Water soluble cadmium(2+) salts: 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 four 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 three 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

Acronyms & Abbreviations

Grouping Rationale

This Tier II assessment considers the environmental risks associated with industrial uses of thirteen water soluble cadmium(2+) salts.

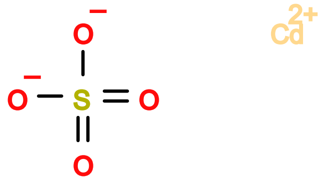
The risk assessment of these chemicals has been carried out as a group because all thirteen cadmium salts are very soluble in water and they can all release bioavailable forms of ionic cadmium. This provides a common source of toxicity for each chemical in the group. For the purposes of assessment, the chemicals have been sub-grouped into cadmium(2+) salts of strong inorganic acids (10 chemicals) and cadmium(2+) salts of short-chain carboxylic acids (three chemicals). All of the inorganic anions present in the salts of this group, except the tetrafluoroborate anion, are ubiquitous, naturally occurring chemical species. The use of the chemicals in this group is unlikely to alter the background concentrations of these ions in the environment and their environmental fate and effects is not further considered in this assessment.

Emissions of cadmium to the environment are of concern because of the toxicity of bioavailable forms of ionic cadmium to wildlife and humans, and the rapid uptake of cadmium ions from soil by agricultural crops. There is some potential for emissions of ionic cadmium to occur from the use of chemicals in this group in applications such as electroplating where cadmium ions may be released into wastewater streams. Approximately 60% of the total load of cadmium entering a sewage treatment plant in wastewater is retained in the biosolids, which are often used to amend agricultural soils in Australia. Consequently, industrial uses of the chemicals in this group may contribute to the cumulative emissions of cadmium both to agricultural soils and to surface waters.

This assessment provides reference information on the environmental fate and effects of ionic cadmium, which may be emitted to the environment from industrial uses of other cadmium containing substances listed on the Inventory. The environmental risks resulting from industrial uses of these remaining cadmium chemicals will be assessed separately.

Chemical Identity

Cadmium Salts of Strong Inorganic Acids

CAS RN	10124-36-4
Chemical Name	Sulfuric acid, cadmium salt (1:1)
Synonyms	cadmium sulfate
Structural Formula	
Molecular Formula	$Cd(SO_4)$
Molecular Weight (g/mol)	208.47

CAS RN	7790-84-3
Chemical Name	Sulfuric acid, cadmium salt (1:1), hydrate (3:8)
Synonyms	cadmium sulfate hydrate (3:8)
Molecular Formula	$3CdSO_4.8H_2O$

Molecular Weight (g/mol)	769.54

CAS RN	7790-79-6
Chemical Name	Cadmium fluoride (CdF_2)
Synonyms	cadmium fluoride cadmium difluoride
Molecular Formula	CdF_2
Molecular Weight (g/mol)	150.41

CAS RN	10108-64-2
Chemical Name	Cadmium chloride ($CdCl_2$)
Synonyms	cadmium chloride
Molecular Formula	$CdCl_2$
Molecular Weight (g/mol)	183.32

CAS RN	7790-78-5
Chemical Name	Cadmium chloride, hydrate (2:5)

Synonyms	cadmium chloride, hydrate
Molecular Formula	$2CdCl_2.5H_2O$
Molecular Weight (g/mol)	456.71

CAS RN	13464-92-1
Chemical Name	Cadmium bromide, tetrahydrate
Synonyms	cadmium dibromide tetrahydrate
Molecular Formula	$CdBr_2.4H_2O$
Molecular Weight (g/mol)	344.28

CAS RN	7790-80-9
Chemical Name	Cadmium iodide (CdI_2)
Synonyms	cadmium iodide
Molecular Formula	CdI_2
Molecular Weight (g/mol)	366.22

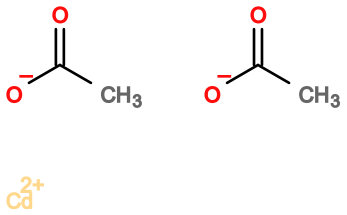
CAS RN	14486-19-2
Chemical Name	Borate(1-), tetrafluoro-, cadmium (2:1)
Synonyms	cadmium tetrafluoroborate
Molecular Formula	$Cd(BF_4)_2$
Molecular Weight (g/mol)	286.02

CAS RN	10325-94-7
Chemical Name	Nitric acid, cadmium salt
Synonyms	cadmium nitrate
Molecular Formula	$Cd(NO_3)_2$
Molecular Weight (g/mol)	236.42

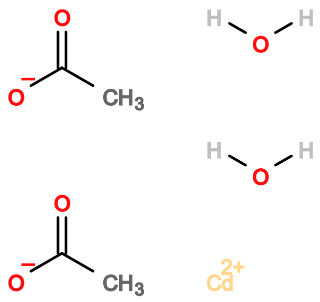
CAS RN	10022-68-1
Chemical Name	Nitric acid, cadmium salt, tetrahydrate
Synonyms	cadmium nitrate tetrahydrate
Molecular Formula	$Cd(NO_3)_2.4H_2O$

