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Toxicant default guideline values for aquatic ecosystem protection

Nickel in freshwater

Technical brief

July 2024

DRAFT

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New Zealand Government



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Summary

Nickel is a commonly occurring natural element that is essential to some organisms. Nickel is mined and processed globally and used for many purposes, including the production of alloys, food preparation equipment, mobile telephones, batteries, medical equipment, automotive and engine components, buildings and power generation. Anthropogenic sources of nickel include motor vehicle emissions, landfills, sewage, stormwater runoff and industries such as mining.

The ANZECC/ARMCANZ (2000) nickel default guideline value (DGV) for 95% species protection in freshwater with a hardness of 30 mg/L CaCO₃ was 11 µg/L, based on chronic toxicity data for seven species from four taxonomic groups. However, water quality parameters other than hardness), particularly pH and dissolved organic carbon (DOC), also affect nickel bioavailability and toxicity in aquatic systems. Bioavailability models have been developed for nickel, including biotic ligand models (BLMs) and trophic-level-specific multiple linear regressions (MLRs), which can be used to derive bioavailability-based DGVs that account for a wider range of water quality parameters compared to the ANZECC/ARMCANZ (2000) DGVs. Since 2000, more chronic toxicity data have become available, including data for tropical and temperate organisms and for Australian and/or New Zealand species, from which updated DGVs have been derived. The DGVs reported in this technical brief are based on the guideline values derived by Stauber et al. (2021), who employed the trophic-level-specific MLR bioavailability models developed by Peters et al. (2021) to account for the influence of pH, hardness and DOC on nickel toxicity.

From a database of chronic toxicity data for 44 species (20 temperate and 24 tropical species), freshwater nickel DGVs were derived using data for 26 species for which test water pH, hardness (i.e. calcium and magnesium concentrations) and dissolved organic carbon (DOC) data were available. The ecotoxicity data for each of these species were normalised to an index water quality condition for these water quality parameters (i.e. pH 7.5, 6 mg/L Ca, 4 mg/L Mg and 0.5 mg/L DOC) using the trophic-level-specific MLRs for microalgae, aquatic plants, invertebrates and fish.

The fit of the species sensitivity distribution to the normalised toxicity data was good, resulting in very high reliability DGVs. With the ability to adjust the DGVs based on the pH, hardness and DOC of the water, the nickel freshwater DGVs for 99%, 95%, 90% and 80% species protection are provided for water over a range of pH (6.0–8.5), calcium (2–70 mg/L), magnesium (1.6–54 mg/L) and DOC (0.5–20 mg/L).

The DGVs for 99%, 95%, 90% and 80% species protection at the index water quality condition are 0.31 µg/L, 2.0 µg/L, 4.6 µg/L and 10 µg/L, respectively. The 95% species protection level DGV is recommended for application to slightly-to-moderately disturbed ecosystems. Where water data for pH, hardness or DOC are not available, the index condition (i.e. pH 7.5, 6 mg/L Ca, 4 mg/L Mg and 0.5 mg/L DOC) should be used. The DGVs can be used for both temperate and tropical water. The DGVs supersede the ANZECC/ARMCANZ (2000) DGVs for nickel in freshwater.

1 Introduction

Nickel is the fifth most common element on earth and occurs extensively in the earth's crust (Nickel Institute 2015). It primarily occurs as oxides, sulfides and silicates (Pyle and Couture 2012). Nickel ores are mined in over 23 countries, and are smelted or refined in 25 countries, including Russia, Canada, New Caledonia, Australia, Indonesia, the Philippines, Cuba, China, South Africa and Brazil. Approximately 2.5 million tonnes of nickel are produced annually, and the world demand for nickel was growing at a compound annual average rate of 5% per annum over 2010–2020 (INSG 2024).

More than two-thirds of nickel produced is used in the production of alloys (e.g. stainless steel) with other metals such as iron, copper and chromium (INSG 2024). Nickel-containing materials include food preparation equipment, mobile telephones, medical equipment, automotive and engine components, buildings, batteries and power generation (Nickel Institute 2015). Anthropogenic sources of nickel include motor vehicle emissions, landfills, sewage, stormwater runoff and industries such as mining. Magmatic sulfide and laterite ores are naturally enriched in nickel. Nickel laterites have a fine dispersive nature and are formed by the extensive chemical and physical weathering of ultramafic rocks under tropical, humid conditions (Mudd 2010). Recent estimates show that 60% of the world's nickel reserves are contained in laterite deposits (USGS 2019). In 2018, 48% of the world's nickel production came from the tropical Asia–Pacific region, including Indonesia, New Caledonia and the Philippines (USGS 2019).

Nickel predominantly occurs in the +2 oxidation state (i.e. Ni^{2+}) and forms stable complexes with inorganic and organic ligands (Eisler 1998; Pyle and Couture 2012). In natural freshwater, the dominant form of nickel is soluble Ni^{2+} , but other forms also exist, predominantly as complexes with sulfate and chloride (Morel and Hering 1993). Based on studies of nickel in temperate freshwater, nickel speciation depends on a variety of factors, including pH, ionic strength, dissolved organic carbon (DOC), ligand type and concentration, temperature, hardness, alkalinity, other cations and the availability of solid surfaces for adsorption. In anaerobic freshwater sediments, nickel is present as nickel sulfide, which reduces its bioavailability to benthic biota. Other solid forms in sediments, such as iron and manganese oxides and organic carbon, can also bind nickel (Brumbaugh et al. 2013; Schlekot et al. 2015). Once nickel has entered an aquatic system, it can be accumulated by biota, including phytoplankton and aquatic plants, or deposited in the sediment by precipitation, complexation and adsorption on clay particles, with subsequent uptake by benthic biota (Cempel and Nikel 2006).

Concentrations of dissolved nickel in unimpacted freshwater typically range from 0.1 $\mu\text{g/L}$ to 0.6 $\mu\text{g/L}$ (Brix et al. 2017), with a world average of 0.5 $\mu\text{g/L}$ (Martin and Windom 1991). In some regions, such as New Caledonia, nickel concentrations in soils and aquatic systems are naturally enriched, but mining of lateritic nickel ores can result in the additional input of metals into freshwaters. Nickel concentrations in groundwater have been measured up to 980 $\mu\text{g/L}$ and up to 87 $\mu\text{g/L}$ in urban stormwater runoff (Begum et al. 2022).

Nickel is an essential nutrient for micro-organisms and terrestrial plants, and at least eight nickel-containing enzymes have been identified (Moreton et al. 2009). In aquatic plants and cyanobacteria,

the necessity of nickel has been documented in urease and hydrogenase metabolism; however, the necessity of nickel in aquatic animals has not been confirmed (Muysen et al. 2004).

The previous default guideline values (DGVs) for nickel were derived from chronic toxicity data for seven species from four taxonomic groups, normalised to a hardness of 30 mg/L CaCO₃ (ANZECC/ARMCANZ 2000). The 95% species protection DGV at this hardness was 11 µg/L. A hardness algorithm was provided to adjust the DGVs based on the hardness of the receiving water. However, water quality parameters other than hardness, particularly pH and DOC, also affect nickel bioavailability and toxicity in aquatic systems. Bioavailability models that capture key toxicity modifying parameters have been developed for nickel, including biotic ligand models (BLMs) (de Schampelaere et al. 2006; Deleebeeck et al. 2008, 2009b; Peters et al. 2018) and trophic-level-specific multiple linear regressions (MLRs) (Peters et al. 2021). These models can be used to derive bioavailability-based guideline values that take into account a wider range of water quality parameters. Recently, such models have been developed or validated for Australian species and water quality conditions (Peters et al. 2018, 2021). Moreover, over the past 20 years, more chronic toxicity data for nickel in freshwater have become available, including data for tropical and temperate organisms and for Australian and New Zealand species. The DGVs reported here are based on the guideline values derived by Stauber et al. (2021), who employed the MLR bioavailability models developed by Peters et al. (2021). These trophic-level-specific MLRs were developed from chronic EC10 (or equivalent) data and included development and/or validation with Australian and New Zealand species.

