Australian Government

Department of Health
Australian Industrial Chemicals Introduction Scheme

Lead and lead manufacturing byproducts

Evaluation statement

30 June 2022

Table of contents

Contents

AICIS evaluation statement

Subject of the evaluation

Lead and lead manufacturing byproducts.

Chemicals in this evaluation

Name	CAS Registry Number
Lead	7439-92-1
Lead oxide	1335-25-7
Lead oxide (PbO)	1317-36-8
Lead alloy, base, dross	69011-59-2
Lead alloy, base, dross (Pb, Sn)	69011-60-5
Lead, dross, antimony rich	69029-45-4
Lead, dross, bismuth rich	69029-46-5
Lead, antimonial	69029-50-1
Lead, antimonial, dross	69029-51-2
Lead, dross	69029-52-3
Slags, lead reverbatory smelting	69029-58-9
Flue dust, lead refining	69029-67-0
Lead ores, sintered	69029-74-9
Residues, lead smelting	69029-79-4
Residues, precious metal recovery lead refining	69029-80-7
Slags, lead smelting	69029-84-1
Slags, precious metal recovery lead refining	69029-85-2
Lead, zinc dross	94551-60-7

Reason for the evaluation

The Evaluation Selection Analysis indicated a potential risk to the environment.

Parameters of evaluation

This evaluation considers the environmental risks associated with lead containing substances that are emitted from industrial facilities that process lead ore concentrate to produce finished lead metal or bullion.

Secondary lead processing facilities, such as those recycling lead acid batteries and lead scrap, are not considered in this evaluation.

Summary of evaluation

Summary of introduction, use and end use

The primary manufacture of lead metal and bullion is undertaken at 2 facilities in Australia, located at Port Pirie, South Australia, and Mount Isa, Queensland. Based on National Pollutant Inventory (NPI) data, these 2 facilities are the major point sources of lead emissions to the Australian environment. Chemicals in this group are products or byproducts of the primary manufacture of elemental lead.

Lead metal is listed on the 2006 Australian High Volume Industrial Chemicals List (AHVICL) with a total reported introduction volume of 100 000–1 000 000 tonnes per year. Lead oxide (PbO) has a reported Australian introduction volume of 100–1000 tonnes per annum. Lead smelting slags are listed on the 2002 AHVICL at a volume band of 10 000–99 999 tonnes per year.

The major end uses of lead metal are export or as a component in lead acid batteries.

Environment

Summary of environmental hazards

The environmental hazards identified in this evaluation are related to the release of ionic lead, which is very toxic to aquatic organisms and which bioaccumulates in most organisms. The environmental hazards of ionic lead were previously assessed under the Inventory Multi-tiered Assessment and Prioritisation (IMAP) framework (NICNAS 2020).

It is not currently possible to categorise the environmental hazards of metals and other inorganic chemicals according to standard persistence, bioaccumulation and toxicity (PBT) hazard criteria.

Environmental hazard classification

These chemicals satisfy the criteria for classification according to the Globally Harmonized System of Classification and Labelling of Chemicals (GHS) for environmental hazards as follows. This evaluation does not consider classification of physical hazards and health hazards.

Environmental Hazard	Hazard Category	Hazard Statement
Acute Aquatic	Acute aq. – Cat. 1	H400: Very toxic to aquatic life
Chronic Aquatic	Chronic aq. – Cat. 1	H410: Very toxic to aquatic life with long lasting effects

Summary of environmental risk

The primary environmental concern for chemicals in this group is the potential for release of ionic lead(2+) to aquatic environments and soils from production at primary lead manufacturing facilities. Current practices and facilities result in the release of lead to all environmental compartments, leading to elevated lead levels in natural waters, sediments, soils and biota. This is of concern because bioavailable forms of ionic lead(2+) are very toxic to aquatic life and many aquatic and terrestrial species can accumulate lead.

The primary manufacture of lead metal occurs at refineries and smelters in Mount Isa and Port Pirie. The environmental risk was characterised by reviewing available environmental monitoring data at these sites and comparing lead concentrations against relevant guideline values in the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZ Water Quality Guidelines) for natural waters and sediments, and the *National Environment Protection (Assessment of Site Contamination) Measure 1999* (Site Contamination NEPM) for soils. Environmental monitoring data from within the last 5 years was available for most compartments. However, environmental concentrations of lead in soils discussed in this evaluation are derived from studies of samples taken in 2012 and earlier, and biomonitoring data from around Mount Isa is from samples taken in 2010. Both sites are subject to state environmental authorities or Environmental Protection Authority (EPA) licenses, and the requirements therein have also been considered.

Significant historical contamination at these sites is also a source of lead emissions to the environment. Although emissions arising from past lead contamination are beyond the parameters of this evaluation, it can be difficult to differentiate between current and historical sources.

At the Mount Isa facility, lead is mainly released via emissions to air, which is deposited to soils and surface water. Lead is emitted to air from point sources (stacks) as well as fugitive sources such as dust arising during processing, manual handling and transport, and from slag stockpiles. The facility includes the smelter and a lead mine, and separating lead emissions arising from mining from those arising from smelting is not always possible.

Around Mount Isa, bioavailable lead contents in several freshwater samples were below site specific water quality thresholds, indicating low risk according to the ANZ Water Quality Guidelines. However, lead concentrations in freshwater around Mount Isa depend on seasonal rainfall and flooding, which can remobilise lead stored in sediments. Bioavailable lead concentrations in sediments exceed the guideline values at many sites. In several cases, sediment toxicity has been demonstrated and lead has not been ruled out as a causal factor. Elevated lead levels in various fish species indicate bioaccumulation of lead in aquatic organisms. These findings indicate potential risks to aquatic ecosystems in this area due to high lead levels in sediments.

Lead contents in soils at Mount Isa exceed Site Contamination NEPM investigation limits. While the soil monitoring studies have focussed on human health, differences in lead concentrations around the township of Mount Isa indicate that ecological investigation limits are likely to be exceeded, suggesting that further investigation is required. In the absence of further information, these findings indicate potential risks to soil-dwelling and other terrestrial life.

An extensive data set regarding the environmental impact of lead smelting at the Mount Isa refinery has been commissioned by industry and is publicly available. The available data set has been used to improve practices at the plant and identify areas for remediation where risks to aquatic life have been identified. The current environmental authority supports an extensive, ongoing environmental monitoring program. However, the most recently published information indicates that further work is required to assess risks to aquatic and terrestrial ecosystems posed by high concentrations of lead in sediments and soils.

The environmental authority covers monitoring and reporting of lead in air, deposited dust, tailings, water releases, groundwater, sediment and soil. Trigger values and objectives are given for lead in ambient air, receiving waters and groundwater, and sediment trigger values are to be developed. Exceedances must be assessed and followed up with appropriate actions to minimise environmental harm. Although adverse effects of atmospheric lead release on soil quality must be monitored, no corresponding trigger values for lead in soils are specified. It is not clear if any environment-focused soil assessment has been undertaken to date.

At the Port Pirie refinery, lead is similarly emitted to air and deposited to soils and surface waters. Lead contaminated waters are also discharged to the surrounding marine environment via First Creek.

In coastal and marine waters adjacent to the Port Pirie facility, the dissolved lead concentration near the First Creek effluent outlet greatly exceeds the 80% protection level for marine ecosystems specified in the ANZ Water Quality Guidelines. Lead concentrations in marine surface waters are high near the First Creek discharge point and decrease rapidly with increasing distance, indicating that ongoing effluent discharge is the source of lead contamination. Dissolved lead partitions to marine sediments in the area, and available data indicate that ongoing deposition of lead to the sediment compartment has not decreased significantly since the 1970s. Combined with observed bioaccumulation of lead in indicator organisms, this signals that there may be risks to aquatic organisms at this location.

Sediment samples in the marine environment near Port Pirie exceed both default and upper ANZ Water Quality Guideline values at many sites, indicating potential high-level toxicity problems. Although the risk posed by high lead concentrations in these sediments may be mitigated by the formation of relatively stable complexes, toxicity studies to support this are absent from the available literature.

Lead contents in soils exceed Site Contamination NEPM investigation limits at Port Pirie. Spatial variation of lead concentrations in soils indicates that lead contamination is caused by aerial deposition from the refinery, arising from both stack and fugitive emissions. While the soil monitoring studies have focussed on human health, lead concentrations around the township of Port Pirie indicate that ecological investigation limits are likely exceeded, suggesting that further investigation is required. Risks to offsite ecological receptors posed by groundwater contamination at the site are currently being assessed. In the absence of further information, these findings indicate potential risks to soil-dwelling and other terrestrial life.

For Port Pirie, the EPA licence covers targets and reportable limits for lead emissions to air and water releases to First Creek. The facility licence does not stipulate monitoring requirements or investigation trigger levels for lead in the surrounding marine water, marine sediments or soils. The current practices and regulations therefore do not appear to ensure protection of the marine or terrestrial ecosystems surrounding Port Pirie. Further environmental risk assessment and ongoing management are required to reduce risks posed to marine and terrestrial ecosystems by lead compounds in water, sediments and soils at this site.

Based on the available environmental and biomonitoring data, the localised emission of lead and lead compounds during the primary manufacture of lead metal remains an environmental concern in Australia.

Proposed means for managing risk

Environment

The environmental risks identified in this evaluation as a result of lead primary manufacturing should continue to be managed and mitigated by the relevant state regulatory authorities. Where potential risks have been identified, further investigation should be undertaken and, if necessary, risk management approaches should be strengthened to reduce the risk. Such management should be supported by ongoing environmental monitoring programs for all impacted environmental compartments.

The routine collection and publication of environmental and biomonitoring data from all facilities that manufacture lead metal and for all impacted environmental compartments is recommended to assist in formulating facility specific risk management measures.

Conclusions

Conclusions of this evaluation are based on the information described in this evaluation statement.

Considering the proposed means of managing risks, the Executive Director is satisfied that the identified environment risks can be managed within existing risk management frameworks. This is provided that all requirements are met under environmental, workplace health and safety and poisons legislation as adopted by the relevant state or territory and the proposed means of managing the risks identified during this evaluation are implemented.

Note: Obligations to report additional information about hazards under *Section 100* of the *Industrial Chemicals Act 2019* apply.

Supporting information

Rationale

This evaluation considers the environmental risks associated with the primary manufacture of lead metal from lead containing mineral concentrates.

The manufacture of lead metal is known to be a source of anthropogenic emissions of lead and lead compounds to the Australian environment. Lead metal is manufactured at 2 sites in Australia: the Mount Isa smelter in Queensland and Port Pirie refinery in South Australia. These facilities are the primary point sources of lead emissions in Australia. Emissions of lead compounds to the environment from these facilities are of concern because they can release bioavailable lead(2+) ions, which are toxic to wildlife and humans.

The primary manufacture of lead is through the refining of lead containing mineral concentrates. This process involves the deliberate and/or incidental formation of 17 lead containing substances which are listed chemicals on the Australian Inventory of Industrial Chemicals (the Inventory). The production of these chemicals during the manufacture of lead metal is expected to contribute to total lead emissions in Australia. This evaluation; therefore, also considers the risks arising from production of these additional lead containing chemicals.

Chemical Identity

The 18 chemicals in this group consist of target products, process intermediates and byproducts from the primary manufacture of lead metal. Most of these compounds are unknown, of variable composition, complex reaction products, or of biological origin (UVCB). Chemical descriptions are based on specific descriptions from ChemID Plus (NLM 2021) and general information on the chemical composition of lead drosses, slags, residues and smelter flue dust.

Drosses are solids that precipitate during the cooling of molten lead in air. They primarily comprise lead oxides, including mixed metal oxides, but may also contain elemental lead and other metal or metal sulfide impurities (Lead REACH Consortium 2018).

Slags are refining byproducts that are separated in the liquid phase during smelting and can contain elemental lead and lead oxide mixed with varying compositions of calcium oxide, iron oxide and silica (Davidson et al. 2014; Noller et al. 2017).

