Mercury: Environment tier II assessment

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Preface

This assessment was carried out by staff of the National Industrial Chemicals Notification and Assessment Scheme (NICNAS) using the Inventory Multi-tiered Assessment and Prioritisation (IMAP) framework.

The IMAP framework addresses the human health and environmental impacts of previously unassessed industrial chemicals listed on the Australian Inventory of Chemical Substances (the Inventory).

The framework was developed with significant input from stakeholders and provides a more rapid, flexible and transparent approach for the assessment of chemicals listed on the Inventory.

Stage One of the implementation of this framework, which lasted 4 years from 1 July 2012, examined 3000 chemicals meeting characteristics identified by stakeholders as needing priority assessment. This included chemicals for which NICNAS already held exposure information, chemicals identified as a concern or for which regulatory action had been taken overseas, and chemicals detected in international studies analysing chemicals present in babies' umbilical cord blood.

Stage Two of IMAP began in July 2016. We are continuing to assess chemicals on the Inventory, including chemicals identified as a concern for which action has been taken overseas and chemicals that can be rapidly identified and assessed by using Stage One information. We are also continuing to publish information for chemicals on the Inventory that pose a low risk to human health or the environment or both. This work provides efficiencies and enables us to identify higher risk chemicals requiring assessment.

The IMAP framework is a science and risk-based model designed to align the assessment effort with the human health and environmental impacts of chemicals. It has 3 tiers of assessment, with the assessment effort increasing with each tier. The Tier I assessment is a high throughput approach using tabulated electronic data. The Tier II assessment is an evaluation of risk on a substance-by-substance or chemical category-by-category basis. Tier III assessments are conducted to address specific concerns that could not be resolved during the Tier II assessment.

These assessments are carried out by staff employed by the Australian Government Department of Health and the Australian Government Department of the Environment and Energy. The human health and environment risk assessments are conducted and published separately, using information available at the time, and may be undertaken at different tiers.

This chemical or group of chemicals are being assessed at Tier II because the Tier I assessment indicated that it needed further investigation.

For more detail on this program please visit: www.nicnas.gov.au.

Disclaimer

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Acronyms & Abbreviations

Rationale

This Tier II assessment considers the environmental risks associated with industrial uses of mercury in its elemental form (elemental mercury).

Elemental mercury occurs naturally in the environment, but it is also an industrial chemical which has been used in large volumes for the recovery of precious metals from minerals and for the production of chlorine and sodium hydroxide (caustic soda) from brines in the chlor-alkali industry. These high volume industrial uses of elemental mercury have been phased out in Australia because of the unacceptable risks they pose to wildlife and humans. This assessment will be concerned with remaining industrial uses of elemental mercury which have the potential to release mercury into the environment.

Elemental mercury is of environmental concern because it is converted into very toxic inorganic and organometallic mercury species by natural processes. The mercury species of highest concern is the monomethyl mercury cation (CH_3Hg^+, or more commonly MeHg), which is exceptionally toxic. This organometallic cation also biomagnifies in aquatic food webs and can reach toxicologically significant concentrations in long-lived predatory fish. As these fish are prey for some species of large mammals and food for humans the biomagnification of monomethyl mercury can also result in the transfer of this very toxic mercury species into other food chains, including the human food chain. Dietary uptake of MeHg is of high concern for human health because it is a neurodevelopmental toxin that can be transferred across the placenta to the unborn child.

Global concerns regarding the impacts of anthropogenic emissions of mercury on human and ecological health have resulted in the negotiation and bringing into force of the *Minamata Convention on Mercury* (the Minamata Convention). The objective of this treaty is to protect human health and the environment from anthropogenic emissions and releases of mercury and mercury compounds, and it commits nations which ratify the convention to reduce their use and emissions of mercury (UNEP, 2013a). In Australia, an estimated 10 to 21 tonnes of mercury is emitted to the environment every year from anthropogenic sources

(AMAP/UNEP, 2013). The purpose of this assessment is to evaluate whether current industrial uses of elemental mercury make a significant contribution to cumulative anthropogenic emissions of mercury in Australia.

This assessment provides information on the environmental fate and effects of the forms of mercury that are of the greatest ecotoxicological concern. This information is necessary to characterise the environmental risks resulting from industrial uses of elemental mercury and compounds of mercury. The environmental risks resulting from industrial uses of mercury compounds that are listed on the Inventory will be evaluated separately.

Chemical Identity

Synonyms	elemental mercury metallic mercury quicksilver
Atomic Weight (g/mol)	200.59

Physical and Chemical Properties

Physical and chemical properties of elemental mercury as reported in references describing industrial chemicals are presented below (DeVito, et al., 2013; HSDB, 2005; Shoichi and Sokichi, 1985; Simon, et al., 2000):

Physical Form	liquid
Density	13.546 g/cm^3 (20°C)
Melting Point	-38.89°C
Boiling Point	357.3°C
Vapour Pressure	0.267 Pa (25°C)
Water Solubility	0.056 mg/L (25°C)
log K_{ow}	0.62 (25°C)

Elemental mercury is a dense silver-coloured liquid under ambient conditions. It has both a uniform volume expansion over its liquid range and high surface tension, which are functional requirements for its industrial uses in measuring devices such as thermometers and manometers. This liquid metal is also both relatively inert and a good conductor of electricity which are functional requirements for its industrial uses in electrical equipment such as certain switches (DeVito, et al., 2013; Simon, et al., 2000).

Elemental mercury forms alloys with most metals, except some transition metals such as iron, which are called amalgams. Amalgamation of sodium is a key functional requirement for the industrial use of elemental mercury as the cathode in the electrolytic production of chlorine and sodium hydroxide from brines in mercury diaphragm cells. This production method was formerly widely used in the chlor-alkali industry, but is now being phased out globally. Amalgams containing silver, tin, copper and zinc have non-industrial uses in dentistry (DeVito, et al., 2013).

The vapour pressure of elemental mercury indicates that it is moderately volatile under ambient conditions. This property is an important factor in the global environmental cycling of mercury as discussed in following sections (HSDB, 2005). The element is also very slightly soluble in water. Measurements of the octanol-water partition coefficient (K_{ow}) also indicate that the element has some solubility in n-octanol (Shoichi and Sokichi, 1985). The K_{ow} for elemental mercury is greater than one, which indicates that it has a tendency to partition from water into biological membranes and lipid-rich tissues.

Mercury in its elemental form can be oxidised to divalent mercuric ions (i.e., mercury(2+)) (Cotton and Wilkinson, 1989). The mercuric ion and its various salts and complexes are the most important forms of inorganic mercury in the environment. All further discussion of *inorganic* mercury in this assessment will mean a salt or complex of mercury(2+), unless otherwise specified.

Import, Manufacture and Use

Australia

A call for information conducted by NICNAS in 1999 indicated that elemental mercury was imported for use in the production of button batteries used in small electrical devices such as hearing aids and watches (NICNAS, 2015). It may also be used in thermometers and switches.