2 Aquatic toxicology

2.1 Mechanism of toxicity

At high concentrations, nickel and nickel compounds can cause ionoregulatory and respiratory impairment, and promote oxidative stress in freshwater invertebrates and fish (Brix et al. 2017). Brix et al. (2017) hypothesised that nickel may cause a range of molecular initiating events, including: disruption of calcium, magnesium and iron homeostasis; reactive oxygen species-induced oxidative damage; and an allergic-type response of respiratory epithelia. However, much of the evidence is from acute studies with prokaryotes and mammals. These events may manifest as reduced calcium availability to support formation of exoskeleton, shell and bone for growth, impaired respiration, and cytotoxicity and tumour formation, which may ultimately reduce growth and reproduction and alter energy metabolism. However, evidence for these effects on aquatic biota from chronic exposures to nickel concentrations found in the environment is limited.

For aquatic plants, in addition to oxidative damage, nickel at high concentrations may displace magnesium from the chlorophyll molecule, leading to inhibition of photosynthesis (Brix et al. 2017).

2.2 Toxicity

For tropical species, reported nickel toxicity values ranged from 1.4 µg/L to 419 000 µg/L (Binet et al. 2018). However, because nickel toxicity varies with water chemistry, comparisons of species sensitivities are most useful when the ecotoxicity data are normalised to the same water chemistry. For freshwater at approximately 30 mg/L CaCO₃, DOC of <1 mg/L, and pH of 6–9, a number of

tropical species were sensitive to nickel, with EC10 values of 4.9–175 µg/L and EC50 values of 19–663 µg/L in chronic tests. These included several species of microalgae (*Pediastrum duplex*, *Pseudokirchneriella* sp., *Spermatozopsis exultans*, *Scenedesmus accuminatus*, *Desmodesmus spinosus*; EC10s ranging 4.9–29 µg/L), two duckweeds (*Lemna aequinoctialis*, *Lemna minor*; EC10s of 8.2–13 µg/L) and a cnidarian (*Hydra viridissima*; EC10 of 175 µg/L).

Tropical bacteria were less sensitive to nickel than other taxa, with an EC50 of 13 000 µg/L (Babich et al. 1986). Likewise, amphibians and fish were lower in sensitivity than most other taxa, with LC50s of 420 µg/L and 2 020 µg/L, respectively (Birge et al. 1978). One exception was the Australian endemic rainbowfish *Melanotaenia splendida splendida*, with chronic 12-d EC50 values of 39–185 µg/L, depending on water chemistry (ESA 2014). For tropical crustaceans, EC50s varied from 250 µg/L to 410 µg/L (Wong et al. 1991; Wong and Pak 2004). Tropical snails were sensitive to nickel (LOEC <88 µg/L) (Factor and de Chavez 2012). However, some of the tropical studies did not report water quality parameters that are known to affect nickel toxicity (e.g. DOC, pH).

For temperate species, the most sensitive species was the snail *Lymnaea stagnalis*, with an EC10 of 1.1 µg/L (Schlekat et al. 2010), followed by crustaceans *Daphnia magna* and *Ceriodaphnia dubia*, with EC10s of 21 µg/L and 2–31 µg/L respectively, at approximately 30 mg/L CaCO₃ hardness (Deleebeek et al. 2008; Nys et al. 2016). There is some uncertainty around the sensitivity of the snail *L. stagnalis* to nickel in different studies, and differences in methods used across the studies have been suggested as possible reasons for this variation (Cremazy et al 2020). The freshwater microalga *Pseudokirchneriella subcapitata* was also sensitive to nickel, with EC10s ranging from 25 µg/L to 365 µg/L depending on water chemistry. Similar to tropical species, other temperate invertebrates and fish were relatively insensitive to nickel.

Peters et al. (2019) suggested that overall there is little difference in the sensitivities of tropical versus temperate freshwater species to nickel. They compared nickel toxicity effect concentrations (typically EC10s and NOECs), overall species sensitivity distributions (SSDs) and closely related groups of species using temperate and tropical freshwater datasets, with and without bioavailability normalisation. While direct comparison of the temperate and tropical SSDs was confounded by the lower taxa diversity, lack of amphidromous species unique to tropical environments, and insensitive species such as molluscs and fish in the tropical SSD, they showed that 95% species protection values for nickel, which ranged from 3.5 µg/L to 8.6 µg/L, were similar between tropical and temperate distributions.

3 Factors affecting toxicity

The dissolved forms of nickel (e.g. the free cation and other inorganic species) are the most toxic forms of nickel to freshwater species. In general, the toxicity of nickel increases with increasing pH, decreasing hardness and decreasing DOC (Peters et al. 2018). Deleebeek et al. (2009a) showed that for the freshwater alga *Pseudokirchneriella subcapitata*, when the pH increased from 6.45 to 7.92, nickel toxicity increased, with 72-h EC50 values decreasing from 145 µg/L to 82 µg/L. Deleebeek et al. (2007a) also examined the individual effects of calcium, magnesium and pH on the long-term (17-d) toxicity of nickel to juvenile rainbow trout (*Oncorhynchus mykiss*), using mortality and growth as endpoints. They found that higher concentrations of Ca²⁺, Mg²⁺ and H⁺ (i.e. low pH) reduced nickel

toxicity, as demonstrated by increased 17-d median lethal concentrations. Similarly, binding nickel to DOC resulted in decreased bioavailability of the dissolved nickel fraction in 21-d reproduction tests with *Daphnia magna* (Deleebeeck et al. 2008).

Other variables such as alkalinity and other major ions (e.g. sodium, potassium) may also influence nickel bioavailability. In studies with euryhaline temperate species, salinity appeared to significantly alter nickel bioavailability and toxicity, with increasing salinity decreasing nickel toxicity. Blewett et al. (2015) studied the effects of changing salinity on nickel accumulation and physiological mechanisms of nickel toxicity for the euryhaline green crab *Carcinus maenas*. Results showed that whole body nickel accumulation in 20% seawater was 3–5 times greater than in 60% or 100% seawater after a 24-h exposure. The authors concluded that nickel affects ionoregulatory function in the green crab in a gill-dependent and salinity-dependent manner. Nickel accumulation was greatest at lower test salinity, likely due to the reduced competition between divalent cations and nickel for uptake. Blewett and Wood (2015) also studied the effect of salinity on nickel toxicity on a euryhaline temperate fish. *Fundulus heteroclitus* was used in acute 96-h exposures to sublethal concentrations of nickel (5 mg/L, 10 mg/L and 20 mg/L) in both freshwater (0‰) and seawater (35‰). The overall findings, similar to that of Blewett et al. (2015), suggested that seawater (i.e. salinity) was protective against nickel toxicity, with a decrease in nickel accumulation and oxidative stress observed in fish exposed to nickel in seawater compared to fish in freshwater. Thus, salinity in freshwater is likely to influence nickel toxicity, although quantitative relationships have not been developed.

Schlekat et al. (2010) observed chronic nickel toxicity for three invertebrates and an aquatic plant in five natural waters that varied in pH, calcium, magnesium and DOC. Nickel toxicity for the three invertebrates varied considerably among the test waters: a 14-fold variation of EC50s for *Lymnaea stagnalis*; a 3-fold variation in EC20s for *Chironomus tentans*; and a 10-fold variation in EC20s for *Brachionus calyciflorus*. Nickel toxicity (EC50) for *Lemna minor* varied by 6-fold among the test waters. The water type and combination of water quality parameters that led to the most sensitive responses varied across the species; however, a combination of high hardness (136–256 mg/L CaCO₃) and high DOC (7 mg/L) generally resulted in less sensitivity to nickel.

These water quality parameters have been incorporated into nickel bioavailability models such as the BLM and MLR (Deleebeeck et al. 2008, 2009b; NiPERA 2012; Brix et al. 2017; Peters et al. 2021), which enable bioavailable concentrations of nickel to be estimated or for guideline values to be adjusted based on water quality.

For nickel, a chronic BLM has been developed and modified by Nys et al. (2016) that incorporates ten parameters (Ca, Mg, Na, K, SO₄, Cl, pH, DOC, temperature, and alkalinity). Simplified tools, which require input of only three or four parameters but are underpinned by the full BLM, have also been developed and used to derive bioavailability-based guideline values (e.g. nickel in the European Union) (NiPERA 2012; Merrington et al. 2016). Peters et al. (2018) showed that this nickel BLM was applicable to freshwater with >50 mg/L CaCO₃ hardness in Australia and New Zealand. However, for soft water, an increased competitive effect of calcium and magnesium with nickel for binding to the biotic ligand was found, so modifications were made to the BLM for its application to water with <50 mg/L CaCO₃ hardness (Peters et al. 2018).

