Water soluble nickel(2+) salts: Environment tier II assessment

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CAS Registry Number: 10028-18-9, 13940-83-5, 7718-54-9, 7791-20-0, 13462-88-9, 7789-49-3, 13138-45-9, 13478-00-7, 7786-81-4, 10101-98-1, 7785-20-8, 13770-89-3, 14708-14-6, 13520-61-1, 3349-06-2, 6018-89-9, 6018-92-4

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.

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Acronyms & Abbreviations

Grouping Rationale

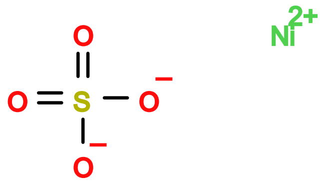
The environmental risks associated with industrial uses of eighteen water soluble nickel(2+) salts are considered in this assessment. These nickel salts are used for the production of other industrial chemicals, metal plating, and research.

The risk assessment of these chemicals has been carried out as a group because all eighteen nickel salts are very soluble in water and they can all potentially release nickel(2+) ions into water. This provides a common source of toxicity for each of the chemicals in this group. For the purposes of assessment, the chemicals have been sub-grouped into nickel salts of strong inorganic acids and nickel salts of short-chain carboxylic acids.

This assessment provides reference information on the environmental fate and effects of ionic nickel which may be released into the environment from the industrial uses of other nickel containing substances listed on the Inventory. The environmental risks of these remaining nickel substances will be assessed separately.

Chemical Identity

Nickel Salts of Strong Inorganic Acids

CAS RN	7786-81-4
Chemical Name	Sulfuric acid, nickel(2+) salt (1:1)
Synonyms	nickel sulfate anhydrous nickel sulfate
Structural Formula	
Molecular Formula	$NiSO_4$
Molecular Weight (g/mol)	154.76

CAS RN	10101-98-1
Chemical Name	Sulfuric acid, nickel(2+) salt (1:1), heptahydrate
Synonyms	nickel sulfate heptahydrate
Molecular Formula	$NiSO_4.7H_2O$
Molecular Weight (g/mol)	280.86

CAS RN	10028-18-9

Chemical Name	Nickel fluoride (NiF_2)
Synonyms	nickel fluoride nickel(2+) fluoride nickel difluoride
Molecular Formula	NiF_2
Molecular Weight (g/mol)	96.69

CAS RN	13940-83-5
Chemical Name	Nickel fluoride (NiF_2), tetrahydrate
Synonyms	nickel fluoride tetrahydrate nickel difluoride tetrahydrate
Molecular Formula	$NiF_2.4H_2O$
Molecular Weight (g/mol)	168.75

CAS RN	7718-54-9
Chemical Name	Nickel chloride ($NiCl_2$)
Synonyms	nickel chloride

Molecular Formula	$NiCl_2$
Molecular Weight (g/mol)	129.60

CAS RN	7791-20-0
Chemical Name	Nickel chloride ($NiCl_2$), hexahydrate
Synonyms	nickel chloride hexahydrate
Molecular Formula	$NiCl_2.6H_2O$
Molecular Weight (g/mol)	237.69

CAS RN	13462-88-9
Chemical Name	Nickel bromide ($NiBr_2$)
Synonyms	nickel bromide
Molecular Formula	$NiBr_2$
Molecular Weight (g/mol)	218.53

CAS RN	7789-49-3

Chemical Name	Nickel bromide ($NiBr_2$), trihydrate
Synonyms	nickel bromide trihydrate
Molecular Formula	$NiBr_2.3H_2O$
Molecular Weight (g/mol)	272.55

CAS RN	13138-45-9
Chemical Name	Nitric acid, nickel(2+) salt
Synonyms	nickel nitrate
Molecular Formula	$Ni(NO_3)_2$
Molecular Weight (g/mol)	182.71

CAS RN	13478-00-7
Chemical Name	Nitric acid, nickel(2+) salt, hexahydrate
Synonyms	nickel nitrate hexahydrate
Molecular Formula	$Ni(NO_3)_2.6H_2O$
Molecular Weight (g/mol)	290.79

CAS RN	14708-14-6
Chemical Name	Borate(1-), tetrafluoro-, nickel(2+) (2:1)
Synonyms	nickel tetrafluoroborate nickel fluoroborate nickel bis(tetrafluoroborate)
Molecular Formula	$Ni(BF_4)_2$
Molecular Weight (g/mol)	232.30

CAS RN	7785-20-8
Chemical Name	Sulfuric acid, ammonium nickel(2+) salt (2:2:1), hexahydrate
Synonyms	ammonium nickel sulfate hexahydrate
Molecular Formula	$(NH_4)_2Ni(SO_4)_2.6H_2O$
Molecular Weight (g/mol)	394.99

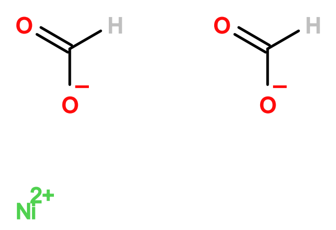
CAS RN	13770-89-3
Chemical Name	Sulfamic acid, nickel(2+) salt (2:1)

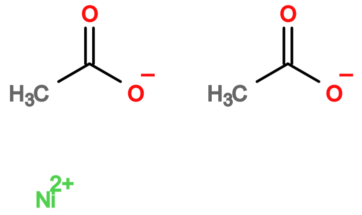
Synonyms	nickel sulfamate
Molecular Formula	$Ni(SO_3NH_2)_2$
Molecular Weight (g/mol)	250.85