Mercury cells were previously used for the production of chlorine and sodium hydroxide at two chlor-alkali plants, one in Victoria and another in New South Wales. These plants have been replaced by membrane cell plants that do not use elemental mercury for the production of these two commodity chemicals (ChemLink Australia, 1997).

The use of elemental mercury in compact and linear fluorescent light globes for commercial and domestic use, and high-pressure mercury vapour lamps for public street and stadium lighting, is industrial use under the ICNA Act. However, the majority of mercury-containing globes and lamps in use are expected to be imported as finished articles (Netbalance, 2013).

In 2015/16, the FluoroCycle program recycled approximately 1200 tonnes of mercury-containing lighting waste, resulting in the recovery of 117 kg of mercury, which was sold to an Australian dental amalgam manufacturer (Lighting Council Australia, 2016). This voluntary lighting waste recycling program was developed by the Australian Government in partnership with industry and was administered by the Lighting Council of Australia. This program was accredited by the Australian Government under the *Product Stewardship Act 2011* from 2014–2019, but is not currently accredited (Australian Government Department of Environment, 2019).

Additional information on non-industrial uses of mercury in Australia was obtained from the Regulatory Impact Statement (RIS) for the proposed ratification of the Minamata Convention (Australian Government Department of the Environment and Energy, 2016). The organometallic mercury compound, (methoxyethyl)mercuric chloride (CAS RN 123-88-6), is a fungicide which is manufactured in Australia from imported elemental mercury and mercuric oxide (CAS RN 21908-53-2). According to information in the RIS, 5.3 tonnes of mercury (calculated on an elemental basis) is released to land in Australia annually as the result of the non-industrial use of (methoxyethyl)mercuric chloride as a fungicide in sugarcane. Information in the RIS also indicates that 1.3 tonnes of mercury is released through the disposal of dental amalgam. Use of elemental mercury in dental amalgams is regulated as a medical device under the *Therapeutics Goods Act* (Australian Government, 1989).

International

Globally, elemental mercury is used in chemical manufacturing including in the chlor-alkali industry, and for the production of vinyl chloride monomer and acetaldehyde. It is used in the manufacture of paints, dental amalgams, and fungicides. Elemental mercury is used in batteries, electrical switches, and measuring devices such as thermometers. A major use historically has been in the artisanal gold mining industry (IPCS, 1991). Total global mercury consumption in 2005 was estimated at between 3000 and 3900 tonnes. Consumption in order of quantity used is: artisanal gold mining (24%); vinyl chloride manufacturing (20%); chlor-alkali plants (15%); batteries (13%); measuring and control devices, and electrical devices (7%); and lighting (4%). Non-industrial applications include use in pesticides (8%) and dental amalgams (8%) (UNEP, 2006).

There has been an increase in demand for mercury over the last ten years associated with artisanal and small-scale gold mining and vinyl chloride monomer manufacturing. In 2015, global demand for mercury was in the range of 4500 to 4900 tonnes, with annual supply at only 3850 to 4400 tonnes. East and Southeast Asia accounted for over 50% of the global mercury consumption. Reduced demand from the chlor-alkali industry has limited the supply of residual mercury available for sale. To meet sustained demand Mexico and Indonesia have increased primary mercury mining (UNEP, 2017). Excess demand is expected to lead to increased informal mercury supply and trade (UNEP, 2017).

Environmental Regulatory Status

Australia

Australia became a signatory to the Minamata Convention in 2013 and is currently considering ratifying the treaty (UNEP, 2013a). A Regulatory Impact Statement was prepared in 2016 to examine the benefits and costs resulting from ratification of the Convention (Australian Government Department of the Environment and Energy, 2016). The RIS process concluded that there is a net benefit to Australia from ratification and recommended the introduction of additional controls on mercury emissions to air. A phase down of mercury used in pesticides and the promotion of dental amalgam waste traps was recommended to control releases to land and water.

An extensive range of national guidelines exist to manage human and environmental exposure to mercury. They reflect the significance attached to the adverse effects on human and ecological health associated with exposure to mercury and mercury compounds.

Mercury and mercury compounds are subject to reporting under the National Pollutant Inventory (NPI) and are listed as 1b and 2b threshold category substances. Under the 1b category, emissions are required to be reported annually by facilities that use or emit more than 5 kg of mercury and mercury compounds per year. Under the 2b threshold category, emissions are required to be reported annually by facilities that burn more than 2000 tonnes of fuel; consume more than 60 000 megawatt hours of electricity (excluding lighting and motive purposes); or have an electricity rating of 20 megawatts during a reporting year (Australian Government Department of the Environment and Energy, 2017). Emissions may be intentional, accidental or incidental releases resulting from industrial processes.

Default Guideline Values (DGV) for inorganic mercury as a toxicant in fresh and marine waters have been developed. The 99% species protection level is recommended for *slightly–moderately disturbed systems* to take account of the potential for transformation of inorganic mercury to methylmercury and for biomagnification of this mercury species in food chains. The DGV for freshwater is 0.06 micrograms of total mercury per litre (µg Hg_T/L) and for marine waters it is 0.1 µg Hg_T/L (ANZECC/ARMCANZ, 2000c; Water Quality Australia, 2018).

Sediment DGVs have been developed for the fine sediment fraction (grain size less than 2 mm). The DGV and Guideline Value-High (GV-high) represent, respectively, the concentration at which 10% and 50% of toxic effects on sediment dwelling organisms are observed. For inorganic mercury in fresh and marine sediments the DGV and GV-high value are 0.15 and 1.0 milligrams of mercury per kilogram of dry sediment (mg Hg/kg dw), respectively (ANZECC, 2019).

The short and long-term trigger guideline values for mercury in agricultural irrigation water are both set at 0.002 milligrams of mercury per litre (mg Hg/L). A soil cumulative contaminant loading (CCL) limit of 2 kg Hg/ha applies to irrigated agricultural soils with no mercury contamination history. It is recommended that once this limit has been reached a site-specific risk assessment is conducted before continuing with irrigation (ANZECC/ARMCANZ, 2000c).

There are no uniform national standards relating to the disposal of sewage sludge on agricultural lands in Australia. Existing jurisdictional regulations apply the classification principles set out in the National Water Quality Management Strategy (NRMMC, 2004). The guideline for a maximum concentration of mercury contaminants in grade C1 dry biosolids which can be applied in an unrestricted manner to all lands, excluding sensitive sites, is 1 mg Hg_T/kg. Dry solids should not be used for any land application where they exceed 15 mg Hg_T/kg (NRMMC, 2004). The South Australian Environmental Protection Agency (SA EPA) guidelines limit the amount of mercury which can be applied to soils in biosolids annually to 0.1 kilograms of mercury per hectare per year on a dry weight of soil basis (kg Hg/ha/yr dry wt) (SA EPA, 1997). In line with the National Water Quality Management Strategy (NRMMC, 2004) for grade C1 dry biosolids, South Australia, Queensland and New South Wales have set a maximum permissible concentration of mercury in soils amended with biosolids used for food production of 1 mg Hg/kg.