Studies on lead smelter flue dust have demonstrated a complex mixture of products. Lead containing components include lead sulfide, lead sulfate, basic lead sulfate, mendipite ($Pb_3O_2Cl_2$) and elemental lead (Davidson et al. 2014; Noller et al. 2017; Sobanska et al. 1999). Non-lead components comprise oxides and sulfides of zinc, iron, and cadmium (Sobanska et al. 1999).

CAS No.	7439-92-1
Chemical Name	Lead

Synonyms	lead metal elemental lead lead flake lead scrap refined lead rough lead bullion
Atomic Weight (g/mol)	207.2

CAS No.	1317-36-8
Chemical Name	lead oxide (PbO)
Synonyms	lead monoxide lead oxide lead(2+) oxide lead(II) oxide litharge plumbous oxide
Molecular Formula	PbO
Molecular Weight (g/mol)	223.2

CAS No.	1335-25-7
Chemical Name	Lead oxide
Molecular Formula	PbO

CAS No.	69029-74-9
Chemical Name	Lead ores, sintered
Synonyms	lead smelter sinter
Chemical Description	Sinter formed by heating finely divided lead concentrates and fluxes to a softening condition to agglomerate without fusion.

CAS No.	69029-50-1
Chemical Name	Lead, antimonial
Synonyms	antimonial lead
Chemical Description	Product from treatment of antimony slag from softening furnace and baghouse product with soda ash and coal.

CAS No.	69029-52-3
Chemical Name	Lead, dross
Chemical Description	A scum formed on the surface of molten lead. Presumed to be primarily lead oxides, including mixed metal oxides, but may also contain elemental lead, other metals or metal sulfides.

CAS No.	69011-59-2
Chemical Name	Lead alloy, base, dross
Chemical Description	A scum formed on the surface of molten lead base alloys. Presumed to contain lead oxides and mixed metal oxides, and may also contain elemental lead, other metals or metal sulfides. Other metals may include aluminium, arsenic, nickel and antimony.

CAS No.	69011-60-5
Chemical Name	Lead alloy, base, dross (Pb, Sn)
Chemical Description	Oxides formed during melting, refining, and casting of solders. Major constituents are oxides of tin, lead and antimony; minor constituents are iron, nickel, sulfur, arsenic, copper and silver.

CAS No.	69029-45-4
Chemical Name	Lead, dross, antimony rich
Synonyms	antimony slag from softening furnace
Chemical Description	A scum or slag formed on the surface of molten lead during the process of removing antimony along with arsenic by oxidation with air. It consists of antimony, arsenic and lead oxides.

CAS No.	69029-46-5
Chemical Name	Lead, dross, bismuth rich

Synonyms	lead refinery bismuth liquation dross
Chemical Description	A scum formed on the surface of molten lead during the process of removing bismuth by the addition of calcium and magnesium. It consists of lead containing calcium and magnesium bismuthides.

CAS No.	69029-51-2
Chemical Name	Lead, antimonial, dross
Synonyms	lead refinery caustic arsenic dross
Chemical Description	A scum formed on the surface of antimonial lead. Consists primarily of sodium arsenate and sodium antimonate with some lead oxide and free caustic soda.

CAS No.	94551-60-7
Chemical Name	Lead, zinc dross
Chemical Description	Presumed to contain lead oxides and zinc oxides, and may also contain elemental lead, other metals or metal sulfides.

CAS No.	69029-84-1
Chemical Name	Slags, lead smelting
Synonyms	lead-smelting slags lead smelter slag smelting slags, lead-smelting
Chemical Description	Slag formed as the feed progresses through the blast furnace in lead smelting. Consists primarily of metallic elements and oxides of calcium, magnesium and silicon.

CAS No.	69029-58-9
Chemical Name	Slags, lead reverbatory smelting
Chemical Description	Byproduct from the smelting of lead ores, scrap lead or lead smelter dross. Consists primarily of oxides and silicates of antimony and lead.

CAS No.	69029-85-2
Chemical Name	Slags, precious metal recovery lead refining

Synonyms	inorganic slag
Chemical Description	Inorganic slags produced from treatment of calcined scrap metals and oxides with borax, litharge and sodium carbonate followed by fusion.

CAS No.	69029-67-0
Chemical Name	Flue dust, lead refining
Synonyms	lead smelter flue dust
Chemical Description	By-product of refining lead ores or lead from secondary sources obtained from baghouse and electrostatic precipitators and as slurry from scrubbers. May contain lead sulfide, lead sulfate, basic lead sulfate, mendipite ($Pb_3O_2Cl_2$) and elemental lead, and oxides and sulfides of zinc, iron, and cadmium.

CAS No.	69029-79-4
Chemical Name	Residues, lead smelting
Synonyms	lead refinery oxides
Chemical Description	Residues from processing equipment used in a lead refinery. Consists primarily of lead and lead oxide.

CAS No.	69029-80-7
Chemical Name	Residues, previous metal recovery lead refining
Chemical Description	Residues from treating lead refinery ores and residues containing precious metals with sodium boroplumbate followed by thermal fusion.

Relevant Physical and Chemical Properties

Elemental lead is a soft, malleable metal with a high density of 11.34 grams per cubic centimetre (g/cm^3). It has a low melting point of 327°C and a vapour pressure of 0.133 kiloPascals (kPa) at 980°C (Davidson et al. 2014). On contact with oxygenated water, metallic lead can be oxidised and dissolve to release lead(2+) ions (Atkins et al. 2006), especially in the presence of oxidising acids and weak organic acids (Davidson et al. 2014). In the presence of carbonate and silicate anions, the corrosion of lead metal is moderated by the formation of poorly soluble lead species that protect the lead surface. In air, lead metal oxidises rapidly in the presence of carbon dioxide to form protective carbonate layers containing lead carbonate ($PbCO_3$) (Carr et al. 2004) and basic lead carbonate ($2PbCO_3{\cdot}Pb(OH)_2$) (Davidson et al. 2014). Such protective species are soluble in certain acids, as well as in aqueous alkalis, in which they form plumbite ions (PbO_2^{2-}) and other oxyanions.

The following table gives water solubility data for lead metal, lead monoxides, lead carbonates and some constituents of lead flue dust in milligrams of dissolved lead per litre (mg Pb_{diss}/L). For lead metal, data obtained using the OECD Transformation and Dissolution protocol (OECD T/Dp) and relevant to the GHS classification strategy for metals (UNECE 2017) are given. The water solubility is taken to indicate the potential of these chemicals to release ionic lead(2+) into water:

Material	**Solubility (mg Pb_{diss}/L)**	**Reported Test Conditions**	**Source**
Pb Metal (powder, 75 µm)	0.390	OECD T/Dp, pH = 6, 1 mg/L loading, 7 days	(REACHa)
Pb Metal (powder, 75 µm)	0.639	OECD T/Dp, pH = 6, 1 mg/L loading, 28 days	(REACHa)
PbO	16–21	20–22 °C	(Weast 1976)
α-PbO	46.8	25 °C	(Carr et al. 2004)
β-PbO	98.9	25 °C	(Carr et al. 2004)
PbS	0.74	18 °C	(Weast 1976)
$PbSO_4$	29.0	25 °C	(Weast 1976)
$PbO \bullet PbSO_4$	35	0 °C	(Carr et al. 2004)
$PbCO_3$	0.85	20 °C	(Weast 1976)
$2PbCO_3 \cdot Pb(OH)_2$	‘Insoluble’	Not reported	(Weast 1976)
$Pb_3O_2Cl_2$	‘Insoluble’	Not reported	(Weast 1976)

Slightly soluble lead sulfide undergoes weathering and oxidation in the environment to generate moderately soluble lead sulfate (Heidel and Tichomirowa 2011; Sutley et al. 1999).

No physical or chemical property data were identified for the 15 UVCBs in this group. However, based on the descriptions of these substances and the way they are formed, they can be classed as lead-containing inorganic solids. Lead drosses, slags and residues from lead refining are understood to be a mixture of lead metal and lead oxides with various other impurities (NICNAS 2019). Therefore, these substances can be conservatively assumed to have solubilities in the range of 0.390–98.9 mg Pb_{diss}/L. Flue dust from lead refining has been shown to contain lead sulfide, lead sulfate, basic lead sulfate and mendipite (Noller et al. 2017; Sobanska et al. 1999), and can; therefore, be conservatively assumed to have a solubility of up to 35 mg Pb_{diss}/L. The water solubilities of these substances are also expected to be dependent on pH and presence of carbonate anions.

Introduction and Use

Australia

Primary lead processing for the manufacture of lead metal (refined and bullion) is undertaken at 2 locations in Australia. Lead bullion is typically exported for further refining. Lead metal and other chemicals in this group are reportedly introduced (imported or manufactured) in high volumes of up to 1 000 000 tonnes annually. The major use of refined lead is in batteries.

Lead metal is manufactured in Australia by primary processing of lead mineral concentrates, which are typically rich in lead sulfide (Davidson et al. 2014). At Port Pirie, primary lead processing is used to produce refined lead metal (99.97–99.99% Pb) for export (Bartel and Gowan 2013). The majority of lead is sold into the lead acid battery market. Mt Isa produces lead bullion (99.6% Pb), which is exported and further refined overseas (Pafumi et al. 2013).

Refined lead metal has industrial uses in the manufacture of batteries, sheeting, lead compounds, alloys, cable sheathing, radiation shielding, ammunition, and hobby uses such as lead weights for sinkers and SCUBA diving (Australian Government 2005). The largest use of lead in Australia is in batteries for transport vehicles and communications (Australian Government 2005; King et al. 2014). However, these uses are beyond the parameters of this evaluation.

Lead metal is listed on the 2006 AHVICL with a total reported introduction volume of 100 000–1 000 000 tonnes per year (NICNAS 2006). Available information indicates that the production of lead bullion has ranged from 68 000 to 231 000 tonnes per year between 1963 and 2007 (ABARE 2008). Nyrstar has also reported the primary production of lead metal at Port Pirie in the range 160 000–195 000 tonnes per year from 2010–2018 (Bartel and Gowan 2013; Nyrstar NV 2014; Nyrstar NV 2016; Nyrstar NV 2018; Nyrstar NV 2019).

Of the 17 remaining chemicals covered in this assessment, only lead smelting slags (CAS No. 69029-84-1) and lead monoxide (CAS No. 1317-36-8) have reported Australian introduction volumes. Information gathered by the previous National Industrial Chemicals Notification and Assessment Scheme (NICNAS) indicated that lead monoxide had an introduction volume of 100–1000 tonnes per year. Lead smelting slags are listed on the 2002 AHVICL at a volume band of 10 000–99 999 tonnes per year (NICNAS 2002).

Many UVCB byproducts produced in the primary manufacture of lead metal are recycled into the manufacturing process or placed into long term on-site storage for future reprocessing. In some cases, high value drosses are sold as source of other valuable metals, such as copper (Pafumi et al. 2013). Smelter slag from Pb-Zn refineries and smelters has historically been used by surrounding communities in landfill, sports fields, driveways, paving material and drainage lines (Morrison and Gulson 2007). However, historical uses of lead refinery slag are beyond the parameters of this evaluation.

International

Internationally, primary lead processing produces over 4 000 000 tonnes annually. Lead monoxide and several other chemicals in this group have high reported international introduction volumes of up to 1 000 000 tonnes per year in the European Union. The major use of lead metal and lead monoxide is in batteries. The remaining chemicals are mainly reported as metal manufacturing intermediates.