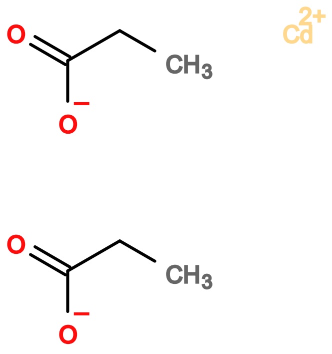
Molecular Weight (g/mol)	308.48

Cadmium Salts of Short-Chain Carboxylic Acids

CAS RN	543-90-8
Chemical Name	Acetic acid, cadmium salt
Synonyms	cadmium acetate cadmium diacetate
Structural Formula	
Molecular Formula	$Cd(CH_3CO_2)_2$
Molecular Weight (g/mol)	230.50
SMILES	[Cd++].CC(=O)([O-]).CC(=O)([O-])

CAS RN	5743-04-4
Chemical Name	Acetic acid, cadmium salt, dihydrate

Synonyms	cadmium acetate dihydrate
Structural Formula	
Molecular Formula	$Cd(CH_3CO_2)_{2.}2H_2O$
Molecular Weight (g/mol)	266.53
SMILES	[Cd++].CC(=O)([O-]).CC(=O)([O-]).[OH2].[OH2]

CAS RN	16986-83-7
Chemical Name	Propanoic acid, cadmium salt
Synonyms	cadmium propionate
Structural Formula	

Molecular Formula	$Cd(CH_3CH_2CO_2)_2$
Molecular Weight (g/mol)	258.55
SMILES	[Cd++].CCC(=O)([O-]).CCC(=O)([O-])

Physical and Chemical Properties

All of the salts in this group are solids under ambient conditions, except cadmium tetrafluoroborate, which is reported to be a colourless hygroscopic liquid (Haynes, 2015, Schulte-Schrepping and Piscator, 2000). Some salts in this group, such as cadmium nitrate tetrahydrate, are deliquescent (Schulte-Schrepping and Piscator, 2000).

All of the cadmium salts of strong acids in this group are readily soluble in water. This characterisation is supported by the following water solubility data that are reported as the mass of the anhydrous cadmium salt dissolved in a fixed mass of water (100 g) at 25ºC (Haynes, 2015):

Chemical	CAS RN	Water Solubility (g/ 100 g H_2O)
cadmium sulfate	10124-36-4	76.7
cadmium fluoride	7790-79-6	4.36
cadmium chloride	10108-64-2	120
cadmium bromide tetrahydrate	13464-92-1	115
cadmium iodide	7790-80-9	86.2
cadmium nitrate	10325-94-7	156

No quantitative water solubility data were located for the cadmium(2+) salts of short-chain carboxylic acids in this group. However, available qualitative descriptions of the water solubility of cadmium acetate indicate that the cadmium salts of both organic acids can also be considered readily soluble in water (Haynes, 2015).

Import, Manufacture and Use

Australia

Cadmium sulfate is used as a conditioner for lead-acid batteries.

No specific Australian use, import, or manufacturing information has been identified for the other chemicals in this group.

International

Currently, the majority of the global consumption of cadmium is for production of rechargeable nickel-cadmium batteries (82%), followed by use in pigments (10%), metal plating (6%), stabilisers in polymers (1.5%), and other uses such as non-ferrous alloys (< 1%) (UNEP, 2010).

Cadmium sulfate, cadmium chloride, and cadmium nitrate are commercially important inorganic cadmium salts with a range of industrial applications which include uses as starting materials in the manufacture of cadmium stabilisers and pigments (ATSDR, 2012, Schulte-Schrepping and Piscator, 2000). Soluble cadmium compounds were also previously used as pesticides for home lawns and golf courses, but all pesticide uses were banned in the United States of America (USA) in 1990 (US EPA, 1990).

Cadmium salts such as cadmium tetrafluoroborate are used by the metal finishing industry in electroplating applications. Cadmium salts may also be used as brighteners in electroless metal plating, but this use has declined (OECD, 2004). Cadmium coatings are very durable and they provide both good corrosion resistance and frictional properties (Schulte-Schrepping and Piscator, 2000). For these reasons they are used for specialised applications where high durability and high reliability of metal coated articles is required (e.g. aerospace and military equipment, marine installations, industrial fasteners) (UNEP, 2010).

Environmental Regulatory Status

A range of measures have been implemented domestically and internationally to minimise the exposure of humans and the environment to cadmium (UNEP, 2010).