The National Code of Practice for fertiliser description and labelling sets a maximum permissible mercury concentration for all fertiliser types at 5 mg Hg/kg of product, with a 0.2 mg Hg/kg impurity concentration trigger value for product labelling requirement of ‘This product contains heavy metal impurities. Its use may result in accumulation of mercury in the soil and may lead to residue levels in plant and animal products in excess of the maximum level specified by the Australia New Zealand Food Standards Code’ (Fertilizer Working Group, 2011).

NSW guidelines for acceptance of liquid trade wastes into the sewerage system set a maximum concentration of 0.01 mg Hg/L, with a daily mass limit of 0.05 g Hg/day (NSW Department of Water and Energy, 2009); while South Australia’s Restricted Wastewater Acceptance Standards limit influent to 1 mg Hg/L (SA Water, 2012).

The Australia New Zealand Food Standards Code prescribes maximum levels of mercury in some foods, including fish. For species known to contain elevated levels of mercury including barramundi, orange roughy and all sharks the mean concentration of mercury should not exceed 1.0 milligram of mercury per kilogram of flesh (mg Hg/kg), while for other fish and for crustaceans the limit is set at 0.5 mg Hg/kg (Australian Government, 2016).

United Nations

The *Minamata Convention on Mercury* as adopted on 10 October 2013 is a global treaty to protect human and environmental health from adverse effects of mercury. The Convention includes a ban on new, and a phase-out of existing, mercury mines; a phase out and phase down of mercury use in a number of products and processes; control measures on emissions to air and on releases to land and water; and the regulation of the informal sector of artisanal and small-scale gold mining. It also covers interim storage and disposal of mercury waste, mercury contaminated sites and health issues. Currently, the Convention has 128 signatories and has been ratified by 115 countries (UNEP, 2019b). It became legally binding for all its Parties on 18th May 2017 after the required 50 instruments of ratification were deposited at the UN headquarters (UNEP, 2019a).

The Convention contains instruments for controlling and reducing the release or emission of mercury from anthropogenic sources. Annex D of the convention lists five categories of anthropogenic point sources of emissions as coal-fired power plants; coal-fired industrial boilers; smelting and roasting processes used in the production of non-ferrous metals; waste incineration facilities; and cement clinker production facilities (UNEP, 2013a).

Mercury compounds including inorganic mercury, alkyl mercury, alkyloxyalkyl and aryl mercury compounds are included in Annex III of the *Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade* (UNEP & FAO, 2017). Australia’s decision guidance includes an exemption for the importation of mercury fungicide for use in the sugar cane industry (FAO, 2019). Mercury-containing wastes and mercury compounds are specifically listed as categories of wastes to be controlled in Annexes I, VIII and IX to the *Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal* (UNEP, 1992).

OECD

Mercury is one of five chemicals that were subject to a Risk Reduction Monograph under the OECD Council Decision – Recommendation on the Co-operative Investigation and Risk Reduction of Existing Chemicals. The council decision was aimed at the reduction of risks from chemicals to the environment, and health of the general public or workers (OECD, 1995). Other chemicals subject to Risk Reduction Monographs are: lead; methylene chloride; selected *brominated flame retardants; and*cadmium.

Elemental mercury was identified as a High Production Volume (HPV) chemical in 2007. This indicates that it was used at more than 1000 tonnes per annum in at least one member country or region (OECD, 2009). Mercury has not been sponsored for assessment under the OECD Cooperative Chemicals Assessment Program (OECD, 2019).

Canada

Canada ratified the Minamata Convention in 2017 (UNEP, 2013a).

Mercury and its compounds are included in the list of toxic substances (schedule 1) managed under the *Canadian Environmental Protection Act 1999* (Government of Canada, 2017).

The Canadian water quality guideline (WQG) for inorganic mercury in freshwater is 0.026 µg Hg/L, and the interim guideline (IWQG) for inorganic mercury in marine waters is 0.016 µg Hg/L (CCME, 2002).

A Canadian tissue residue guideline to protect wildlife that consume aquatic animals has also been developed, as it is recognised that the mercury which has the potential to cause secondary poisoning in terrestrial organisms is more likely to be found in aquatic prey organisms than in water. The guideline is based on MeHg as this is the form of mercury which is bioaccumulated in the tissues of aquatic organisms. The guideline value for secondary poisoning is 33.0 µg MeHg/kg dry tissue weight (CCME, 2000).

European Union

The European Union ratified the Minamata Convention in 2017 (UNEP, 2013a).

Mercury and mercury compounds are restricted under Annex XVII (Restriction) of the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) legislation (ECHA, 2017a). The restrictions on mercury relate to its use in measuring devices after 3 April 2009. Restrictions are also placed on substances or mixtures intended to be used to prevent fouling of boat hulls or any totally submerged equipment such as cages, floats and nets used for fish or shellfish; in wood preservation; in impregnation of textiles and yarn; and in the treatment of industrial waters (ECHA, 2017b; 2017c)

United States of America

The USA ratified the Minamata Convention in 2013 (UNEP, 2013a).

Mercury is ranked third in the substance priority list of theAgency for Toxic Substances and Disease Registry which prioritises substances based on a combination of their frequency, toxicity, and potential for human exposure at facilities on the National Priority List sites (ATSDR, 2017). Mercury use is subject to two specific environmental laws in the USA, the *Mercury Export Ban Act 2008* (USA Government, 2008) and the *Mercury-Containing and Rechargeable Battery Management Act 1996* which phases out the use of mercury in batteries and provides for appropriate disposal of existing mercury batteries (USA Government, 1996). Other environmental laws to limit mercury exposure that apply are: *Clean Air Act 1990* which put mercury on a list of toxic pollutants that need to be controlled to the greatest possible extent; *Clean Water Act 1972* which sets mercury environmental water quality and effluent emissions criteria; *Resource Conservation and Recovery Act 1976* which provides for the recovery and safe disposal of mercury from discarded materials and regulates its management as a hazardous waste (US EPA, 2017).

The national recommended water quality criteria for inorganic mercury lists both acute (Criterion Maximum Concentration (CMC)) and chronic (Criterion Continuous Concentration (CCC)) values for fresh and marine waters. For freshwaters the CMC is 1.4 micrograms of dissolved mercury(2+) per litre (µg $Hg(II)_{diss}$/L), while the CCC is 0.77 µg $Hg(II)_{diss}$/L. For marine waters the CMC and CCC are 1.8 µg $Hg(II)_{diss}$/L and 0.94 µg $Hg(II)_{diss}$/L respectively (US EPA, 2009).

Japan

Japan ratified the Minamata Convention in 2016 (UNEP, 2013a).

