium is released into the environment both by natural processes and from anthropogenic sources. The general population may be exposed to aluminium via diet and drinking water, through medicinal (such as vaccines, antacids, analgesics, dialysis fluids) and cosmetic products (such as antiperspirants), and by inhalation of ambient air. Infants may also be exposed via breast milk or infant formulae. Occupational exposure to aluminium occurs in the refining of the primary metal, in secondary industries that produce and use aluminium products, and in welding.

Aluminium is poorly absorbed following either oral or inhalation exposure and is essentially not absorbed dermally. Under normal circumstances, the absorption of aluminium by the gastrointestinal tract is low (usually, 0.1-1% of ingested aluminium is absorbed), since the gastrointestinal tract represents a barrier to aluminium absorption and aluminium is precipitated in the small intestine and excreted in the faeces. The rate of absorption largely depends on the form of ingested aluminium and the presence of dietary constituents which can complex with aluminium and thereby enhance or inhibit its absorption by forming absorbable (usually water-soluble) complexes or not-absorbable (usually water-insoluble) compounds (HCN 2009). When absorption does occur (primarily for more soluble compounds), aluminium is distributed mainly in bone, liver, testes, kidneys, and brain.

Although in general absorption and bioavailability appear to parallel water solubility, insufficient data are available to directly extrapolate from solubility in water to bioavailability and/or toxicity. However, most aluminium compounds can be separated into 2 groups: compounds not soluble in water (including metallic aluminium) and compounds soluble in water (including aluminium chloride, aluminium nitrate, aluminium lactate and aluminium sulfate). Most toxicological information is available for soluble aluminium compounds.

Aluminium (soluble compounds) has been shown to produce neurotoxic effects as well as bone and blood toxicity in humans undergoing medical treatment and in some specific occupational environments. Whilst not applicable to the general population this evidence does support the identification of neurotoxicity and developmental neurotoxicity as endpoints of concern in the human health risk assessment for aluminium. Limited data suggests that exposure to aluminium is linked to Alzheimer’s disease, however the weight of evidence for causality for the observed associations is weak. At this time the hypothesis has not been rejected, though there is a lack of evidence supporting this relationship. (CEPA 2010).

The limited data available does not suggest that aluminium compounds are carcinogenic. It is noted that IARC has not classified aluminium compounds, however it has classified the exposure circumstance of aluminium production as carcinogenic to humans. Genotoxicity studies have reported both positive and negative results. Review of the positive results by EFSA identified that these were the result of indirect mechanisms that were not likely to be of relevance to humans (CEPA 2010).

4.3.2 Identification of Quantitative Toxicity Reference Values

For the quantification of risks associated with exposure to aluminium in the environment (soil and water) an appropriate toxicity reference value relevant to ingestion (in particular) needs to be identified. Based on the available information in relation to adverse health effects associated with exposures to aluminium (where aluminium has not been identified as a genotoxic carcinogen), it is appropriate that a threshold dose-response approach is adopted.

The following table presents a summary of the currently available toxicity reference values for aluminium, based on published peer-reviewed sources as outlined in enHealth 2012.