Australia

Cadmium and cadmium compounds are subject to reporting under the Australian National Pollutant Inventory (NPI). Under the NPI, emissions of cadmium and cadmium compounds are required to be reported annually by facilities that use or emit more than 10 tonnes of cadmium or cadmium compounds, 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, 2014). Emissions may be intentional, accidental or incidental releases arising through industrial processes. Diffuse emissions data are updated much less frequently than facility data.

In Australia, high reliability trigger values for cadmium in freshwater and marine water have been determined. The freshwater trigger values have been adjusted to account for the effects of water hardness on the toxicity of ionic cadmium in aquatic systems. The current trigger value for cadmium in low hardness water (30 mg as $CaCO_3$/L) is 0.2 (micrograms of cadmium per litre) µg Cd/L, which will protect 95% of species in a *slightly-moderately disturbed* freshwater ecosystem (ANZECC, 2000a). It is recommended that this trigger value is adjusted for water hardness at each specific site to give a hardness-modified trigger value (HMTV) for freshwater. The 99% protection level for cadmium in marine waters (0.7 µg Cd/L) is currently recommended for *slightly-moderately disturbed marine ecosystems* (ANZECC, 2000a). The higher protection level is recommended because there is a risk associated with secondary poisoning caused by bioaccumulation of cadmium in marine ecosystems (ANZECC, 2000b).

In 2002, the National Cadmium Minimisation Committee (NCMC) was established to implement a National Cadmium Minimisation Strategy (NCMS) to address management of cadmium in soil at a national level (NCMC, 2007). The primary aim of the NCMS was to minimise additions of cadmium to agricultural soils, and to reduce the accumulation of cadmium in food crops.

Two of the key outputs were fertiliser regulations and guidelines for cadmium in biosolids (NCMC, 2007). A maximum permissible concentration (MPC) for cadmium in phosphatic fertilisers of 300 mg Cd/kg phosphorus has been established as a result of this work.

The National Water Quality Management Strategy 2004 recommends an upper limit for cadmium of 1 mg/kg dry weight in Grade C1 biosolids which can be applied in an unrestricted manner to all lands, excluding sensitive sites (NRMMC, 2004). In recommending this limit they note that it reflects food safety concerns regarding uptake of cadmium by plants and recommend that application of biosolids to agricultural land should be limited to 30 g (total cadmium) per hectare per year for a maximum period of five years (i.e., 150 g Cd/ha over 5 years). The cumulative contaminant loading limit (CCL) trigger value for irrigated agricultural soils is 2 kg Cd/ha. This limit applies to agricultural soils with no cadmium contamination history and once this limit has been reached a site-specific risk assessment is recommended before continuing with irrigation (ANZECC, 2000c).

United Nations

The chemicals in this group are not currently identified as Persistent Organic Pollutants (UNEP, 2001), ozone depleting substances (UNEP, 1987) or hazardous substances for the purpose of international trade (UNEP and FAO, 1998).

OECD

Cadmium sulfate is listed as an OECD High Production Volume (HPV) chemical (OECD, 2009). Chemicals on the HPV list are produced or imported at a level greater than 1000 tonnes per year in at least one member country of the OECD.

Canada

Chemicals containing cadmium are listed as a broad class of compounds (‘Inorganic cadmium compounds’) under Schedule 1 (the Toxic Substances List) of the *Canadian Environmental Protection Act 1999* (CEPA 1999) (Government of Canada, 2016).

Cadmium sulfate, cadmium chloride, cadmium iodide, cadmium nitrate, cadmium tetrafluoroborate, and cadmium acetate are listed on the Canadian Domestic Substances List (DSL). These cadmium salts were all categorised as Persistent (P), not Bioaccumulative (not B), and Inherently Toxic to the Environment (iT_E) during the Categorization of the DSL (Environment Canada, 2013). These six chemicals are also prioritised for further assessment under the Chemicals Management Plan (CMP) (Government of Canada, 2013).

European Union

Chemicals containing cadmium are listed in Annex XVII (Restriction) under the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) legislation as a broad class of compounds (‘Cadmium and its compounds’) (ECHA, 2016). This regulated group includes all chemicals in this assessment except cadmium bromide tetrahydrate. The restrictions relate to the use of these chemicals in polymers (plastic material), plastic articles, paints, painted articles, articles containing recovered PVC, cadmium metal plating, cadmium plated articles, brazing fillers and jewellery.

Ten chemicals in this group have been pre-registered for use in the European Union under REACH (ECHA, 2015a). Four of these chemicals have undergone the full registration process (cadmium sulfate, cadmium chloride, cadmium nitrate, and cadmium nitrate tetrahydrate) (ECHA, 2015b).

Three chemicals in this group (cadmium sulfate, cadmium fluoride, and cadmium chloride) have been identified as a Substance of Very High Concern (SVHC) under the REACH legislation due to their carcinogenic and mutagenic activity, reproductive toxicity and ‘equivalent level of concern having probable serious effects to human health’ (ECHA, 2017). These chemicals are currently listed on the Candidate List for Eventual Inclusion in Annex XIV to REACH. Once included in Annex XIV to REACH (the Authorisation List), use of the chemical may be severely restricted.