In 2018, global primary production of refined lead was in excess of 4 000 000 tonnes across more than 70 countries (International Lead and Zinc Study Group 2019). The majority of global lead metal production (both primary and secondary) occurs in China, followed by the United States of America and South Korea. In Asia, primary refining accounts for 49% of lead metal production. Secondary lead production, which is outside the parameters of this evaluation, is the major manufacture source in the Americas. Lead metal is mainly used in the production of lead acid batteries, rolled and extruded products, lead compounds, shot and ammunition (Davidson et al. 2014; International Lead and Zinc Study Group 2019; King et al. 2014). The production of lead acid batteries accounts for 85% to 86% of the global lead metal consumption (Davidson et al. 2014; International Lead and Zinc Study Group 2019).

While lead monoxide occurs as an intermediate in the lead production process, isolated lead monoxide is mainly used as plates for lead sulfuric acid batteries (Carr et al. 2004; US EPA 2016). Lead monoxide also has further uses including optical and electronic glasses, glazes, as a vulcanizing agent for rubbers and plastics, as a high temperature lubricant and as an intermediate in the synthesis of other lead derived chemicals. In the European Union, lead monoxide is registered under Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) legislation at volumes of 100 000–1 000 000 tonnes annually (REACHb). In the USA, 45 400–113 000 tonnes of lead monoxide were produced annually in 2011–2015 according to the United States Environmental Protection Agency (US EPA) Chemical Data Reporting (CDR) data (US EPA 2016).

Of the remaining 15 chemicals, several are registered under REACH (ECHA 2020b) and are reported in the US EPA CDR data (US EPA 2016). These are mostly reported as intermediates in metals recovery, with some use in batteries and as fillers. Lead smelting slags (CAS No. 69029-84-1) also have reported use in concrete applications and water works (REACHc). The introduction volumes of these chemicals are given in the following table:

Inventory Chemical Name	REACH Total Tonnage Band	CDR 2016 Aggregate Production Volume
Lead alloy, base, dross	N/A	45–227 tonnes
Lead alloy, base, dross (Pb, Sn)	10 000–100 000 tonnes	454–4 540 tonnes
Lead, dross, antimony rich	1000–10 000 tonnes	N/A
Lead, dross, bismuth rich	1000–10 000 tonnes	N/A
Lead, antimonial	N/A	250 000 tonnes
Lead, antimonial, dross	1000–10 000 tonnes	50 tonnes
Lead, dross	1000–10 000 tonnes	113 000–227 000 tonnes
Slags, lead reverbatory smelting	100 000–1 000 000 tonnes	113 000–227 000 tonnes
Flue dust, lead refining	10 000–100 000 tonnes	45 400–113 000 tonnes
Slags, lead smelting	100 000–1 000 000 tonnes	62 000 tonnes

Existing Australian Regulatory controls

A detailed assessment of the regulatory status of lead in Australia and internationally is given in the IMAP Environment Tier II Assessment for water soluble lead(2+) salts (NICNAS 2020). The discussion below highlights the regulations and standards that are relevant to this evaluation.

Environment

Lead and lead compounds are subject to reporting under the Australian NPI. Under the NPI, emissions of lead and lead compounds are required to be reported annually by facilities that exceed emission, fuel and electricity demand thresholds (NPI 2019). Reportable emissions include direct release to air, surface water and land as well as those resulting from fuel combustion and other ancillary activities (NPI 1999). Discharges to groundwater are included as emissions to land. Discharges to tailing storage facilities are not reported as emissions, but emissions from such facilities are reportable to NPI.

For ambient air quality, the *National Environment Protection (Ambient Air Quality) Measure* (Air Quality NEPM) sets a national environment protection standard for lead of 0.5 micrograms per cubic metre (µg/m^3), calculated as an annual average (Commonwealth of Australia 2016), measured on total suspended particles.

For surface waters, medium and low reliability default guideline values have been published for lead in the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZ Water Quality Guidelines) (ANZECC 2000b). To protect 95% of species in a *slightly to moderately disturbed* ecosystem, the guideline values are 3.4 and 4.4 micrograms of lead per litre (µg Pb/L) for freshwater and marine water, respectively. For *highly disturbed systems*, these same guideline values should apply. However, where this is not possible, application of the corresponding 80% protection levels of 9.4 and 12 µg Pb/L, respectively, may sometimes be negotiated. Where default guideline values are exceeded, corrections for site *high*specific water hardness may be applied (ANZG 2018a).

Sediment default guideline values for the fine sediment fraction (grain size less than 2 mm) are included in the ANZ Water Quality Guidelines. The default guideline value and upper guideline value (GV-high) represent, respectively, the concentration below which there is a low risk of unacceptable effects occurring and the concentration at which toxicity related adverse effects might already be expected. For lead the default guideline value and GV-high are 50 milligrams of lead per kilogram of dry sediment (mg Pb/kg dw) and 220 mg Pb/kg dw, respectively (ANZG 2018b).

Groundwater guidelines follow those given for surface waters and are based on current and possible use scenarios. Where groundwater is used as a source of drinking water a limit of 10 µg/L is adopted (NEPC 2013).

In soils, added contaminant limits for lead in the Site Contamination NEPM have been developed to protect soil-dwelling species (Commonwealth of Australia 2013). Ecological investigation limits (EILs) represent the level above which further investigation or evaluation is required and are the sum of the added contaminant limit and ambient background concentration at the site. For soils where the contaminant has been present for less than 2 years (i.e. a freshly contaminated soil where the toxic effects of lead are expected to be greater than in aged or leached soils), the added contaminant limit for the protection of 80% of species, applied to urban residential areas and public open space, is 270 mg added Pb/kg (Commonwealth of Australia 2013). The Site Contamination NEPM also specifies health investigation levels (HILs) ranging from 300 mg Pb/kg for residential areas to 1500 mg Pb/kg for commercial/industrial areas, above which appropriate health investigation and evaluation is required. For irrigated soil, a cumulative contaminant loading limit (CCL) guideline value has been set at 260 kilograms of lead per hectare (kg Pb/ha) (ANZECC 2000b). Nationally, an upper limit on lead contamination in biosolids has been recommended (300 mg Pb/kg dry weight) (NRMMC 2004).

The emission of lead and other pollutants at the 2 sites where lead is manufactured in Australia is regulated under state legislation with reference to national guidelines. Licensing arrangements made by each state specify emission standards requiring monitoring and reporting of emissions, as well as other activities.

State Regulatory Controls – Queensland

In Queensland, the state government issues environmental authorities, which regulate environmentally relevant activities through the *Environmental Protection Act (1994)*. The environmental authority for the lead smelter in Mount Isa mandates monitoring and reporting for lead in air, tailings, mine affected water, groundwater, sediment and soil and specifies trigger values and contaminant limits that are consistent with national guidelines (Queensland Government 2021).

Point source (stack) air emissions, tailings and groundwater are to be monitored quarterly for lead. Ambient air quality is to be monitored in the community for lead containing total suspended particulates and dust deposition with a contaminant limit of 0.5 µg/m^3 and trigger value of 100 micrograms per square metre per day (µg/m^2/day), respectively, calculated as an annual average. The former is consistent with the Air Quality NEPM (Commonwealth of

Australia 2016). Potential adverse environmental effects on soil quality caused by release of contaminants to air must be monitored.

Water quality must be monitored at various downstream compliance points. For controlled release of mine affected water, release limits for total lead range from 4 micrograms per litre (µg/L) to 401.2 µg/L, depending on monitoring location and increasing according to flow rate. The lowest release limit, for the lowest flow rate, also represents a water quality objective for receiving waters, and is based on the hardness-adjusted default guideline value from the ANZ Water Quality Guidelines (ANZECC 2000b). Containment systems for surface water must be in place, but, in the case that all appropriate measures have been taken and uncontrolled release from the containment area cannot be prevented, total lead measured at a downstream monitoring point is limited to 67 µg/L.

For groundwater, low and high trigger values for dissolved lead range from 3.4 µg/L to 11 µg/L depending on the groundwater environment. The low trigger values are consistent with the 95% default guideline value for freshwater (ANZECC 2000b).

The environmental authority also requires that sediment monitoring trigger levels and contaminant limits be developed with reference to the ANZ Water Quality Guidelines. If trigger levels are exceeded, the results must be compared to levels from reference points to determine if these are also exceeded.

Exceedances caused by activities at the site must be reported within 48 hours, followed by a report detailing the cause and actions to prevent or minimise environmental harm.

State Regulatory Controls – South Australia

In South Australia, emissions of lead and other pollutants at the Port Pirie refinery are regulated under the *Environmental Protection Act (1993)* through an operating licence issued by the Environment Protection Authority (EPA) of South Australia (SA).

Total suspended particulate lead in air is to be monitored in the community with limits between 0.4 µg/m^3 and 1.6 µg/m^3, based on an annual average, and 0.45 µg/m^3 to 2.2 µg/m^3, based on a quarterly average, depending on the distance from the refinery (SA EPA 2021a). The lowest of the annual averages is within the Air Quality NEPM standard (Commonwealth of Australia 2016). Submission of a dust management plan is required, which must specify trigger values for particulate emissions, though not necessarily in terms of lead concentrations.

Water discharged from the sedimentation ponds to First Creek is also subject to total lead monitoring based on a 7 day rolling average, for which the lead target value is 680 µg/L and the reportable limit is 1715 µg/L.

The licence also stipulates that air quality monitoring data be made publicly available. The EPA and public are to be notified within 72 hours of exceedances, and details of causes and remedial actions are to be reported to the EPA.

The EPA have also approved a voluntary site contamination assessment proposal submitted pursuant to section 103I of the *Environment Protection Act (1993)* and submission of a restricted scope site contamination audit report (SA EPA 2022). The objectives of the audit were to assess the current and potential future risk to offsite human and ecological receptors posed by groundwater contamination from the site.

International Regulatory Status

United Nations

Wastes containing lead and lead compounds are listed in Annex I to the Basel Convention Controlling Transboundary Movements of Hazardous Wastes and their Disposal (UNEP 1989).

Canada

Lead is listed under Schedule 1 (the Toxic Substance List) of the *Canadian Environmental Protection Act 1999* (Government of Canada 2020).

An Environmental Code of Practice for base metal smelters and refineries includes primary lead manufacture (Environment Canada 2006b). For lead, this recommends a target ambient air quality of 2 µg/m^3, a maximum month mean concentration in water effluent of 0.2 milligrams per litre (mg/L), and target ambient water quality guideline objectives of 1−7 µg/L (Environment Canada 2006a).

European Union

Lead metal and lead oxide (PbO) (CAS RN 1317-36-8) have been identified as Substances of Very High Concern (SVHC) under the REACH legislation, due to their reproductive toxicity. These substances are currently listed on the Candidate List for SVHC for Authorisation for inclusion in Annex XIV to REACH (ECHA 2020a). Once included in Annex XIV to REACH (the Authorisation List), use of these chemicals may be severely restricted.

Environmental Exposure

Lead metal, refined and bullion, is a primary product from the zinc-lead refinery in Port Pirie, SA, and the lead smelter in Mount Isa, QLD. Lead metal is derived from mineral concentrates of predominantly lead sulfide. Generally, the production of lead metal proceeds as follows: 1) lead ore is concentrated by flotation, 2) the lead sulfide concentrate is sintered to remove sulfur and produce lead oxide, 3) the sintered material is reduced to lead metal in a blast furnace, and 4) impurities are removed through drossing, softening, desilvering and final refining (Bartel and Gowan 2013; Davidson et al. 2014; Pafumi et al. 2013). The preparation and concentration of lead ore is beyond the parameters of this evaluation.

In the sintering step, mineral concentrate, recycled solids, and process chemicals are combined and roasted at high temperature (sintered) to remove sulfur and produce a lead oxide intermediate (Pafumi et al. 2013). The hot sinter off-gases are treated in spray chambers to reduce the off-gas temperature and are passed through a baghouse to remove the majority of the particulates before being vented through stack (Pafumi et al. 2013).

Sintered lumps of lead oxide are then mixed with coke and fed to the blast furnace which yields crude, molten lead metal. Lead containing emissions from off-gas treatment are as described for the sintering process. Slag from the blast furnace is granulated with high volumes of water before being dewatered and transported to the lead slag stockpile for storage or future treatment, such as concentrating and reprocessing.