Table 2: Available Toxicity Reference Value for Aluminium

Source	Toxicity Reference Value/Guideline	Basis/Comments
NHMRC (NHMRC 2011)	No health based drinking water guideline established Aesthetic guideline of 0.2 mg/L	Intakes of aluminium from drinking water are very low (with bioavailability from water the same/similar to food). Review by NHMRC considered the available toxicological data for aluminium insufficient to set a guideline.
WHO (WHO 2011)	A water quality guideline of 0.9 mg/L could be derived from the JECFA PTWI	Derived value found to be higher than practicable levels (and aesthetic levels) when used for coagulation in drinking water. Drinking water intakes only contribute <5% of the total intake. Uncertainty remains in relation to absorption from drinking water
JECFA (2011)	Provisional tolerable weekly intake = 2 mg/kg PTDI = 0.3 mg/kg/day	Value is derived for aluminium compounds in food including food additives. Based on a NOAEL of 30 mg/kg/day and consideration of a 100 fold safety factor. It is noted that the assessment identified that much of the aluminium ingested may be insoluble and poorly absorbed however additional data is required to demonstrate that aluminium is not bioavailable from potassium aluminium silicate-based pearlescent pigments.
ATSDR (ATSDR 2008)	Chronic oral MRL = 1 mg/kg/day	MRL based on a LOAEL of 100 mg/kg/day associated with neurological effects in mice exposed to soluble aluminium lactate in the diet during gestation, lactation and postnatal for 2 years, and an uncertainty factor of 300. An adjustment factor of 0.3 was also used to account for the higher bioavailability of aluminium lactate compared with aluminium in the diet and drinking water.
Health Canada (CEPA 2010)	LOAEL = 50 mg/kg/day	Derived from evaluation of range of studies where LOAELs could be determined from studies on soluble aluminium salts. A safety factor of 100 fold was considered in the evaluation of exposure using this value.
USEPA	Provisional RfD = 1 mg/kg/day	Provision peer-reviewed toxicity value available from the USEPA, used in the derivation of Regional Screening Levels for aluminium in soil. The full basis for the RfD is not publically available.

Based on the above, where a guideline has been established it is generally in the order of **1 mg/kg/day**, hence this value has been adopted in this assessment. The guidelines that have been established relate to soluble aluminium compounds. For other insoluble aluminium compounds it is expected that very little will be absorbed into the body and hence there are no guidelines available for these compounds. At this site the form of aluminium in the soil has not been determined (however it is unlikely to be present in the forms considered as food additives by JECFA), hence it is a conservative assumption that the form of aluminium present in soil is soluble. In groundwater, it is reasonable that a guideline based on soluble aluminium compounds is adopted provided it is compared against a filtered water sample.

In relation to background intakes of aluminium, there is limited data available for Australia (particularly given the poor absorption of aluminium from most sources), however review of intakes in Canada (CEPA 2010) found intakes from all sources (drinking water, food/beverages and air) comprised up to 0.27 mg/kg/day for children aged 6 months to 4 years (most sensitive group evaluated in this assessment). The proportion of daily intake that is from soluble compounds is not defined and is expected to be only a small fraction of this intake as the intake is dominated by food, where soluble aluminium compound use is limited. For the purpose of this assessment it has been conservatively assumed that background intakes comprise 30% of the oral TRV.

4.3.3 Consideration of Other Uptake Pathways

Dermal absorption of aluminium is considered to be negligible based on the available data (CEPA 2010).

The potential for uptake of aluminium into home-grown produce is considered to be negligible as review (ATSDR 2008) indicated that aluminium is not taken up into plants, rather it is bio-diluted (where present as a soluble compound only).

4.3.4 Derived Soil Criteria

For the range of land-use scenarios evaluated the following preliminary screening levels are derived (on the basis of the equations and assumptions adopted in enHealth 2012 and the NEPM revision):

- **Residential = 100,000 mg/kg**. This is based on the most sensitive receptor being a young child resident, and the potential for intakes via ingestion and dust inhalation;
- **Recreational = 210,000 mg/kg**;
- **Commercial/industrial = not limiting** (the calculated concentration is 2,900,000 mg/kg or 2.9 kg Al/kg soil which is not possible, hence it has been determined as not limiting).

As noted in Section 4.2.5, the approach adopted for establishing the above preliminary soil criteria for aluminium is conservative.

4.3.5 Recreational Water Quality Criteria

For most contaminants, a recreational water quality guideline can be derived from the drinking water guideline using a factor that accounts for the difference in water intakes during swimming (taken to be up to 200 mL/day) compared with drinking water (2000 mL/day). This then allows a 10 fold factor to be applied to the drinking water criteria. This approach is suitable where the compound being evaluated is not commonly found in drinking water. Low levels of aluminium are present in drinking water and hence it is appropriate that such an approach is adopted for this compound.