CAS RN	13520-61-1
Chemical Name	Perchloric acid, nickel(2+) salt, hexahydrate
Synonyms	nickel perchlorate hexahydrate
Molecular Formula	$Ni(ClO_4)_2.6H_2O$
Molecular Weight (g/mol)	365.69

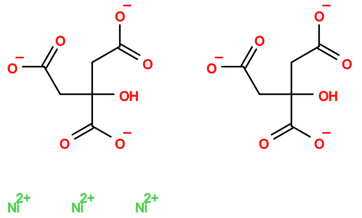
Nickel Salts of Short-Chain Carboxylic Acids

CAS RN	3349-06-2
Chemical Name	Formic acid, nickel(2+) salt
Synonyms	nickel formate nickel(2+) formate nickel diformate
Structural Formula	

	
Molecular Formula	$Ni(HCO_2)_2$
Molecular Weight (g/mol)	148.76
SMILES	[Ni++].C([H])(=O)[O-].C([H])(=O)[O-]

CAS RN	373-02-4
Chemical Name	Acetic acid, nickel(2+) salt
Synonyms	nickel acetate
Structural Formula	
Molecular Formula	$Ni(CH_3CO_2)_2$
Molecular Weight (g/mol)	176.78
SMILES	[Ni++].[O-]C(=O)C.[O-]C(=O)C

CAS RN	6018-89-9
Chemical Name	Acetic acid, nickel(2+) salt, tetrahydrate
Synonyms	nickel acetate tetrahydrate
Molecular Formula	$Ni(CH_3CO_2)_2.4H_2O$
Molecular Weight (g/mol)	248.84

CAS RN	6018-92-4
Chemical Name	1,2,3-Propanetricarboxylic acid, 2-hydroxy-, nickel(2+) salt (2:3)
Synonyms	nickel citrate trinickel dicitrate
Structural Formula	
Molecular Formula	$Ni_3(C_6H_5O_7)_2$
Molecular Weight (g/mol)	544.30
SMILES	C(C(=O)[O-])C(C(=O)[O-])(O)C(C(=O)[O-]).C(C(=O)[O-])C(C(=O)[O-])(O)C(C(=O)[O-]).[Ni++].[Ni++].[Ni++]

Physical and Chemical Properties

Based on the available information, all of the nickel salts in this group are solids under ambient conditions (WHO, 1990).

The anhydrous and hydrated forms of nickel salts in this group are chemically equivalent in aqueous solution. However, they can have some significantly different properties as solids. For example, the rate of dissolution of anhydrous nickel sulfate in unbuffered water is several orders of magnitude slower than that for nickel sulfate hexahydrate (WHO, 1990).

The chemicals in this group are used industrially as very water soluble sources of dissolved nickel(2+) ions. An important example is metal plating where high concentrations of dissolved nickel salts (such as nickel sulfate) are required for some common aqueous plating bath formulations (OECD, 2004). The typical characterisation of the nickel salts in this group as very water soluble is supported by the following water solubility data that are reported as the mass of the anhydrous nickel salt dissolved in a fixed mass of water (100 g) at the specified temperature (Haynes, 2015):

Chemical	CAS RN	Water Solubility (g/ 100 g H_2O)
nickel fluoride	10028-18-9	2.6 (25°C)
nickel chloride	7718-54-9	67.5 (25°C)
nickel bromide	13462-88-9	131 (20°C)
nickel nitrate	13138-45-9	99.2 (25°C)
nickel sulfate	7786-81-4	40.4 (25°C)
ammonium nickel sulfate hexahydrate	7785-20-8	6.5 (20°C)
nickel perchlorate hexahydrate	13520-61-1	158.8 (25°C)
nickel acetate tetrahydrate	6018-89-9	16 (20°C)

Import, Manufacture and Use

Australia

According to industry information obtained for this assessment, nickel sulfate, nickel chloride, and nickel sulfamate are used in the domestic metal plating industry. Nickel sulfate is also an intermediate in processes used to refine nickel ores at some nickel refineries operating in Australia. Nickel nitrate is reported to have uses in metal pre-treatment solutions that are used to manufacture coil extrusion products.

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

International

Nickel metal accounts for 95% of the total consumption of nickel, where approximately 85% is used in the manufacture of stainless steel and other alloys (Danish-EPA, 2015; Nickel Institute, 2016). The nickel chemicals in this group constitute a small proportion of the total global consumption of nickel. Nickel sulfate is used in the highest volume (15 000 tonnes per year) based on estimates from the European Union Risk Assessment Report (EU RAR) on nickel (ECB, 2008). Some of the chemicals in this group have significant uses in the metal finishing industry for processes such as metal plating and anodising (OECD, 2004).

Quantitative use data are available for nickel chloride, nickel sulfate and nickel nitrate in the EU (ECB, 2008). Nickel sulfate and nickel chloride are used primarily for plating (89% and 71%, respectively) and the production of catalysts (11% and 29%, respectively) (ECB, 2008). Furthermore, nickel sulfate and nickel chloride (and their hydrated forms) are the most commonly used nickel salts in nickel plating formulations (Nickel Institute, 2013). Nickel nitrate is mainly used for the production of catalysts (50–74%) and in the manufacture of Ni-Cd batteries (10–50%) (ECB, 2008).

