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Canadian Environmental Protection Act, 1999

Federal Environmental Quality Guidelines

Rare Earth Elements:
Cerium, Lanthanum, Neodymium and Yttrium

Environment and Climate Change Canada

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Canada

Introduction

Federal Environmental Quality Guidelines (FEQGs) are recommended chemical thresholds to support federal priorities and programs. They can be developed for a variety of environmental media and can be grouped into preventative or remedial guidelines. Preventative FEQGs, often developed for water, biological tissue and sediment, provide thresholds of acceptable quality of the ambient environment. Remedial FEQGs, often developed for soil and groundwater, are remediation values protective of ecological functions used to assess and help manage contaminants at contaminated sites. Irrespective of which media they represent, FEQGs are based on the toxicological effects, that is, the hazards of specific substances or groups of substances.

FEQGs can serve a number of functions. They can:

- be an aid to prevent pollution by providing targets for acceptable environmental quality;
- assist in evaluating the significance of concentrations of chemical substances currently found in the environment (that is, monitoring);
- serve as thresholds for the remediation of contaminated sites; and
- serve as performance measures of the success of risk management activities.

The development of FEQGs is the responsibility of the federal Minister of the Environment under the *Canadian Environmental Protection Act, 1999* (CEPA) (GC 1999). The intent is to develop FEQGs as an adjunct to the risk assessment/risk management of priority chemicals identified in the Chemicals Management Plan (CMP) or other federal initiatives. The use of FEQGs is voluntary unless prescribed in permits or other regulatory tools.

Where data permit, FEQGs are derived following Canadian Council of Ministers of the Environment (CCME) guideline derivation protocols. FEQGs are developed where there is a federal need for a new or updated guideline, but where CCME guidelines for the substance have not yet been developed or are not reasonably expected to be updated in the near future. More information on FEQGs is available at Federal Environmental Quality Guidelines (FEQG).

This factsheet describes FEQGs for the rare earth elements (REEs) of cerium, lanthanum, neodymium and yttrium in fresh water and sediment (Table 1). There are no existing FEQGs or CCME guidelines for these elements. The FEQGs for water follow CCME methods and meet CCME minimum data requirements for Type A or Type B2 approaches (CCME 2007) (see *Federal Water Quality Guidelines* section for details). Marine water quality guidelines were considered; however, sufficient data were not available to meet CCME minimum data requirements (see *Marine exposure* section). The FEQGs for sediment followed CCME protocol (CCME 1995) to the fullest extent possible; however, they did not strictly meet minimum data requirements in terms of the number of available studies. Cerium, lanthanum, neodymium and yttrium were selected for guideline development because they have sufficient toxicity data available, were identified as priorities for information gathering under the CMP and are on Canada's critical minerals list. Environmental quality guidelines for REEs are needed for environmental impact assessment and successful development of an environmentally sustainable REE industry in Canada.

Table 1. Federal Environmental Quality Guidelines for Rare Earth Elements (REEs)[a,b].

Element	Short-term freshwater benchmark (µg/L)	Long-term freshwater guideline (µg/L)	Sediment freshwater guideline[c] (mg/kg dw)
Cerium	81 (total)[d]	1.6 (dissolved)[e]	25
Lanthanum	160 (total)[d]	2.4 (dissolved)[e]	27
Neodymium	23 (dissolved)[e]	1.1 (dissolved)[e]	29
Yttrium	22 (dissolved)[e]	1.9 (dissolved)[e]	24

[a] These guidelines are not applicable to nanoparticles.
[b] Final guideline values are rounded to two significant figures.
[c] Normalized to 1% organic carbon (OC). Monitoring data should be normalized to 1% OC to assess whether the guideline value is exceeded.

[d]Applies to total concentration of the substance.
[e]Applies to dissolved concentration of the substance.

Substance Identity

Lanthanides are a group of 15 consecutive elements on the periodic table from lanthanum to lutetium. They are chemically similar, and along with scandium and yttrium, they constitute the group of REEs (González et al. 2014). REEs are generally soft, malleable and ductile (NRCan 2016). They are generally good conductors and may have unique magnetic properties (NRCan 2016). Among REEs, cerium and lanthanum are the most abundant. FEQGs were derived for cerium (Ce; molar mass 140.116 g/mol; Chemical Abstracts Service registry number (CAS RN) 7440-45-1), lanthanum (La; molar mass 138.905 g/mol; CAS RN 7439-91-0), neodymium (Nd; molar mass 144.24 g/mol; CAS RN 7440-00-8), and yttrium (Y; molar mass 88.905 g/mol; CAS RN 7440-65-5) (PubChem 2024) based on data availability and identified priorities.

REEs co-occur in many of the same mineral deposits (GC 2014). The term “rare” does not refer to the relative abundance of REEs in the Earth’s crust, but rather to the fact that REEs do not concentrate in pure ore deposits as do other elements (González et al. 2014). REEs rarely occur in concentrations that are sufficiently enriched to be economically exploitable; rather, they are found together with other elements and are difficult to separate for extraction (GC 2014). Based on their atomic numbers, REEs are divided into light (lanthanum through gadolinium) and heavy (terbium through lutetium) categories (Gosen et al. 2014; NRCan 2016). The ionic radius of each element decreases from light REEs (LREEs) to heavy REEs (HREEs) (Wells and Wells 2012).

The most common mineral deposits whereby REEs are found include monazite, bastnasite and xenotime (NRCan 2016). They are strongly attracted to both oxygen and phosphate (Brown et al. 1990 as reported in NRCan 2016) and are generally found in compounds as trivalent cations in oxides, phosphates, carbonates and silicates (Hedrick 2002).

Sources and Uses

REEs have become essential in high-tech and green technologies, and their increasing anthropogenic use has led to REE releases and detection in all environmental media. However, their potential impacts on ecosystems are poorly understood (Lachaux et al. 2022b). REEs do not occur in concentrated deposits, therefore large quantities (>90%) of excess and unused material are generated while mining for REEs (Reisman et al. 2013).

REEs have received significant attention in recent years because of the increasing demand for these elements as well as geopolitical concerns. China is the largest producer of REEs, accounting for 70% of annual global production while most of the remaining production is from United States (14%), Australia (6%), Myanmar (4%), and Thailand (2%) (NRCan 2024). China produced an estimated 210,000 tonnes (t) in 2022, while the production for the rest of the world was 91,000 t (NRCan 2024). Canada has some of the largest known global reserves of REEs, estimated at over 15 million t of rare earth oxides in 2023 (NRCan 2024). The first demonstration project for REE mining in Canada commenced in June 2021 at the Nechalacho mine near Yellowknife and there are a number of advanced exploration projects in Canada. Many of these projects are in northern Quebec, the Northwest Territories and Ontario’s Ring of Fire region.