The manufacture, placing on the market, and use of cadmium sulfate; cadmium fluoride; cadmium chloride; cadmium chloride, hydrate; and cadmium acetate dihydrate is restricted. These substances are banned for sale to the general public.

Cadmium plating has been banned in the EU since 1995 except for applications in the aerospace, mining, offshore and nuclear industries (UNEP, 2010).

United States of America

Most of the chemicals in this group (seven substances) are listed on the inventory of chemicals manufactured or processed in the USA, as published under the Toxic Substances Control Act 1976 (TSCA) (US EPA, 2014b). 'Cadmium and cadmium compounds' are on the 2014 Update to the TSCA Work Plan list of existing chemicals for assessment (US EPA, 2014a).

In 2016, revised aquatic life ambient water quality criteria (AWQC) for cadmium were published by the US EPA. The current freshwater acute criterion for dissolved cadmium (Cd_{diss}) is 1.8 µg Cd_{diss}/L, and the chronic criterion is 0.72 µg Cd_{diss}/L (US EPA, 2016). The dissolved cadmium concentration is the concentration of cadmium that remains in water following filtration of a water sample through a 0.45 µm filter (ANZECC, 2000b).

Environmental Exposure

Based on available information, the most significant industrial use for the cadmium chemicals in this group in Australia is expected to be in the metal finishing industry for specialised electroplating applications. This use pattern is, therefore, considered to provide the most likely pathway for emissions of ionic cadmium to the environment from chemicals in this group.

However, it should be noted that emissions of ionic cadmium from electroplating will likely constitute a very small proportion of total anthropogenic cadmium emissions compared to mining and refining of non-ferrous metals, fossil fuel combustion, and the use of phosphate fertilisers (ATSDR, 2012). The significance of any emissions of cadmium from industrial applications must also consider the speciation and background concentrations of cadmium, which occurs naturally in all compartments of the environment.

The aqueous plating baths used in cadmium electroplating contain high concentrations of ionic cadmium and potential release of cadmium ions to wastewater streams is the environmental emission scenario of most concern in this assessment. Disposal of electroplating bath solutions is very rare and does not occur directly to sewers as facilities must meet stringent standards for discharges of heavy metals in trade wastes (ANZECC, 1994, NSW DoWE, 2009, OECD, 2004). Release of cadmium to wastewater is more likely to occur from drag-out (the solution lost from the plating bath when the plated article is removed) which is then transferred to rinse waters. Smaller losses may occur during maintenance procedures (OECD, 2004).

Cadmium that enters a sewage treatment plant (STP) is partially removed from wastewater by adsorption to sludge, which may then be applied to land as biosolids. The proportion of cadmium removed from wastewater varies widely depending on the specific STP. For example, data from Denmark indicate removal efficiencies between 11% and 59% (UNEP, 2010), whereas other international data have shown higher removal efficiencies (60% to > 80% (EU RAR, 2007)). In the 2007 European Union Risk Assessment Report for Cadmium and Cadmium Oxide (EU RAR), a removal rate of 60% was used. Given this partitioning behaviour, the release of ionic cadmium to both environmental surface waters and soils are considered as part of this assessment.

Environmental Fate

Dissolution, speciation and partitioning

The cadmium(2+) salts in this group dissociate in water to release dissolved ionic cadmium species and their respective anions. The fully dissociated cadmium aquo ion (Cd^{2+}) is a labile chemical species that is also a weak acid (Basolo and Pearson, 1967). The cadmium aquo ion is the dominant form of dissolved cadmium in surface freshwater at pH ≤ 8.5 (ANZECC, 2000b). The fraction of cadmium present as dissolved ionic cadmium in freshwaters generally increases with decreasing pH. In aerated seawater, nearly 100% of ionic cadmium exists in the form of dissolved mono-nuclear cadmium chloride complexes (e.g., $CdCl^+$ and $CdCl_2$) (Förstner, 1980).

Water hardness and the concentration of organic matter also affect cadmium speciation. In waters with a high concentration of organic matter, more than 50% of cadmium may be present as organic complexes, whereas in hard waters, cadmium carbonate is predominant (ATSDR, 2012, Turner, 1987). The speciation of ionic cadmium in the environment is dominated by the divalent (+2) state and is not directly controlled by the reduction-oxidation potential in the water phase (ANZECC, 2000b). However, under reducing conditions, ionic cadmium may precipitate in the form of insoluble cadmium sulfide (ATSDR, 2012).

There have been some reports of the formation of monomethylcadmium species by bacteria in oceans in the polar regions (Pongratz and Heumann, 1999). However, organometallic cadmium species do not appear to play a significant role in the overall fate of cadmium in the environment.