Applying this approach to the WHO health based guideline of 0.9 mg/L results in a preliminary health based recreational screening level of 9 mg/L. This guideline is relevant to soluble aluminium compounds, i.e. those reported in a filtered water sample. In addition it is noted that the value is higher than the aesthetic guideline of 0.2 mg/L. Aluminium is soluble at pH values less than 6.0 and at higher pH values a milky white precipitate can form which is not desirable. pH values within the notified area and downgradient are consistently above pH 6.0 and a milky white precipitate has not been observed. Therefore demonstrating that a milky white precipitate is not likely at the concentrations present and adopting the aesthetic is unnecessarily conservative.

As noted in Section 4.2.6, the approach adopted for establishing the above preliminary recreational water quality guideline for aluminium is conservative.

4.4 Uncertainty

As discussed in Sections 0 and 4.2.6 the approach adopted for establishing soil and recreational water preliminary screening levels for fluoride (in particular) are conservative and will result in an overestimation of risk. The assumptions adopted in the preliminary criteria can be further refined to enable the derivation of more site-specific derived criteria. This includes consideration of the following:

- Characterising the concentration of fluoride in drinking water in the area.
- Characterising the bioavailability of fluoride in soil.
- Determining the most likely exposure scenarios that may occur in relation to potential surface water bodies that may be constructed/located in the areas evaluated.

5 Comparison of preliminary screening levels to measured soil and water concentrations

Tables 3 and 4 compare preliminary measured soil and water concentrations to the preliminary screening levels for fluoride and aluminium. Table 3 represents the limited evaluation of soil concentrations for soluble fluoride within the vegetation impacted area and shows that concentrations in soils are below the screening level that is protective of human health for residential use and less sensitive land use.

Table 3: Evaluation of Soil concentrations – Summary Table (mg/kg)

Analyte	n	Maximum	n > PSL residential	n > PSL recreational
Soluble fluoride	7	324	0	0

Samples collected from with the vegetation impact area
PSL – preliminary screening level

Concentrations in surface water presented in Table 4 for a limited number of samples collected from Swamp Creek show concentrations of fluoride and aluminium both below the preliminary screening level for recreational use of surface water with the exception of one minor exceedance in September 2012.

Table 4: Evaluation of Surface Water Analytical Results for recreational use – Summary Table (mg/L)

Analyte	August 2012			September 2012		
	n	Maximum	n >PSL	n	Maximum	n >PSL
Soluble Fluoride	5	1.5	0	5	1.6	1
Total Aluminium	5	0.59	0	5	1.7	0

Samples collected from Swamp Creek (SW1, SW2, SW4, SW5, SW6).
PSL – preliminary screening level

5.1 Adequacy of the Assessment

This preliminary screening level assessment has been undertaken to assess the potential of health risks arising from the presence of fluoride and aluminium in soil and water. The investigation data collated to date in these media is considered to be limited in extent and does not represent a detailed site investigation. However, the data collected to date is considered sufficient to provide a preliminary indication of the health risks posed by the site and to focus further site investigations.

6 Conclusions

The information presented in this report is a preliminary screening evaluation only and further assessment is needed to better characterise the potential risks. The assumptions made are highly conservative and have likely resulted in an overestimation of the risks. Specifically, assumptions regarding the existing level of fluoride in drinking water in the area, the potential bioavailability of fluoride in soil (where elevated levels are present) and most likely/realistic recreation water use scenarios.

The preliminary screening levels developed for the notified area show that the most likely end land use comprising recreational or less sensitive uses will be acceptable, subject to further detailed evaluation of the soil concentrations present.

The preliminary screening level of fluoride in surface water was exceeded on one occasion in the limited sampling undertaken. Further evaluation of surface water may be necessary to better evaluate any health risk and assess variability within the system.

7 References

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8 Limitations

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

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.