REEs were historically used for fluid cracking catalysts and in glass polishing; however, they have now become critical to Canadian and global economies for their essential use in new and green technologies (NRCan 2016). Due to their unique characteristics, there are no easy substitutes for them in most applications (GC 2014). Examples of technology requiring REEs include hybrid vehicles, wind turbines, rechargeable batteries, mobile phones, computers, liquid-crystal display (LCD) screens, radar systems and catalytic converters (NRCan 2016). Some specific uses of lanthanum are in carbon lighting applications (studio and projection lighting), optical glass, camera lenses, nodular cast iron, ceramics, electronic applications, microwave crystals, metal alloys, high-temperature furnaces, magnetic cooling and as a catalyst in petroleum refining (NRCan 2016). Lanthanum is also a component of Phoslock, a lanthanum-modified clay that has been used in Canada to manage cyanobacterial blooms in lakes (Nürnberg 2017). Additionally, cerium and lanthanum are components of mischmetal alloy, used for example in 'flints' of cigarette lighters, as well as in glass polishing and in fuel cell technology. Other specific uses of cerium include in carbon arc lighting, metallurgical and nuclear applications, mildew-proofing, incandescent gas mantles, self-cleaning ovens, photoelectric cells, medical applications, and as a catalyst in petroleum refining (NRCan 2016). The main use of neodymium is in permanent magnets for hybrid vehicles and generators in wind turbines, and in magnets used in medical devices and disk drives. Neodymium is also used in mischmetal, didymium glass, colourants for glass and enamels, astronomical work, magnets for toys and some handheld devices, electronics, petroleum refining and rubber catalyst applications (NRCan 2016). Yttrium, cerium and lanthanum are used in the phosphors in fluorescent lights (Tan et al. 2015) and as colouring and decolouring agents in glass (De Lima 2016). Yttrium is also used in microwave filters, acoustic sound, synthetic diamond, laser systems, medical uses, glass and ceramic industry, stainless steel production and fuel cell technology (NRCan 2016).

Ambient Concentrations

The National Guidelines and Standards Office of Environment and Climate Change Canada (ECCC) compiled the water quality monitoring datasets for cerium, lanthanum, neodymium and yttrium from provinces and territories as well as data from unpublished research. Total and dissolved concentrations were available from the National Long-term Water Quality Monitoring (NLTWQM) database (ECCC 2022), the BC Environmental Monitoring System (Government of British Columbia 2022), the Ontario Geological Survey (Handley and Dyer 2022), and the *Banque de données sur la qualité du milieu aquatique* (BQMA) (MELCC 2022). Cerium, lanthanum, neodymium and yttrium concentrations in surface waters of Canada available up to December 2021 are summarised in Table 2a-d. It is to be noted that the concentrations summarized here are for broader guidance because of the inherent variability among the monitoring programs.

When concentrations in surface water were grouped according to province, the median concentrations ranged from 0.009 to 0.20 (dissolved) and 0.023 to 3.05 (total) µg/L for cerium; 0.01 to 0.35 (dissolved) and 0.06 to 1.29 (total) µg/L for lanthanum; and 0.03 to 0.096 (dissolved) and 0.08 to 1.07 (total) µg/L for yttrium. Across all sites in Canada (Table 2a-b), the minimum and maximum concentrations for cerium were 0.001 and 44.5 (dissolved, n=5,653) and 0.001 and 182 (total, n=17,775), while for lanthanum these values were 0.001 and 21.6 (dissolved, n=8,311) and 0.001 and 79 (total, n=24,654). For yttrium, minimum and maximum values were 0.001 and 40 (dissolved, n=6,073) and 0.001 and 90 (total, n=17,957) (Table 2d).

Neodymium monitoring data were only available from Quebec and Ontario (Table 2c). Ontario data were exclusively from the McFaulds Lake region, also known as the "Ring of Fire". In Quebec, dissolved concentrations ranged from 0.009 to 0.92 µg/L with a median of 0.2 µg/L, whereas total concentrations ranged from 0.007 to 7.7 µg/L with a median value of 0.67 µg/L. In Ontario, dissolved concentrations were not available, but total concentrations ranged from 0.002 to 0.077 µg/L with a median concentration of 0.013 µg/L.

The data from Table 2a-d show that median dissolved concentrations are 2 to 42 times lower than total concentrations (average of 9.6). Therefore, these data demonstrate that un-dissolved or particulate forms of these REEs are on average ten times higher in concentration than dissolved forms.

Table 2a. Cerium concentrations (µg/L) in surface waters of Canada.

Location	Years	Sites (Samples)[a]	Median[a]	Min[a]	Max[a]	Sites (Samples)[b]	Median[b]	Min[b]	Max[b]
AB	2002-2019	16 (762)	0.041	0.001	2.35	16 (781)	0.584	0.001	104
BC	2001-2021	23 (2563)	0.009	0.001	4.49	49 (10747)	0.090	0.001	49.6
MB	2014-2019	4 (378)	0.073	0.011	3.45	4 (377)	3.050	0.094	32.3

Location	Years	Sites (Samples)[a]	Median[a]	Min[a]	Max[a]	Sites (Samples)[b]	Median[b]	Min[b]	Max[b]
NL	2003-2019	N/A (N/A)	N/A	N/A	N/A	74 (1429)	0.353	0.001	11.6
NT	2002-2019	30 (1098)	0.038	0.001	44.50	30 (1260)	0.265	0.001	182
ON	2011-2013	N/A (N/A)	N/A	N/A	N/A	1323 (1323)	0.023	0.002	0.32
SK	2014-2019	7 (337)	0.034	0.001	1.14	7 (337)	0.513	0.001	25.4
YT	2002-2019	1 (28)	0.023	0.005	0.32	11 (1041)	0.118	0.002	22.8
QC	2016-2019	177 (487)	0.204	0.007	1.07	116 (480)	0.884	0.003	19.0

Data for Alberta, Manitoba, Newfoundland, Northwest Territories, Saskatchewan and Yukon are from the National Long Term Water Quality Monitoring database (NLTWQM) (ECCC 2022).
Data for British Columbia are from the BC Environmental Monitoring System (BC EMS) (Government of British Columbia 2022).
Data for Ontario are from the Ontario Geological Survey on behalf of Ontario Ministry of Energy, Northern Development and Mines (Handley and Dyer 2022).
Data for Quebec are aggregated from *Banque de données sur la Qualité du Milieu Aquatique* (BQMA) (MELCC 2022) and unpublished river data provided by Dr. Marc Amyot, University of Montreal, personal communication.
Province and territory names have been abbreviated to their two-letter form.
[a] Dissolved (µg/L)
[b] Total (µg/L)
N/A – not available

Table 3b. Lanthanum concentrations (µg/L) in surface waters of Canada.