Nickel MLRs based on relationships between toxicity (as EC10) and pH, hardness (Ca and Mg) and DOC, have recently been developed for freshwater microalgae, aquatic plants, invertebrates and fish,

and validated for use in Australia and New Zealand (Peters et al. 2021). Each of the MLRs included data for at least one Australian species as part of either the development or the validation of the models, while the performance of the models was tested for 10 Australian and 10 New Zealand freshwaters with varying water chemistries (Peters et al. 2021). Stauber et al. (2021) recommended using these trophic-level-specific MLRs to derive bioavailability-based guideline values for Australia and New Zealand, as they were: better predictors of nickel toxicity, and were easier to use, than existing nickel BLMs or a pooled MLR; and developed/validated for Australian and New Zealand species and water quality conditions. The trophic-level-specific MLRs are shown in Table 1. More details on the development, validation and comparison of the various models are discussed by Peters et al. (2021) and Stauber et al. (2021).

Table 1 Trophic-level-specific MLRs

Trophic level	MLR ^a
Algae	$\text{Log}_e(\text{EC10}) = \text{Sensitivity}^b + 0.28.\text{log}_e[\text{DOC}] + 0.50.\text{log}_e[\text{Mg}] - 0.20.\text{pH}$
Aquatic plants	$\text{Log}_e(\text{EC10}) = \text{Sensitivity} + 0.96.\text{log}_e[\text{DOC}] - 1.44.\text{pH}$
Invertebrates	$\text{Log}_e(\text{EC10}) = \text{Sensitivity} + 2.09.\text{log}_e[\text{DOC}] + 0.19.\text{log}_e[\text{Ca}] + 0.40.\text{log}_e[\text{Mg}] - 0.40.\text{pH} - 0.24.\text{log}_e[\text{DOC}].\text{pH}$
Fish	$\text{Log}_e(\text{EC10}) = \text{Sensitivity} - 1.05.\text{log}_e[\text{DOC}] + 3.55.\text{log}_e[\text{Mg}] - 0.07.\text{pH} + 0.19.\text{log}_e[\text{DOC}].\text{pH} - 0.42.\text{log}_e[\text{Mg}].\text{pH}$

Note: table sourced from Peters et al. (2021).

a The parameters in the MLR equations have been rounded up to two decimal places.

b Sensitivity is a species-specific coefficient calculated as the difference between the observed (experimental) value ($\text{log}_e\text{EC10}_{\text{expt}}$) and the MLR predicted value ($\text{log}_e\text{EC10}_{\text{pred}}$) for each species at each water chemistry combination tested (see Table 2).

Each MLR includes a sensitivity coefficient calculated as the difference between the observed (experimental) value ($\text{log}_e\text{EC10}_{\text{expt}}$) and the MLR predicted value ($\text{log}_e\text{EC10}_{\text{pred}}$) for each species at each water chemistry combination tested. The geometric mean of the calculated sensitivity coefficients for an individual species across all the available tests for that species is used as the species-specific sensitivity value in the MLR. These are given for each species in Table 2.

Table 2 Species-specific sensitivity coefficients to use in MLRs to normalise ecotoxicity data

Trophic level	Species	Sensitivity coefficient ^b
Algae	<i>Navicula pelliculosa</i>	4.50
	<i>Chlorella</i> sp. (Kakadu isolate) ^a	5.97
	<i>Chlorella</i> sp. 12 (PNG isolate) ^a	3.91
	<i>Monoraphidium arcuatum</i> ^a	5.40
	<i>Nannochloropsis</i> sp. ^a	3.53
	<i>Pediastrum duplex</i> ^a	5.69
	<i>Pseudokirchneriella subcapitata</i>	5.01
Aquatic plants	<i>Lemna aequinoctialis</i> ^a	12.5
	<i>Lemna minor</i> ^a	13.6
Invertebrates	<i>Brachionus calyciflorus</i> ^a	7.71
	<i>Hyalella azteca</i>	5.82
	<i>Alona affinis</i>	4.14

Trophic level	Species	Sensitivity coefficient ^b
	<i>Ceriodaphnia dubia</i>	3.25
	<i>Ceriodaphnia pulchella</i>	5.48
	<i>Ceriodaphnia quadrangula</i>	5.18
	<i>Daphnia longispina</i>	6.54
	<i>Daphnia magna</i>	5.14
	<i>Peracantha truncata</i>	5.75
	<i>Simocephalus serrulatus</i>	6.21
	<i>Simocephalus vetulus</i>	5.54
	<i>Lymnaea stagnalis</i>	2.04
	<i>Hydra viridissima</i> ^a	6.38
	<i>Chironomus tentans</i>	6.98
	<i>Clistoronia magnifica</i>	6.43
Fish	<i>Melanotaenia splendida splendida</i> ^{a,c}	3.35
	<i>Pimephales promelas</i>	5.83

Note: table sourced from Peters et al. (2021).

a Tropical species.

b Rounded to three significant figures.

c *Melanotaenia splendida splendida* is a subspecies of the *Melanotaenia splendida* complex.

4 Default guideline value derivation

The DGVs were derived in accordance with the method described in Warne et al. (2018) and using Burrlioz 2.0 software. Some additional details of the derivation are provided in Stauber et al. (2021).

4.1 Toxicity data used in derivation

A summary of all the quality assessed nickel toxicity data, together with the water chemistry for each test for each species used to develop, validate and apply the nickel MLRs, is provided as supporting documentation. Details of the data quality assessment are also provided as supporting documentation.

Due to the large size of the nickel toxicity dataset, it was initially divided into temperate species data and tropical species data. Temperate species were isolated from temperate regions and/or had a natural geographical distribution outside of the Tropics of Cancer and Capricorn, and toxicity tests were conducted at temperatures <25°C. Tropical species had a natural geographical distribution between the Tropic of Cancer and the Tropic of Capricorn, and the toxicity tests were conducted at ≥25°C. Chronic nickel toxicity data that passed the quality assessment and screening process were available for 20 temperate species from six taxonomic groups and for 24 tropical species from six taxonomic groups. A comparison of the temperate and tropical datasets by Stauber et al. (2021) showed a large overlap in the toxicity values and found that the two datasets resulted in similar protective concentrations (i.e. for 80%, 90%, 95% and 99% species protection) with overlapping confidence intervals. Consequently, there was insufficient justification to derive climatic zone specific DGVs, and the two datasets were combined for the DGV derivation. The combined dataset included more taxonomic groups (Stauber et al. 2021), which ultimately improved the confidence in the DGVs.

The combined dataset comprised chronic toxicity data for 44 species from nine taxonomic groups. The toxicity data included LC/EC10, NOEC, LOEC and LC/EC50 values. However, of the 44 species in the combined dataset, only 26 species (diatom, green microalgae, duckweed, rotifer, crustaceans, gastropod, cnidarian, insects and fish) had sufficient test water chemistry data to apply the MLR bioavailability corrections. The data for these 26 species were all EC10s or NOECs, except for two LOECs, one LC50 and one EC50, which were converted to EC10 equivalents by dividing by 2.5, 5 and 5 respectively, in accordance with Warne et al. (2018).

The trophic-level-specific MLRs were used to predict negligible effect (i.e. EC10/NOEC) values for each of the 26 species at an index condition. The index condition is a specific combination of water quality parameters, usually representing high metal bioavailability conditions. The index condition for Australia and New Zealand was established as: pH 7.5, 6 mg/L Ca, 4 mg/L Mg (i.e. hardness of approximately 30 mg/L CaCO₃) and 0.5 mg/L DOC (Stauber et al. 2021). The algal MLR was applied to the chronic algae data, the aquatic plant MLR to chronic duckweed data, the invertebrate MLR to chronic invertebrate data and the fish MLR to chronic fish data. The resulting dataset of predicted negligible effect values was then used to derive the DGVs, as described in Warne et al. (2018). The predicted negligible effect values after normalisation to the index condition are in Table 3.