The molten lead from the blast furnace flows to the drossing kettle where it is cooled and sulfur is added to separate copper as dross. The drossed lead is then cast as ingots for export at Mount Isa or further purified to a saleable metal product at Port Pirie. High grade dross contains significant amounts of copper and can be sold as a process by-product. Low grade dross contains significant amounts of lead and is fed back into the smelting process at the blast furnace.

While efforts have been made to reduce the emissions of lead and related compounds at both sites, NPI data indicates that primary lead production is one of the most significant industry sources of lead emissions to the Australian environment (NPI 2021b). Approximately 1100 tonnes of lead and lead compounds were released into the Australian environment from all reporting sources in 2019–2020. More than half of these emissions (670 tonnes) were attributed to diffuse sources, mainly dust disturbance from paved and unpaved roads (520 tonnes), and industry sources accounted for approximately 390 tonnes. By facility, Nyrstar Port Pirie and Mount Isa Mines were the 2 largest point sources of these lead emissions (NPI 2021b), contributing a combined 93 tonnes (8% of total emissions, 24% of industry emissions).

According to NPI data for 2019–2020, stack emissions release lead and lead compounds to air at both facilities (NPI 2021a; NPI 2021c). Stack emissions released 5.2 tonnes and 18 tonnes of lead and compounds to air in at Port Pirie and Mount Isa, respectively. In the same reporting year, 34 and 15 tonnes of lead and compounds, respectively, were released to air from fugitive sources, which are defined as emissions not released through a vent or stack (NPI 1999). Such fugitive emission sources may include dust arising during processing, manual handling and transport, and from slag stockpiles. Emissions to water may arise from spray chambers used in the sintering step and the large amounts of water used during slag processing. At Port Pirie, 20 tonnes of lead and lead compounds was released to water in 2019–2020. At Mount Isa, used process water is returned to the process water head tank for re-use (Pafumi et al. 2013), and the Mount Isa Smelter has reported no emissions of lead and lead compounds to water in the same reporting year. However, emissions to land, which include any release to groundwater, of 0.033 tonnes were reported. No emissions to land were reported at Port Pirie.

Significant historical contamination at these primary manufacturing sites is also a source of lead emissions to the environment (Noller et al. 2009; Public Health Services 2013). Furthermore, lead smelting and refining involves the release of multiple other pollutants of environmental concern, including, but not limited to, sulfur dioxide, fluoride compounds, cadmium, antimony, zinc, and arsenic (NPI 2021a; NPI 2021c). However, emissions arising from past lead contamination and environmental impacts from other pollutants are beyond the parameters of this evaluation.

Environmental Fate

The environmental fate of lead compounds emitted during the primary manufacturing of lead metal is site-specific.

Port Pirie sits within a typical temperate system adjacent to coastal and marine environments in Germein Bay on the eastern shore of the Spencer Gulf (Vandeleur 2020). The smelter is situated on the Port Pirie River and effluent is discharged to First Creek, both of which flow into the Spencer Gulf (Ferguson 1983; Lafratta et al. 2019).

Mount Isa is located in the semiarid, seasonally tropical upper Leichardt River catchment (Mackay and Taylor 2013). Leichardt River flows north into the Gulf of Carpentaria, and is ephemeral and subject to seasonal flooding during the annual wet season (Noller et al. 2012). The lead smelter is part of the Mount Isa Mines lease area on the western banks of the river, and Lake Moondarra, a man made reservoir, is immediately downstream. The mining lease includes a lead mine, and separating contamination arising from mining, which is outside the parameters of this evaluation, and smelting is not always possible.

Chemicals in this evaluation are expected to react and dissolve under environmental conditions in order to ultimately release ionic lead(2+). A detailed discussion of the environmental fate of ionic lead(2+) is available in the IMAP Environment Tier II Assessment for water soluble lead(2+) salts (NICNAS 2020). A summary of fate characteristics which are relevant to the Port Pirie and Mount Isa sites is presented below.

Speciation, Partitioning and Mobility

Lead compounds are released to all environmental compartments during the primary manufacture of refined lead metal and bullion. Lead compounds emitted to air and water predominantly partition to sediments and soils. These lead emissions may be sequestered in soils and sediments but can be remobilised through changes in environmental chemistry, such as variations in pH and/or water hardness, and perturbation from seasonal rainfall.

Lead-containing particles emitted from the primary lead manufacturing process have particle sizes ranging from <0.1 µm to >250 µm, with most particulates in the range 1–100 µm (Noller et al. 2017; Sobanska et al. 1999). Larger particles, >2 µm, settle out of the atmosphere rapidly and are deposited close to the emission source (UNEP 2010). Fine particulate matter is dispersed by wind and the small particle size promotes solubility. Lead compounds are removed from the atmosphere by wet and dry deposition to soils and surface water. At Port Pirie and Mount Isa, isotopic compositions of lead indicate that surrounding sediment and soils have been contaminated by atmospheric deposition of lead compounds from the smelters (Lafratta et al. 2019; Mackay et al. 2013).

The fate of lead compounds in soils is influenced by their solubility and mobility under local environmental conditions. The bioavailability of lead compounds in soil is dependent on their composition or mineral form, particle size and the presence of encapsulating materials, such as slag (Ruby et al. 1999). The mobility of lead in soils is controlled by the soil pH, content of humic acids, amount of organic matter, presence of clays/silts/iron oxides and manganese oxides and redox conditions (Davies 1990; Ruby et al. 1999; UNEP 2010). Generally, lead is considered not to be very mobile in soil, except under acidic conditions where it can be remobilised to groundwater. Emissions associated with the Mount Isa smelter may also be remobilised through perturbation of surface soils and sediments due to seasonal rainfall and floodwaters (Mackay and Taylor 2013; Taylor and Hudson-Edwards 2008).

Lead contaminated wastewater is discharged from First Creek into the marine environment adjacent to the Port Pirie refinery (SA EPA 2021a). The marine receiving environment shows elevated levels of total and dissolved lead (Chakraborty and Owens 2014; Edwards et al. 2001; Ferguson 1983). In seawater, lead(2+) is complexed by chloride ions. These complexes account for more than 90% of the speciation of ionic lead in seawater (ANZECC 2000a). Lead sorption onto clay particles, humic substances and iron, aluminium and manganese (oxy)hydroxides is an important process for the removal of lead natural surface waters (ANZECC 2000a). A dramatic decrease in the amount of dissolved lead in marine waters within ~5 km of First Creek is; however, largely attributed to dilution by seawater (Ferguson 1983).

Marine sediments in the Spencer Gulf adjacent to Port Pirie are heavily contaminated with lead (Chakraborty and Owens 2014; Lafratta et al. 2019; Ward and Young 1981). Lead is incorporated into marine sediments through adsorption to humates, organic matter, clay and mineral surfaces, and hydrous iron and manganese oxides (ANZECC 2000a; UNEP 2010). Adsorption affinity generally increases with increasing pH and decreasing water hardness, although lead-humate complexes are relatively stable across a large pH range. As with dissolved lead concentration, the lead content of the contaminated sediment decreases by 2 orders of magnitude within ~5 kilometres (km) of the First Creek outfall (Ward and Young 1981). A recent study indicates that the lead concentration of sediments ~1 km from the First Creek discharge point peaked in the 1970s and had not decreased significantly since then (at the time of sample collection in 2014) (Lafratta et al. 2019).

At Mount Isa, the environmental partitioning of lead between sediments and the freshwater compartment depends on seasonal rainfall. Aerial fallout of lead compounds and legacy lead contamination from the lead ores and mine contribute to the lead content of sediment in the tributaries around the mine lease and the Leichhardt River (Mackay and Taylor 2013; Noller et al. 2012; Taylor et al. 2010). Runoff collected in these channels is captured downstream in Lake Moondarra (Taylor et al. 2009). Analysis of the sediments from these areas has demonstrated high levels of lead contamination (Noller et al. 2012; Taylor et al. 2009). During the dry season, the ephemeral Leichhardt River is characterised by isolated pools that store lead contaminated water and sediment (Noller et al. 2012; Taylor et al. 2009). During the wet season, adsorption and desorption at the sediment surface is promoted by high loads of total suspended sediment and a slightly acidic to alkaline pH range in the river waters. Lead is transported in floodwaters both in solution and adhered to suspended sediments, with approximately 90% in the particulate phase (Mackay and Taylor 2013; Taylor et al. 2009).

Bioaccumulation and biomonitoring

Lead released during the primary lead manufacture has the potential to bioaccumulate, and elevated levels of lead in various aquatic organisms has been demonstrated at both Port Pirie and Mount Isa.

Lead is known to be bioaccumulative and a portion of the lead compounds emitted from primary lead manufacturing is known to be bioavailable (UNEP 2010). The lead(2+) ions released from these compounds may pose a bioaccumulation hazard depending on the bioavailability of the metal ion, which will be controlled by its speciation in the local environment. The IMAP Environment Tier II Assessment for water soluble lead(2+) salts provides a discussion on lead bioaccumulation (NICNAS 2020).

Elevated lead concentrations in mussels have been used to indicate the bioavailability of lead compounds emitted from primary lead manufacturing at Port Pirie. In the area adjacent to Port Pirie, lead concentrations in blue mussels (*Mytilus galloprovincialis*) were approximately 129 times higher than in baseline samples (Gaylard et al. 2011).

An analysis of fish flesh samples from *Sillago schomburgkii* and *Aldrichetta forsteri* from the waters around Port Pirie showed higher lead levels than in samples from species collected at a nearby industrially-impacted site, Barker Inlet, and a geographically separate reference site, Wills Creek (Edwards et al. 2001). Macroalgae species adjacent to Port Pirie were also found to have accumulated concentrations of lead several times higher than algae and in surrounding, less contaminated, waters (Chakraborty and Owens 2014).

In the Mount Isa area, the flesh and/or livers of several detritivorous, carnivorous and omnivorous fish species collected from the Leichhardt river, tributaries and Lake Moondarra catchment yielded mean lead concentrations exceeding the Australian New Zealand Food Standards Code (ANZFSC) guideline value of 0.5 mg Pb/kg (Noller et al. 2012). Elevated lead levels in omnivores and carnivores indicate accumulation through the food chain.

Environmental Transport

Atmospheric lead emissions have the potential for long range transport. Historical lead depositions indicate intercontinental atmospheric transport from Australia occurred as a result of lead smelting.

Lead compounds emitted to the atmosphere from the primary manufacturing process demonstrate a wide range of particle sizes. Lead distributed on larger particles, several microns and larger, is deposited close to the emission source. Smaller particulates can be subject to long range atmospheric transport (UNEP 2010). Lead can be removed from the atmosphere through dry and wet deposition.

Historical anthropogenic lead emissions have been recorded in ice cores collected from the Law Dome, Antarctica (Burn-Nunes et al. 2011; Vallelonga et al. 2002). Based on isotopic lead ratios in the ice cores and relevant ore bodies, increases in lead concentrations between 1884 and 1908 have been attributed to the mining and smelting of lead ore at Broken Hill, NSW, and Port Pirie, SA.

Predicted Environmental Concentration (PEC)

A PEC was not calculated for chemicals in this evaluation. This section contains a discussion of lead monitoring data in environmental compartments around the Mount Isa and Port Pirie smelters.

Available environmental concentrations are compared to relevant national guideline values. When considering guideline values for metals, the ANZ Water Quality Guidelines recommend that, if total metals concentrations exceed guideline values, dissolved and bioavailable fractions may be determined for comparison (ANZG 2018a). Total concentrations include particulate plus dissolved fractions. Dissolved fractions, measured after passing through a 0.45 µm filter membrane, may not necessarily reflect the extent of bioavailability of the metals, which may be determined by various other techniques. Default guideline values should be tailored to account for local water conditions, where possible. Accordingly, total, dissolved and bioavailable concentrations are discussed below, along with site specific hardness-adjusted guideline values, where available.