Adsorption of cadmium to clay, minerals and biota is the most important process for removal of cadmium from water. Sorption increases with pH until a threshold is reached near pH 8 (ANZECC, 2000b). Although sediment is a sink for cadmium in aquatic systems, it can return to the water column in particulate or dissolved forms (US EPA, 2016).

The behaviour of cadmium in sediments is influenced by the sediment geochemistry and the properties of the sediment pore water (e.g. pH, concentrations of dissolved oxygen, sulfide) and activity of sediment infauna. Only a small fraction of the total amount of cadmium in sediment will be bioavailable. In oxic sediments, cadmium will mostly bind to organic matter and hydrous iron and manganese oxides (Simpson, et al., 2013). In anoxic sediments, cadmium will bind strongly with sulfide minerals and the more reactive acid-volatile sulfide (AVS) phases to form relatively insoluble sulfides. Particle size has the greatest influence on the amount of cadmium in these phases, where adsorption increases as the proportion of small particles increases (< 63 µm) (i.e. fine clay and silt particles) (Simpson, et al., 2013).

In oceans, cadmium exhibits a nutrient-type distribution, where it is recycled through the phytoplankton layer and, unlike some other heavy metals (e.g., lead), does not readily move to the deep ocean sediments. Cadmium has an intermediate residence time in oceans (15 000 years) and deep-sea sediments are the only long-term sink (UNEP, 2010).

The mobility of cadmium in soil increases as soil pH decreases. Mobility also increases in sandy soils (i.e. low clay content) and in soils with a low concentration of organic matter. The presence of carbonates or hydrous oxides of iron and manganese may also influence cadmium mobility. Chloride ions can mobilise cadmium in soil and significantly increase its uptake by plants (McLaughlin, et al., 1994). Acid soils that are permeable and have a high rate of run-off can potentially increase the concentration of cadmium in nearby surface waters (UNEP, 2010).

Bioaccumulation

Cadmium is a non-essential element and can bioaccumulate in aquatic and terrestrial organisms (UNEP, 2010). Due to the capacity of many organisms to detoxify and store accumulated cadmium, there is no clear correlation between the total tissue concentrations of cadmium and adverse effects (US EPA, 2016).

In aquatic organisms, accumulation of cadmium can occur through dietary uptake or direct uptake from water, where the importance of each uptake route varies between species (US EPA, 2016). Filter feeding bivalve molluscs such as the mussel, *Mytilus edulis*, which live attached to hard substrate and within the water column, bioconcentrate cadmium. Under laboratory conditions, tissue concentrations of cadmium continued to increase with prolonged exposure to cadmium in the exposure medium under flow-through conditions (WHO, 1992). Cadmium concentrations in three Canadian freshwater invertebrates, the gastropods *Bithynia tentaculata* and *Physa gyrina*, and the amphipod *Gammarus fasciatusis* were more closely linked to cadmium in their diet than in water (Desy, et al., 2002).

The extent of bioconcentration in aquatic organisms is influenced by water hardness, pH, the presence of complexing agents and cadmium concentration (EU RAR, 2007). Bioaccumulation factors (BAF) are significantly higher than bioconcentration factors and range from 4 to 170 000 L/kg (EU RAR, 2007). Biomagnification of cadmium up to 15 times within two trophic levels in a San Francisco Bay epiphyte-based freshwater food web has been demonstrated (Croteau, et al., 2005).

Benthic infauna can accumulate cadmium from sediment pore water, overlying water, diet and direct sediment ingestion. The marine bivalves, Sydney cockle *Anadara trapezia* and *Tellina deltoidalis*, exposed for two months to 10 mg Cd/kg dry mass sediment concentration accumulated dry mass tissue cadmium concentrations of 13 µg Cd/g and 12 µg Cd/g, respectively (Taylor and Maher, 2012, 2013).

Terrestrial plants can accumulate cadmium, generally in the leaves (UNEP, 2010). Although the cadmium aquo ion is the dominant species available for plant uptake, its concentration in soil cannot be directly correlated with bioaccumulation in plants.

The carboxylic acid components of the chemicals in this group are not expected to pose a bioaccumulation hazard as they are naturally occurring, ubiquitous organic acids that are water soluble and readily biodegradable (LMC, 2013).

Transport

The cadmium salts considered in this assessment do not undergo long-range transport.

Cadmium compounds that are emitted to the atmosphere can associate with particulate matter and be transported through the atmosphere when associated with these particles (UNEP, 2010). This emission pathway is not relevant to the known industrial uses of the cadmium salts in this group and will therefore not be considered in this assessment.

Predicted Environmental Concentration (PEC)

A PEC for ionic cadmium in surface waters and soil was not calculated for this assessment.