Table 3 Summary, chronic toxicity negligible effect values, normalised to index condition, used to derive nickel guideline values

Taxonomic group	Species	Life stage	Duration	Toxicity endpoint	Normalised toxicity value (µg/L)
Diatom	<i>Navicula pelliculosa</i>	–	72 h	Growth rate	32.7
Green microalga	<i>Chlorella</i> sp. (Kakadu isolate) ^a	–	72 h	Growth rate	142
	<i>Chlorella</i> sp. 12 (PNG isolate) ^a	–	72 h	Growth rate	18.2
	<i>Monoraphidium arcuatum</i> ^a	–	72 h	Growth rate	81
	<i>Nannochloropsis</i> sp. ^a	–	72 h	Growth rate	12.5
	<i>Pediastrum duplex</i> ^a	–	72 h	Growth rate	108
	<i>Pseudokirchneriella subcapitata</i>	–	72 h	Growth rate	54.6
Macrophyte (duckweed)	<i>Lemna aequinoctialis</i> ^a	–	96 h	Growth rate	2.78
	<i>Lemna minor</i> ^a	–	7 d	Growth rate	7.94
Crustacean (rotifer)	<i>Brachionus calyciflorus</i> ^a	Neonates	48 h	Population growth rate	217
Crustacean (amphipod)	<i>Hyalella azteca</i>	7–8 d old	14 d	Survival	32.5
Crustacean (cladoceran)	<i>Alona affinis</i>	Neonates	16 d	Survival	6.1
	<i>Ceriodaphnia dubia</i>	Neonates	7 d	Reproduction	2.5
	<i>Ceriodaphnia pulchella</i>	Neonates	17 d	Reproduction	23.3
	<i>Ceriodaphnia quadrangula</i>	Neonates	17 d	Reproduction	17.2
	<i>Daphnia longispina</i>	Neonates	21 d	Reproduction	66.9
	<i>Daphnia magna</i>	Neonates	5 broods	Reproduction	16.6
	<i>Peracantha truncata</i>	Neonates	17 d	Reproduction	30.4
	<i>Simocephalus serrulatus</i>	Neonates	17 d	Reproduction	48.1
	<i>Simocephalus vetulus</i>	Neonates	21 d	Reproduction	24.6

Bimodal or multimodal toxicity was determined to be unlikely, based on a visual inspection of the SSD and the available knowledge on the mechanism of chronic toxicity of nickel to aquatic biota. Although nickel may have an additional mode of action in plants and algae (i.e. displacement of magnesium from the chlorophyll molecule), toxicity values for these phototrophic groups were spread evenly across the SSD curve.

4.3 Default guideline values

It is important that the DGVs (Table 4) and associated information in this technical brief are used in accordance with the detailed guidance provided on the Australian and New Zealand Guidelines for Fresh and Marine Water Quality [website](#) (ANZG 2018).

With the ability to adjust the DGVs based on the pH, hardness and DOC of the water, the nickel freshwater DGVs for 99%, 95%, 90% and 80% species protection are provided for water with different pH (6.0–8.5), calcium (2–70 mg/L), magnesium (1.6–54 mg/L) and DOC (0.5–20 mg/L). The DGVs for 99%, 95%, 90% and 80% species protection at the index water quality condition are in Table 4, and the DGVs for water with different pH, calcium, magnesium and DOC are in Appendix A: Nickel default guideline values for differing pH, hardness and DOC. The 95% species protection level DGV is recommended for application to slightly-to-moderately disturbed ecosystems. Where water data for pH, hardness or DOC are not available, the index condition should be used.

Table 4 Default guideline values, nickel in freshwater, very high reliability

Level of protection (% species)	DGV for nickel in freshwater ($\mu\text{g/L}$) ^a
99	0.31
95	2.0
90	4.6
80	10

^a DGVs at water index condition: pH 7.5, 6 mg/L Ca, 4 mg/L Mg (i.e. hardness approximately 30 mg/L CaCO₃) and 0.5 mg/L DOC. DGVs were derived using Burrlioz 2.0 software. They have been rounded to two significant figures.

4.4 Reliability classification

The nickel in freshwater DGVs have a very high reliability classification (Warne et al. 2018) based on the outcomes for the following three criteria:

- sample size—26 (preferred)
- type of toxicity data—chronic, including EC10, NOEC and converted EC50, LC50 and LOEC
- SSD model fit—good.

Glossary

Term	Definition
acute toxicity	A lethal or adverse sublethal effect that occurs as the result of a short exposure period to a chemical relative to the organism's life span.
benthic	Refers to organisms living in or on the sediments of aquatic habitats (e.g. lakes, rivers, ponds).
BLM	Biotic ligand model.
chronic toxicity	A lethal or sublethal adverse effect that occurs after exposure to a chemical for a period of time that is a substantial portion of the organism's life span or an adverse effect on a sensitive early life stage.
default guideline value (DGV)	A guideline value recommended for generic application in the absence of a more specific guideline value (e.g. site-specific guideline value) in the Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Formerly known as 'trigger values'.
DOC	Dissolved organic carbon.
EC50 (median effective concentration)	The concentration of a substance in water or sediment that is estimated to produce a 50% change in the response being measured or a certain effect in 50% of the test organisms relative to the control response, under specified conditions.
endpoint	The specific response of an organism that is measured in a toxicity test (e.g. mortality, growth, a particular biomarker).
euryhaline	Describes organisms that are capable of osmo-regulating over a wide range of salinities.
guideline value	A measurable quantity (e.g. concentration) or condition of an indicator for a specific community value below which (or above which, in the case of stressors such as pH, dissolved oxygen and many biodiversity responses) there is considered to be a low risk of unacceptable effects occurring to that community value. Guideline values for more than one indicator should be used simultaneously in a multiple lines of evidence approach.
index condition	A specific combination of water chemistry parameters, usually representing high metal bioavailability conditions.
LC50 (median lethal concentration)	The concentration of a substance in water or sediment that is estimated to be lethal to 50% of a group of test organisms, relative to the control response, under specified conditions.
LOEC (lowest observed effect concentration)	The lowest concentration of a material used in a toxicity test that has a statistically significant adverse effect on the exposed population of test organisms as compared with the controls.
macrophyte	A member of the macroscopic plant life of an area, especially of a body of water; large aquatic plant.
MLR	Multiple linear regression.
NOEC (no observed effect concentration)	The highest concentration of a material used in a toxicity test that has no statistically significant adverse effect on the exposed population of test organisms as compared with the controls.
species (biological)	A group of organisms that resemble each other to a greater degree than members of other groups and that form a reproductively isolated group that will not produce viable offspring if bred with members of another group.
SSD (species sensitivity distribution)	A method that plots the cumulative frequency of species' sensitivities to a toxicant and fits a statistical distribution to the data. From the distribution, the concentration that should theoretically protect a selected percentage of species can be determined.

Term	Definition
toxicity	The inherent potential or capacity of a material to cause adverse effects in a living organism.
toxicity test	The means by which the toxicity of a chemical or other test material is determined. A toxicity test is used to measure the degree of response produced by exposure to a specific level of stimulus (or concentration of chemical) for a specified test period.