Lead contents are elevated in natural waters, sediments and soils influenced by primary lead manufacturing around Port Pirie and Mount Isa. At Mount Isa, bioavailable lead contents in several freshwater samples were below site specific water quality thresholds. Total and bioavailable lead contents in sediments considerably exceed sediment quality thresholds in both locations. Lead contents in soils exceed Site Contamination NEPM investigation limits in both locations. Lead concentrations in aquatic life exposed to natural waters around Port Pirie are significantly elevated compared to baseline levels.

Lead is a naturally occurring element that is present in low levels in most environmental compartments. Depending on the region, background lead levels may be elevated due to the widespread historical use of leaded fuel additives. Concentrations are in the range of 1–30 mg Pb/kg in uncontaminated rocks and soils (Davies 1990), 0.1–10 µg Pb/L in lake and river waters and 0.01–0.03 µg Pb/L in surface ocean waters (Ewers and Schlipkoter 1991). At Mount Isa, natural occurrences of lead containing minerals may also influence background lead concentrations (Noller et al. 2012).

The following table summarises key reported lead concentrations around Port Pirie and Mount Isa in marine water, freshwater, sediments and soils. Maximum measured concentrations are given by compartment, alongside the highest associated mean or median concentration and relevant background concentrations, where reported. Where background concentrations were not reported, minimum measured values are given. Where different types of lead concentrations have been reported (total lead, dissolved lead or bioavailable lead), the maximum measured concentration for each concentration type is given, as indicated. Where several studies were available, values are given from the most recent or most comprehensive studies. Relevant trigger values from ANZ Water Quality Guidelines or the Site Contamination NEPM (ANZECC 2000b; ANZG 2018a; ANZG 2018b; NEPC, 2013) are presented for comparison, and whether the trigger value has been exceeded is indicated:

Compartment, Location	**Source**	**Pb concentration (total/dissolved/bioavailable)**			**Trigger value**	**Exceed trigger value?**
		Highest mean/ median	Maximum	Background range/ Minimum		
Marine, Port Pirie	(Chakraborty and Owens 2014; Vandeleur 2020)	-	55 µg/L (dissolved)	0.6 µg/L (dissolved)	4.4 µg/L*	Yes
Freshwater, Mount Isa	(Noller et al. 2012)	-	24 µg/L (bioavailable)	-	91 µg/L†	No
Freshwater, Mount Isa	(FRC Environmental 2021)	-	124 µg/L (dissolved)	<1–6 µg/L (dissolved)	3.4 µg/L*	Yes
Sediment, Port Pirie	(Vandeleur 2020)	-	9166 mg/kg (total)	0.10–7.7 mg/kg (total)	50 mg/kg*	Yes
Sediment, Mount Isa	(Noller et al. 2012)	-	2650 mg/kg (bioavailable)	11–140 mg/kg (bioavailable)	50 mg/kg*	Yes
Sediment, Mount Isa	(Taylor et al. 2009)	1649 mg/kg	8092 mg/kg (total)	36 mg/kg (total)	50 mg/kg*	Yes
Soil, Port Pirie	(Public Health Services 2013)	434 mg/kg	7546 mg/kg (total)	6 mg/kg (total)	270 mg/kg‡	Yes
Soil, Mount Isa	(Taylor et al. 2010)	105 mg/kg	5800 mg/kg (total)	1 mg/kg (total)	270 mg/kg‡	Yes

*ANZ Water Quality Guidelines default guideline values, 95% species protection for marine and freshwater
†ANZ Water Quality Guidelines default guideline values, 95% species protection, hardness-modified
‡Site Contamination NEPM added contaminant limit for ecological investigation in freshly contaminated soil, 80% species protection

Marine waters

In the 1980s, reported dissolved lead concentrations in marine waters within approximately 5 km of the Port Pirie refinery water outflow ranged from 1.1 to 750 µg Pb/L, with lead levels decreasing with increasing distance from the outflow (Ferguson 1983). The lead concentrations in close proximity to the outflow can significantly exceed the 80% species protection threshold for marine waters of 12 µg Pb/L, but as dilution occurs in the Spencer Gulf the lead concentration rapidly falls below the 95% species protection threshold of 4.4 µg Pb/L (ANZECC 2000b). More recent studies that took samples in 2010 and 2018 have reported values ranging from 0.6 to 55 µg Pb/L within approximately 20 km of the Port Pirie smelter (Chakraborty and Owens 2014; Vandeleur 2020). In the most recent of these studies, water samples were taken from marine and coastal areas within approximately 20 km x 20 km around the smelter. Out of 60 samples, 20 samples had lead concentrations exceeding the 95% threshold of 4.4 µg Pb/L, of which 7 also exceeded the 80% threshold of 12 µg Pb/L.

Freshwater

Several studies and monitoring programs have determined total and dissolved lead concentrations in surface waters of various waterways around Mount Isa during the 2006–2008 wet and dry seasons and 2020–21 wet and post-wet seasons. Total lead concentrations ranged from <1 to 3600 µg Pb/L for unfiltered samples, and dissolved lead concentrations ranged from <1 to 124 µg Pb/L (FRC Environmental 2021; Mackay and Taylor 2013; Taylor et al. 2009). In the most recent of these reports, dissolved lead concentrations at 6 monitoring sites exceeded the default 95% species protection threshold 3.4 µg Pb/L, 5 of which exceeded the default freshwater 80% protection threshold value of 9.4 µg Pb/L (ANZECC 2000b). Dissolved lead concentrations at reference sites ranged from <1 to 6 µg Pb/L.

A study commissioned by Mount Isa Mines and conducted from 2008–2010 determined total and dissolved lead concentrations at sites around the smelter, as well as corresponding bioavailable lead concentrations and hardness-adjusted guideline values. In this study, 7 aquatic sampling sites around the smelter had total lead concentrations exceeding the freshwater 95% threshold value of 3.4 µg Pb/L, at concentrations of 6.6–434 µg Pb/L (Noller et al. 2012). Corresponding dissolved lead concentrations at these sites were 1.8–180 µg Pb/L. However, only 2 of the dissolved concentrations exceeded site-specific hardness-adjusted 95% guideline values, which ranged from 3.4 to 91 µg Pb/L depending on the site. According to the ANZ Water Guidelines, in such cases the bioavailable metal concentration may be determined and compared to trigger values (ANZECC 2000b), and the bioavailable metal concentrations of 0.1–24 µg Pb/L were found to be below the hardness-adjusted guideline values at these sites.

Sediments

Sediments in the waters adjacent to Port Pirie and in the tributaries and rivers associated with Mount Isa have accumulated lead due to both modern and historical practices.

In the 1980s at Port Pirie, lead concentrations reported in the uppermost layers, likely to indicate modern contributions, ranged from 74 to 5270 mg Pb/kg dw depending on the sampling distance from the refinery (Ward and Young 1981). Background sediment lead concentrations from less polluted surrounding areas of the Spencer Gulf ranged from 2 to 35 mg Pb/kg dw. All of the measured lead concentrations in the samples from the Port Pirie area exceeded the sediment default guideline value of 50 mg Pb/kg and many of the sites sampled exceeded the GV-high of 220 mg Pb/kg (ANZECC 2000b). More recent studies that took samples between 2010 and 2019 have reported values ranging from 0.10 to 9166 mg Pb/kg in surface sediments within approximately 20 km of the Port Pirie smelter, and background concentrations of 0.10 and 7.77 mg Pb/kg. (Chakraborty and Owens 2014; Lafratta et al. 2019; Vandeleur 2020). In the most recent of these studies, out of 84 surface sediment samples taken from marine and coastal areas within approximately 20 km x 20 km around the smelter, concentrations at 55 sites exceeded the default guideline value, including all of those from within the Port Pirie river/mouth and First Creek vicinity. Concentrations at 33 sites also exceeded the GV-high. Recent sediment core samples have shown that the bulk of metal concentrations in these sediments are contained within the top layers, and that the deposition of lead to the sediment compartment has been relatively constant over the last 50 years (Lafratta et al. 2019; Vandeleur 2020).

Sediment monitoring in the channels and tributaries around Mount Isa has demonstrated lead levels ranging from <1 to 20 000 mg Pb/kg (Noller et al. 2012; Taylor et al. 2009). The highest of these values was taken prior to completion of a remediation project in 2008 that removed a large amount of contaminated sediment. The highest lead concentration from sediments sampled after the remediation was 2650 mg Pb/kg (Noller et al. 2012). These concentrations were obtained following extraction with 1 molar hydrochloric acid (1 M HCl), which is a method of determining bioavailable lead content. In 2 separate sampling campaigns commissioned by Mount Isa Mines after the remediation program, bioavailable lead content of aquatic sediments was assessed using 1 M HCl extraction. In total, 89 samples exceeded the default guideline value of 50 mg Pb/kg and 53 exceeded the GV-high of 220 mg Pb/kg (ANZG 2018b; Noller et al. 2012). Analysis of 32 regional/background sites revealed a mean background lead concentration of 51 mg Pb/kg. Lead levels at 16 of these sites exceeded the 50 mg Pb/kg default guideline value, which was mainly attributed to historical mining activities and natural mineralisation (Noller et al. 2012). None of the regional/background site concentrations exceeded the GV-high. A more recent monitoring program sampled sediments at 20 sites in 2020–21, reporting dilute acid extractable lead concentrations of 2.09–759 mg Pb/kg (FRC Environmental 2021). Of these, 7 concentrations exceeded the default guideline value and 2 exceeded the GV-high.

Soil

Studies on soil samples taken from around the town of Port Pirie in 2012 indicated that lead concentrations are highly spatially variable but decrease with increasing distance from the refinery. In a study undertaken by SA Health, lead concentrations in soil samples from 353 sites varied from 6 to 7546 mg Pb/kg, with 72 sites exceeding the Site Contamination NEPM HIL for public open spaces of 600 mg Pb/kg (Public Health Services 2013). In the suburbs near or downwind of the refinery, the geometric mean was reported as 434 mg Pb/kg, decreasing to 102 mg Pb/kg in the suburbs furthest south from the smelter. Determination of ambient background concentrations and differentiation between fresh and historical lead contamination was not part of this study, as it is focussed on human health and is not designed for the application of EILs. However, the difference in mean lead concentrations in the most and least contaminated suburbs is 332 mg Pb/kg, which exceeds the EIL added contaminant limit for lead of 270 mg added Pb/kg for freshly contaminated soil (Commonwealth of Australia 2013). A separate study measured lead concentrations in 73 soil samples from within a 5 km radius of the smelter, along with 2 background samples collected outside this radius (Maliki et al. 2015). Total lead concentrations were consistent with the range measured in the SA Health study, with a maximum total lead concentration of 5002 mg/kg and a mean of 592 mg/kg.

Soils in the Mount Isa area have accumulated lead from historical and modern mining and smelting practices. A survey of 60 soil samples collected in the urban Mount Isa area in 2003 found lead concentrations ranging from 1 to 5800 mg Pb/kg (Taylor et al. 2010). Finer grain samples had higher lead concentrations than coarser grain samples, with geometric means of 105 and 51 mg Pb/kg, respectively. In a survey commissioned by Mount Isa Mines, lead concentrations were analysed in garden soil samples collected in 2010. Lead concentrations ranged from 12 to 1070 mg Pb/Kg across fine grain fractions of 75 samples with a median concentration of 163 mg Pb/kg. (Noller et al. 2017). At 18 of the 67 houses from which the samples were collected, measured lead concentrations exceeded the Site Contamination NEPM HIL for residential sites with gardens of 300 mg Pb/kg (Commonwealth of Australia 2013). Although the study focusses on human health, and therefore does not report background soil concentrations or contaminant age, the difference between the minimum and maximum lead concentrations considerably exceed EIL added contaminant limits for freshly contaminated soils. Subsurface soil profiles also showed that surface soils were enriched with lead compared to samples at 10–20 centimetre depths, and soil metal concentrations were significantly higher within 2 km of the smelter stack, consistent with atmospheric deposition origin (Taylor et al. 2010).