Cadmium is naturally present at very low background concentrations in all environmental compartments. Natural weathering and erosion of rocks and soils releases significant amounts of cadmium to aquatic environments. Globally, total anthropogenic emissions of cadmium to the aquatic environment in 1983 were estimated to be between 1 200 and 13 400 tonnes (excluding inputs from atmospheric deposition). Anthropogenic emissions of cadmium to aquatic environments in industrialised countries are now expected to be somewhat lower due to improved industrial processes and water treatment technologies (UNEP, 2010).

No current data were identified for natural background concentrations of cadmium in Australian surface waters. However, in European freshwaters, the typical concentration is approximately 0.05 µg Cd_{diss}/L (UNEP, 2010). In open marine waters, background levels range from < 0.005 to 0.110 µg Cd/L, with higher concentrations recorded in coastal zones (ATSDR, 2012).

Limited domestic data are available on the sources and concentration of cadmium in wastewater entering local STPs. However, industrial sources and stormwater run-off are likely to contribute the greatest proportion of cadmium, with minimal contributions from domestic wastewater (Tjadraatmadja and Diaper, 2006). According to the NPI, the indicative concentrations of cadmium in Australian wastewater influent are 0.25 µg Cd/L (for typical domestic sewage) and 0.5 µg Cd/L (for mixed domestic and industrial sewage) (NPI, 2011). Assuming wastewater treatment removes 60% of the total quantity of cadmium that enters an STP, the concentration of cadmium in effluent discharged to Australian surface waters is expected to be up to 0.3 µg Cd/L. This estimate is comparable with the measured concentrations of cadmium in effluent from three South Australian STPs (0.5 µg/L) (SA EPA, 2005).

In general, Australian soils have background concentrations of cadmium in the range < 0.1 to 0.5 mg Cd/kg. These values are lower than background concentrations in European and North American soils (UNEP, 2010).

The release of cadmium to Australian agricultural soils has primarily been through the application of phosphate fertilisers (McLaughlin, et al., 1996). The concentration of cadmium in Australian biosolids is in the range from < 0.5 to 5.4 mg Cd/kg (Warne, et al., 2008). The application of biosolids and atmospheric deposition contribute significantly less cadmium to Australian agricultural soils than fertilisers (1% and 11%, relative to fertilisers, respectively) (McLaughlin, et al., 2006). It has been estimated that 32 tonnes of cadmium is added to Australian agricultural soils per year as a result of fertiliser application (Australian Government, 2005).

Environmental Effects

The environmental effects of the cadmium salts in this group will primarily result from the release of ionic cadmium species into the environment. The toxic effects of all of these chemicals have, therefore, been assessed collectively by reference to the extensive ecotoxicity data available for ionic cadmium.

Effects on Aquatic Life

Cadmium bioaccumulates in aquatic organisms and bioavailable forms of ionic cadmium are very toxic to aquatic life in short and long-term exposures. The toxicity of ionic cadmium to aquatic organisms varies considerably between species and is strongly influenced by water chemistry.

Acute toxicity

The following measured acute median lethal concentrations (LC50) and acute median effective concentration (EC50) values for model organisms across three trophic levels are presented together with the reported water hardness (as $CaCO_3$) for each test:

Taxon	Endpoint	Method
Fish	96 h LC50 = 0.77 µg Cd/L	*Oncorhynchus mykiss* (Rainbow trout) $CaCO_3$ = 20 mg/L (CCME, 2014)
Invertebrates	48 h EC50 = 24 µg Cd/L	*Daphnia magna* (Water flea) $CaCO_3$ = 26–32 mg/L (CCME, 2014)
Algae	96 h EC50 = 203 µg Cd/L	*Chlamydomonas reinhardii* (Green algae) $CaCO_3$ = 24 mg/L (US EPA, 2016)

The acute toxicity of ionic cadmium varies considerably between aquatic organisms, even between closely related species (UNEP, 2010). Variability in acute toxicity values has also been observed for individual species. For example, L(E)C50 values normalised to a water hardness of 50 mg $CaCO_3$/L, range from 0.61 to 9.3 µg Cd/L for the fish, *Oncorhynchus mykiss* (Rainbow trout), and from 1.2 to 386 µg/L for the invertebrate, *Daphnia magna* (Water flea) (Mebane, 2010). The large variation in sensitivity of the daphnid may be attributed to genetic variability.

For most freshwater species, the acute toxicity of cadmium generally decreases with increasing water hardness (US EPA, 2016). In addition to water quality parameters, variability in toxicity can also be attributed to exposure time, life stage of the organism, presence of other ions, and acclimation of the test organisms (EU RAR, 2007). Cadmium uptake can occur through the gills or from the diet; however, there is conflicting evidence as to which route is more toxic as it tends to be species specific (EU RAR, 2007).