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Appendix A: Nickel default guideline values for differing pH, hardness and DOC

Table A 1 Default guideline values, nickel in freshwater, 99% species protection

Parameter	DGV (µg/L)								
pH	6.0								
Hardness (mg/L CaCO₃)	12	23	31	39	83	166	223	397	
Calcium (mg/L)	2	4	6	7	15	30	40	70	
Magnesium (mg/L)	1.6	3.1	4	5.3	11	22	30	54	
DOC (mg/L)	0.5	0.5	0.8	1.0	1.2	1.7	2.4	2.7	3.4
	1	0.7	1.3	1.5	1.8	2.7	3.8	4.4	5.7
	3	1.1	2.0	2.5	3.1	5.1	7.5	8.7	12
	5	1.3	2.3	2.9	3.6	6.3	9.8	12	15
	10	1.8	2.7	3.3	4.2	7.7	13	16	58
	15	2.1	3.0	3.6	4.4	8.3	14	18	25
	20	2.5	3.3	3.8	4.6	8.4	15	19	28
pH	6.5								
Hardness (mg/L CaCO₃)	12	23	31	39	83	166	223	397	
Calcium (mg/L)	2	4	6	7	15	30	40	70	
Magnesium (mg/L)	1.6	3.1	4	5.3	11	22	30	54	
DOC (mg/L)	0.5	0.5	0.7	0.8	0.9	1.2	1.4	1.5	1.8
	1	0.7	1.0	1.2	1.4	2.0	2.5	2.7	3.1
	3	1.0	1.6	2.0	2.4	3.8	5.2	5.9	7.2
	5	1.1	1.9	2.4	2.9	4.8	7.0	8.1	10
	10	1.4	2.3	2.9	3.5	6.1	9.7	12	15
	15	1.6	2.6	3.2	3.9	6.9	11	14	19
	20	1.8	2.8	3.4	4.2	7.4	12	15	21
pH	7.0								
Hardness (mg/L CaCO₃)	12	23	31	39	83	166	223	397	
Calcium (mg/L)	2	4	6	7	15	30	40	70	
Magnesium (mg/L)	1.6	3.1	4	5.3	11	22	30	54	
DOC (mg/L)	0.5	0.4	0.5	0.6	0.6	0.7	0.8	0.9	1.0
	1	0.6	0.8	0.9	1.0	1.2	1.4	1.5	1.7
	3	0.8	1.3	1.5	1.8	2.5	3.2	3.4	4.0
	5	1.0	1.5	1.9	2.2	3.2	4.4	4.9	5.8
	10	1.2	1.9	2.3	2.7	4.4	6.4	7.3	9.2
	15	1.3	2.1	2.5	3.0	5.0	7.6	8.9	12
	20	1.4	2.2	2.7	3.3	5.5	8.5	10	13

Parameter	DGV ($\mu\text{g/L}$)								
pH	7.5								
Hardness (mg/L CaCO₃)	12	23	31	39	83	166	223	397	
Calcium (mg/L)	2	4	6	7	15	30	40	70	
Magnesium (mg/L)	1.6	3.1	4	5.3	11	22	30	54	
DOC	0.5	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.4
	1	0.4	0.5	0.5	0.6	0.6	0.6	0.7	0.7
	3	0.7	0.9	1.1	1.1	1.4	1.6	1.7	1.7
	5	0.8	1.1	1.3	1.5	2.0	2.4	2.5	2.7
	10	0.9	1.4	1.7	1.9	2.8	3.7	4.0	4.6
	15	1.0	1.5	1.8	2.1	3.3	4.6	5.1	6.1
	20	1.0	1.6	2.0	2.3	3.6	5.2	5.9	7.3
pH	8.0								
Hardness (mg/L CaCO₃)	12	23	31	39	83	166	223	397	
Calcium (mg/L)	2	4	6	7	15	30	40	70	
Magnesium (mg/L)	1.6	3.1	4	5.3	11	22	30	54	
DOC	0.5	0.2	0.2	0.2	0.1	0.1	0.2	0.2	0.2
	1	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
	3	0.5	0.6	0.6	0.7	0.7	0.7	0.7	0.6
	5	0.5	0.7	0.8	0.9	1.1	1.1	1.1	1.0
	10	0.6	0.9	1.1	1.2	1.7	1.9	2.0	2.0
	15	0.6	1.0	1.2	1.3	2.0	2.5	2.7	2.8
	20	0.6	1.0	1.2	1.4	2.2	2.9	3.2	3.6
pH	8.5								
Hardness (mg/L CaCO₃)	12	23	31	39	83	166	223	397	
Calcium (mg/L)	2	4	6	7	15	30	40	70	
Magnesium (mg/L)	1.6	3.1	4	5.3	11	22	30	54	
DOC	0.5	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2
	3	0.3	0.3	0.4	0.4	0.3	0.3	0.3	0.3
	5	0.3	0.4	0.5	0.5	0.6	0.5	0.4	0.4
	10	0.4	0.5	0.6	0.7	0.9	1.0	1.0	0.8
	15	0.4	0.5	0.7	0.7	1.1	1.3	1.3	1.3
	20	0.3	0.5	0.7	0.8	1.1	1.5	1.6	1.7

Table A 2 Default guideline values, nickel in freshwater, 95% species protection

Parameter	DGV (µg/L)								
pH	6.0								
Hardness (mg/L CaCO₃)	12	23	31	39	83	166	223	397	
Calcium (mg/L)	2	4	6	7	15	30	40	70	
Magnesium (mg/L)	1.6	3.1	4	5.3	11	22	30	54	
DOC (mg/L)	0.5	2.7	4.1	4.8	5.5	7.9	11	12	16
	1	3.9	6.1	7.3	8.4	12	17	20	25
	3	6.5	10	13	15	23	33	39	51
	5	8.1	13	16	19	30	44	51	68
	10	11	17	20	24	40	61	72	106
	15	13	20	23	28	46	71	86	118
	20	15	22	26	30	50	79	96	134
pH	6.5								
Hardness (mg/L CaCO₃)	12	23	31	39	83	166	223	397	
Calcium (mg/L)	2	4	6	7	15	30	40	70	
Magnesium (mg/L)	1.6	3.1	4	5.3	11	22	30	54	
DOC (mg/L)	0.5	2.4	3.4	3.9	4.4	6.1	7.9	8.9	11
	1	3.4	5.0	5.8	6.6	9.4	12	14	18
	3	5.3	8.2	9.9	12	17	24	28	35
	5	6.5	10	12	14	22	32	37	47
	10	8.4	13	16	19	30	44	52	69
	15	9.9	15	18	22	35	53	62	84
	20	11	17	20	24	38	59	70	96
pH	7.0								
Hardness (mg/L CaCO₃)	12	23	31	39	83	166	223	397	
Calcium (mg/L)	2	4	6	7	15	30	40	70	
Magnesium (mg/L)	1.6	3.1	4	5.3	11	22	30	54	
DOC (mg/L)	0.5	1.9	2.6	2.9	3.3	4.3	5.6	6.2	7.7
	1	2.7	3.8	4.3	4.8	6.5	8.5	9.5	12
	3	4.3	6.3	7.4	8.4	12	16	18	23
	5	5.1	7.7	9.1	10	15	21	24	30
	10	6.5	9.8	12	14	21	30	34	44
	15	7.4	11	13	16	24	35	41	55
	20	8.2	12	15	17	27	40	47	62

Parameter	DGV (µg/L)								
pH	7.5								
Hardness (mg/L CaCO₃)	12	23	31	39	83	166	223	397	
Calcium (mg/L)	2	4	6	7	15	30	40	70	
Magnesium (mg/L)	1.6	3.1	4	5.3	11	22	30	54	
DOC (mg/L)	0.5	1.4	1.8	2.0	2.2	2.8	3.4	3.8	4.6
	1	2.0	2.7	3.0	3.3	4.2	5.2	5.7	6.8
	3	3.2	4.5	5.2	5.7	7.7	9.8	11	13
	5	3.8	5.5	6.4	7.2	10	13	14	17
	10	4.7	6.9	8.2	9.3	14	19	21	26
	15	5.2	7.8	9.3	11	16	22	25	32
	20	5.7	8.5	10	12	18	25	29	37
pH	8.0								
Hardness (mg/L CaCO₃)	12	23	31	39	83	166	223	397	
Calcium (mg/L)	2	4	6	7	15	30	40	70	
Magnesium (mg/L)	1.6	3.1	4	5.3	11	22	30	54	
DOC (mg/L)	0.5	1.0	1.2	1.3	1.4	1.6	2.0	2.3	3.0
	1	1.4	1.8	2.0	2.1	2.4	2.9	3.1	3.9
	3	2.3	3.0	3.4	3.7	4.7	5.5	5.9	6.7
	5	2.6	3.7	4.2	4.7	6.2	7.5	8.0	9.0
	10	3.1	4.5	5.3	6.0	8.4	11	12	14
	15	3.3	5.0	5.9	6.7	9.7	13	15	18
	20	3.5	5.3	6.3	7.2	11	15	17	20
pH	8.5								
Hardness (mg/L CaCO₃)	12	23	31	39	83	166	223	397	
Calcium (mg/L)	2	4	6	7	15	30	40	70	
Magnesium (mg/L)	1.6	3.1	4	5.3	11	22	30	54	
DOC (mg/L)	0.5	0.7	0.8	0.8	0.8	1.1	1.5	1.7	2.1
	1	1.0	1.2	1.2	1.3	1.4	1.9	2.2	2.8
	3	1.5	2.0	2.2	2.3	2.8	3.0	3.2	4.0
	5	1.7	2.3	2.6	2.9	3.7	4.2	4.3	4.9
	10	1.9	2.7	3.2	3.6	4.9	6.2	6.7	7.3
	15	2.0	2.9	3.4	3.9	5.6	7.4	8.2	9.4
	20	2.0	3.0	3.6	4.1	6.0	8.2	9.2	11