Location	Years	Sites (Samples)[a]	Median[a]	Min[a]	Max[a]	Sites (Samples)[b]	Median[b]	Min[b]	Max[b]
AB	2002-2019	16 (2133)	0.012	0.001	2.12	16 (2134)	0.119	0.002	67.5
BC	2000-2022	33 (2651)	0.010	0.001	2.09	70 (12037)	0.060	0.001	20.0
MB	2003-2019	4 (890)	0.038	0.006	1.72	4 (891)	1.290	0.008	30.6
NL	2003-2019	N/A (N/A)	N/A	N/A	N/A	74 (4260)	0.216	0.001	20.0
NS	2017-2019	N/A (N/A)	N/A	N/A	N/A	21 (44)	0.070	0.030	0.44
NT	2002-2019	30 (1098)	0.033	0.001	21.60	30 (1325)	0.143	0.001	79.0
ON	2011-2013	N/A (N/A)	N/A	N/A	N/A	1323 (1323)	0.012	0.001	0.19
SK	2003-2019	7 (1025)	0.018	0.001	1.70	7 (1029)	0.232	0.001	19.5
YT	2000-2019	1 (28)	0.023	0.005	0.32	11 (1457)	0.076	0.003	11.6
QC	2016-2019	177 (486)	0.353	0.011	2.130	18 (154)	1.274	0.006	11.0

Data for Alberta, Manitoba, Newfoundland, Northwest Territories, Saskatchewan and Yukon are from the National Long Term Water Quality Monitoring database (NLTWQM) (ECCC 2022).
Data for British Columbia are from the BC Environmental Monitoring System (BC EMS) (Government of British Columbia 2022).
Data for Ontario are from the Ontario Geological Survey on behalf of Ontario Ministry of Energy, Northern Development and Mines (Handley and Dyer 2022).
Data for Quebec are aggregated from *Banque de données sur la Qualité du Milieu Aquatique* (BQMA) (MELCC 2022) and unpublished river data provided by Dr. Marc Amyot, University of Montreal, personal communication.
Province and territory names have been abbreviated to their two-letter form.
[a] Dissolved (µg/L)
[b] Total (µg/L)
N/A – not available

Table 4c. Neodymium concentrations (µg/L) in surface waters of Canada.

Location	Years	Sites (Samples)[a]	Median[a]	Min[a]	Max[a]	Sites (Samples)[b]	Median[b]	Min[b]	Max[b]
ON	2011-2013	N/A (N/A)	N/A	N/A	N/A	1323 (1323)	0.013	0.002	0.077

QC	2016-2019	177 (486)	0.200	0.009	0.924	18 (154)	0.671	0.007	7.70

Data for Ontario are from the Ontario Geological Survey on behalf of Ontario Ministry of Energy, Northern Development and Mines (Handley and Dyer 2022).
Data for Quebec are aggregated from *Banque de données sur la Qualité du Milieu Aquatique* (BQMA) (MELCC 2022) and unpublished river data provided by Dr. Marc Amyot, University of Montreal, personal communication.
Province and territory names have been abbreviated to their two-letter form.
[a] Dissolved (µg/L)
[b] Total (µg/L)
N/A – not available

Table 5d. Yttrium concentrations (µg/L) in surface waters of Canada.

Location	Years	Sites (Samples)[a]	Median[a]	Min[a]	Max[a]	Sites (Samples)[b]	Median[b]	Min[b]	Max[b]
AB	2002-2019	16 (761)	0.049	0.001	1.03	16 (785)	0.280	0.009	48.5
BC	2004-2022	45 (2985)	0.030	0.001	40	84 (11190)	0.086	0.001	90.0
MB	2014-2019	4 (378)	0.071	0.024	1.31	4 (377)	1.070	0.061	12.4
NL	2014-2019	N/A (N/A)	N/A	N/A	N/A	74 (1420)	0.181	0.022	3.41
NT	2002-2019	30 (1098)	0.044	0.001	9.30	30 (1325)	0.172	0.004	64.8
ON	2011-2013	N/A (N/A)	N/A	N/A	N/A	1323 (1323)	0.011	0.002	0.06
SK	2014-2019	7 (337)	0.057	0.003	0.34	7 (337)	0.242	0.003	10.1
YT	2002-2019	1 (28)	0.042	0.019	0.17	11 (1046)	0.089	0.006	17.0
QC	2016-2019	177 (486)	0.096	0.010	0.419	18 (154)	0.295	0.009	3.00

Data for Alberta, Manitoba, Newfoundland, Northwest Territories, Saskatchewan and Yukon are from the National Long Term Water Quality Monitoring database (NLTWQM) (ECCC 2022).
Data for British Columbia are from the BC Environmental Monitoring System (BC EMS) (Government of British Columbia 2022).
Data for Ontario are from the Ontario Geological Survey on behalf of Ontario Ministry of Energy, Northern Development and Mines (Handley and Dyer 2022).
Data for Quebec are aggregated from *Banque de données sur la Qualité du Milieu Aquatique* (BQMA) (MELCC 2022) and unpublished river data provided by Dr. Marc Amyot, University of Montreal, personal communication.
Province and territory names have been abbreviated to their two-letter form.
[a] Dissolved (µg/L)
[b] Total (µg/L)
N/A – not available

MacMillan et al. (2019) reported large regional variations in REE concentrations in surface waters (>200-fold) and lake sediments (10-fold), largely due to differences in bedrock geology and environmental conditions. REE concentrations in surface water increased with increasing sediment concentrations and decreased with lake depth, suggesting that REE mobilization from sediments was a source to the water column (MacMillan et al. 2019).

MacMillan et al. (2019) reported sum concentrations of lanthanides and yttrium in lake sediments from various ecosystems in eastern Canada. Sampled lakes were located in regions where no REE mining or exploitation had occurred and thus were considered uncontaminated. Sum concentrations ranged from 141.1 to 463.5 µg/g dw in subarctic lakes, 90.2 to 352.1 µg/g dw in arctic tundra lakes, 41.7 to 92.2 µg/g dw in polar desert lakes and 72.5 to 281.4 µg/g dw in temperate lakes. Concentrations of yttrium alone ranged from 9.1 to 30.5 µg/g dw in subarctic lakes, 8.6 to 47.4 µg/g dw in arctic tundra lakes, 5.5 to 11.0 µg/g dw in polar desert lakes, and 12.2 to 29.8 µg/g dw in temperate lakes (concentrations of other individual REEs not reported) (MacMillan et al. 2019). Marginson et al. (2023) examined sediment concentrations in undisturbed arctic environments and found mean concentrations of ∑REEs of 716.29 nmol/g dw, and a range of 161.8 to 1126 nmol/g dw. These findings were similar to other studies conducted in remote, undisturbed locations (Amyot et al. 2017; MacMillan et al. 2019). ∑REE concentrations in sediment sampled from Northern Quebec in an undisturbed and REE-rich geological area ranged from 71.3 to 184.9 µg/g dw (Romero-Freire et al. 2018), which is comparable to the 22.2 to 155 µg/g dw range observed in Nunavik, Quebec (Marginson et al. 2023).

REE concentrations in deep (>15 cm depth) and shallow (<15 cm depth) lake sediments (sieved before analysis), sampled in Ontario between 2011 and 2013, are summarized in Table 3. The median cerium, lanthanum, neodymium and yttrium concentrations in shallow sediments were 9.45, 4.78, 4.22 and 2.11 µg/g dw, respectively, whereas median concentrations in deep lake sediment were higher: 17 µg/g dw for cerium, 8 µg/g dw for lanthanum, 5.28 µg/g dw for neodymium and 2.62 µg/g dw for yttrium.

Table 6. Cerium, lanthanum, neodymium and yttrium concentrations in lake sediment from the McFaulds Lake region in Ontario.