8.1 User Reliance

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

Attachment A

Tables

Derivation of Investigation Levels
HIL A - Low Density Residential

Summary of Exposure Parameters		Abbreviation	units	Parameter	References/Notes
Soil and Dust Ingestion Rate	- Young children (0-5 years)	IR_{SC}	mg/day	100	Schedule B7, Table 5
Time Spent Outdoors		ETo	hours	4	Schedule B7, Table 5
Time Spent Indoors		ETi	hours	20	Schedule B7, Table 5
Lung Retention Factor		RF	-	0.375	Schedule B7, Table 5
Particulate Emission Factor		PEFo	(m^3/kg)	2.9E+10	Calculated for scenario, refer to Equations 19 and 20 and assumptions in Schedule B7
Indoor Air Dust Factor		PEFi	(m^3/kg)	2.6E+07	As per Equation 21 based assumptions presented in Schedule B7
Fraction of indoor dust comprised of outdoor soil		TF	-	0.5	Assume 50% soil concentration present in dust as noted in Schedule B7
Body weight	- Young children (0-5 years)	BW_C	kg	15	Schedule B7, Table 5
Exposure Frequency		EF	days/year	365	Schedule B7, Table 5
Exposure Duration	- Young children (0-5 years)	ED_C	years	6	Schedule B7, Table 5
Averaging Time (noncarcinogenic)		AT_T	days	ED*365	Calculated based on ED for each relevant age group, multiplied by 24 hours for the assessment of inhalation exposures
Averaging Time (carcinogenic)		AT_{NT}	days	25550	Based on lifetime of 70 years, multiplied by 24 hours for the assessment of inhalation exposures

Threshold Calculations - Young Child Aged 2-3 years

Compound	Toxicity Reference Value Oral (TRV_O) (mg/kg/day)	GI Absorption (GAF) (unitless)	Toxicity Reference Value Dermal (TRV_D) (mg/kg/day)	Oral Bioavailability BA_O (%)	Dermal Absorption Factor (DAF) (unitless)	Background Intake Oral/Dermal (BI_O) (% of TDI)	Toxicity Reference Value Inhalation (TRV_I) (mg/m^3)	Background Intake Inhalation (BIi) (% of TC)		Plant Uptake Factor (incl % intake) Adults (kg/day) (eqn 16)	Plant Uptake Factor (incl % intake) Children (kg/day) (eqn 16)	Pathway Specific HILs (mg/kg)				Derived Soil HIL (not rounded) (mg/kg) (eqn 2 for relevant pathways)	Derived Soil HIL (to 1 or 2 s.f.) (mg/kg)
												Soil Ingestion (eqn 3)	Home grown produce (eqn 15)	Dermal (eqn 6)	Dust (eqn 9)		
fluoride	0.04	1		100%		90%	0.14	90%			7.0E-05	6.0E+02	1.7E+03	NA	2.3E+06	445	**440**
aluminium	1	1		100%		30%	3.50	30%				1.1E+05	NA	NA	4.0E+08	104973	**100000**

Derivation of Investigation Levels
HIL C - Recreational

Summary of Exposure Parameters		Abbreviation	units	Parameter	References/Notes
Soil and Dust Ingestion Rate	- Young children (0-5 years)	IR_{SC}	mg/day	50	50% of HIL A assumption, Schedule B7, Table 5
Time Spent Outdoors		ETo	hours	2	Schedule B7, Table 5
Time Spent Indoors		ETi	hours	0	Schedule B7, Table 5
Lung Retention Factor		RF	-	0.375	Schedule B7, Table 5
Particulate Emission Factor		PEFo	(m^3/kg)	2.6E+07	As per Equation 21 based assumptions presented in Schedule B7
Body weight	- Young children (0-5 years)	BW_C	kg	15	Schedule B7, Table 5
Exposure Frequency		EF	days/year	365	Schedule B7, Table 5
Exposure Duration	- Young children (0-5 years)	ED_C	years	6	Schedule B7, Table 5
Averaging Time (noncarcinogenic)		AT_T	days	ED*365	Calculated based on ED for each relevant age group, multiplied by 24 hours for the assessment of inhalation exposures
Averaging Time (carcinogenic)		AT_{NT}	days	25550	Based on lifetime of 70 years, multiplied by 24 hours for the assessment of inhalation exposures