Table A 3 Default guideline values, nickel in freshwater, 90% species protection

Parameter	DGV (µg/L)								
pH	6.0								
Hardness (mg/L CaCO₃)	12	23	31	39	83	166	223	397	
Calcium (mg/L)	2	4	6	7	15	30	40	70	
Magnesium (mg/L)	1.6	3.1	4	5.3	11	22	30	54	
	0.5	5.6	8.1	9.5	11	15	21	24	31
	1	8.1	12	14	16	24	33	38	50
	3	14	21	26	30	45	64	74	97
DOC (mg/L)	5	18	27	32	38	59	85	99	130
	10	25	37	44	51	81	120	141	154
	15	29	44	51	61	96	144	171	231
	20	33	49	58	68	107	163	194	265
pH	6.5								
Hardness (mg/L CaCO₃)	12	23	31	39	83	166	223	397	
Calcium (mg/L)	2	4	6	7	15	30	40	70	
Magnesium (mg/L)	1.6	3.1	4	5.3	11	22	30	54	
	0.5	4.8	6.7	7.8	8.8	12	17	19	25
	1	6.8	9.7	11	13	18	25	29	37
	3	11	17	20	23	33	47	54	70
DOC (mg/L)	5	14	21	25	29	43	61	71	92
	10	18	28	33	38	59	85	100	133
	15	22	33	39	45	70	103	121	162
	20	25	36	43	51	78	116	137	185
pH	7.0								
Hardness (mg/L CaCO₃)	12	23	31	39	83	166	223	397	
Calcium (mg/L)	2	4	6	7	15	30	40	70	
Magnesium (mg/L)	1.6	3.1	4	5.3	11	22	30	54	
	0.5	3.9	5.3	6.1	6.8	9.4	13	15	19
	1	5.4	7.5	8.6	9.7	14	18	21	27
	3	8.6	12	14	16	24	32	37	48
DOC (mg/L)	5	11	15	18	21	30	42	48	62
	10	14	20	24	27	41	58	67	88
	15	16	23	28	32	48	69	81	107
	20	17	26	31	36	54	78	91	121

Parameter	DGV (µg/L)								
pH	7.5								
Hardness (mg/L CaCO₃)	12	23	31	39	83	166	223	397	
Calcium (mg/L)	2	4	6	7	15	30	40	70	
Magnesium (mg/L)	1.6	3.1	4	5.3	11	22	30	54	
DOC (mg/L)	0.5	3.0	4.0	4.6	5.1	6.8	9.0	10	13
	1	4.1	5.6	6.4	7.1	9.6	13	14	18
	3	6.4	9.0	10	12	16	21	24	31
	5	7.7	11	13	14	20	27	31	39
	10	9.6	14	16	19	27	37	43	55
	15	11	16	19	21	31	44	51	66
	20	12	17	20	23	35	49	57	75
pH	8.0								
Hardness (mg/L CaCO₃)	12	23	31	39	83	166	223	397	
Calcium (mg/L)	2	4	6	7	15	30	40	70	
Magnesium (mg/L)	1.6	3.1	4	5.3	11	22	30	54	
DOC (mg/L)	0.5	2.3	3.0	3.3	3.6	4.7	6.1	7.0	9.1
	1	3.1	4.0	4.5	5.0	6.4	8.2	9.2	12
	3	4.5	6.2	7.1	7.9	11	14	15	18
	5	5.3	7.4	8.5	9.5	13	17	19	23
	10	6.3	9.1	11	12	17	23	26	32
	15	6.9	10	12	13	20	27	31	39
	20	7.3	11	13	15	21	30	34	44
pH	8.5								
Hardness (mg/L CaCO₃)	12	23	31	39	83	166	223	397	
Calcium (mg/L)	2	4	6	7	15	30	40	70	
Magnesium (mg/L)	1.6	3.1	4	5.3	11	22	30	54	
DOC (mg/L)	0.5	1.7	2.1	2.3	2.5	3.5	4.7	5.4	6.7
	1	2.2	2.9	3.2	3.4	4.2	5.8	6.6	8.5
	3	3.1	4.2	4.7	5.2	6.8	8.3	9.2	12
	5	3.5	4.8	5.5	6.2	8.3	10	11	14
	10	3.9	5.6	6.6	7.4	10	14	15	19
	15	4.1	6.0	7.1	8.0	12	16	18	22
	20	4.3	6.3	7.4	8.5	12	17	20	25

Table A 4 Default guideline values, nickel in freshwater, 80% species protection

Parameter	DGV (µg/L)								
pH	6.0								
Hardness (mg/L CaCO₃)	12	23	31	39	83	166	223	397	
Calcium (mg/L)	2	4	6	7	15	30	40	70	
Magnesium (mg/L)	1.6	3.1	4	5.3	11	22	30	54	
DOC (mg/L)	0.5	11	16	19	21	31	43	49	65
	1	17	24	29	33	47	66	76	100
	3	30	44	52	60	89	126	146	192
	5	39	58	68	78	116	167	194	256
	10	55	81	96	111	166	240	280	256
	15	66	98	116	134	203	294	345	464
	20	74	112	132	154	233	340	399	538
pH	6.5								
Hardness (mg/L CaCO₃)	12	23	31	39	83	166	223	397	
Calcium (mg/L)	2	4	6	7	15	30	40	70	
Magnesium (mg/L)	1.6	3.1	4	5.3	11	22	30	54	
DOC (mg/L)	0.5	9.6	13	16	18	26	36	42	55
	1	14	19	23	26	37	52	60	80
	3	23	34	39	45	65	92	107	142
	5	30	43	50	58	84	119	139	184
	10	40	59	69	79	118	168	196	261
	15	48	70	83	95	142	204	238	318
	20	54	80	94	108	162	233	273	365
pH	7.0								
Hardness (mg/L CaCO₃)	12	23	31	39	83	166	223	397	
Calcium (mg/L)	2	4	6	7	15	30	40	70	
Magnesium (mg/L)	1.6	3.1	4	5.3	11	22	30	54	
DOC (mg/L)	0.5	7.9	11	13	14	21	29	34	46
	1	11	15	18	20	29	40	47	63
	3	18	25	29	33	47	67	77	103
	5	22	31	36	41	60	84	97	130
	10	29	42	48	55	81	115	133	177
	15	34	49	57	65	96	137	159	212
	20	37	55	64	73	109	155	180	240

Parameter	DGV (µg/L)								
pH	7.5								
Hardness (mg/L CaCO₃)	12	23	31	39	83	166	223	397	
Calcium (mg/L)	2	4	6	7	15	30	40	70	
Magnesium (mg/L)	1.6	3.1	4	5.3	11	22	30	54	
DOC (mg/L)	0.5	6.5	9.0	10	12	17	24	27	36
	1	8.5	12	14	15	22	31	36	48
	3	13	18	21	24	34	48	55	73
	5	16	22	25	29	41	58	67	89
	10	20	28	33	37	54	76	88	117
	15	23	32	38	43	63	89	103	137
	20	25	36	42	48	70	99	115	153
pH	8.0								
Hardness (mg/L CaCO₃)	12	23	31	39	83	166	223	397	
Calcium (mg/L)	2	4	6	7	15	30	40	70	
Magnesium (mg/L)	1.6	3.1	4	5.3	11	22	30	54	
DOC (mg/L)	0.5	5.3	7.3	8.4	9.5	13	19	21	28
	1	6.6	9.1	11	12	17	23	27	35
	3	9.2	13	15	17	24	33	39	51
	5	11	15	17	20	28	39	46	60
	10	13	19	22	24	35	49	57	75
	15	15	21	24	27	40	56	65	86
	20	16	22	26	30	43	61	71	94
pH	8.5								
Hardness (mg/L CaCO₃)	12	23	31	39	83	166	223	397	
Calcium (mg/L)	2	4	6	7	15	30	40	70	
Magnesium (mg/L)	1.6	3.1	4	5.3	11	22	30	54	
DOC (mg/L)	0.5	4.3	5.9	6.7	7.5	11	15	17	22
	1	5.1	7.0	8.1	9.1	13	17	20	26
	3	6.5	9.1	11	12	17	23	27	35
	5	7.3	10	12	13	19	26	30	40
	10	8.3	12	14	16	22	31	36	47
	15	9.0	13	15	17	24	34	40	52
	20	9.4	13	16	18	26	36	42	56

References

Sources cited in technical brief

ANZECC/ARMCANZ (2000) *Australian and New Zealand guidelines for fresh and marine water quality*, Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand.