Element	Sediment Depth	Sites/Samples	Median (µg/g dw)	Min (µg/g dw)	Max (µg/g dw)
Cerium	Shallow	1304	9.45	0.95	59.6
Cerium	Deep	1274	17.00	1.50	110
Lanthanum	Shallow	1304	4.78	0.40	26.3
Lanthanum	Deep	1274	8.00	0.50	51.0
Neodymium	Shallow	1304	4.22	0.61	22.8
Neodymium	Deep	1274	5.28	0.30	38.0
Yttrium	Shallow	1304	2.11	0.39	9.68
Yttrium	Deep	1274	2.62	0.36	21.3

Data are from the Ontario Geological Survey on behalf of Ontario Ministry of Energy, Northern Development and Mines (Handley and Dyer 2022).

Mode of Action

Joonas et al. (2017) stated that while information on mode of action for individual REEs may be limited for some elements, REEs are a physicochemically homogenous group and their modes of toxic action appear to be similar. REEs induce toxicity through oxidative stress, creating reactive oxygen species, damage to cells, and alterations to metabolic pathways and redox balance (Banaee et al. 2025). Sneller et al. (2000) broadly summarized mechanisms of toxic action for REEs in general, including: (i) competition between calcium/magnesium and lanthanum, causing disruption of bone integrity and cellular signalling; (ii) replacement of calcium/magnesium; (iii) reaction with proteins where calcium/magnesium are not typically involved; (iv) substitution of other elements; (v) lipid-peroxidation caused by redox cycling of REE which can exist in multiple oxidation states; and (vi) phosphate deficiency caused by precipitation of phosphate-REE. These mechanisms summarized by Sneller et al. (2000) were observed for various REEs in various organisms (both aquatic and terrestrial), including micro-organisms, nematodes, crustaceans, insects, mammals and plants.

Some specific information was available regarding mode of action for individual REEs, in particular for lanthanum. The ionic radius of lanthanum is similar to that of calcium (Ca^{2+}), which may cause displacement or replacement of calcium in various cell functions (Das et al. 1988; Barry and Meehan 2000; Gonzalez et al. 2014; Egler et al. 2023). Lanthanum can react with tissue components and compete for active binding sites, which may result in interactions with calcium-dependent biological systems and cause toxicity or impaired function (Das et al. 1988; Barry and Meehan 2000; Egler et al. 2023). Ionic forms of lanthanum and yttrium (La^{3+} and Y^{3+}) have been identified as potential inhibitors of calcium (Ca) transporters using *in-vitro* preparations of rat liver mitochondria (Korotkov et al. 2014). Interaction with mitochondria explained the toxicity of yttrium to *Daphnia magna*, *Chironomus riparius* and *Oncorhynchus mykiss* and revealed a wide range of subcellular handling strategies (Cardon et al. 2019). In algal tests with lanthanum, the formation of insoluble phosphate may have lowered the availability of free phosphorus and caused adverse effects from starvation rather than toxicity of lanthanum (Gonzalez et al. 2015). Similarly, a connection between algal growth inhibition and phosphate removal from the test medium was found by Joonas et al. (2017) in experiments with lanthanum and cerium.

The uptake of REEs in aquatic organisms can be via absorption from water or from ingestion of contaminated food. Regarding uptake from the water, REEs may be absorbed from the water by ion exchange and replace ions such as calcium or magnesium in organism tissues or can diffuse across cell membranes (Banaee et al. 2025). REEs may enter fish via the gill and then be taken up by ion transporters. For other organisms, REEs may be absorbed via the skin or adsorbed to exoskeletons (Banaee et al. 2025).

Fate, Behaviour and Partitioning in the Environment

Like many metals, the speciation of REEs in natural waters is complex and dictated by many factors. Elderfield et al. (1990) first proposed that REEs fractionate into three main forms: insoluble particles, organically and inorganically bound colloids, and dissolved ions. All these forms together represent the "total" or "unfiltered" fraction (>0.45 µM), and the colloidal and dissolved forms together represent the "dissolved" or "filtered" fraction (<0.45 µM) (Byrne and Sholkovitz 1996). Colloidal forms are larger than the truly dissolved forms and as such they can be captured by filters between 0.22-0.45 µM in size.

The presence of colloidal surfaces and ligands largely dictates the relative concentrations of REE fractions (Sholkovitz 1992). REEs bound to colloids appear to be a major fraction present in fresh water (Elderfield et al. 1990; Byrne and Sholkovitz 1996) and represents a key factor in the fate and transportation of REEs (Sholkovitz 1992). REEs readily adsorb to the high surface area of iron (Fe)-containing colloids, and in fresh water LREEs show a higher affinity to Fe-containing colloids compared to HREEs which tend to remain as truly dissolved ions (Elderfield et al. 1990; Pokrovsky and Schott 2002; Tang and Johannesson 2003). For both LREEs and HREEs, the presence of ligands also represents a key factor in determining their fractionation. REEs form strong complexes with organic and inorganic ligands such as nitrates, chlorides, sulphates, carbonates, phosphates and hydroxides, with the latter three being very insoluble in water (Liu and Byrne 1997; Wells and Wells 2012). As a result, REEs tend to precipitate out of solution when bound to carbonates, phosphates, and hydroxides, thereby remaining in their "total" fraction and greatly limiting their bioavailability in aquatic environments (Tang and Johannesson 2003; Gonzalez et al. 2014). This tendency to competitively bind to REEs and reduce their bioavailability in the environment occurs most notably with hardness (as Ca^{2+}-Mg^{2+} and carbonate) (Barry and Meehan 2000; Cardon et al. 2019; NRCan 2021b), alkalinity (as carbonate) (Moermond et al. 2001; Australian Government Department of Health 2014), pH (as H^{+} ions) (Sholkovitz 1992; Moermond et al. 2001; Bouchaud et al. 2012; El-Akl et al. 2015), and dissolved organic matter (as various acids) (Tang and Johannesson 2003; Marang et al. 2008; Lachaux et al. 2022a; Zilber et al. 2024).

Unlike in fresh water, where many factors characterize the speciation of REEs, in the marine environment REE fate and behaviour are largely driven by the abundance of carbonate present (Henderson 1984; Cantrell and Byrne 1987; Byrne and Sholkovitz 1996). In general, oceans tend to be HREE-enriched (Elderfield et al. 1988; Piepgras and Jacobsen 1992; Piarulli et al. 2021), suggested to be as a result of their stability in the dissolved phase, compared to LREEs which more readily complex to carbonate (Yang and Haley 2016; Sutorius et al. 2022). The lateral and vertical distribution of REEs varies greatly in seawater. On a large scale, the vertical distribution of REEs is affected by the process of metal scavenging, causing REEs to settle as insoluble particles and become sequestered by sediments (Piarulli et al. 2021). As a result, marine environments generally see an increase in REE concentrations at greater depths (Elderfield et al. 1988; Piepgras and Jacobsen 1992; Piarulli et al. 2021).

REEs typically occur in the trivalent state in aquatic systems, however, cerium may also be present as its oxidized form, Ce^{4+} (Elderfield et al. 1988; Railsback 2012). Cerium's oxidation potential causes it to be a notable outlier in its behaviour. In both freshwater and marine environments, Ce^{4+} forms an insoluble complex, CeO_2, causing it to be depleted from the water column to a greater extent than other REEs (Elderfield et al. 1988; De Baar et al. 1991; Weltje et al. 2002b). The formation of this complex is strongly dependent on pH, with higher pH values yielding greater CeO_2 concentrations (Elderfield et al. 1990).