Chronic toxicity

The chronic toxicity of ionic cadmium to freshwater and marine species was critically evaluated for the compilation of water quality trigger values for environmental contaminants in the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC, 2000a). Chronic toxicity values were adjusted to a uniform hardness of 30 mg $CaCO_3$/L and converted to no-observed effect concentration (NOEC) equivalent values. These values are reported for fish, invertebrates and algae:

Taxon	Endpoint	Method

Taxon	Endpoint	Method
Fish	NOEC = 0.6 µg Cd/L	*Oncorhynchus mykiss* (Rainbow trout) (ANZECC, 2000b)
Invertebrates	NOEC = 0.08 µg Cd/L	*Daphnia magna* (Water flea) (ANZECC, 2000b)
Algae	NOEC = 8.2 µg Cd/L	*Scenedesmus acutus* (Green algae) (ANZECC, 2000b)

Based on chronic toxicity data, the sensitivity of aquatic organisms to cadmium decreases in the order invertebrates ≥ fish/amphibians > primary producers (algae). Long term exposure to cadmium can affect the reproduction, endocrine and immune systems, development, growth and behaviour of aquatic organisms ((McGeer, et al., 2011) in (US EPA, 2016)). The long-term toxicity of cadmium is primarily influenced by water hardness, pH and the concentration of dissolved organic matter (DOM) (UNEP, 2010).

Effects on Sediment-Dwelling Life

Bioavailable forms of ionic cadmium can be toxic to sediment dwelling organisms.

Benthic invertebrates, together with planktonic invertebrates, are the most sensitive organisms to cadmium in freshwater (UNEP, 2010). Cadmium indirectly increases reactive oxygen species (ROS) production by inhibiting antioxidant enzymes. This can impair growth and reproduction, and damage the DNA of sediment-dwelling species (Taylor and Maher, 2016).

There are limited data available for the toxicity of cadmium to Australian sediment-dwelling species. Cadmium bioaccumulation in Australian sediment dwelling bivalve molluscs has been linked to oxidative stress, loss of cellular integrity and genotoxic damage, biomarkers of sub-lethal impairment that are expected to lead to population level effects (Taylor and Maher, 2012, 2013).

The Australian Sediment Quality Guidelines are currently under revision. However, the proposed Sediment Guideline Values for marine and fresh water sediments are consistent with the current Interim Sediment Quality Guidelines (SQG-low 1.5 Cd mg/kg dry weight and SQG-high 10 Cd mg/kg dry weight) (ANZECC, 2000a, Simpson, et al., 2013).

Effects on Terrestrial Life

Bioavailable forms of ionic cadmium can be toxic to terrestrial organisms.

Plants and soil microorganisms are more sensitive to cadmium than soil invertebrates (UNEP, 2010). In nutrient solutions, cadmium is toxic to plants at concentrations between 0.1 to 1 mg Cd/L. However, as cadmium accumulates in plants, the main hazard is to organisms higher in the food chain. For example, the accumulation of cadmium in food crops is the primary way that cadmium enters the human food chain and this can occur at sub-phytotoxic concentrations. For this reason, Australian soil guidelines for cadmium have been set to ensure that plant tissue concentrations of cadmium in crops do not exceed food standard guidelines – rather than for the protection of terrestrial life itself (ANZECC, 2000c).

The toxicity of cadmium differs between plant species and soil type. Root crops, leafy vegetables and cereal grains have a high potential to accumulate cadmium and therefore present a higher risk in terms of cadmium entering the food chain (ANZECC, 2000c).

The hazards associated with ionic cadmium in soil can be strongly influenced by other metal ions; for example, iron can mitigate the inhibitory effects of cadmium on plant growth (Shao, et al., 2007). Similarly, when zinc is applied to zinc deficient agricultural soils, the concentration of cadmium in crops can significantly decrease (NCMC, 2007). In contrast with other metals (e.g. zinc and nickel), ageing has a limited effect on the bioavailability of cadmium in soil (EU RAR, 2007, Smolders, et al., 1999).

Predicted No-Effect Concentration (PNEC)

The primary environmental effects of the chemicals in this group are expected to be caused by the release of ionic cadmium. Given that the focus of this assessment is the release of ionic cadmium to wastewater streams and aquatic environments, existing guideline values for cadmium in aquatic ecosystems were considered.

In place of PNECs for the water and sediment compartments, the trigger values published for cadmium in the Australian and New Zealand Guidelines for Fresh and Marine Water Quality have been used (ANZECC, 2000a). The water quality trigger values represent thresholds above which further assessment of potential toxicity may be required to ensure environmental quality. For *slightly-moderately disturbed* freshwater ecosystems, the high reliability water quality guideline value for protection of 95% of species is 0.2 µg Cd/L (in low hardness water). For cadmium in *slightly-moderately disturbed* marine waters, the water quality guideline value at the 99% species protection level is recommended (0.7 µg Cd/L). The interim sediment quality guideline value for cadmium is 1.5 mg Cd/kg dry weight.

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).