ANZG (2018) [Australian and New Zealand Guidelines for Fresh & Marine Water Quality](#) [website], Australian and New Zealand governments and Australian state and territory governments.

Babich H, Shopsis C and Borenfreund E (1986) 'Cadmium-nickel toxicity interactions towards a bacterium, filamentous fungi, and a cultured mammalian cell line', *Bulletin of Environmental Contamination and Toxicology*, 37: 550–557.

Begum W, Rai S, Banerjee S, Bhattacharjee S, Mondal MH, Bhattarai A and Saha B (2022) 'A comprehensive review on the sources, essentiality and toxicological profile of nickel' *RSC advances*, 12: 9139–9153.

Binet MT, Adams MS, Gissi F, Golding LA, Schlekot CE, Garman ER, Merrington G and Stauber JL (2018) 'Toxicity of nickel to tropical freshwater and sediment biota: a critical literature review and gap analysis', *Environmental Toxicology and Chemistry*, 37:293–317.

Birge WJ (1978) 'Aquatic toxicology of trace elements of coal and fly ash', in Thorp JH and Gibbons JW (eds) *Energy and Environmental Stress in Aquatic Systems, Proceedings of the DOE Symposium, University of Georgia, November 2–4, 1977, CONF-771114*, Athens, Georgia, US.

Blewett T and Wood C (2015) 'Salinity-dependent nickel accumulation and oxidative stress responses in the euryhaline killifish (*Fundulus heteroclitus*)', *Archives of Environmental Contamination and Toxicology*, 68:382–394.

Blewett TA, Glover CN, Fehsenfeld S, Lawrence MJ, Niyogi S, Goss GG and Wood CM (2015) 'Making sense of nickel accumulation and sub-lethal toxic effects in saline waters: fate and effects of nickel in the green crab, *Carcinus maenas*', *Aquatic Toxicology*, 164:23–33.

Brix KV, Schlekot CE and Garman ER (2017) 'The mechanisms of nickel toxicity in aquatic environments: an adverse outcome pathway (AOP) analysis', *Environmental Toxicology and Chemistry*, 36:1128–1137.

Brumbaugh WG, Besser JM, Ingersoll CG, May TW, Ivey CD, Scheklat CE and Garman ER (2013) 'Preparation and characterization of nickel-spiked freshwater sediments for toxicity tests: toward more environmentally realistic nickel partitioning', *Environmental Toxicology*, 32:2482–2494.

Cempel M and Nikel G (2006) 'Nickel: a review of its sources and environmental toxicology', *Polish Journal of Environmental Studies*, 15:375–382.

- Cremazy A, Brix KV, Smith DS, Chen W, Grosell M, Schlekot CE, Garman ER, Middleton ET and Wood CM (2020) 'A mystery tale: nickel is fickle when snails fail – investigating the variability in Ni toxicity to the great pond snail', *Integrated Environmental Assessment and Management*, 16:983–997.
- De Schamphelaere K, van Laer L, Deleebeeck N, Muysen B, Degryse F, Smolders E and Janssen C (2006) *Nickel speciation and ecotoxicity in European surface waters: development, refinement and validation of bioavailability models*, Draft 3 Final, report to NiPERA.
- Deleebeeck NME, De Laender F, Chepurinov VA, Vyerman W, Janseen CR and De Schamphelaere KAC (2009b) 'A single bioavailability model can accurately predict Ni toxicity to green microalgae in soft and hard surface waters', *Water Research*, 43:1935–1947.
- Deleebeeck NME, de Schamphelaere KAC and Janssen CR (2007a) 'A bioavailability model predicting the toxicity of nickel to rainbow trout (*Oncorhynchus mykiss*) and fathead minnow (*Pimephales promelas*) in synthetic and natural waters', *Ecotoxicology and Environmental Safety*, 67:1–13.
- Deleebeeck NME, De Schamphelaere KAC and Janssen CR (2008) 'A novel method for predicting chronic nickel bioavailability and toxicity to *Daphnia magna* in artificial and natural waters', *Environmental Toxicology and Chemistry*, 27:2097–2107.
- Deleebeeck NME, De Schamphelaere KAC and Janssen CR (2009a) 'Effects of Mg²⁺ and H⁺ on the toxicity of Ni²⁺ to the unicellular green alga *Pseudokirchneriella subcapitata*: model development and validation with surface waters', *Science of the Total Environment*, 407:1901–1914.
- Eisler R (1998) 'Nickel hazards to fish, wildlife, and invertebrates: a synoptic review', *Contaminant Hazard Reviews*, Report 34: Biological Science Report USGS/BRD/BSR--1998-0001, Patuxent Wildlife Research Center, US Geological Survey.
- ESA (2014) *Toxicity of nickel under varying physico-chemical conditions*, test report May 2014, report to NiPERA, Ecotox Services Australia.
- Factor CJB and de Chavez ERC (2012) Toxicity of arsenic, aluminium, chromium and nickel to the embryos of the freshwater snail, *Radix quadrasii* von Moellendorf 1898', *Philippine Journal of Science*, 141:207–216.
- INSG (2024) [Nickel: Production, Usage and Price](#), International Nickel Study Group website, accessed 1 March 2024.
- Martin IM and Windom H (1991) 'Present and future role of ocean margins in regulating marine biogeochemical cycles of trace elements', in Mantoura RFC, Martin JM and Wollast R (eds) *Marginal Sea Processes in Global Change, Proceedings Dahleirn Conference*, Wiley, New York.
- Merrington G, Peters A and Schlekot CE (2016) 'Accounting for metal bioavailability in assessing water quality: a step change?', *Environmental Toxicology and Chemistry*, 35:257–265.
- Morel FMM and Hering JG (1993) *Principles and Applications of Aquatic Chemistry*, John Wiley & Sons, New York.
- Moreton BM, Fernandez JM and Dolbecq MBD (2009) 'Development of a field preconcentration/elution unit for routine determination of dissolved metal concentrations by ICP-

OES in marine waters: application for monitoring of the New Caledonia Lagoon', *Geostandards and Geoanalytical Research*, 33:205–218.

Mudd GM (2010). 'Global trends and environmental issues in nickel mining: Sulfides versus laterites', *Ore Geology Reviews*, 38:9–26.

Muyssen BTA, Brix KV, Deforest DK and Janssen CR (2004) 'Nickel essentiality and homeostasis in aquatic organisms', *Environmental Reviews*, 12:113–131.

Nickel Institute (2015). [About Nickel](#) [website]. Nickel Institute.

NiPERA (2012) 'The derivation and implementation of an environmental quality standard for nickel in European surface waters', *Fact Sheet: European Union Environmental Risk Assessment of Nickel*, Special Issue 1, Nickel Producers Environmental Research Association and Nickel Institute.

Nys C, Janssen CR, Van Sprang P and De Schampheleere KAC (2016) 'The effect of pH on chronic aquatic nickel toxicity is dependent on the pH itself: extending the chronic Ni bioavailability models', *Environmental Toxicology and Chemistry*, 35:1097–1106.

Peters A, Merrington G, Leverett D, Wilson I, Schlekot C and Garman E (2019) 'Comparison of the chronic toxicity of nickel to temperate and tropical freshwater species', *Environmental Toxicology and Chemistry*, 38:1211–1220.