Threshold Calculations - Young Child Aged 2-3 years

Compound	Toxicity Reference Value Oral (TRV_O) (mg/kg/day)	GI Absorption (GAF) (unitless)	Toxicity Reference Value Dermal (TRV_D) (mg/kg/day)	Oral Bioavailability BA_O (%)	Dermal Absorption Factor (DAF) (unitless)	Background Intake Oral/Dermal (BI_O) (% of TDI)	Toxicity Reference Value Inhalation (TRV_I) (mg/m^3)	Background Intake Inhalation (BIi) (% of TC)		Pathway Specific HILs (mg/kg)			Soil Vapour HIL (mg/m^3) (eqn 12)	Derived Interim Soil Gas HIL - Threshold (to 1 or 2 s.f.) (mg/m3)	Derived Soil HIL (not rounded) (mg/kg) (eqn 2 for relevant pathways)	Derived Soil HIL (to 1 or 2 s.f.) (mg/kg)
										Soil Ingestion (eqn 3)	Dermal (eqn 6)	Dust (eqn 9)				
fluoride	0.04	1		100%		90%	0.14	90%		1.2E+03	NA	1.1E+07			1200	**1200**
aluminium	1	1		100%		30%	3.50	30%		2.1E+05	NA	2.0E+09			209978	**210000**

Derivation of Investigation Levels
HIL D - Commercial / Industrial

Summary of Exposure Parameters	Abbreviation	units	Parameter	References / Notes
Soil and Dust Ingestion Rate - Adults	IR_{SA}	mg/day	25	50% of HIL A assumption, Schedule B7, Table 5
Time Spent Outdoors	ETo	hours	1	Schedule B7, Table 5
Time Spent Indoors	ETi	hours	8	Schedule B7, Table 5
Lung Retention Factor	RF	-	0.375	Schedule B7, Table 5
Particulate Emission Factor	PEFo	(m^3/kg)	3.7E+10	Calculated for scenario, refer to Equations 19 and 20 and assumptions in Schedule B7
Indoor Air Dust Factor	PEFi	(m^3/kg)	2.6E+07	As per Equation 21 based assumptions presented in Schedule B7
Fraction of indoor dust comprised of outdoor soil	TF	-	0.5	Assume 50% soil concentration present in dust as noted in Schedule B7
Body weight - Adults	BW_C	kg	70	Schedule B7, Table 5
Exposure Frequency	EF	days/year	240	Schedule B7, Table 5
Exposure Duration - Adults	ED_C	years	30	Schedule B7, Table 5
Averaging Time (noncarcinogenic)	AT_T	days	ED*365	Calculated based on ED for each relevant age group, multiplied by 24 hours for the assessment of inhalation exposures
Averaging Time (carcinogenic)	AT_{NT}	days	25550	Based on lifetime of 70 years, multiplied by 24 hours for the assessment of inhalation exposures

Threshold Calculations - Adult Worker

Compound	Toxicity Reference Value Oral (TRV_O) (mg/kg/day)	GI Absorption (GAF) (unitless)	Toxicity Reference Value Dermal (TRV_D) (mg/kg/day)	Oral Bioavailability BA_O (%)	Dermal Absorption Factor (DAF) (unitless)	Background Intake Oral / Dermal (BI_O) (% of TDI)	Toxicity Reference Value Inhalation (TRV_I) (mg/m^3)	Background Intake Inhalation (BIi) (% of TC)		Pathway Specific HILs (mg/kg) Soil Ingestion (eqn 3)	Dermal (eqn 6)	Dust (eqn 9)	Soil Vapour HIL (mg/m^3) (eqn 12)	Derived Interim Soil Gas HIL - Threshold (to 1 or 2 s.f.) (mg/m3)	Derived Soil HIL (not rounded) (mg/kg) (eqn 2 for relevant pathways)	Derived Soil HIL (to 1 or 2 s.f.) (mg/kg)
fluoride	0.04	1		100%		90%	0.14	90%		1.7E+04	NA	8.7E+06			17000	**17000**
aluminium	1	1		100%		30%	3.50	30%		3.0E+06	NA	1.5E+09			2975031	**3000000**

Attachment B

Figure