Aquatic life

The mean lead concentration in blue mussels (*Mytilus galloprovincialis*) placed in coastal waters adjacent to Port Pirie was determined to be 22.0 µg/g dw, with a maximum concentration of 310 µg/g dw being recorded (Gaylard et al. 2011). The mean lead concentration in blue mussels prior to being placed in the waters was 0.17 µg/g dw (Gaylard et al. 2011). More recently, seafood sampling undertaken by SA Health in 2020 around Port Pirie River Estuary found levels in various bivalve molluscs ranging from <2–180 mg Pb/kg (SA Health 2020).

The seafood sampling undertaken by SA Health in 2020 also found average lead levels in blue-swimmer crab (*Portunus pelagicus*) of 0.52 and 15 mg Pb/kg, and maximum levels of 0.95 and 26 mg Pb/kg (SA Health 2020).

An analysis of fish flesh samples from *Sillago schomburgkii* and *Aldrichetta forsteri* from the waters around Port Pirie showed lead levels of 0.819–0.979 mg Pb/kg (Edwards et al. 2001). A comparison of fish samples from the species collected at the geographically removed Wills Creek area showed lower levels of 0.253–0.380 mg Pb/kg. In 2020, SA Health found levels in fish samples from *Sillago schomburgkii*, *Pelates octolineatus* and *Aldrichetta forsteri* ranging from <0.5–1.9 mg Pb/kg (SA Health 2020).

A study of the macroalgae species *Hormophysa cuneiformis* and *Blidingia marginata* from the waters surrounding Port Pirie demonstrated lead concentrations of 202–974 µg Pb/g (Chakraborty and Owens 2014). Samples from algae collected from low and moderately contaminated surrounding waters yielded lead concentrations of 0.9–6.1 µg Pb/g and 17.9–34.6 µg Pb/g, respectively.

Environmental Effects

The environmental effects of lead metal and the lead compounds in this evaluation primarily result from the release of bioavailable ionic lead(2+) species to the environment. The toxic effects of this group have been collectively assessed by reference to the extensive ecotoxicity data available for ionic lead(2+).

A detailed account of the ecotoxicity of ionic lead is available in the IMAP Environment Tier II Assessment for water soluble lead(2+) salts (NICNAS 2020), a summary of which is presented here.

Effects on Aquatic Life

Lead bioaccumulates in aquatic organisms and bioavailable forms of lead are very toxic to aquatic life in both short and long term exposures scenarios. The toxicity of ionic lead(2+) to aquatic organisms varies considerably between species and can be strongly influenced by water chemistry.

Acute toxicity

Dissolved lead(2+) causes severe acute toxicological and physiological effects to aquatic organisms. The toxicity of dissolved lead is strongly dependent on water conditions such as salinity, pH, concentration of dissolved organic carbon, presence of iron and manganese oxides and water hardness, all of which moderate the bioavailability of ionic lead(2+) (UNEP 2010).

The acute toxicity of ionic lead(2+) varies considerably between species of aquatic organisms and early developmental stages are more susceptible than adult stages (UNEP 2010). The IMAP Environment Tier II Assessment for water soluble lead(2+) salts identified a 72 hour median effective concentration (EC50) test on the microalgae *Pseudokirchneriella subcapitata* as the most sensitive endpoint for the acute toxicity of ionic lead at 21 µg Pb/L (growth rate) (NICNAS 2020).

Chronic toxicity

Chronic toxicity of ionic lead to aquatic organisms follows similar trends to acute toxicity. The chronic toxicity of lead(2+) is strongly dependent on the water chemistry of the environment, which moderates the bioavailable fraction of ionic lead. Long term exposure to lead has been shown to affect hatching, growth, development, embryonic development, survival and reproduction across a wide range of organisms in marine and freshwater environments (UNEP 2010).

The lowest chronic toxicity value identified in the IMAP Environment Tier II Assessment for water soluble lead(2+) salts was an effective concentration for 10% of the test population (EC10) for *Pseudokirchneriella subcapitata* of 6.2 µg Pb/L (NICNAS 2020).

Effects on Terrestrial Life

Bioavailable forms of lead(2+) are toxic to terrestrial organisms.

Lead is strongly adsorbed to organic matter and minerals in soil and; therefore, bioavailability is typically limited. Mean no observed effect concentration (NOEC) values for terrestrial invertebrates range from 129 mg Pb/kg soil for the earthworm *Dendrobaena rubida* to 1797 mg Pb/kg soil for the springtail *Fautrix candida*. Plants are also susceptible to lead toxicity, with mean NOEC values ranging from 50 mg Pb/kg soil for barley (*Hordeum vulgare*) to 546 mg Pb/kg soil for the loblolly pine (*Pinus taeda*). Reproductive toxicity and impaired growth are listed as the most common toxic effects (Commonwealth of Australia 2013).

Effects on Sediment Dwelling Life

Bioavailable forms lead(2+) are very toxic to sediment dwelling organisms. Toxicity is highly dependent on sediment chemistry, which depends on parameters such as dissolved oxygen, pH and the geochemistry of sediment particles (ANZECC 2000a).

The available NOEC value equivalents for select sediment dwelling organisms (corrected to a $CaCO_3$ concentration of 30 mg/L) include a NOEC of 5.1 µg Pb/L for the amphipod *Gammarus pseudolimnaeus* and a NOEC of 28 µg Pb/L for the midge *Tanytarsus dissimilis* (ANZECC 2000a).

Limited data are available indicating direct toxic effects of lead on sediment dwelling organisms in the areas surrounding Port Pirie or Mount Isa. A sediment toxicity study conducted on lead containing samples from around the Mount Isa Mine showed reduced survival rates for *Ceriodaphnia spp* (48 hr) and *Corophium spp* (10-day, whole sediment) and 72 hr inhibition for *Pseudokirchneriella subcapitata* (Noller et al. 2012). However, due to the presence of other toxicants in the samples a specific causal link could not be identified.

Predicted No-Effect Concentration (PNEC)

The primary environmental effects of chemicals in this group are expected to be caused by the release of bioavailable lead(2+) ions. Given the extensive release of lead and lead compounds to all environmental compartments at the Port Pirie and Mount Isa facilities, guideline values for lead in soils and aquatic systems were considered.

In place of a PNEC for the soil compartment, the EIL for lead from the Site Contamination NEPM has been used (Commonwealth of Australia 2013). This represents the level above which further investigation or evaluation is required and is the sum of the added contaminant limit and ambient background concentration at the site. For freshly contaminated soils where the contaminant has been present for less than 2 years, the added contaminant limit urban residential areas and public open space is 270 mg added Pb/kg soil (Commonwealth of Australia 2013).

In place of PNECs for aquatic and sediment compartments, the default guideline values from the ANZ Water Quality Guidelines have been used. These values represent thresholds above which further assessment of potential toxicity may be required to ensure environmental quality. For *slightly-moderately disturbed* freshwater ecosystems with low water hardness (30 mg/L $CaCO_3$), a guideline value for protection of 95% of species of 3.4 µg Pb/L is applied. The equivalent values for the protection of marine and sediment-dwelling species are 4.4 µg Pb/L and 50 mg Pb/kg dw, respectively (ANZECC 2000b; ANZG 2018b).

Categorisation of Environmental Hazard

It is not currently possible to categorise the environmental hazards of metals and other inorganic chemicals according to standard PBT hazard criteria. These criteria were developed for organic chemicals and do not take into account the unique properties of inorganic substances and their behaviour in the environment (UNECE 2007).

As a result, environmental hazard categorisation according to domestic PBT criteria has not been performed for chemicals in this group. Nevertheless, there is an international consensus that bioavailable forms of ionic lead are highly toxic to the environment and that lead is a bioaccumulation hazard.

GHS Classification of Environmental Hazard

The aquatic hazards of lead metal and lead oxide have been classified based on the available acute toxicity values for the soluble lead(2+) ion, in accordance with the classification procedure for metals and metal compounds under the GHS (UNECE 2017a). The aquatic hazards associated with chemicals in this group are dependent on their capacity to release ionic lead at concentrations that exceed identified acute toxicity thresholds.

All the substances in this evaluation are classified as Acute Aquatic Category 1. They are also classified as Chronic Aquatic Category 1 as lead(2+) bioaccumulates in aquatic organisms.

For lead metal, data obtained in accordance with the OECD Transformation and Dissolution protocol (UNECE 2017a) was used for classification. The concentration of dissolved lead determined using the 7 day transformation/dissolution test at the low loading rate of 1 mg/L exceeds the most sensitive acute toxicity values for ionic lead.

For lead oxides, the dissolved lead concentration indicated from solubility data exceeds the most sensitive acute toxicity values for ionic lead. For lead drosses, slags and residues, the estimated maximum lead concentration at saturation is based on read-across from lead oxide.

For flue dust from lead refining, the estimated maximum lead concentration at saturation is based on read-across from basic lead sulfate, which dissolves to give a lead concentration that exceeds the most sensitive acute toxicity values for ionic lead.

For the remaining UVCB materials, there are insufficient solubility data available to classify their aquatic toxicity hazards according to the procedure outlined above. Accordingly, these chemicals are cautiously assumed to be sufficiently soluble to release lead(2+) ions at concentrations which exceed the relevant ecotoxicological endpoints.

It is preferable to classify the hazard posed by metals and metal compounds using available solubility data or the findings of a study conducted in accordance with the OECD Transformation and Dissolution protocol (UNECE 2017b). Therefore, should solubility data or a study conducted in accordance with this protocol suggest a lower hazard classification is warranted, some chemicals may be reclassified as appropriate.

Environmental Risk Characterisation

The production of chemicals in this group can release bioavailable lead(2+) ions to the environment. Anthropogenic emissions of lead to the environment are acknowledged to be of concern, both domestically and internationally, due to the bioaccumulation properties and high toxicity of bioavailable forms of lead. Environmental contamination by lead is of particular concern because high exposure to lead compounds can cause neurological defects and reproductive toxicity across a range of organisms, including humans, plants and animals (UNEP 2010). Smelters and refineries associated with the primary manufacturing of lead metal are the major point sources of anthropogenic lead emissions in Australia (NPI 2021b).

The primary manufacture of lead metal occurs at refineries and smelters in Port Pirie and Mount Isa. Current practices and facilities result in the release of lead to all environmental compartments, leading to elevated lead levels in natural waters, sediments, soils and biota.

In coastal and marine waters adjacent to the Port Pirie facility, the dissolved lead concentration near the First Creek effluent outlet greatly exceeds the 80% protection level for marine ecosystems. Combined with observed bioaccumulation of lead in indicator organisms, this signals that there may be risks to sensitive aquatic organisms at this location.

Sediment samples in the marine environment near Port Pirie exceed both default and upper guideline values at many sites, indicating potential high level toxicity problems. Although the risk posed by high lead concentrations in these sediments may be mitigated by the formation of relatively stable complexes, toxicity studies to support this are absent from the available literature.

Around Mount Isa, bioavailable lead contents in several freshwater samples were below site specific water quality thresholds, indicating low risk according to the ANZ Water Quality Guidelines. However, lead concentrations in freshwater around Mount Isa depend on seasonal rainfall and flooding, which can remobilise lead stored in sediments. Bioavailable lead concentrations in sediments exceed the guideline values at many sites. In several cases, sediment toxicity has been demonstrated and lead has not been ruled out as a causal factor. Elevated lead levels in various fish species indicate bioaccumulation of lead in aquatic organisms. These findings indicate potential risks to aquatic ecosystems in this area due to high lead levels in sediments.