In combination with existing laws, regulations and their amendments, the use, storage and disposal of mercury and mercury compounds is controlled under the 2015 Act On Preventing Environmental Pollution of Mercury (Government of Japan, 2015). The Japanese National Environmental and Emission Standards for elemental mercury set the following annual average concentration values: Air mercury vapour < 40 nanograms mercury per cubic metre (ng Hg/m^3); water and groundwater < 0.0005 milligrams of total mercury per litre (mg Hg_T/L); effluent < 0.005 mg Hg_T/L; soil < 0.0005 mg Hg_T/L (water elution standard) and 15 milligrams of mercury per kilogram of soil (mg Hg/kg) (bulk soil content standard) (Ministry of the Environment Japan, 2013).

Environmental Exposure

Elemental mercury vaporises readily under ambient conditions and it is the dominant form of mercury in the atmosphere, where it is stable and can travel for long distances. Atmospheric mercury is redeposited to land and oceans worldwide, where it can enter food chains. Mercury is methylated in aquatic environments forming MeHg, which biomagnifies through food chains.

Globally, anthropogenic mercury emissions are five times greater than those from natural geological processes. The contribution of anthropogenic mercury emissions has led to the formation of an enhanced global mercury cycle and resulted in a substantial increase in mercury concentrations in the atmospheric and aquatic compartments (Outridge, et al., 2018).

Anthropogenic emissions of mercury in Australia are estimated to be in the range of 10–21 tonnes annually accounting for approximately 1% of global emissions (AMAP/UNEP, 2013; Australian Government Department of the Environment, 2019; Pirrone, et al., 2010). The contribution of industrial uses of elemental mercury to Australia’s total emissions are presented here with reference to the major emission sources and environmental cycling. Environmental exposure pathways leading to the formation of MeHg are of greatest concern.

Emission data available for this assessment show that in Australia mercury is primarily emitted as a waste product from non-ferrous metal refineries, coal fired electricity generators and during cement production (AMAP/UNEP, 2013; Australian Government Department of the Environment, 2019; Nelson, et al., 2012; Pirrone, et al., 2010). Emissions from these processes occur due to the presence of mercury as a contaminant in raw materials.

Until recently, non-ferrous metal production including zinc, lead, aluminium, gold and copper collectively accounted for between 50 and 80% of Australia’s anthropogenic mercury emissions (AMAP/UNEP, 2013; Australian Government Department of the Environment, 2019; Pirrone, et al., 2010). More recent information suggests that this contribution has declined significantly due to a decrease in emissions of mercury from large scale gold production (AMAP/UNEP, 2019). Coal fired electricity generation and cement manufacturing are the next most significant sources (AMAP/UNEP, 2013; Pirrone, et al., 2010). Collectively, these industries are estimated to account for greater than 95% of Australia’s point source mercury emissions (AMAP/UNEP, 2013).

Non-ferrous metal refining, coal combustion and cement manufacturing emit mercury to the atmosphere during high temperature processes such as calcination and combustion (Driscoll, et al., 2013; Pirrone, et al., 2010). Approximately 50% of this mercury is oxidised and deposited locally, while the remainder is present as elemental mercury in the vapour phase which is able to undergo long range transport (Driscoll, et al., 2013). Emission controls such as electrostatic precipitators, spray dryer absorbers, fabric filters and flue gas desulfurisation are able to reduce the emission of mercury compounds from industrial waste gases by up to 90% (Pirrone, et al., 2010).

Additional non-industrial contributions to total anthropogenic sources of mercury in Australia include the use of the mercury-containing fungicide Shirtan in sugarcane farming, the disposal of mercury vapour lamps, and the disposal of mercury-containing dental amalgam (Australian Government Department of the Environment and Energy, 2016).

The major industrial uses of elemental mercury that still occur internationally such as use in chemical manufacturing and artisanal gold mining are not expected to occur in Australia. Based on the evaluation of national and international emission data, industrial uses of elemental mercury are expected to account for significantly less than 5% of Australia’s total mercury emissions.

Understanding of the significance of any mercury emissions to the environment from industrial uses of elemental mercury must also consider natural background mercury levels, speciation and transfer of mercury through all environmental compartments. Transformation of elemental mercury in the environment, and partitioning to the atmosphere, environmental surface waters, aquatic sediments, soils and biota are, therefore, all relevant considerations for this assessment.

Environmental Fate

Partitioning and Speciation

Mercury is mobilised in the environment due to anthropogenic and natural processes. Mercury is transformed and transported between the major environmental compartments as part of the global mercury cycle until it is immobilised through deposition in sediments and subsurface soils. Mercury cycling is driven by the characteristics of different mercury species which are transformed through biotic and abiotic processes in the environment.

Ninety-five percent of atmospheric mercury is in the gaseous elemental form. Elemental mercury is stable in the atmosphere and it has a residence time in this compartment that has been estimated to be in the range from six months up to one year (Driscoll, et al., 2013; Holmes, et al., 2010). The extended residence time of elemental mercury facilitates long range transport before it is redeposited to the terrestrial and aquatic compartments in remote areas (AMAP/UNEP, 2013; Outridge, et al., 2018).

Mercury is removed from the atmosphere by oxidative processes that result in deposition to the terrestrial and aquatic compartments. The oxidation of atmospheric elemental mercury to mercury(2+) occurs in both the gas and aqueous phases. The most important oxidants are believed to be ozone, hydroxyl radicals and bromine/bromine monoxide (AMAP/UNEP, 2013). Oxidised inorganic mercury has a limited atmospheric residence time and is typically transferred to the terrestrial or aquatic compartments within a few days by wet and dry deposition (Driscoll, et al., 2013).

Inputs of mercury to soil include direct atmospheric deposition and as mercury contained in plant biomass. In soils, mercury is strongly retained within the organic fraction through interaction with sulfur-based functional groups. Mercury can be returned to the atmosphere from surface soils during the decomposition of organic matter where it is reduced back to elemental mercury (Driscoll, et al., 2013). Estimates indicate that 50 to 90% of mercury deposited to surface soils is returned to the atmosphere (Driscoll, et al., 2013).

Globally, direct atmospheric deposition is the most significant source of mercury to freshwater and marine environments. Emissions of mercury from activities such as metal refining and coal combustion, and releases from waste water treatment can dominate inputs at a local scale (AMAP/UNEP, 2013; Driscoll, et al., 2013; Macleod and Coughanowr, 2019).

The dominant form of mercury in most aquatic systems is inorganic mercury which is present in dissolved and particulate form. Dissolved elemental mercury comprises less than 30% of the total mercury pool, with dissolved methyl and dimethylmercury accounting for less than 20% of the total (AMAP/UNEP, 2013).

In freshwater and marine ecosystems, inorganic mercury is associated with particulate matter and is removed from the water column through deposition to sediments (AMAP/UNEP, 2013; Environment Canada, 2003). Dissolved inorganic mercury can be reduced to elemental mercury which, due to its low water solubility and volatility, ultimately partitions back to the atmospheric compartment. Reduction of inorganic mercury is inhibited by the formation of complexes with chloride ions and dissolved organic matter (Luoma and Rainbow, 2008).