While quantitative use data are not available for the remaining chemicals in this group, the nickel salts of strong inorganic acids are mainly used in catalyst production and for specific metal finishing applications (Antonsen, 2000). For example, nickel sulfamate is commonly used for plating when a functional coating is required (e.g. in electroforming) (Nickel Institute, 2013).

Similarly, for the nickel salts of short-chain carboxylic acids in this group, their main industrial use is also expected to be for specialised metal finishing applications. For example, nickel acetate is used as a sealing agent in anodising processes (OECD, 2004).

Environmental Regulatory Status

Australia

Nickel and nickel compounds are subject to reporting under the Australian National Pollutant Inventory (NPI). Under the NPI, emissions of nickel and nickel compounds are required to be reported annually by facilities that use or emit more than 10 tonnes of nickel or nickel 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, 2013). 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 default guideline values for nickel in freshwater and marine water have been determined. The freshwater guideline values have been adjusted to account for the effects of water hardness on the toxicity of nickel in aquatic systems. The current default guideline value for nickel in low hardness water is 11 micrograms of nickel per litre (µg Ni/L) which will protect 95% of species in a *slightly-moderately disturbed* freshwater ecosystem (ANZECC, 2000a). The 99% protection level for nickel in marine waters (7 µg Ni/L) is currently recommended for *slightly-moderatelydisturbed marine ecosystems (ANZECC, 2000a).*

For irrigated soil, a cumulative contaminant loading limit (CCL) trigger value has been set at 85 kilograms of nickel per hectare (kg Ni/ha) (ANZECC, 2000a). Nationally, an upper limit on nickel contamination in Grade C1 biosolids has been recommended (60 mg Ni/kg dry weight) (National Water Quality Management Strategy, 2004). Grade C1 biosolids can be applied in an unrestricted manner to all lands excluding sensitive sites.

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 & FAO, 1998).

OECD

Nickel chloride, nickel chloride hexahydrate, nickel nitrate, nickel nitrate hexahydrate and nickel sulfate are listed as OECD High Production Volume (HPV) chemicals (OECD, 2009). The chemicals are produced at a level greater than 1000 tonnes per year in at least one member country of the OECD.

Nickel chloride, nickel nitrate and nickel sulfate have been sponsored for assessment under the Cooperative Chemicals Assessment Programme (CoCAP). The 27th Screening Information Dataset (SIDS) Initial Assessment Meeting (SIAM 27) found that all three chemicals are candidates for further work based on the chronic toxicity of bioavailable forms of nickel in the environment (OECD, 2013).

Canada

Chemicals containing nickel are listed as a broad class of compounds (‘Oxidic, sulphidic, and soluble inorganic nickel compounds’) under Schedule 1 (the Toxic Substances List) of the *Canadian Environmental Protection Act 1999* (CEPA 1999) (Government of Canada, 2013a).

Nickel chloride, nickel nitrate, nickel sulfate, nickel sulfamate and nickel acetate are listed on the Canadian Domestic Substances List (DSL). These nickel 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. These five chemicals are also prioritised for further assessment under the Chemicals Management Plan (CMP) (Government of Canada, 2013b).

European Union

Fifteen chemicals in this group have been pre-registered for use in the European Union under the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) legislation (ECHA, 2015b). Seven of these fifteen nickel salts have undergone the full registration process (ECHA, 2015a).

United States of America

Most of the chemicals in this group (10 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, 2014).

Environmental Exposure

In Australia, the most significant industrial use for the nickel chemicals in this group is in the metal finishing industry for applications such as metal plating. This use pattern is therefore considered to provide the most likely pathway for emission of the nickel chemicals in this group to the environment. However, it should be noted that emissions of nickel from nickel plating will likely constitute a very small proportion of total anthropogenic nickel emissions compared to other known sources such as the combustion of fossil fuels and nickel mining, smelting and refining operations (ECB, 2008). The significance of any emissions of nickel from industrial applications of nickel chemicals must also consider the speciation and quantities of nickel which occur naturally in all compartments of the environment (ATSDR, 2005).

The aqueous plating baths used in nickel plating contain high concentrations of ionic nickel and release of nickel(2+) ions to waterways and wastewater streams is therefore the environmental release scenario of most concern in this assessment. Nickel can be present in the vapour emitted from so-called electroless nickel plating solutions. However, such discharges are expected to be captured by extraction systems (OECD, 2004).

The release of nickel to wastewater is most likely to occur during the disposal of spent plating bath solutions (NPI, 1999; OECD, 2004). However, 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). Electroless nickel plating has greater potential for emissions than electrolytic plating as the solutions used in the former technique have a finite lifetime. During normal plating operations, minor releases can also occur from a) drag-out (the solution lost from the bath when the plated article is removed), and b) wash-off (when the plated article is rinsed, the drag in material will be diluted in the rinse bath which is subsequently removed in the rinse effluent) (OECD, 2004).

Based on data collected in Australia, 40% of nickel that enters a sewage treatment plant (STP) is removed from wastewater by adsorption to sludge which may be applied to land as biosolids (Tjadraatmadja & Diaper, 2006). Removal rates for nickel in STPs in the range 9–59% have been reported internationally (ECB, 2008). Therefore, emissions of nickel(2+) to both environmental surface waters and soils are considered as part of this assessment.