Lead contents in soils exceed Site Contamination NEPM investigation limits in both locations. While the soil monitoring studies have focussed on human health, differences in lead concentrations around the townships of Port Pirie and Mount Isa indicate that ecological investigation limits are likely to be exceeded, suggesting that further investigation is required. In the absence of further information, these findings indicate potential risks to soil dwelling and other terrestrial life.

This evaluation has identified exposure routes of lead to humans as a result of environmental contamination associated with primary manufacture of lead metal. Lead concentrations in soils at both Port Pirie and Mount Isa exceed relevant health investigation levels. Elevated lead levels in natural waters and biota may also ultimately impact human health. While these risks are outside of the parameters of this environmental evaluation, they require further consideration.

Both sites are subject to state environmental authorities or EPA licenses.

Current management – Mount Isa

For Mount Isa, the environmental authority covers monitoring and reporting of lead in air, deposited dust, tailings, water releases, groundwater, sediment and soil. Trigger values and objectives are given for lead in ambient air, receiving waters and groundwater, and a sediment trigger values are to be developed. These trigger values are or will be generally consistent with national guidelines. Although adverse effects of atmospheric lead release on soil quality must be monitored, no corresponding trigger values for lead in soils are specified.

Mount Isa Mines has commissioned 3 studies to understand the extent of lead contamination in the environment around the mine and smelter site (Noller et al. 2009; Noller et al. 2012; Noller et al. 2017). Remediation by removal of contaminated sediment has been undertaken as a result of some of these studies, and subsequent sediment ecotoxicity tests suggest reduced risks to aquatic life (Noller et al. 2013). However, studies of sediment samples taken after this remediation in 2009 indicated that further assessment was required and ongoing management may be necessary to reduce the risk posed by lead compounds in sediments at this site (Noller et al. 2012), and the most recent data indicates that lead concentrations in many sediment samples are above relevant guideline values (FRC Environmental 2021). The environmental authority requires that exceedances must be assessed and followed up with appropriate actions to minimise environmental harm.

Furthermore, lead levels in soils require further investigation for potential effects on soil dwelling and other terrestrial life. According to the environmental authority, such potential adverse effects due to impacts on soil quality must be monitored, though it is not clear if any environment focused soil assessment has been undertaken to date.

Current management – Port Pirie

For Port Pirie, the EPA licence covers targets and reportable limits for lead emissions to air and water releases to First Creek. Exceedances of air quality limits are to be publicly reported. In 2020, Nyrstar Port Pirie exceeded their lead-in-air emission limits of 0.4 $\mu g/m^3$ (annual average) at the Pirie West monitoring site (SA EPA 2021b). In 2018, refinery operations were suspended in order to avoid exceeding a lead-in-air emission limit of 0.5 $\mu g/m^3$ (Nyrstar NV 2019). In the same year, 26 instances of water quality requirement breaches were documented, though it is not specified what these involved. The SA EPA has advised that regulatory effort commencing from the July 2020 licence renewal has resulted in improved performance. An Environmental Improvement Plan (Nyrstar Port Pirie Pty Ltd, 2020) is a requirement of the current EPA licence and actions within it address dust, lead in air, metals in wastewater, waste and legacy plant and equipment.

Further environmental risk assessment and ongoing management are required to reduce risks posed to marine ecosystems by lead compounds in water and sediments at this site. Lead concentrations in marine surface waters are high near the First Creek discharge point and decrease rapidly with increasing distance, indicating that ongoing effluent discharge is the source of lead contamination. Dissolved lead partitions to marine sediments in the area, and available data indicate that ongoing deposition of lead to the sediment compartment has not decreased significantly since the 1970s. The facility licence does not stipulate monitoring requirements or investigation trigger levels for lead in the surrounding marine water and marine sediments.

Lead levels in soils require further investigation for potential effects on soil dwelling and other terrestrial life. Spatial variation of lead concentrations in soils indicates that lead contamination is caused by aerial deposition from the refinery. The facility licence limits lead-in-air emissions and requires dust management but does not stipulate monitoring requirements or investigation trigger levels for lead in surrounding soils. In 2014, Nyrstar and the State of South Australia entered a Targeted Lead Abatement Program agreement, which includes developing a soil remediation program with the aim of reducing human health impacts (TLAP 2015). (SA EPA 2022) However, no environment focused soil assessment or remediation appears to have been undertaken to date.

The SA EPA have advised that the reservoirs of legacy environmental lead are being addressed by TLAP in its forthcoming Port Pirie Greening Program, and investment in programs to remediate soils for the purpose of protecting children’s health will be the priority for the coming years. Furthermore, under its Voluntary Site Contamination Assessment Proposal, Nyrstar was required to submit a site contamination audit in order to assess current and potential future risks to offsite human and ecological receptors posed by groundwater contamination from the site. The final report was submitted in April 2022 and is currently under review by the SA EPA (SA EPA 2022).

Uncertainty

This evaluation was conducted based on information that may be incomplete or limited in scope. Some relatively common data limitations can be addressed through use of conservative assumptions (OECD 2019) or quantitative adjustments such as assessment factors (OECD 1995). Others must be addressed qualitatively, or on a case-by-case basis (OECD 2019).

The most consequential areas of uncertainty for this evaluation are:

- Environmental concentrations were taken from a range of different sources and sampling campaigns, and therefore trends over time were not clear. Therefore, the progress of any ongoing risk management measures, such as remediation, could not be considered based on the available data, but may influence environmental concentrations. Should information become available to indicate that environmental concentrations at the relevant sites are currently decreasing, the outcome of this evaluation may change.
- Environmental concentrations of lead in soils discussed in this evaluation are derived from studies of samples taken in 2012 and earlier. Biomonitoring data from around Mount Isa is from samples taken in 2010. Should information become available to indicate that environmental concentrations at the relevant sites have reduced significantly in later years, the outcome of this evaluation may change.
- Many of the exceedances of guideline values discussed in this evaluation should be followed up by further assessment of site-specific conditions and lead bioavailability to determine if there is a risk to the environment. In the absence of such information, the potential for environmental risks to occur has been noted. However, should data become available from follow up investigations that indicate low risk, the outcome of this evaluation may change.
- At both of the sites discussed in the evaluation, significant historical contamination is a source of lead emissions to the environment. At Mount Isa, lead emissions also arise due to lead mining on site. Emissions arising from past lead contamination and mining are beyond the parameters of this evaluation. However, much of the available

information does not allow for clear separation between lead contamination arising from smelting, mining and past contamination.

References

ABARE (2008). *Mineral and energy commodities - Lead*. ABARES, Canberra, ACT, Australia. Accessed January 2021

ANZECC (2000a). *Australian and New Zealand Guidelines for Fresh and Marine Water Quality (Vol II) Aquatic Ecosystems — Rationale and Background Information (Chapter 8)*. Artamon, NSW, Australia. Accessed April 2021

ANZECC (2000b). *Australian and New Zealand Guidelines for Fresh and Marine Water Quality (Vol I). The Guidelines (Chapters 1-7)*. Sydney, Australia. Accessed April 2021

ANZG (2018a). *Australian and New Zealand Guidelines for Fresh and Marine Water Quality: Accounting for local conditions*. Canberra, Australia. Accessed April 2021

ANZG (2018b). *Toxicant Default Guideline Values for Sediment Quality*. Australian and New Zealand Governments and Australian state and territory governments (ANZG), Canberra, Australia. Accessed March 2021.

Atkins P, Overton T, Rourke J, Weller M and Armstrong F (2006). *Shriver & Atkins Inorganic Chemistry* (Fourth ed). Oxford University Press ; W.H. Freeman and Co., New York.

Australian Government (2005). *Lead in Australia*. Prepared by the Australian Government for the United Nations Environment Programme, Canberra, ACT, Australia.

Bartel G and Gowan S (2013).Fact Sheet Nyrstar. In: Rankin WJ, ed. *Australasian Mining and Metallurgical Operating Practices*. The Australian Institute of Mining and Metallurgy, Carlton, Victoria, Australia, pp 1619 - 1622.

Burn-Nunes LJ, Vallelonga P, Loss RD, Burton GR, Moy A, Curran M, Hong S, Smith AM, Edwards R, Morgan VI and Rosman KJR (2011). Seasonal variability in the input of lead, barium and indium to Law Dome, Antarctica. *Geochimica et Cosmochimica Acta,* **75**(1), pp 1 - 20.

Carr DS, Spangenberg WC, Chronley K and Meshri DT (2004).Lead Compounds. In: Wiley-VCH, ed. *Kirk-Othmer Encyclopedia of Chemical Technology*. pp 1 - 26.

Chakraborty S and Owens G (2014). Metal distributions in seawater, sediment and marine benthic macroalgae from the South Australian coastline. *Int. J. Environ. Sci. Technol.,* **11**, pp 1259 - 1270.

Commonwealth of Australia (2013). *National Environment Protection (Assessment of Site Contamination) Measure 1999*. Canberra, Australia. Accessed April 2021.

Commonwealth of Australia (2016). *National Environment Protection (Ambient Air Quality) Measure*. Canberra, Australia. Accessed April 2021

Davidson A, Ryman J, Sutherland CA, Milner EF, Kerby RC, Teindl H, Melin A and Bolt HM (2014).Lead. In: Wiley-VCH, ed. *Ullmann's Encyclopedia of Industrial Chemistry*. pp 1-55.

Davies BE (1990).Lead. In: Alloway BJ, ed. *Heavy Metals in Soil*. Blackie, Glasgow and London, pp 177 - 196.

ECHA (2020a). *Candidate List of Substances of Very High Concern for Authorisation*. European Chemicals Agency (ECHA), Helsinki, Finland. Accessed March 2021.

ECHA (2020b). *Registered substances*. European Chemicals Agency (ECHA), Helsinki, Finland. Accessed March 2021.

Edwards JW, Edyvane KS, Boxall VA, Hamann M and Soole KL (2001). Metal Levels in Seston and Marine Fish Flesh Near Industrial and Metropolitan Centres in South Australia. *Marine Pollution Bulletin,* **42**(5), pp 389 - 396.

Environment Canada (2006a). *Environmental Code of Practice for Base Metals Smelters and Refineries: Chapter 4*. Quebec, Canada. Accessed May 2021

Environment Canada (2006b). *Environmental Code of Practice for Base Metals Smelters and Refineries: Code of Practice, Canadian Environmental Protection Act, 1999.* Quebec, Canada. Accessed May 2021.

Ewers U and Schlipkoter H-W (1991).Lead. In: Merian E, ed. *Metals and Their Compounds in the Environment - Occurence, Analysis, and Biological Relevance*. VCH, Weinheim, Federal Republic of Germany, pp 971 - 1014.

Ferguson J (1983). Concentrations and Speciation of Lead, Zinc and Cadmium in Seawater-like Smelter Effluent and Adjacent Marine Environments, Port Pirie, South Australia. *Aust. J. Mar. Freshw. Res.,* **34**, pp 375 - 385.

FRC Environmental (2021). *Mount Isa Mines 2020 – 2021 Receiving Environment Monitoring Program* Brisbane, Queensland (Unpublished Report).

Gaylard S, Thomas S and Nelson M (2011). An assessment of the current status of bioavailable metal contamination across South Australia using translocated mussels *Mytilus Galloprovincalis*. *Transactions of the Royal Society of South Australia,* **135**(1), pp 39 - 54.

Government of Canada (2020). *Toxic substances list: schedule 1*. Government of Canada, Ottawa, Ontario, Canada. Accessed March 2021.

Heidel C and Tichomirowa M (2011). Galena oxidation investigations on oxygen and sulphur isotopes. *Isotopes in Environmental and Health Studies,* **47**(2), pp 169 - 188.

International Lead and Zinc Study Group (2019). *The world lead factbook 2019*. ILZSG, Lisbon, Portugal. Accessed January 2021

King M, Prengaman RD, DeVito SC and Breen J (2014).Lead and Lead Alloys. In: Wiley-VCH, ed. *Kirk-Othmer Encyclopedia of Chemical Technology*. pp 1 - 55.