The formation of MeHg is the most important process in the mercury cycle with regard to the risks to the environment and human populations. The pool of mercury available for methylation is dependent on transport processes leading to deposition of mercury in reducing freshwater sediments or oceanic waters (AMAP/UNEP, 2013; Driscoll, et al., 2013; Luoma and Rainbow, 2008). Freshwater environments which contribute to mercury methylation include wetlands and low oxygen sediments. Mercury is transported to these reducing environments through direct atmospheric deposition to waterways followed by sorption to particulate matter and transfer to sediments (AMAP/UNEP, 2013; Driscoll, et al., 2013). Mercury is principally transported to the ocean through atmospheric deposition. Mercury input from rivers is only significant in estuaries and coastal environments (Driscoll, et al., 2013; Outridge, et al., 2018).

Transformation

Biomethylation of mercury occurs in anoxic sediments and in oceans and is a key process in the cycling of mercury in the aquatic environment. Methylmercury is a highly toxic form of mercury.

Methylation is a pivotal stage in the global mercury cycle as it greatly increases the biomagnification and toxicity of mercury in biota. Methylmercury is formed in anoxic freshwater sediments, coastal sediments, as well as within the upper 1000 m of the oceanic water column (Driscoll, et al., 2013; Mason, et al., 2012). While oceanic methylation is the primary source of human exposure to methylmercury globally, production in freshwater systems and estuaries can be significant at the scale of local populations and ecosystems. The concentration of methylmercury in individual environmental compartments is the net result of dynamic processes involving methylation and demethylation (Driscoll, et al., 2013; Mason, et al., 2012).

In freshwater systems methylmercury is produced by sulfate reducing bacteria (SRB) and iron reducing bacteria (FeRB) (Skyllberg, 2010). Lakes with low oxygen bottom waters and soils subject to frequent or permanent inundation such as in wetlands have the highest potential for methylmercury production (Skyllberg, 2010). The rate and extent of net mercury methylation in freshwater environments is influenced by the composition of available forms of mercury; temperature; the presence of oxygen or nitrate (NO_3^-); the availability of sulfate and iron(III); pH; and the presence of dissolved organic carbon (Driscoll, et al., 2013; Skyllberg, 2010).

Methylmercury is formed in ocean waters by dynamic processes operating between subsurface and surface waters (Driscoll, et al., 2013; Mason, et al., 2012). Riverine inputs have minimal influence on the concentration of MeHg in the open oceans. Mercury methylation occurs at depths between 100 and 1000 m in association with the decomposition of organic matter. Unlike in freshwater environments, methylation in the oceans can occur in the presence of oxygen (Driscoll, et al., 2013; Mason, et al., 2012).

Oceanic methylation produces dimethylmercury ($(CH_3)_2Hg$) in addition to methylmercury (CH_3Hg). The higher volatility of dimethylmercury favours its transport to surface waters where photochemical and biotic degradation lead to the production of elemental mercury and methylmercury (Driscoll, et al., 2013; Mason, et al., 2012).

Methylation processes operating in the open oceans are the most important pathway leading to exposure of the human population to MeHg. In the United States, over 90% of the population-wide MeHg intake is from the consumption of marine and estuarine fish (Mason, et al., 2012). As the major source of mercury inputs to the oceans is from atmospheric deposition, anthropogenic emissions of mercury have a significant, but indirect effect on human exposure to mercury (Mason, et al., 2012).

Bioaccumulation

Methylmercury bioaccumulates in terrestrial and aquatic organisms. At higher trophic levels MeHg biomagnification occurs due to slow rates of removal from organisms coupled with efficient assimilation from food. The most significant exposure pathway for humans to MeHg worldwide is through consumption of oceanic fish.

Methylmercury and inorganic mercury are both retained by aquatic plants and invertebrates (Luoma and Rainbow, 2008; OECD, 1995). In these organisms less than 50% of the mercury present is methylmercury (ANZECC/ARMCANZ, 2000b; CCME, 2002). Aquatic invertebrates have similar rates of uptake and loss for both MeHg and inorganic mercury, with total body burden reflecting concentrations found in their food source (Luoma and Rainbow, 2008).

The proportion of MeHg is significantly higher in fish and terrestrial organisms accounting for 90 to 100% of total mercury (ANZECC/ARMCANZ, 2000b; Driscoll, et al., 2013; Mason, et al., 2012). Elimination rates for MeHg in vertebrates are typically ten times slower than invertebrates (Luoma and Rainbow, 2008). Efficient dietary uptake can result in predatory fish and marine mammals with MeHg concentrations above levels expected to cause toxic effects. Biomagnification of MeHg has led to concentrations in fish from one million to one hundred million times higher than in the surrounding water (ANZECC/ARMCANZ, 2000b; Driscoll, et al., 2013; Mason, et al., 2012).

While it is clear that MeHg biomagnifies in birds and mammals that feed on aquatic organisms, less is known about the biomagnification of this form of mercury in exclusively terrestrial food webs (Driscoll, et al., 2013; Mason, et al., 2012; Tsui, et al., 2019). A recent study observed that the concentration of MeHg in forest floor invertebrates increased with trophic level at a rate similar to that observed in freshwater ecosystems (Tsui, et al., 2019). Despite this evidence, terrestrial organisms that feed on fish and other aquatic organisms are at greatest risk for dietary exposure to MeHg (US EPA, 2002).

Bioaccumulation of mercury in crop plants has recently gained attention due to the potential for human exposure. This work has focused on crops grown in regions with an anthropogenic point source of mercury emissions such as coal fired power plants or metal refineries (Li, et al.; Rai, et al., 2019). Rice crops have received particular attention due to the presence of reducing soil conditions during cultivation and subsequent potential for mercury methylation. Average bioaccumulation factors (BAF) for MeHg in rice are reported to range from 4.3 to 6.6, with BAFs for total mercury generally reported below 1 (Rothenberg, et al., 2014). Bioaccumulation factors have been measured for edible mushrooms and range from 65 to 140 (ATSDR, 1999). Mercury contamination of leafy vegetables and grains in the vicinity of coal fired power stations has been reported internationally (Li, et al., 2017).

Predicted Environmental Concentration (PEC)

A PEC was not calculated for elemental mercury.

Very few data are available to characterise mercury concentrations in Australian environmental compartments (Jardine and Bunn, 2010). Where data are available they indicate elevated mercury concentrations occur only in association with local emission sources and that the atmospheric deposition rate is likely to be low (Jardine and Bunn, 2010; Macleod and Coughanowr, 2019).

Mercury concentrations in Australian environmental compartments have been hypothesised to be low based on relatively low emission and deposition rates in comparison to a large land area (Jardine and Bunn, 2010). Available biomonitoring data indicate that point source emissions of mercury are responsible for mercury biomagnification within local environments (Einoder, et al., 2018; Macleod and Coughanowr, 2019). In Australia local mercury contamination is expected to occur in close proximity to industrial processes that emit mercury as a waste product. These emissions are not considered to be associated with the industrial use or manufacture of elemental mercury.