Peters A, Merrington G, Schlekot, De Schampheleere K, Stauber J, Batley G, Harford A, van Dam R, Pease C, Mooney T, Warne M, Hickey C, Glazebrook P, Chapman J, Smith R and Krassoi R (2018) 'Validation of the nickel biotic ligand model for locally relevant species in Australian freshwaters', *Environmental Toxicology and Chemistry*, 37:2566–2574.

Peters A, Merrington G, Stauber J, Golding L, Batley G, Gissi F, Adams M, Binet M, McKnight K, Schlekot CE, Garman E and Middleton E (2021) 'Empirical bioavailability corrections for nickel in freshwaters for Australia and New Zealand water quality guideline development', *Environmental Toxicology Chemistry*, 40:113–126.

Pyle G and Couture P (2012) 'Nickel', in AP Farrell, CM Wood and CJ Brauner (eds) *Homeostasis and Toxicology of Non-Essential Metals*, Academic Press, London.

Schlekot CE, Garman ER, Vangheluwe MLU and Burton GA (2015) 'Development of a nickel bioavailability-based risk assessment approach for nickel in freshwater sediments', *Integrated Environmental Assessment and Management*, 12:735–746.

Schlekot CE, Van Genderen EJ, De Schampheleere KAC, Antunes PMC, Rogevich EC and Stubblefield WA (2010) 'Cross-species extrapolation of chronic nickel Biotic Ligand Models', *Science of the Total Environment*, 408:6148–6157.

Stauber JL, Golding L, Peters A, Merrington G, Adams MS, Binet MT, Batley GE, Gissi F, McKnight K, Garman E, Middleton E, Gadd J & Schlekot C (2021) 'Application of bioavailability models to derive guideline values for nickel in freshwaters of Australia and New Zealand', *Environmental Toxicology Chemistry*, 40:100–112.

USGS (2019) [Nickel Statistics and Information](#) [website], National Minerals Information Center, US Geological Survey.

Warne MSTJ, Batley GE, van Dam RA, Chapman JC, Fox DR, Hickey CW, and Stauber JL (2018) *Revised method for deriving Australian and New Zealand water quality guideline values for toxicants – update of 2015 version*, Australian and New Zealand governments and Australian state and territory governments.

Wong CK and Pak AP (2004) 'Acute and subchronic toxicity of the heavy metals copper, chromium, nickel, and zinc, individually and in mixture, to the freshwater copepod *Mesocyclops pehpeinsis*', *Bulletin of Environmental Contamination and Toxicology*, 73:190–196.

Wong CK, Wong PK and Tao H (1991) 'Toxicity of nickel and nickel electroplating water to the freshwater cladoceran *Moina macrocopa*', *Bulletin of Environmental Contamination and Toxicology*, 47:448–454.

Sources cited in datasheets

Appenroth K-J, Krech K, Keresztes A, Fischer W and Koloczek H (2010) 'Effects of nickel on the chloroplasts of the duckweeds *Spirodela polyrhiza* and *Lemna minor* and their possible use in biomonitoring and phytoremediation', *Chemosphere*, 78:216–223.

Blaylock BG and Frank ML (1979) 'A comparison of the toxicity of nickel to the developing eggs and larvae of carp (*Cyprinus carpio*)', *Bulletin of Environmental Contamination and Toxicology*, 21:604–611.

Deleebeeck NME, Muysen BTA, De Laender F, Janssen CR and De Schamphelaere KAC (2007b) 'Comparison of nickel toxicity to cladocerans in soft versus hard surface waters', *Aquatic Toxicology*, 84:223–235.

Ensernik E, Maas-Diepevee JL and Van Leeuwen CJ (1991) 'Combined effects of metals; an ecotoxicological evaluation', *Water Research*, 25:679–687.

Herkovits J, Perez-Coll CS and Herkovits D (2000) 'Evaluation of nickel-zinc interactions by means of bioassays with amphibian embryos', *Ecotoxicology and Environmental Safety*, 45:266–273.

Keithly J, Brooker JA, DeForest DK, Wu BK and Brix KV (2004) 'Acute and chronic toxicity of nickel to a cladoceran (*Ceriodaphnia dubia*) and an amphipod (*Hyallela azteca*)', *Environmental Toxicology and Chemistry*, 23:691–696.

Kienle C, Kohler HR and Gerhardt A (2009) 'Behavioural and developmental toxicity of chlorpyrifos and nickel chloride to zebrafish (*Danio rerio*) embryos and larvae', *Ecotoxicology and Environmental Safety*, 72:1740–1747.

Kienle C, Kohler HR, Filser J and Gerhardt A (2008) 'Effects of nickel chloride and oxygen depletion on behaviour and vitality of zebrafish (*Danio rerio*, Hamilton, 1822) (Pisces, Cypriniformes) embryos and larvae', *Environmental Pollution*, 152:612–620.

Kszos LA, Stewart AJ and Taylor PA (1992) 'An evaluation of nickel toxicity to *Ceriodaphnia dubia* and *Daphnia magna* in a contaminated stream and in laboratory tests', *Environmental Toxicology and Chemistry*, 11:1001–1012.

Kuhn R, Pattard M, Pernak K-D and Winter A (1989) 'Results of the harmful effects of water pollutants to *Daphnia magna* in the 21 day reproductive test', *Water Research*, 23:510–510.

Munzinger A (1990) 'Effects of nickel on *Daphnia magna* during chronic exposure and alterations in the toxicity to generations pre-exposed to nickel', *Water Research*, 24:845–852.

Nagai T and De Schamphelaere KAC (2016) 'The effect of binary mixtures of zinc, copper, cadmium, and nickel on the growth of the freshwater diatom *Navicula pelliculosa* and comparison with mixture toxicity model predictions', *Environmental Toxicology and Chemistry*, 35:2765–2773.

Nebeker AV, Savonen C and Stevens DG (1985) 'Sensitivity of rainbow trout early life stages to nickel chloride', *Environmental Toxicology and Chemistry*, 4:233–239.

Nebeker AV, Savonen C, Baker RJ and McCrady JK (1984) Effects of copper, nickel and zinc on the life cycle of the caddisfly *Clistoronia magnifica* (Limnephilidae)', *Environmental Toxicology and Chemistry*, 3:645–649.

Nebeker AV, Stinchfield A, Savonen C and Chapman GA (1986) 'Effects of copper, nickel and zinc on three species of Oregon freshwater snails', *Environmental Toxicology and Chemistry*, 5:807–811.

Niyogi S, Brix KV, Grosell M (2014) 'Effects of chronic waterborne nickel exposure on growth, ion homeostasis, acid-base balance, and nickel uptake in the fresh water pulmonate snail, *Lymnaea stagnalis*', *Aquatic Toxicology*, 150, 36–44.

Nys C, Janssen CR and De Schamphelaere KAC (2017) 'Development and validation of a metal mixture bioavailability model (MMBM) to predict chronic toxicity of Ni-Zn-Pb mixtures to *Ceriodaphnia dubia*', *Environmental Pollution*, 220:1271–1281.

Nys C, Van Regenmortel T, Janssen CR, Blust R, Smolders E and De Schamphelaere KAC (2017) 'Comparison of chronic mixture toxicity of nickel-zinc-copper and nickel-zinc-copper-cadmium mixtures between *Ceriodaphnia dubia* and *Pseudokirchneriella subcapitata*', *Environmental Toxicology and Chemistry*, 36:1056–1066.

Pereira CMS, Deruytter D, Blust R and De Schamphelaere KAC (2017), 'Effect of temperature on chronic toxicity of copper, zinc, and nickel to *Daphnia magna*', *Environmental Toxicology and Chemistry*, 36:1909–1916.

Peters A, Merrington G and Kosmala-Grzechnik S (2014) *Parameterisation of biotic ligand models for nickel to Australian test species*, Project Number P0313-12-13, wca environment.

van Frankenhuyzen K and Geen GH (1987) 'Effects of low pH and nickel on growth and survival of the shredding caddisfly *Clistoronia magnifica* (Limnephilidae)', *Canadian Journal of Zoology*, 65:1729–1732.