The ammonium, fluoride, chloride, bromide, sulfate, and nitrate ions present as constituents of some salts in this group are ubiquitous, naturally occurring inorganic species. The use of the chemicals in this group is not considered likely to alter the background concentrations of these ions in the environment and their environmental fate and effects is not further considered in this assessment.

Environmental Fate

Dissolution, Speciation and Partitioning

The behaviour of the nickel(2+) ion is strongly dependent on the chemistry of the environmental compartment into which it is released.

The nickel(2+) ion is known to form only relatively weak complexes with halide and simple carboxylate anions in aqueous solution (Bjerrum, 1988; Bunting & Thong, 1970). Dissolution of the salts in this group in water will therefore result in dissociation into the nickel(2+) di-cation and the respective anions. The fully dissociated nickel di-cation is present in water as the hexaaquanickel(2+) complex ion, $[Ni(H_2O)_6]^{2+}$ (Basolo & Pearson, 1967; IPCS, 1991). This complex cation is a very weak acid and dissolved ionic nickel will therefore not undergo significant hydrolysis under typical environmental conditions.

In natural waters (pH 5–9), nickel(2+) ions may adsorb to Fe/Mn oxides or dissolved organic matter (DOM), or form complexes with inorganic ligands (OH^-, SO_4^{2-}, Cl^- or NH_3) (IPCS, 1991). These interactions produce a complex mixture of nickel species and compounds that are largely determined by the chemistry of the aquatic compartment.

In aquatic systems, > 90% of nickel is associated with particulate matter or sediments (Hart, 1982). However, this distribution between phases is affected by pH. At pH > 6, nickel(2+) readily adsorbs to suspended organic matter or precipitates with iron and manganese hydroxides (ANZECC, 2000b). Conversely, in acidic waters (pH < 6), adsorption of nickel(2+) to organic matter plays a minor role and ionic nickel is relatively mobile (ANZECC, 2000b).

In soils (and soil solution), nickel can exist in many forms and its speciation will be determined by many site-specific factors including soil type, abiotic factors (e.g. pH) and the presence of complexing ligands (humic acid), soil organic matter, DOM, clay and iron hydroxides, and silica and hydrous oxides (ATSDR, 2005).

Nickel can be removed from the soil solution and become less bioavailable following adsorption to clay particles, iron and manganese hydrous oxides and DOM (ATSDR, 2005). Over time, bioavailability can decrease following the adsorption of nickel to soil components (US EPA, 2007) and the formation of insoluble precipitates (e.g. in double layered hydroxide soils) (ECB, 2008). It is noted that the amount of nickel that can be leached from soils does not always correlate with the total nickel concentration (ATSDR 2005). For example, in some Australian soils that contain naturally high concentrations of nickel, < 2.5% of the total amount of nickel can be leached from the soil using strong extraction techniques (ATSDR 2005).

Depending on soil type, nickel can be relatively mobile in soil (IPCS, 1991) and is considered more mobile than other di-valent heavy metal ions (e.g. lead, cadmium, zinc) (ATSDR, 2005). In general, the mobility of nickel is greater in acidic soils (pH 4.4–6.6) compared to alkaline soils (6.7–8.8) (ECB, 2008). In addition to soil pH, other key factors that determine the mobility of nickel in soil are soil type and cation exchange capacity (CEC). The concentrations of organic matter and extractable nickel are also important factors (Weng, et al., 2004; Zhang, et al., 2015).

Overall, the solid-solution partitioning of nickel in soil has a complex dependence on soil properties, but is mainly determined by soil pH, CEC and the concentration of both clay and DOM (Danish-EPA, 2015). Recently, the partition coefficients (K_d values) for nickel in 500 soils with varying physical and chemical properties were measured as part of a large-scale European geochemical survey (Janik, et al., 2015). The median log K_d value (2.74) was in close agreement with that reported previously (2.08) (Commonwealth of Australia, 2011).

Abiotic transformation

The nickel cation is not considered to be subject to abiotic transformation, except as discussed above.

The tetrafluoroborate anion (BF_4^-) hydrolyses in water in a stepwise manner to give hydroxyfluoroborates, then boric acid (Ullmann's Encylopedia of Industrial Chemicals, 2014). These degradation products are naturally ubiquitous in the environment.

Biotransformation

The nickel cation is not considered to be subject to biotransformation.

Perchlorate anions (ClO_4^-) occur naturally in the environment and are relatively stable. Due to their negative charge, perchlorates do not readily partition to soil (MacMillan, et al., 2007). The precise degradation processes for perchlorates in aquatic systems have not been determined. However, laboratory studies suggest that the most likely route is throughreduction by anaerobic microbial organisms (ATSDR, 2008). During this step-wise process, ClO_4^- is reduced to chlorate (ClO_3^-) followed by chlorite (ClO_2^-) and finally to chloride (Cl^-). Abiotic factors are unlikely to contribute to degradation of perchlorates in aquatic systems (ATSDR, 2008).

The distribution of sulfamates in the environment is limited; however, they are believed to be a component of the organic sulfur fraction in soils (Fitzgerald, 1976; Janzen & Ellert, 1998). The concentrations of sulfamate in soils are therefore expected to be regulated by geochemical processes.

The carboxylic acid components of the chemicals in this group are naturally occurring organic acids that undergo rapid biodegradation in the environment. For example, citric acid (CAS RN 77-92-9) has been found to undergo 77% degradation in 14 days in a study conducted in accordance with OECD Test Guideline (TG) 301C (LMC, 2013).