Because of their affinity for particle surfaces, REEs are mainly bound to sediments or suspended particles in the water column (MacMillan et al. 2017). The composition of sediment has an impact on the bioavailability of REEs to aquatic organisms, with grain size and organic content being factors that influence release and mobility in the water column (Banaee et al. 2025). Sediment-water partition coefficients (Log $Kp_{(sed/w)}$) for laboratory and field for yttrium, lanthanum, cerium and neodymium have been reported as 5.18 and 6.04, 5.52 and 6.37, 5.78 and 6.31, and 5.67 and 6.27, respectively (Stronkhorst and Yland 1998 as reported in Sneller et al. 2000) demonstrating the relatively high affinity of REEs to sediment (Sneller et al. 2000).

REE levels have been shown to decrease with trophic position among biota samples in the Canadian Arctic, indicating low potential for biomagnification (MacMillan et al. 2017). Geometric Mean (GM) ∑REE tissue concentrations in resident species varied from 0.013 to 103 nmol/g dw and the highest GM concentrations were found in biota at the base of the food chain, particularly in lichen/moss (42 ±81 nmol/g dw), marine invertebrates (sea urchins 17 ±7.6 nmol/g dw, blue mussels 38 ±5.9 nmol/g dw) and freshwater invertebrates (benthic invertebrates 33 ±85 nmol/g dw, zooplankton 103 ±484 nmol/g dw) (MacMillan et al. 2017). Similar results were seen in temperate lake food webs, whereby REE tissue concentrations decreased with trophic position, indicating that REEs are subject to the process of trophic dilution (Amyot et al. 2017). Further evidence of bio-dilution comes from Dang et al. (2023) who reported lower enrichment of REEs in zooplankton (lanthanum = 11.6 ±8.3 mg/kg) than phytoplankton (lanthanum = 26.4 ±4.8 mg/kg). In Canadian lakes that are located away from the mining activity, Amyot et al. (2017) found that individual and total REE concentrations were strongly related with each other in different components of food webs and the median bioaccumulation factors (BAFs) ranged from 1.3, 3.7, 4.0 and 4.4 L/kg (ww) for fish muscle, zooplankton, predatory invertebrates and nonpredatory invertebrates, respectively.

Aquatic Toxicity

The current status of REE toxicity data represents significant progress since 2014 when the members of the Canadian Rare Earth Elements Network (CREEN) noted that data on toxic effects of REEs were limited and that further work was required to develop methods of safe management of REE tailings (GC 2014). Based on CREEN recommendations, Natural Resources Canada (NRCan) established a multi-year program to address data gaps for REEs, including gaps in ecotoxicity data. NRCan efforts have successfully fulfilled the minimum toxicity data requirements for CCME long-term Type A freshwater quality guidelines for cerium, lanthanum, neodymium and yttrium. The water toxicity data in this factsheet are current to July 2024.

Because REEs tend to precipitate out of solution during toxicity tests, the studies commissioned by NRCan were conducted in soft waters to maintain a relatively higher degree of solubility during toxicity tests; however, solubility remained a concern. Endpoints were based on the measured dissolved concentrations at the beginning of the test (at Time 0). In the present case, where the concentrations in the medium may well decrease during the period before the next renewal, the actual exposure concentration will be overestimated (and hence toxicity will be underestimated). In other words, this approach will not represent the true exposure concentration. A preferable approach would be determining the average concentration at the beginning and the end of the renewals or statistically calculated geometric mean if test concentrations decrease exponentially. The influence of various factors affecting solubility of REEs in toxicity tests has been evaluated by NRCan, including test containers, addition of food, and test organisms, as well as consideration of speciation of REEs in toxicity tests and calculation of time-weighted averages of exposure concentrations (NRCan 2021b). Time-weighted correction factors, derived by comparing average to initial exposure concentrations, were calculated for some species and elements and were found to range from 0.09 to 0.71 (NRCan 2021b). Due to the differences across tests and the lack of availability for all species and elements, correction factors were not applied to the current REE dataset; however, implementation may be considered in the future as the science develops.

The aquatic toxicity of REEs can be influenced by several factors such as hardness, alkalinity, pH, dissolved organic matter (DOM) and the presence of various ligands. These toxicity modifying factors (TMFs) primarily affect the bioavailability of REEs through competitive binding, thereby removing REEs from solution and providing a protective effect to the test organism. Increases in water hardness and alkalinity reduce the toxicity of REEs across a number of taxa due to their complexation with carbonate and Ca^{2+} ions (Barry and Meehan 2000; Borgmann et al. 2005; Kang et al. 2022; EGLE 2024; Zhang et al. 2024). Increases in pH (from pH 5 to 9.5) have been shown to reduce the toxicity of REEs due to their complexation with OH^- and carbonate ions, as observed in Kang et al. (2022) and Zhang et al. (2024). Increases in DOM can also reduce the toxicity of REEs in invertebrates through REE-DOM complexation (Vukov et al. 2016; Lachaux et al. 2022a; Zhang et al. 2024); but conversely, DOM may increase the accumulation of REEs in algae through its effects on the membrane permeability of algal cells, resulting in greater than expected toxicity (Zilber et al. 2024). Despite meeting the minimum toxicity data requirements for guideline development, insufficient data were available for the normalization of REE toxicity endpoints to these water quality parameters. As the science develops, the effects of TMFs in modulating toxicity responses could be considered for interpreting and applying Federal Water Quality Guidelines (FWQGs) on a case-by-case (site-specific) basis.

The use of phosphorus (often as phosphate, K_2HPO_4) in algal and plant toxicity tests represents a considerable challenge given its necessity in the growth media, and its ability to precipitate REEs during the test exposure (Barry and Meehan 2000; Lürling and Tolman 2010; Joonas et al. 2017). As a result, when phosphate is used in algae/plant growth mediums, the growth inhibition observed may very well be due to the depletion of phosphate (through complexation with REEs) as opposed to the direct toxicity of REEs. This confounding effect can be addressed by using a phosphorus-replete species (*Chlorella fusca*) which can grow in the absence of phosphorus (Aharchaou et al. 2020) or by using organic-phosphorus (like β-glycerophosphate) in the growth medium, which provides phosphorus to the organisms but does not induce precipitation (NRCan 2021a). For example, Aharchaou et al (2020) observed that in test solutions at pH 5.5 with no precipitate formation, toxicity thresholds for lanthanum and cerium were 10 to 1000 times lower than those reported in earlier studies and suggested several likely factors, such as (i) insoluble phosphate species did not form in their exposure media; (ii) presence of protective chemical species (for example calcium) at various levels in the different studies; and/or (iii) marked differences in the sensitivity of species. For FWQGs, only algal/plant studies that used either a phosphorus-replete species or organic phosphorus were deemed acceptable for use in guideline derivation.