Natural background concentrations of total mercury in freshwater are generally less than 5 nanograms per litre (ng Hg_T/L) (ATSDR, 1999). Flowing freshwater streams in an uncontaminated region of New South Wales have been reported to have mercury levels of 7 ng Hg_T/L (Jardine and Bunn, 2010).

Domestic wastewater in Australian capital cities has mercury levels in the range of < 0.5 to 1 µg Hg_T/L. Sewage treatment plants (STPs) using secondary treatment are able to remove approximately 65% of mercury from wastewater, giving an expected effluent concentration of 0.33 to 0.65 µg Hg_T/L (ANZECC/ARMCANZ, 1994). This range is consistent with measured mercury concentrations in the effluent of three South Australian STPs of 0.5 µg Hg_T/L (Wilkinson, et al., 2003).

It is difficult to determine the main contributing sources of mercury in these waste streams. Industrial activity and stormwater input may contribute a significant proportion of mercury to STPs, with waste dental amalgam being a likely additional source (Australian Government Department of the Environment and Energy, 2016).

The Western Treatment Plant in Victoria receives approximately 55% of Melbourne's effluent including 90% of industrial waste water and is estimated to release 10–20 kg of mercury annually (Australian Government Department of the Environment, 2019; Fabris, et al., 1999). Treated effluent from this plant is discharged to the estuarine waters of Port Phillip Bay along with urban storm water runoff. Average total mercury concentration in the bay are 3 ng Hg_T/L (Fabris, et al., 1999).

Application of biosolids from STPs to agricultural land is a potential mercury exposure pathway to soil. The National Biosolids Research Program measured average mercury concentrations in Australian biosolids of 3 mg Hg/kg dw (SA EPA, 2017).

Mercury concentrations in excess of 10 ng Hg_T/L are generally only encountered in association with contamination from mining operations (Luoma and Rainbow, 2008). An Australian estuary that receives waste water from a non-ferrous metal refinery has periodically been observed with mercury concentrations above 60 ng Hg_T/L (Nyrstar, 2018). Total mercury concentrations in excess of 0.04 ng Hg_T/L are associated with MeHg enriched food webs (Luoma and Rainbow, 2008).

Undisturbed sediments typically have mercury concentrations of less than 0.1 micrograms of total mercury per gram of sediment (µg Hg_T/g) dry weight (Luoma and Rainbow, 2008). Australian sediments associated with point source emissions of mercury from metal refineries have been measured between 8.5 and 48 µg Hg_T/g (Macleod and Coughanowr, 2019).

The median background concentration of mercury in most Australian soils is 30 ng/g (ANZECC/ARMCANZ, 2000a). Uncontaminated soils in New South Wales were measured with mercury concentrations of 48 ng Hg_T/g (Howard and Edwards, 2018). The average mercury content of uncontaminated surface soils from a number of countries, ranged from 20 to 625 ng Hg_T/g (ATSDR, 1999).

Atmospheric background concentrations of mercury in Australia are low by global standards. Australian background measurements range from 0.86 and 0.95 ng Hg/m^3, compared to the global average of 1.6 ng Hg/m^3. Preindustrial atmospheric mercury concentrations are estimated to have been 0.5 ng Hg/m^3 (Howard, et al., 2017; Howard and Edwards, 2018; Luoma and Rainbow, 2008). The net atmospheric flux of mercury to the land surface was observed to be close to zero in an uncontaminated alpine region in NSW (Howard, et al., 2017; Howard and Edwards, 2018).

Routine monitoring of mercury in biota and environmental compartments surrounding known point sources of emissions are generally not available in Australia (Jardine and Bunn, 2010). However, biomonitoring data are available for an estuary adjacent to a metal refinery that is a known point source of mercury emissions. White-bellied sea eagle feathers (*Haliaeetus leucogaster*) collected in the vicinity of the refinery have been observed with mercury concentrations of 35 mg Hg/kg (Einoder, et al., 2018). At the same location flathead (*Platycephalus bassensis*), yellow-eye mullet (*Aldrichetta forsteri*), sea-run brown trout (*Salmo trutta*) and black bream (*Acanthopagrus butcheri*) were observed with total mercury concentrations of 0.53, 0.32, 0.68 and 1.57 mg Hg_T/kg, respectively. Mercury in fish has been shown to be 80–100% MeHg (Verdouw, et al., 2011). In uncontaminated Australian marine environments total mercury concentrations in fish are low, typically less than 0.1 mg Hg_T/kg. Larger fish are found with higher mercury concentrations (Pethybridge, et al., 2010).

Environmental Effects

The mercury species most likely to cause environmental effects is MeHg, due to its high toxicity and biomagnification potential. Environmental organisms will primarily be exposed to MeHg through dietary sources. Inorganic and organomercury species may cause environmental effects though waterborne exposure to aquatic organisms.

Methylmercury has a much higher biomagnification potential than inorganic mercury. Dietary sources of MeHg are therefore considered to be the most concerning exposure pathway for this highly toxic form of mercury, particularly for biota of higher trophic levels, in which MeHg may comprise greater than 90% of the total mercury body burden (ANZECC/ARMCANZ, 2000b; CCME, 2002). Methylmercury also has high chronic aquatic toxicity; however, water borne exposure to MeHg is of secondary importance in the consideration of adverse environmental effects of this species.

Inorganic mercury is the dominant form of mercury present in surface waters (AMAP/UNEP, 2013). Though less toxic and less bioaccumulative than MeHg, this form of mercury has high acute and chronic toxicity to aquatic organisms.

Effects on Aquatic Life

Mercury bioaccumulates in aquatic organisms and all bioavailable forms of mercury are toxic in short and long term exposures. Biomagnification of MeHg in food webs is generally regarded as being the key concern for the effects of mercury on aquatic ecosystems (ANZECC/ARMCANZ, 2000b).

Acute toxicity

The following acute median lethal concentration (LC50s) and median effective concentration (EC50s) values for freshwater and marine organisms across three trophic levels are presented below. In some studies, the test substance is not specified, and the test concentrations are instead presented in terms of Hg/L. Given that many of the test concentrations exceed the solubility of elemental mercury, in these cases it has been assumed that mercury was present as the mercuric ion. Toxicity endpoints derived from these studies are given in µg Hg/L except where the test substance is specified (Rahimibashar and Alipoor, 2012; US EPA, 2015; Valenti, et al., 2005):

Taxon	Endpoint	Method
Fish	96 h LC50 = 78 µg $HgCl_2$/L	*Esox Lucius* (freshwater pike) (Rahimibashar and Alipoor, 2012)

Taxon	Endpoint	Method
	96 h LC50 = 4 (2–6) µg Hg/L	*Chrysophrys major* (Red Sea bream) Larval toxicity test (US EPA, 2015)
Invertebrates	96 h LC50 = 99 µg $HgCl_2$/L	*Villosa iris* (rainbow mussel) Juvenile toxicity test (Valenti, et al., 2005)
	96 h LC50 = 10 µg Hg/L	*Acartia clausi* (marine copepod) (US EPA, 2015)
Algae	24 h EC50 = 30 µg Hg/L	*Pseudokirchneriella subcapitata* (freshwater green algae) Population growth (US EPA, 2015)
	48 h EC50 = 30 µg Hg/L	*Thalassiosira pseudonana* (marine diatom) Population growth (US EPA, 2015)

The toxicity of inorganic mercury is dependent on a number of environmental factors (ANZECC/ARMCANZ, 2000b). Mercury uptake increases with decreasing water hardness in freshwater, and increases with decreasing salinity in marine waters. The bioaccumulation potential and toxicity of mercury decreases with increasing selenium concentrations.