Bioaccumulation

Nickel does not bioaccumulate to a significant extent in aquatic or terrestrial organisms (ECB, 2008). The exception to this is nickel hyperaccumulator plants which actively accumulate nickel in plant leaf tissue (≥ 1000 µg Ni/g) by uptake of nickel from the soil (van der Ent, et al., 2013).

Several aquatic plant species have the ability to remove nickel from water. However, such species typically do not meet the criteria necessary to be classified as hyperaccumulators (Prasad & de Oliveira Freitas, 2003). For other aquatic organisms, the highest accumulators of nickel appear to be certain species of marine bivalves (ECB, 2008). Although data are limited for the biomagnification of nickel, most studies indicate that biomagnification does not occur in aquatic (ECB, 2008) or terrestrial (Commonwealth of Australia, 2011) food chains.

Assessment of nickel bioaccumulation and biomagnification is complicated by the fact that nickel is an essential micronutrient for many species of microorganisms, plants and many higher animals (ECB, 2008). Furthermore, conventional measures of bioaccumulation as applied to organic chemicals are not appropriate for metal ions. These measures do not consider the potential for metals to accumulate in specific tissues, the physiological mechanisms available to organisms to regulate internal metal concentrations, and the influence of environmental factors (US EPA, 2007).

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

The nickel(2+) ions released from the salts in this group may have some mobility in surface water due to complexation by dissolved organic matter and/or synthetic chelating agents present in wastewater (Nowack, 2002). However, nickel released to water will eventually become bound to sediment. In soil, nickel is relatively immobile, except in soils with low pH where there is an increased potential for transport through the soil compartment.

Nickel compounds that are emitted to the atmosphere can associate with particulate matter and be transported over long distances through the atmosphere when associated with these particles (ATSDR, 2005). This emission pathway is not relevant for the known industrial uses of the nickel salts in this group and will therefore not be considered in this assessment.

Predicted Environmental Concentration (PEC)

A PEC was not calculated for the chemicals or their ionic components addressed under this assessment.

The background concentrations of nickel in the environment vary widely, but are usually low (ATSDR, 2005). In Australian soils, background concentrations range from 1.4 to 55 mg Ni/kg, where agricultural soils have intermediate background levels (21.9 mg Ni/kg) (Commonwealth of Australia, 2011; EPA SA, 2009). No reliable or current data were identified for background concentrations of nickel in Australian freshwaters. The mean concentration in European freshwaters is 3.3 µg Ni/L (ECB, 2008).

The most likely source of emissions of nickel chemicals in this group is from their use in nickel plating operations. The concentrations of nickel in electroplating and electroless plating baths range from 60 to 84 g Ni/L (US EPA, 1996) and approximately 8 to 10 g Ni/L (respectively) (OECD, 2004). The concentration of nickel in spent electroless bath solutions is approximately 5 g Ni/L (OECD, 2004). Depending on the size of the plant and the viability of implementing recovery measures, nickel may be recovered from waste solutions and re-used within the plant. However, if recovery is incomplete, a proportion of nickel may be released with the treated effluent (OECD, 2004).

No specific data regarding nickel emissions to wastewater from metal plating facilities in Australia were identified for this assessment. However, the concentration of nickel in Australian wastewater entering STPs is in the range 4 to 11 µg Ni/L (NPI, 2011). Wastewater treatment is expected to remove up to 40% of the total quantity of nickel that enters an STP (ECB, 2008). Given this rate of removal and measured concentrations of nickel in wastewater, the concentration of nickel in treated effluents discharged to surface waters is expected to be < 10 µg/L.

This estimated concentration of nickel in treated effluent is comparable with findings in Europe. In the EU, approximately 1370 kg of nickel is released each year from plating operations. This includes emissions directly to surface waters (e.g. Sweden and Italy) and to wastewater streams (e.g. UK and Germany) (ECB, 2008). Downstream of the discharge point (3 km), measured nickel concentrations have been recorded between < 5 µg/L and 8 µg/L (ECB, 2008).

As a result of wastewater treatment, approximately 40% of nickel in wastewater influent will partition to biosolids (ECB, 2008). The average nickel concentration in Australian biosolids is 32 mg/kg (Warne, et al., 2008) and the National contaminant limit for Grade C1 biosolids (lowest level of contaminants) is 60 mg Ni/kg (dry weight) (National Water Quality Management Strategy, 2004). This contamination threshold is only applied when specific State guidelines have not been developed. In South Australia and Western Australia, nickel was removed from the list of contaminants to be monitored in biosolids as current nickel concentrations were deemed unlikely to significantly perturb background soil concentrations (21.9 mg Ni/kg) (EPA SA, 2009; Government of Western Australia, 2012).

Environmental Effects

The environmental effects of the nickel salts in this group will be determined by the release of nickel(2+) ions into the environment. The effects of the chemicals in this group have therefore been assessed collectively by reference to the extensive ecotoxicity data available for ionic nickel.

The assessment of the aquatic toxicity of ionic nickel in this assessment distinguishes between “total nickel” (Ni_{total}) and “dissolved nickel” (Ni_{diss}) exposure concentrations where possible. The dissolved nickel concentration is usually a more reliable indicator of the concentration of bioavailable forms of nickel in solution and provides a more useful toxicity indicator value for comparative hazard evaluation and risk assessment.