Lafratta A, Serrano O, Masque P, Mateo MA, Fernandes M, Gaylard S and Lavery PS (2019). Seagrass soil archives reveal centennial-scale metal smelter contamination while acting as natural filters. *Science of The Total Environment,* **649**, pp 1381 - 1392.

Lead REACH Consortium (2018). *Lead, dross (Boundary Composition)*. Association LRCIL, United Kingdom. Accessed May 2021.

Mackay AK and Taylor MP (2013). Floodwater Metal Contaminants in an Australian Dryland River: A Baseline for Assessing Change Downstream of a Major Lead-Zinc-Silver and Copper Mine. *Journal of Environmental Quality,* **42**(2), pp 474 - 483.

Mackay AK, Taylor MP, Munksgaard NC, Hudson-Edwards KA and Burn-Nunes L (2013). Identification of environmental lead sources and pathways in a mining and smelting town: Mount Isa, Australia. *Environmental Pollution,* **180**, pp 304 - 311.

Maliki AA, Bruce D and Owens G (2015). Spatial distribution of Pb in urban soil from Port Pirie, South Australia. *Environmental Technology & Innovation,* **4**, pp 123-136.

Morrison AL and Gulson BL (2007). Preliminary findings of chemistry and bioaccessibility in base metal smelter slags. *Science of The Total Environment,* **382**, pp 30 - 42.

NEPC (2013). *National Environment Protection (Assessment of Site Contamination) Measure Amendment Measure 2013 Schedule B1: Guideline on investigation levels for soil and groundwater*. National Environment Protection Council, Canberra, Australia. Accessed March 2021.

NICNAS (2002). *Australian High Volume Industrial Chemical List*. National Industrial Chemicals Notification and Assessment Scheme, Sydney, Australia. Accessed June 2019.

NICNAS (2006). *Australian High Volume Industrial Chemical List*. National Industrial Chemicals Notification and Assessment Scheme (NICNAS), Sydney, Australia. Accessed January 2021.

NICNAS (2019). *Industrial use lead by-products: Human health tier II assessment*. National Industrial Chemicals Notification and Assessment Scheme (NICNAS), Sydney, Australia. Accessed March 2021.

NICNAS (2020). *Water Soluble Lead(2+) Salts: Environment Tier II Assessment*. National Industrial Chemicals Notification and Assessment Scheme (NICNAS), Sydney, Australia. Accessed January 2021.

NLM (2021). *ChemIDplus Advanced*. U.S. National Library of Medicine (NLM), Bethesda, Maryland, USA. Accessed October 2021.

Noller B, Matanitobua VP and Ng JC (2009). *Study of Heavy Metals and Metalloids in the Leichardt River and Surronding Locations Lead Pathways Study - Phase 1 (Emissions to Land)*. Centre for Mined Land Rehabilitation, Brisbane, QLD. Accessed February 2021.

Noller B, Huynh T, Ng J, Zheng J and Harris H (2012). *Lead Pathways Study - Water: Sources and Pathways of Contaminants to the Leichardt River*. Centre for Mined Land Rehabilitation, Brisbane, QLD. Accessed February 2021.

Noller B, Zheng J, Huynh T, Ng J, Diacomanolis V, Taga R and Harris H (2017). *Lead Pathways Study - Air: Health Rish Assessment of Contaminants to Mount Isa City*. Centre for Mined Land Rehabilitation, Brisbane, QLD. Accessed February 2021.

Noller BN, Ng JC, Matanitobua V and Huynh T (2013). Assessment of Heavy Metals and Metalloids from Historical Mine Practices in the Leichhardt River, Queensland, Australia using Ecotoxicity Testing. *Journal of Environment and Safety,* **4**(2), pp 145-152.

NPI (1999). *Emission Estimation Technique Manual for Lead Concentrating, Smelting and Refining*. National Pollutant Inventory (NPI), Department of Agriculture, Water and the Environment, Canberra, Australia. Accessed November 2021.

NPI (2019). *Substance list and thresholds*. National Pollutant Inventory (NPI), Department of Agriculture, Water and the Environment, Canberra, Australia. April 2021.

NPI (2021a). *2019/2020 report for Nyrstar Port Pirie Pty Ltd, Nyrstar Port Pirie - Port Pirie, SA*. National Pollutant Inventory (NPI), Department of Agriculture, Water and the Environment, Canberra, Australia. Accessed November 2021.

NPI (2021b). *2019/2020 data within Australia - Lead & compounds from All Sources*. National Pollutant Inventory (NPI), Department of Agriculture, Water and the Environment, Canberra, Australia. Accessed November 2021.

NPI (2021c). *2019/2020 report for Mount Isa Mines Limited, Mount Isa Mines - Mount Isa, QLD*. National Pollutant Inventory (NPI), Department of Agriculture, Water and the Environment, Canberra, Australia. Accessed November 2021.

NRMMC (2004). *National Water Quality Management Strategy, Guidelines for Sewerage Systems Biosolids Management*. NRMMC, Artamon, NSW, Australia. Accessed April 2021.

Nyrstar NV (2014). *Transforming for Tomorrow Annual Report 2013*. Nyrstar NV, Balen, Belgium. Accessed January 2021.

Nyrstar NV (2016). *Annual Report 2015*. Nyrstar NV, Balen, Belgium. Accessed January 2021.

Nyrstar NV (2018). *Annual Report 2017*. Nyrstar NV, Balen, Belgium. Accessed January 2021.

Nyrstar NV (2019). *Annual Report 2018*. Nyrstar NV, Balen, Belgium. Accessed January 2021.

Nyrstar Port Pirie Pty Ltd (2020). *Environment Improvement Program*. Nyrstar Port Pirie Pty Ltd, Port Pirie, SA, Australia.

OECD (1995). *Guidance document for aquatic effects assessment*. Organisation for Economic Co-operation and Development, Paris.

OECD (2019). *Guiding Principles and Key Elements for Establishing a Weight of Evidence for Chemical Assessment, Series on Testing and Assessment No. 311, Environment, Health and Safety Division, Environment Directorate*.

Pafumi J, Rossberg F, Golling J, Armstrong C, Walker R, Grobler J, Boyer J, Meyer R and Beer A (2013).George Fisher Mine Xstrata Zinc. In: Rankin WJ, ed. *Australasian Mining and Metallurgical Operating Practices*. The Australasian Institute of Mining and Metallurgy, Carlton, Victoria, Australia, pp 1639 - 1660.

Public Health Services, SA Health (2013). *Port Pirie Soil Lead Concentrations Report*. Government of South Australia, Adelaide, South Australia. Accessed February 2021.

Queensland Government (2021). *Environmental authority EPML00977513*. Queensland Government, QLD, Australia. Accessed April 2022.

REACHa. *REACH registration dossier for Lead (CAS RN 7439-92-1)*. Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), Brussels, Belgium. Accessed March 2021.

REACHb. *REACH registration dossier for Lead Monoxide (CAS RN 1317-36-8)*. Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), Brussels, Belgium. Accessed March 2021.

REACHc. *REACH registration dossier for Slags, lead smelting (CAS RN 69029-84-1)*. Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), Brussels, Belgium. Accessed November 2021.

Ruby MV, Schoof R, Brattin W, Goldade M, Post G, Harnois M, Mosby DE, Casteel SW, Berti W, Carpenter M, Edwards D, Cragin D and Chappell W (1999). Advances in Evaluating the Oral Bioavailability of Inorganics in Soil for Use in Human Health Risk Assessment. *Environmental Science & Technology,* **33**(21), pp 3697 - 3705.

SA EPA (2021a). *EPA Licence 775*. South Australian Environment Protection Authority (SA EPA), Adelaide, SA, Australia. Accessed April 2022.

SA EPA (2021b). *Nyrstar data confirms licence breach*. South Australian Environment Protection Authority (SA EPA), Adelaide, SA, Australia. Accessed March 2021.

SA EPA (2022). *Update on Nyrstar site report*. South Australian Environment Protection Authority (SA EPA), Adelaide, South Australia. Accessed April 2022.

SA Health (2020). *Fact Sheet: Port Pirie River Estuary 2020 Seafood sampling Results*. Government of South Australia, Adelaide, South Australia. Accessed April 2022.

Sobanska S, Ricq N, Laboudigue A, Guillermo R, Bremard C, Laureyns J, Merlin JC and Wignacourt JP (1999). Microchemical Investigations of Dust Emitted by a Lead Smelter. *Environ. Sci. Technol.,* **33**, pp 1334 - 1339.

Sutley S, Gustkiewicz M-S, Mayer W and Leach D (1999). *USGS Open File REport - 99-394 Mineralogy and chemistry of oxidized ores from the Upper Silesia Mississippi Valley-type zinc-lead deposits, Poland*. Denver, Colorado, USA.

Taylor MP and Hudson-Edwards KA (2008). The dispersal and storage of sediment-associated metals in an arid river system: The Leichhardt River, Mount Isa, Queensland, Australia. *Environmental Pollution,* **152**(1), pp 193 - 204.

Taylor MP, Mackay A, Kuypers T and Hudson-Edwards K (2009). Mining and urban impacts on semi-arid freshwater aquatic systems: the example of Mount Isa, Queensland. *Journal of Environmental Monitoring,* **11**, pp 977 -986.

Taylor MP, Mackay AK, Hudson-Edwards KA and Holz E (2010). Soil Cd, Cu, Pb and Zn contaminants around Mount Isa city, Queensland, Australia: Potential sources and risks to human health. *Applied Geochemistry,* **25**(6), pp 841 - 855.

TLAP (2015). *Report on the Activities of the TLAP Committee for 2014*. Targeted Lead Abatement Program (TLAP). Accessed February 2022.

UNECE (2007). *Annex 9: Guidance on Hazards to the Aquatic Environment*. United Nations Economic Commission for Europe, Geneva, Switzerland. Accessed April 2021.

UNECE (2017a). *Globally Harmonized System of Classification and Labelling of Chemicals (GHS), Seventh Revised Edition*. United Nations Economic Commission for Europe (UNECE), Geneva, Switzerland. Accessed April 2022.

UNECE (2017b). *Globally Harmonized System of Classification and Labelling of Chemicals (GHS), Seventh Revised Edition*. United Nations Economic Commission for Europe (UNECE), Geneva, Switzerland. Accessed March 2021.

UNEP (1989). *The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal*. United Nations Environment Programme (UNEP) Secretariat of the Basel Convention, Châtelaine, Switzerland. Accessed March 2021.

UNEP (2010). *Final review of scientific information on lead*. UNEP Chemicals Branch, DTIE, Geneva, Switzerland.

US EPA (2016). *2016 CDR Industrial Processing and Use (May 2020)* United States Environmental Protection Agency (US EPA), Washington DC, USA. Acessed March 2021.

Vallelonga P, Velde KVd, Candelone J-P, Morgan VI, Boutron CF and Rosman KJR (2002). The lead pollution history of Law Dome, Antarctica, from isotopic measurements on ice cores: 1500 AD to 1989 AD. *Earth and Planetary Science Letters,* **204**, pp 291 - 306.

Vandeleur H (2020). *Port Pirie Phase 1 Project:Measuring, monitoring and managing legacies of marine pollution as new resources*. UniSA, Flinders Ports, Nyrstar Port Pirie and the SA EPA, Adelaide, South Australia. Accessed March 2022.

Ward TJ and Young PC (1981). Trace Metal Contamination of Shallow Marine Sediments near a Lead Smelter, Spencer Gulf, South Australia. *Aust. J. Mar. Freshw. Res.,* **32**, pp 45 - 56.

Weast RC (1976).Section B The Elements and Inorganic Compounds. In: Weast RC, ed. *Handbook of Chemistry and Physics* (57th ed). CRC Press, Cleveland, Ohio.