Despite some progress being made on elucidating the toxic effects of REEs, knowledge gaps remain regarding the relative toxicities of each fraction (total, colloidal and truly dissolved) on aquatic organisms (Zhang et al. 2024). A few studies on invertebrates have suggested that the particulate, or total, fraction could induce toxic effects; however, the authors were unable to separate out the effects of the dissolved (truly dissolved and colloidal) fraction (Stauber and Binet 2000; Blinova et al. 2018). Other studies have demonstrated that complexed REEs, presumably existing as colloids, may be responsible for inducing toxic effects; however, these studies are so far limited only to plant (*Lemna minor*) (Weltje et al. 2002a; NRCan 2021b; Sharma et al. 2024) and algae models (*Chlamydomonas reinhardtii*) (Crémazy et al. 2013; Yang et al. 2014; Zhao and Wilkinson 2015). Much of the information currently available points to the dissolved form, and in some cases the free-ion form, likely being the best representation of what is bioavailable to aquatic organisms (Herrmann et al. 2016; Vukov et al. 2016; Aharchaou et al. 2020; Banaee et al. 2025). Therefore, where data permitted, guidelines were based on dissolved concentrations to best reflect the bioavailable form. Researchers continue to make progress on understanding the influence of bioavailability and fractionation on the toxicity of REEs to aquatic organisms.

Currently, there is no consensus regarding the relative toxicities of REEs on the basis of their atomic properties (Vignati et al. 2024). Similar toxicity across the REE series has been noted for algae and invertebrates (as reviewed by Blinova et al. 2020), which is in accordance with Lachaux et al. (2022b) that noted that *Daphnia magna* had homogenous toxicity to neodymium, gadolinium and ytterbium. On the other hand, Gonzales et al. (2014) argued that factors such as the composition of test solutions, and differences in test endpoints and species present too many inconsistencies to confidently verify the presence or absence of uniformity. Overall, more research is needed to confirm whether REEs show comparable toxicities across a wide range of test organisms and conditions as a function of their chemical similarities.

Federal Water Quality Guidelines

A detailed review of available aquatic toxicity studies was performed by ECCC following guidance from CCME (2007) for data quality, and Robust Study Summary (RSS) evaluation forms were completed for each study. Determinants of test acceptability included, but were not limited to, exposure duration, documentation of control response, use of suitable biological endpoints and inclusion of appropriate statistical analyses. Due to the propensity of REEs to precipitate in solution, special consideration was given to whether concentrations were measured and/or maintained throughout the test, the type and duration of the test, the use of phosphate in algae and plant toxicity tests, and if standard procedures were followed. Nominal (unmeasured) concentration data were only accepted for chronic aquatic exposures if there was renewal of test concentrations, due to the issues with solubility and precipitation. Data were categorized as acceptable (either primary or secondary data quality) or unacceptable for use in guideline derivation (see Appendices A-D). Data were not considered for mixtures or for nanoparticles of REEs, given that their modes of action and toxicities may differ. While nanomaterials containing REEs that may be present in environmental media or in products are not explicitly considered, measured concentrations in the environment could in part include REEs from these sources. Toxicity studies that were considered irrelevant for guideline derivation or that were inaccessible are listed in Appendix L.

Federal Water Quality Guidelines (FWQGs) are preferably developed following CCME protocol (CCME 2007). The preferred derivation method[a] is a Type A approach (Species Sensitivity Distribution (SSD)), followed by a Type B approach (application of a safety factor) (CCME 2007). In summary, the long-term CCME Type A guideline requires acceptable chronic toxicity data for at least three fish species (including one salmonid and one non-salmonid), three invertebrates (one planktonic crustacean and two additional aquatic or semi-aquatic species) and at least one vascular plant or algal species (two additional non-target plants required if plants are among the most sensitive species). Toxicity endpoints for amphibians are desirable, but not essential. The long-term FWQGs for cerium, lanthanum, neodymium and yttrium all met CCME minimum data requirements for a Type A approach for freshwater exposure. For acute exposure, CCME Type A approach requires acceptable acute data for three fish species (including one salmonid and one non-salmonid) and three invertebrates (including one planktonic crustacean). Algal and amphibian species are desirable but not required. The short-term freshwater benchmarks for cerium and lanthanum met CCME minimum data requirements for a Type A guideline. Neodymium and yttrium short-term benchmarks did not meet requirements for Type A; however, they did meet minimum data requirements for Type B2 guidelines, which at minimum require acceptable acute data for two fish species (one salmonid and one non-salmonid) and two invertebrates (including one planktonic crustacean).

For the short-term benchmarks, the-acute toxicity datasets used acceptable LC_{50} endpoints or equivalents (CCME 2007). For the long-term guidelines, the most preferred endpoints were selected from the acceptable chronic toxicity data for deriving the long-term freshwater guidelines following CCME protocol (2007). Some endpoints in the dataset were derived from the CETIS (Comprehensive Environmental Toxicity Information System) outputs included in the appendices of the NRCan reports. The range of toxicity data used to derive the individual REE guidelines are summarized in the relevant sections below. Overall, toxicity data showed that the relative toxicity of these REEs varied among taxonomic groups and that species sensitivity was not consistent. Species included in guideline development were either resident species of Canada or were determined to be appropriate surrogates (see Appendix I).

Aquatic toxicity for marine exposure was also considered; however, data were limited. Toxicity of various individual REEs to marine organisms includes adverse effects on development, cell and tissue

[a] CCME (2007) provides two approaches for developing water quality guidelines, depending on the availability and quality of the available data. The preferred approach is to use the statistical distribution of all acceptable data to develop Type A guidelines. The second approach is based on extrapolation from the lowest acceptable toxicity endpoint to develop Type B guidelines. For further details on the minimum data requirements for CCME guidelines see CCME (2007).

damage, oxidative stress and neurotoxicity (Piarulli et al. 2021). Acceptable data specifically for lanthanum, cerium, neodymium and yttrium are summarized in the *Marine exposure* section; however, insufficient data were available for guideline derivation.

Species Sensitivity Distributions

The R package (R version 4.4.2) ‘ssdtools’ (version 2.2.0) and the corresponding user-friendly web application ‘shinyssdtools’ (version 0.3.5; Thorley and Schwarz 2018; Dalgarno 2021) were used to create model averaged SSDs for cerium, lanthanum, neodymium and yttrium. The package fits several default cumulative distribution functions (log-normal, log-logistic, gamma, log-Gumbel, Weibull, log-normal mixture) to the data using maximum likelihood estimation as the regression method. A model averaged hazardous concentration at 5% (HC_5) was established using Akaike information criterion corrected for small sample size (AICc; Burnham and Anderson 2004). The HC_5 is then used as the short-term benchmark or long-term guideline value. See Thorley and Schwarz (2018) and Fox et al. (2021) for more information on the approach. The full R script and model fit results are available in Appendices J-K.