The dissolved nickel concentration is the concentration of nickel that remains in water following filtration of a water sample through a 0.45 µm filter (ANZECC, 2000b). The dissolved nickel fraction includes many simple ionic nickel species such as the $[Ni(H_2O)_6]^{2+}$ cation, and other (typically low to moderate molecular weight) inorganic and organic complexes of the nickel(2+) ion. The speciation of nickel in the dissolved fraction can vary greatly depending on the chemistry of the water in which the nickel ion is dissolved.

Effects on Aquatic Life

Bioavailable forms of nickel(2+) are very toxic to aquatic life in short and long term exposures. The toxicity of ionic nickel to aquatic organisms varies considerably between species and is strongly influenced by water chemistry.

Acute toxicity

The following acute median lethal concentrations (LC50s) and median effective concentrations (EC50s) for model organisms across three trophic levels are presented together with relevant water chemistry parameters. The acute toxicity values for fish are based on total nickel concentrations, rather than dissolved nickel, as the LC50 values were similar in this case (Hoang, et al., 2004):

Taxon	Endpoint	Method
Fish	96 h LC50 = 270 µg Ni_{total}/L	*Pimephales promelas* (fathead minnow) age < 1d $CaCO_3$ = 12 mg/L, pH = 7.3, DOC = 0.9 mg/L (Hoang, et al., 2004)
	96 h LC50 = 3500 µg Ni_{total}/L	*Pimephales promelas* (fathead minnow) age < 1d $CaCO_3$ = 102 mg/L, pH = 8.8, DOC = 8.6 mg/L (Hoang, et al., 2004)
Invertebrates	48 h EC50 = 35 µg Ni_{diss}/L	*Ceriodaphnia dubia* (daphnid) $CaCO_3$ = 108.4 mg/L, pH = 7.95, DOC = 5.02 mg/L (De Schamphelaere, et al., 2006)

Taxon	Endpoint	Method
	48 h EC50 = 183 µg Ni_{diss}/L	*Ceriodaphnia dubia* (daphnid) $CaCO_3$ = 131.6 mg/L, pH = 7.51, DOC = 23.6 mg/L (De Schamphelaere, et al., 2006)
Algae	72 h EC50 = 483 µg Ni_{diss}/L	*Pseudokirchneriella subcapitata* $CaCO_3$ = 116 mg/L, pH = 6.35, DOC = 6.62 mg/L (Deleebeeck, et al., 2009b)
	72 h EC50 = 1630 µg Ni_{diss}/L	*Pseudokirchneriella subcapitata* $CaCO_3$ = 178 mg/L, pH = 7.37, DOC = 25.8 mg/L (Deleebeeck, et al., 2009b)

The acute toxicity of nickel to freshwater organisms varies at both the interspecies and intraspecies level. Differences in intraspecies acute nickel toxicity can be attributed to abiotic and biotic factors including water hardness, pH and dissolved organic carbon (DOC) (Deleebeeck, et al., 2009a). In addition, fish age is also an important factor influencing toxicity where older fish are more tolerant than younger fish.

Chronic toxicity

The chronic toxicity of nickel(2+) 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). Only studies that considered the complex relationship between water chemistry and toxicity were considered, and no-observed effect concentration (NOEC) equivalent values were derived. The calculated values were corrected for water hardness and converted to a uniform hardness of 30 mg $CaCO_3$/L. These values are reported below for a fish and invertebrate species.

Chronic toxicity values for additional fish and invertebrate species are also given below together with values for algae and an aquatic plant species. For tests that did not specify dissolved or total nickel concentrations, it was assumed that exposure concentrations referred to total nickel in solution (Ni_{total}):

Taxon	Endpoint	Method

Taxon	Endpoint	Method
Fish	28 d LC50 = 18.5 µg Ni_{total}/L	*Oncorhynchus mykiss (rainbow trout)* $CaCO_3$ = 30 mg/L, pH = 6.3–7.7, DOC (not reported) (ANZECC, 2000b)
	32 d NOEC = 57 µg Ni_{total}/L	*Pimephales promelas* (fathead minnow) $CaCO_3$ = 102.6 mg/L, pH = 7.4, DOC = 0 mg/L (estimated) (Birge WJ, et al., 1984)
Invertebrates	5–30 d EC50 = 67 µg Ni_{total}/L	*Daphnia magna* (water flea) $CaCO_3$ = 30 mg/L, pH = 6.3–7.7, DOC (not reported) (ANZECC, 2000b)
	10 d EC10 = 9.0 µg Ni_{diss}/L	*Ceriodaphnia dubia* (daphnid) $CaCO_3$ = 15 mg/L, pH = 6.56, DOC = 6.36 mg/L (De Schamphelaere, et al., 2006)
Algae	72 h EC10 = 90 µg Ni_{diss}/L	*Pseudokirchneriella subcapitata* $CaCO_3$ = 116 mg/L, pH = 6.35, DOC = 6.62 mg/L (Deleebeeck, et al., 2009b)
Freshwater Plant	7 d EC10 = 36 µg Ni_{total}/L	*Lemna minor* (common duckweed) $CaCO_3$ = 96 mg/L, pH = 7.6, DOC = 7.1 mg/L (ECB, 2008)

In addition to these chronic toxicity data from single species laboratory tests, a freshwater microcosm study with a community of algae, zooplankton, and snails showed that gastropods (snails) are sensitive to nickel. In this study, no snails were found in microcosms after 12 weeks of continuous exposure to 48 µg and 96 µg Ni_{total}/L. The population density of snails was the most sensitive end-point monitored in these microcosms and the NOEC for chronic effects under these conditions is 12 µg Ni/L (Hommen, et al., 2015).