Therefore, environmental hazard categorisation according to domestic PBT criteria has only been performed for the organic components of the chemicals in this group, as presented below.

Persistence

Not Persistent (Not P). Based on results obtained from ready biodegradation studies, the organic components of all chemicals in this group are categorised as Not Persistent.

Bioaccumulation

Not Bioaccumulative (Not B). Based on the high water solubility of short-chain carboxylic acids, the organic components of all chemicals in this group are categorised as Not Bioaccumulative.

Toxicity

Not Toxic (Not T). Based on available acute ecotoxicity values greater than 1 mg/L, and chronic ecotoxicity values greater than 0.1 mg/L, the organic components of all chemicals in this group are categorised as Not Toxic.

Summary

The organic components of acetic acid, cadmium salt; acetic acid, cadmium salt, dihydrate; and propanoic acid, cadmium salt are all categorised as:

- Not P
- Not B
- Not T

An environmental hazard categorisation for the common ionic cadmium component of the chemicals in this group has not been assigned for the reasons discussed above. Nevertheless, there is an international consensus that bioavailable forms of ionic cadmium are highly toxic to the environment and that cadmium is a bioaccumulation hazard.

Risk Characterisation

Risk quotients (RQs) have not been calculated for the chemicals in this group.

The majority of anthropogenic emissions of cadmium to the environment are from mining and refining of non-ferrous metals, fossil fuel combustion, and the use of phosphate fertilisers. The release of cadmium from the metal finishing industry will, therefore, contribute only a small proportion of the total anthropogenic emissions of cadmium to the environment. Nevertheless, emissions of ionic cadmium from metal plating facilities into wastewater may occur, which contributes to the total anthropogenic cadmium load added to surface waters and soils in treated effluents and biosolids produced by sewage treatment plants.

The available domestic monitoring data for cadmium in STP effluents suggests that the concentration of total cadmium are comparable to the 95% species protection levels in freshwater and below the 99% protection level for the marine environment. This indicates that current emissions of cadmium present a low risk to surface waters. Since electroplating will contribute only a small fraction of total cadmium released into wastewaters it is concluded that the risks to the environment are currently low.

The levels of cadmium in biosolids in Australia can be above the recommended limit for grade C1 biosolids. However, there are extensive state and national guidelines available to manage the addition of cadmium to agricultural land in Australia. It is expected that adherence to these guidelines will limit the potential for excessive application of cadmium to agricultural soils in Australia.

The quantities of cadmium that are released from metal plating facilities into sewage treatment systems in Australia are considered to pose a low risk to aquatic and soil ecosystems based on the currently available information.

Key Findings

The principal environmental concern for cadmium salts in this group is the potential for release of ionic cadmium to aquatic environments and soil from metal plating facilities. This is of potential concern because bioavailable forms of ionic cadmium are very toxic to aquatic life and many aquatic and terrestrial species can accumulate cadmium.

Emissions of ionic cadmium from use of the chemicals in this group are not currently considered to be of environmental concern based on the measured concentrations of cadmium in treated effluent from STPs in Australia. Some biosolids may exceed the recommended limit for cadmium in biosolids, which may be applied to agricultural land. However, there are extensive national guidelines and codes of practice in place to limit the application of cadmium to agricultural soils in Australia.

The risks posed to the environment from chemicals in this group are expected to be managed by industrial practices and trade waste agreements, which minimise emissions of heavy metals, including cadmium, to wastewater systems. Adherence to these practices, and current environmental guidelines for cadmium in aquatic systems, biosolids, and soils, are considered sufficient to manage the environmental risks from the use of these chemicals in the metal finishing industry.

Recommendations

The chemicals in this group are not prioritised for further assessment under the IMAP framework.

Environmental Hazard Classification

The classification of the environmental hazards of sulfuric acid, cadmium salt (1:1); sulfuric acid, cadmium salt (1:1), hydrate (3:8); cadmium fluoride (CdF_2); cadmium chloride ($CdCl_2$); cadmium chloride, hydrate (2:5); cadmium bromide, tetrahydrate; cadmium iodide (CdI_2); borate(1-), tetrafluoro-, cadmium (2:1); nitric acid, cadmium salt; nitric acid, cadmium salt, tetrahydrate; acetic acid, cadmium salt; acetic acid, cadmium salt, dihydrate; and propanoic acid, cadmium salt according to the third 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 aquatic hazards of the chemicals in this group have been classified based on the available acute toxicity values for ionic cadmium in accordance with the classification procedure for metals and metal compounds under the GHS (UNECE, 2007). The classifications for each salt were made after correcting for the molecular weight of the respective cadmium salts. The L(E)C50 values available for dissolved ionic cadmium across multiple trophic levels are < 1 mg/L and all of the cadmium salts in this group are, therefore, classified as Acute Aquatic Category 1 and Chronic Aquatic Category 1.

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