Cerium

Short-term benchmark

Acceptable acute data were available for cerium to meet CCME minimum data requirements for a short-term freshwater benchmark following a Type A approach (CCME 2007). The dataset included three fish and three invertebrate species, with the most sensitive being *Oncorhynchus mykiss* (96-h LC_{50} of 130 µg Ce/L) and the least sensitive being *Hyalella azteca* (96-h LC_{50} of 11200 µg Ce/L). The endpoint for *O. mykiss* was obtained from a REACH registration dossier for cerium as reported to the ECHA (European Chemicals Agency) Chemicals Database, and while a full RSS form was completed based on available information in the data entry and was deemed acceptable, the original report was not available for verification. Therefore, there is some uncertainty associated with this endpoint; however, it was included as it fulfilled minimum data requirements for a salmonid endpoint and was the most sensitive endpoint in the acute cerium dataset. The acute dataset and SSD for cerium can be seen in Table 4 and Figure 1, respectively. The short-term benchmark concentration, derived from the HC_5 of the acute SSD, is 81 µg Ce/L. The available acute dataset contained both dissolved and total endpoints, as it was not possible to fulfil minimum data requirements based solely on one fraction. Therefore, the short-term benchmark applies to total concentrations of cerium measured in water samples, and the inclusion of the dissolved endpoints in the dataset errs on the side of conservatism.

Table 7. Acute freshwater toxicity data for deriving the short-term benchmark for cerium.

Group	Species Latin Name	Species Common Name	Endpoint	Effect Concentration (µg Ce/L)	Concentration Type	Reference
Fish	*Oncorhynchus mykiss*	Rainbow trout	96-h LC_{50}	130	Measured[a]	ECHA 2011
Invertebrate	*Daphnia magna*	Water flea	48-h LC_{50}	244.59	Total	Galdiero et al. 2019
Invertebrate	*Hydra attenuata*	Hydra	96-h EC_{50} (morphological change/ mortality)	1797	Dissolved	Gonzales et al. 2015
Fish	*Danio rerio*	Zebrafish	96-h LC_{50}	1849.53	Dissolved	Kang et al. 2022
Fish	*Pimephales promelas*	Fathead minnow	96-h LC_{50}	3490	Total	EGLE 2024
Invertebrate	*Hyalella azteca*	Lawn shrimp	96-h LC_{50}	11200	Total	EGLE 2024

[a] Measured concentration not specified in data source as total or dissolved
h – hour, EC – effect concentration, LC – lethal concentration

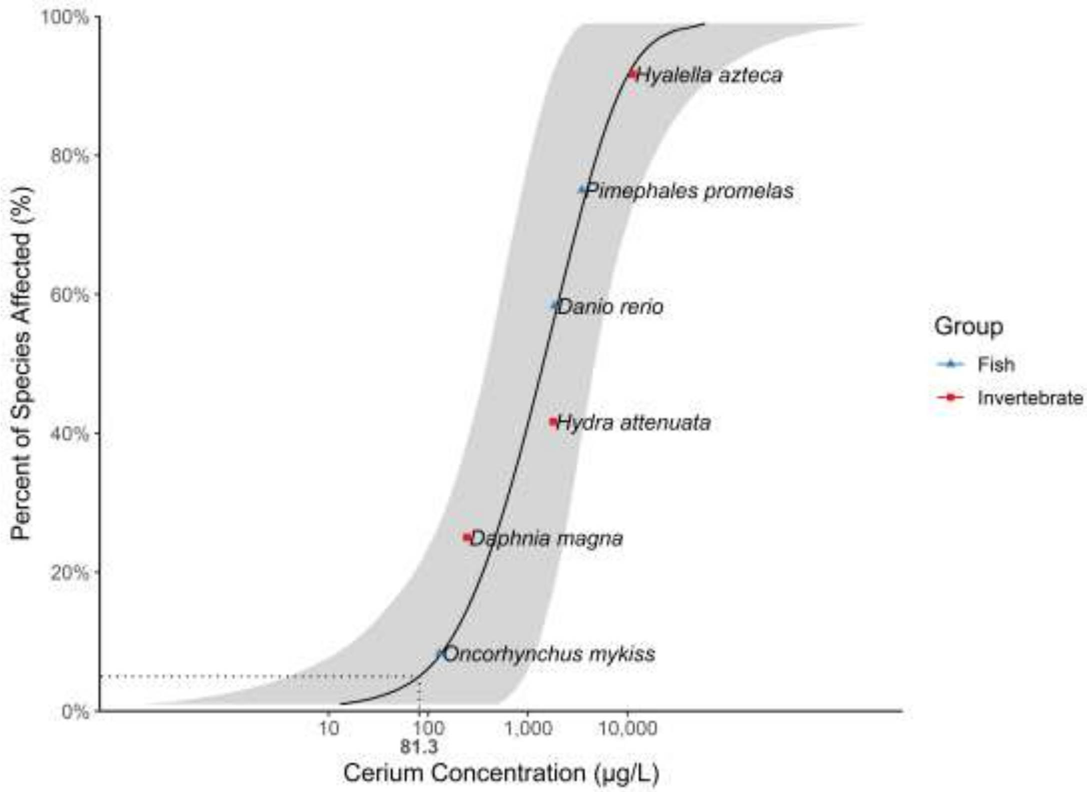

Figure 1. Species sensitivity distribution (SSD) for the acute toxicity of cerium in freshwater. The HC_5 (dotted line) is 81 µg Ce/L (rounded to two significant figures), and the shaded area shows the confidence intervals.

Long-term guideline

Acceptable data were available for cerium to meet CCME minimum data requirements for a long-term freshwater guideline following a Type A approach (CCME 2007). The chronic cerium dataset included no- or low-effect data for 17 species, including three fish, nine invertebrates and five plant or algal species (Table 5). *Ceriodaphnia dubia* was the most sensitive species (7-day IC_{10} of 2.3 µg Ce/L), while *Spirodela polyrhiza* was the least sensitive (10-day IC_{10} of 1945 µg Ce/L). The dataset and SSD for chronic exposure to cerium can be seen in Table 5 and Figure 2, respectively. The long-term FWQG, derived from the HC_5 of the chronic SSD, is 1.6 µg Ce/L. The long-term guideline applies to dissolved concentrations of cerium, as the majority of the dataset represented the dissolved fraction. A sensitivity analysis demonstrated that exclusion of the nominal endpoints from the dataset had a minimal effect on the guideline value. Therefore, the nominal endpoints were retained to increase species representation.

Table 8. Chronic freshwater toxicity data for deriving the long-term guideline for cerium.

Group	Species Latin Name	Species Common Name	Endpoint	Effect Concentration (µg Ce/L)	Concentration Type	Reference
Invertebrate	*Ceriodaphnia dubia*	Water flea	7-d IC_{10} (reproduction)	2.32	Dissolved	NRCan 2018
Invertebrate	*Lymnaea stagnalis*	Great pond snail	28-d EC_{10} (embryo hatching success)	2.7	Nominal	Casey et al. 2019