The chronic toxicity of nickel is strongly dependent on the bioavailability of nickel(2+) which is influenced by the following three key parameters: pH; water hardness; and concentration of DOC. In general, nickel toxicity is greatest in waters with alkaline pH, low water hardness and a low concentration of DOC. For example, the European Risk Assessment of nickel compounds found that the most sensitive exposure conditions occurred in waters with a pH of 7.7, 48 mg $CaCO_3$/L and 2.5 mg DOC/L (ECB, 2008).

Nickel toxicity to fish and invertebrates decreases with pH over the whole pH range of natural waters. At low pH, H^+ ions compete with nickel(2+) for the biotic ligand surfaces of exposed aquatic organisms (e.g. fish gills). In algae, toxicity decreases at high pH as well as low pH (ECB, 2008). For some freshwater invertebrates, the effect of pH on nickel(2+) ion toxicity is more important in chronic exposures than acute (De Schamphelaere, et al., 2006).

Nickel toxicity decreases with increasing water hardness due to competition of other divalent cations (e.g. Ca^{2+} and Mg^{2+}) for binding sites on the biotic ligand. This effect is linear down to water hardness levels of approximately 20 mg $CaCO_3$/L (ANZECC, 2000a).

The presence of DOC reduces nickel toxicity to all species across all pH ranges and water hardness values. The mitigating effect of DOC on toxicity is more pronounced at higher pH levels in softer waters (ECB, 2008).

The dissolved nickel(2+) concentration alone is generally not a sufficient indicator of aquatic toxicity as abiotic factors strongly influence nickel bioavailability as discussed above. The mechanisms by which these factors affect toxicity are well understood and as a result, a bioavailability-based approach has been implemented in Europe for setting Environmental Quality Guidelines for nickel. Biotic ligand modelling (BLM) takes into account a) the affect of abiotic factors on aqueous speciation (Schlekat, et al., 2010), and b) the competition between nickel(2+) and other cations for binding to the biotic ligands of aquatic organisms (ECB, 2008; NiPERA, 2015b). Nickel BLMs can be used to normalise toxicity test results that are carried out in different water conditions provided that critical water chemistry parameters have been characterised (Merrington, et al., 2016).

Effects on Sediment-Dwelling Life

Bioavailable forms of nickel(2+) can have some toxic effects on sediment-dwelling organisms.

The chronic toxicity of nickel is influenced by several physico-chemical properties of sediments including total organic carbon (TOC), total recoverable iron, the concentration of acid-volatile sulfides (AVS) and CEC (Besser, et al., 2013; Schlekat, et al., 2016). These characteristics of sediments can mitigate the toxicity of nickel to sediment-dwelling organisms.

Chronic toxicity values for the effects of nickel on sediment-dwelling invertebrates have been obtained for amphipods, insects, oligochaetes and mussels (ECB, 2008; Vangheluwe, et al., 2013). Based on a worst-case scenario (low sediment AVS and TOC), a 28 d EC20 of 149 mg Ni/kg was obtained for the amphipod *Hyalella azteca*. Under the same exposure conditions, the most tolerant sediment-dwelling species were midges (*Chironomus riparius* and *Chironomus dilutes*) and mussels (*Lampsilis siliquoidea*), where the no-observed effect concentration (NOEC) exceeded the highest nickel concentration (> 762 mg Ni/kg). An intermediate toxicity value was found for the freshwater oligochaete, *Lumbriculus variegates* (worm) (EC10 = 554 mg Ni/kg) (Vangheluwe, et al., 2013).

Effects on Terrestrial Life

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

The bioavailability and toxicity of nickel in soil is strongly influenced by soil properties, especially cation exchange capacity (NiPERA, 2015a).

Soil Quality Guidelines (SQG) have been derived for nickel in Australian soils (Commonwealth of Australia, 2011). The guidelines were derived from NOEC and EC10 values for plants, microbial processes and invertebrates exposed to nickel in the form of nickel metal, nickel sulfate, nickel chloride, nickel nitrate or nickel carbonate (CAS RN 3333-67-3). Over 330 toxicity data points were available, with the majority relating to microbial processes and enzymes. The lowest NOEC/EC10 values for nickel toxicity to plants, microbial processes and invertebrates are 26.9 mg Ni/kg (*Spinacia oleracea*, spinach), 81.3 mg Ni/kg (nitrification) and 103 mg Ni/kg (*Eisenia veneta*, earthworm), respectively (geometric mean values) (Commonwealth of Australia, 2011).

Predicted No-Effect Concentration (PNEC)

The primary environmental effects of the chemicals in this group are expected to be caused by the release of nickel(2+) ions. Given that the focus of this assessment is the release of nickel to wastewater streams and aquatic environments, existing guideline values for nickel in soils and aquatic systems were considered.

In place of a PNEC for the soil compartment for nickel(2+), the Added Contaminant Limits (ACL) published for nickel in the *National Environment Protection (Assessment of Site Contamination) Measure 2011* have been used. It is not possible to present a single set of SQG values as they will be site specific. The generic ACLs range from 6 to 95 mg added Ni/kg of soil depending on land use (e.g. National park or industrial area), and represent the level above which further investigation or evaluation is required after considering naturally occurring background levels.