A number of acute aquatic ecotoxicity studies on MeHg are available, though aqueous exposure pathways over short timeframes are not expected to be of high environmental relevance for this form of mercury. Acute 48 h LC50 toxicity data for methylmercury chloride from the US EPA ECOTOX database for fish ranged from 24 µg MeHg/L for rainbow trout (*Oncorhynchus mykiss*) up to 420 µg MeHg/L for Japanese medaka (*Oryzias latipes*). Toxicity values for invertebrates (water fleas) ranged from < 4 µg MeHg/L for *Ceriodaphnia dubia* up to 30 µg MeHg/L for *Daphnia magna* (US EPA, 2015). Acute 24 h EC50 toxicity values for methylmercury chloride exposure in blue green algae ranged from 3.5 µg MeHg/L in *Anabaena flos-aquae* up to 6.3 µg MeHg/L in *Anacystis nidulans* (Environment Canada, 2003).

Chronic toxicity

The chronic toxicity of inorganic mercury to freshwater and marine organisms was critically evaluated for the derivation of the Australian and New Zealand Guidelines for Fresh and Marine Water Quality mercury WQG protection values. No-observed effect concentration (NOEC), lowest-observed effect concentrations (LOECs) and 10% effect concentrations (EC10s) for the freshwater vertebrate and invertebrate taxonomic groups in the pH range 7 to 8.7 are shown below, along with values from other studies. Endpoints based on concentrations of the mercuric ion are given in µg Hg/L (US EPA, 2015; Valenti, et al., 2005):

Taxon	Endpoint	Method
Fish	4 d EC50 = 40 µg Hg/L	*Etheostoma spectabile* (freshwater orangethroat darter) Embryo growth (US EPA, 2015)
Invertebrates	15 d NOEC = 12 µg Hg/L	*Artemia salina* (brine shrimp) Growth (US EPA, 2015)
	21 d NOEC = 4 µg $HgCl_2$/L	*Villosa iris* (rainbow mussel) Juvenile growth (Valenti, et al., 2005)
Algae	48 h EC10 = 2 µg Hg/L	*Pseudokirchneriella subcapitata* (freshwater green algae) Biomass (US EPA, 2015)
	48 h LOEC= 5 µg Hg/L	*Gymnodinium splendens* (marine dinoflagellate) Growth (US EPA, 2015)

The values for chronic inorganic mercury toxicity in aquatic organisms are variable between species within trophic groups. The Canadian WQG report that 7 to 21 day chronic, growth, impaired reproduction and development tests showed invertebrates are about as sensitive to inorganic mercury as fish. Invertebrate EC50s ranged from 1.28 to 12.0 µg Hg/L while fish in 5 to 60 day tests returned chronic values between 0.26 to > 64.0 µg Hg/L (CCME, 2002).

Comparative tests demonstrate that MeHg has much higher chronic toxicity than inorganic mercury. In one test, exposure of *D. magna* to methylmercuric chloride over 21 days caused a decrease in reproductive output from 40 ng/L (0.04 µg/L) mercury (Biesinger, et al., 1982). In an equivalent test using mercuric chloride, decreased survival was seen at 2.7 µg/L mercury. In a multigenerational fish study with brook trout (*Salvenlinus fontinalis*), 0.93 µg/L methylmercuric chloride caused high mortality in the second generation (ANZECC/ARMCANZ, 2000b; McKim, et al., 1976).

Chronic effects of MeHg to fish were reviewed by Depew et al. (2012) who concluded that reproductive effects are more sensitive compared with biochemical, behavioural and growth effects. Adverse effects related to mortality were uncommon, and adverse effects related to growth occurred at dietary concentrations > 2.5 mg MeHg/g wet weight. Fish behaviour effects were seen over a wide range of effective dietary concentrations, but generally occurred at > 0.5 mg MeHg/g wet weight, while effects on reproduction and other subclinical endpoints occurred at much lower (< 0.2 mg MeHg/g wet wt) dietary concentrations.

Effects on Sediment-dwelling Life

Sediments are the critical compartment for biotransformation of inorganic mercury to methylmercury in freshwater systems. Benthic organisms are therefore directly exposed to inorganic mercury and MeHg through sediment pore water, and by ingestion of sediment particles. Benthic organisms act as vectors for transfer of mercury from sediment to higher trophic level organisms.

Significant relationships between mercury deposition to aquatic systems, biotransformation to MeHg and bioaccumulation in food webs have been shown. Orihel et al. (2006; 2007) demonstrated that isotopically labelled inorganic mercury spiked into an aquatic mesocosm system was distributed between water, sediment, suspended particles, and periphyton (benthic algae) within 3 weeks. Labelled MeHg was detected in these same compartments within 8 weeks. The labelled MeHg was incorporated into the food web, with significant linear relationships between the amount of spiked isotopically labelled inorganic mercury and MeHg accumulation by zooplankton, benthic invertebrates and fish.

Benthic bivalves are some of the most efficient vectors for mercury transfer to higher order organisms (Luoma and Rainbow, 2008). These invertebrates are exposed to both inorganic mercury and MeHg through water, sediment, and food, with dietary uptake the dominant pathway.

Adverse biological effects reported for benthic organisms exposed to mercury include lethality, reduced fertilisation, and impaired development of early life stages (CCME, 1999b). Mortality of the marine amphipod, *Leptocheirus plumulosus*, was reported at sediment concentrations of between 0.05 and 0.180 mg Hg/kg (CCME, 1999b).

Effects on Terrestrial Life

Mercury toxicity has been characterised across all compartments of the terrestrial system from soil invertebrates to mammals and birds. As with the aquatic system the biomagnification of MeHg up to apex predators, particularly those that consume aquatic organisms, is of concern.

There are few toxicological data for inorganic mercury in wildlife as the focus has been on the major toxicity pathway of MeHg (CCME, 1999a). Terrestrial mammal toxicity related to the inhalation of elemental mercury vapour has been more extensively assessed in the IMAP Human health Tier II assessment for elemental mercury (NICNAS, 2015).

Methylmercury is absorbed largely through the diet, and terrestrial mammals and birds which feed on fish and other aquatic organisms are most at risk of exposure. A review of mercury dietary assimilation studies indicated that MeHg generally has an uptake efficiency greater than 80%, with few studies reporting less than 50% (Bradley, et al., 2017). Comparatively, reports of inorganic mercury assimilation efficiency were almost exclusively less than 50%.

Methylmercury can pass through the blood-brain barrier to accumulate in the central nervous system, where it may cause effects in vertebrates including ataxia, staggering, and hind-limb paralysis. A Canadian tissue residue guideline of 33 µg/kg ww MeHg in aquatic biota was derived for the protection of wildlife, such as sea birds, that consume those biota (CCME, 2000).

Inorganic mercury accumulation and toxicity in soil invertebrates has been measured at low soil concentrations (CCME, 1999a). Inorganic mercury concentrations of 0.79 mg/kg dry weight in soil were toxic to 50% of the earthworms in a 60-day study, and 100% mortality was observed at 5 mg/kg (Abbasi and Soni, 1983).

Predicted No-Effect Concentration (PNEC)

A PNEC was not calculated for elemental mercury.

Given that the main focus of this assessment is the release of mercury to aquatic environments, existing guidelines for inorganic mercury in the water compartment and sediments were considered. There are no Australian guidelines for MeHg in any environmental compartment.

In place of PNECs for the water and sediment compartments, the default guideline values (DGV) for freshwater, marine waters and sediments have been used (ANZECC/ARMCANZ, 2000c; Water Quality Australia, 2018). These values represent thresholds above which further assessment of potential toxicity may be required to ensure environmental protection. The high-reliability water quality guideline value for protection of 99% of species in *slightly-moderately disturbed* freshwater and marine ecosystems is 0.06 µg Hg/L and 0.1 µg Hg/L respectively. For sediments, the DGV and GV-high are 0.15 and 1.0 mg Hg/kg dw respectively.

Categorisation of Environmental Hazard

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. 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; US EPA, 2007).

Although an environmental hazard categorisation for elemental mercury has not been assigned there is an international consensus that elemental mercury and mercury compounds are of high concern because they are transformed into very toxic methylmercury in the environment (UNEP, 2013b). The natural cycling of mercury in the environment and the biomagnification of methylmercury in aquatic and terrestrial food webs contributes to the long-term dietary exposure of wildlife and humans to elevated levels of MeHg.

Risk Characterisation

In Australia, mercury is emitted to the atmosphere primarily as a result of industrial processes such as non-ferrous metal refining, coal-fired electricity generation and the manufacture of cement. Approximately 50% of these emissions are expected to be deposited in the vicinity of the emission source. The remainder will undergo long range transport in the atmosphere with eventual diffuse deposition to the terrestrial or aquatic compartments. Available Australian monitoring data indicate that mercury is typically only found at high concentrations in association with point emission sources.

Once released to the environment, mercury cycles between all major environmental compartments through changes in speciation, volatilisation and deposition for decades to centuries, before being more permanently sequestered by natural processes. In low oxygen freshwater environments, sediments and the open ocean mercury may be converted to MeHg which is known to biomagnify and is highly toxic. Biomagnification of MeHg leads to concentrations of mercury in apex predators that far exceed mercury concentrations in the surrounding environment. High concentrations of mercury in fish are of significant concern due to the potential for dietary exposure to fish-eating wildlife and humans. Anthropogenic emissions of mercury, therefore, contribute to very long-term adverse effects on human and ecological health.

Monitoring data for mercury releases from Australian STPs suggest that concentrations in effluent may exceed the 99% species protection default guideline values of 0.06 and 0.1 µg Hg/L for fresh and marine waters, respectively. There are incomplete data available regarding sources of mercury emissions into waste water in Australia. However, release of dental amalgam waste is likely to be a significant non-industrial source of mercury inputs to waste water. Industrial uses of elemental mercury are expected to contribute only a very small fraction of the quantities of mercury currently released to waste water in Australia.

Global anthropogenic emissions and releases of mercury are expected to decline as more countries ratify the Minamata Convention and further restrict the production and use of mercury. Australia is currently considering ratifying the Convention which would involve the phase out of the use of mercury in pesticides, and certain lighting types, and the phase down of dental amalgam, as well as the reduction of emissions and releases from waste associated with these three uses. Emissions and releases of mercury from point sources resulting from metal refining, coal-fired electricity generation and other manufacturing may also be reduced through implementation of emission controls and waste disposal requirements under the Convention. These measures could significantly reduce cumulative anthropogenic emissions and releases of mercury in Australia.

Key Findings

Industrial uses of elemental mercury contribute a very small fraction of Australia’s total anthropogenic mercury emissions and releases. Historical industrial uses of elemental mercury in the chlor-alkali and gold refining industries have been phased out in recent decades. Greater than 95% of Australia’s mercury emissions from point sources are generated during non-ferrous metal refining, coal-fired electricity generation and cement manufacturing.

The environmental risks of elemental mercury are greatly increased by methylation in freshwater and marine environments. Methylation increases the toxicity of mercury and enables biomagnification of mercury through food webs. Biomagnification of mercury in predatory fish as well as aquatic mammals and birds has been observed at levels believed to cause toxic effects. Biomagnification of MeHg in marine and freshwater fish also presents a risk of adverse effects in human populations.

Currently, anthropogenic sources contribute five times more mercury to the global mercury cycle than natural geogenic processes. Due to its volatility elemental mercury is highly mobile in the environment and is widely distributed by atmospheric transport. As recognised in the Minamata Convention, effective management of anthropogenic sources of mercury requires a comprehensive approach which includes reducing or phasing out uses of mercury and mercury compounds, as well as reducing emissions from industrial processes which are major point sources of mercury.

Recommendations

It is recommended that the Australian Government Department of Agriculture, Water and the Environment note the findings of this report as part of the current domestic treaty-making process which is considering ratification of the Minamata Convention.

Environmental Hazard Classification

In addition to the categorisation of environmental hazards according to domestic environmental thresholds presented above, the classification of the environmental hazards of mercury (elemental mercury) according to the fifth edition of the United Nations' Globally Harmonised System of Classification and Labelling of Chemicals (GHS) is presented below (UNECE, 2009):

Hazard	GHS Classification (Code)	Hazard Statement
Acute Aquatic	Category 1 (H400)	Very toxic to aquatic life
Chronic Aquatic	Category 1 (H410)	Very toxic to aquatic life with long lasting effects

The classification strategy for metals under the GHS considers the potential for the metal to undergo transformation into more water soluble ionic forms. There is a standardised protocol available to evaluate the potential for a metal to be transformed into a more bioavailable ionic form in aquatic ecosystems suitable for classification purposes (UNECE, 2007). However, no data from a standardised transformation test were identified for this assessment. Instead, the rapid oxidation of elemental mercury into mercuric ions in oxygenated surface waters is taken to be sufficient to indicate that elemental mercury is rapidly transformed into bioavailable inorganic mercury species in aquatic ecosystems. In accordance with the classification procedure, elemental mercury is classified as Acute Aquatic Category 1 and Chronic Aquatic Category 1 because the acute toxicity values for the mercury(2+) ion are < 1 mg/L. These classifications also take into account the higher aquatic toxicity of the monomethylmercury transformation product and the biomagnification of this very toxic mercury species in aquatic food webs.

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