In place of PNECs for aquatic and sediment compartments, the default guideline values published for nickel in the Australian and New Zealand Guidelines for Fresh and Marine Water Quality have been used (ANZECC, 2000a). These values represent thresholds above which further assessment of potential toxicity may be required to ensure environmental quality, and have been normalised using a water hardness of 30 mg $CaCO_3$/L. For *slightly-moderately disturbed* freshwater ecosystems, a high reliability guideline value for protection of 95% of species has been determined to be 11 µg Ni/L. The equivalent values for the protection of marine and sediment-dwelling species are 7 µg Ni/L and 21 mg Ni/kg (dry weight), respectively (ANZECC, 2000a).

The default guideline values provided for nickel in the aquatic environment are not intended to be applicable for all situations. The Guidelines provide options to refine guideline values for metal ions by taking into account local variations in bioavailability that result from differences in the chemistry of natural waters (ANZG, 2018). These methods can be used to provide a more accurate prediction of the adverse effect concentration of ionic nickel in a specific water body if the values for key water chemistry parameters are available. This approach can be useful for site-specific risk assessments but is beyond the scope of this assessment.

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 formic acid, nickel(2+) salt; acetic acid, nickel(2+) salt; acetic acid, nickel(2+) salt, tetrahydrate; and 1,2,3-propanetricarboxylic acid, 2-hydroxy-, nickel(2+) salt (2:3) are all categorised as:

- Not P
- Not B
- Not T

An environmental hazard categorisation for the inorganic components of the nickel chemicals in this group has not been assigned for the reasons discussed above. Nevertheless, it is noted that bioavailable forms of nickel are very toxic to aquatic organisms.

Risk Characterisation

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

The majority (96%) of anthropogenic emissions of nickel to the environment are from fossil fuel combustion, nickel metallurgical processes, incineration and steel/alloy production. The release of nickel from the metal finishing industry will therefore contribute a small proportion of the total anthropogenic emissions of nickel to the environment. Nevertheless, emissions of ionic nickel from metal plating facilities into wastewater can occur, which contributes to the total anthropogenic nickel load added to surface waters and soils in treated effluents and biosolids produced by sewage treatment plants.

An analysis of domestic monitoring data for nickel in wastewater entering sewage treatment plants shows that cumulative loads of nickel are currently low. Although no monitoring data for nickel concentrations in domestic surface waters have been identified, the concentrations of nickel in wastewater entering STPs are already at or below the trigger values for nickel in freshwater ecosystems before considering partial removal of nickel in biosolids. This indicates a low risk to surface waters from the quantities of nickel (including those quantities that may be released from metal finishing facilities) present in treated sewage treatment plant effluent.

Similarly for biosolids, the levels of nickel in biosolids in Australia are below guideline values and several jurisdictions no longer require nickel to be monitored in biosolids being disposed of to land, including agricultural land. This finding indicates a low risk to soil from the quantities of nickel (including those quantities that may be released from metal finishing facilities) that are present in biosolids.

Based on currently available monitoring data, the quantities of nickel 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.

Key Findings

The main domestic industrial use of chemicals in the Water Soluble Nickel(2+) Salts group is in the metal finishing industry for processes such as nickel plating.

The principal environmental concern for nickel salts in this group is the potential for release of ionic nickel to aquatic environments and soil from metal plating facilities. This poses a concern because bioavailable forms of ionic nickel are very toxic to aquatic organisms.

Nickel sulfate, nickel chloride, and nickel sulfamate are the chemicals in this group most likely to emit nickel to surface waters and soil based on release of ionic nickel into sewage treatment systems from metal plating facilities. Emissions of nickel from these sources are not currently considered to be of environmental concern based on the concentrations of nickel in wastewater entering sewage treatment plants and the concentrations of nickel in biosolids.

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 nickel, to wastewater systems. Adherence to these practices, and current environmental guidelines for nickel 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 evaluation.

Environmental Hazard Classification

The classification of the environmental hazards of nickel fluoride (NiF_2); nickel fluoride (NiF_2), tetrahydrate; nickel chloride ($NiCl_2$); nickel chloride ($NiCl_2$), hexahydrate; nickel bromide ($NiBr_2$); nickel bromide ($NiBr_2$), trihydrate; nitric acid, nickel(2+) salt; nitric acid, nickel(2+) salt, hexahydrate; sulfuric acid, nickel(2+) salt (1:1); sulfuric acid, nickel(2+) salt (1:1), heptahydrate; sulfuric acid, ammonium nickel(2+) salt (2:2:1), hexahydrate; sulfamic acid, nickel(2+) salt (2:1); borate(1-), tetrafluoro-, nickel(2+) (2:1); perchloric acid, nickel(2+) salt, hexahydrate; formic acid, nickel(2+) salt; acetic acid, nickel(2+) salt; acetic acid, nickel(2+) salt, tetrahydrate; and 1,2,3-propanetricarboxylic acid, 2-hydroxy-, nickel(2+) salt (2:3) 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 the soluble nickel(2+) ion 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 nickel salts. The EC50 of the dissolved nickel(2+) ion is < 1 mg/L and all of the nickel salts in this group are therefore classified as Acute Aquatic Category 1 and Chronic Aquatic Category 1.

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