Group	Species Latin Name	Species Common Name	Endpoint	Effect Concentration (µg Ce/L)	Concentration Type	Reference
Algae/Plant	*Chlorella vulgaris*	Green alga	72-h IC_{10} (cell yield)	3.85	Dissolved	NRCan 2021a
Algae/Plant	*Raphidocelis subcapitata*	Green alga	72-h IC_{10} (cell yield)	5.50	Dissolved	NRCan 2021a
Fish	*Salmo trutta*	Brown trout	28-d IC_{10} (length)	6.66	Dissolved	NRCan 2021a
Fish	*Pimephales promelas*	Fathead minnow	7-d larval IC_{10} (biomass)	15.7	Dissolved	NRCan 2017
Invertebrate	*Heterocypris incongruens*	Ostracod	6-d EC_{10} (growth inhibition)	16	Dissolved	Gonzales et al. 2015
Fish	*Oncorhynchus kisutch*	Coho salmon	35-d IC_{10} (dry weight)	17.4	Dissolved	NRCan 2018
Invertebrate	*Hyalella azteca*	Lawn shrimp	14-d IC_{10} (dry weight)	20.4	Dissolved	NRCan 2018
Algae/Plant	*Chlorella fusca*	Green alga	5-d EC_{20} (growth)	56.05	Total dissolved[a]	Aharchaou et al. 2020
Invertebrate	*Daphnia magna*	Water flea	21-d MATC (reproduction)	71.34	Nominal	Ma et al. 2016
Invertebrate	*Brachionus calyciflorus*	Rotifer	48-h EC_{10} (reproduction)	93	Dissolved	Gonzales et al. 2015
Algae/Plant	*Lemna minor*	Common duckweed	7-d IC_{10} (dry weight)	134.97	Nominal	NRCan 2021a
Invertebrate	*Chironomus dilutus*	Midge	10-d IC_{10} (dry weight)	490	Dissolved	NRCan 2019b
Invertebrate	*Neocloeon triangulifer*	Mayfly	14-d IC_{10} (dry weight)	1020	Dissolved	NRCan 2019b
Invertebrate	*Sphaerium sp.*	Fingernail clam	28-d LC_{10}	1345	Dissolved	NRCan 2019b
Algae/Plant	*Spirodela polyrhiza*	Common duckmeat	10-d IC_{10} (frond yield)	1945	Nominal	Carpenter et al. 2019

[a] Samples were filtered through two superimposed 2µm filters.

d – days, EC – effect concentration, h – hour, IC – inhibition concentration, LC – lethal concentration, MATC – maximum acceptable toxicant concentration

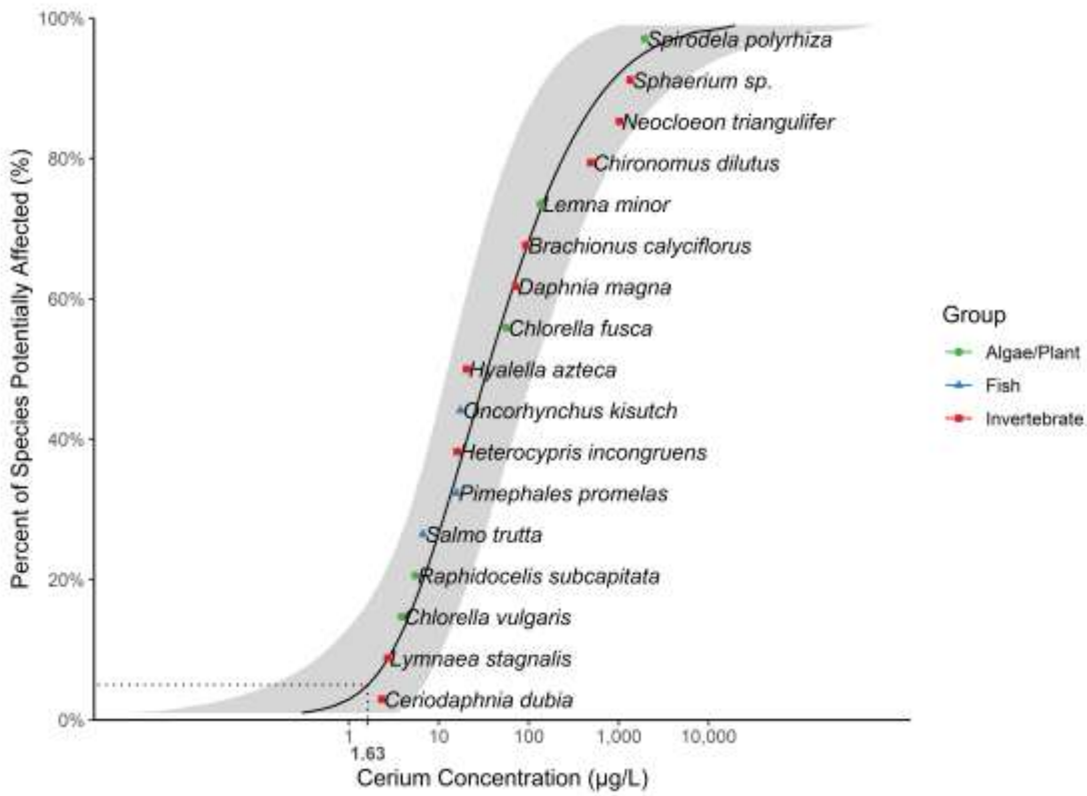

Figure 2. Species sensitivity distribution (SSD) for the chronic toxicity of cerium in freshwater. The HC_5 (dotted line) is 1.6 µg Ce/L (rounded to two significant figures), and the shaded area shows the confidence intervals.

Lanthanum

Short-term benchmark

The acceptable acute dataset for lanthanum met CCME minimum data requirements for a short-term freshwater benchmark following a Type A approach (CCME 2007). The acute dataset contained LC_{50} or equivalent endpoints for nine species, including four fish and five invertebrates. The most sensitive species was *Hydra attenuata* (96-h LC_{50} of 210 µg La/L), while the least sensitive was *Tetrahymena shanghaiensis* (24-h IC_{50} of 277,810 µg La/L). The endpoint for *O. mykiss* was obtained from a REACH registration dossier for lanthanum as reported to the ECHA Chemicals Database, and while a full RSS form was completed on the data entry and deemed acceptable, the original report was not available for verification. Therefore, there is some uncertainty associated with this endpoint; however, it was included in the dataset to meet minimum data requirements for a salmonid species and because it was the second most sensitive endpoint. The acute SSD dataset and figure for lanthanum can be seen in Table 6 and Figure 3, respectively. The HC_5 and short-term benchmark for lanthanum in fresh water is 160 µg La/L. The acute dataset was comprised of both dissolved and total concentrations, as it was not possible to fulfil minimum data requirements based solely on one fraction. Therefore, the short-term benchmark applies to total concentrations of lanthanum sampled in water, and the inclusion of the dissolved endpoints in the dataset errs on the side of conservatism.

Table 9. Acute freshwater toxicity data for deriving the short-term benchmark for lanthanum.

Group	Species Latin Name	Species Common Name	Endpoint	Effect Concentration (µg La/L)	Concentration Type	Reference
Invertebrate	*Hydra attenuata*	Hydra	96-h LC_{50}	210	Nominal	Blaise et al. 2018
Fish	*Oncorhynchus mykiss*	Rainbow trout	96-h LC_{50}	420	Dissolved	ECHA 2014
Fish	*Gobiocypris rarus*	Rare minnow	96-h LC_{50}	1920	Nominal	Hua et al. 2017
Fish	*Danio rerio*	Zebrafish	96-h LC_{50}	2194.70	Dissolved	Kang et al. 2022
Invertebrate	*Daphnia magna*	Water flea	48-h LC_{50}	3200	Dissolved	Shu et al. 2023
Fish	*Pimephales promelas*	Fathead minnow	96-h LC_{50}	3610	Total	EGLE 2024
Invertebrate	*Daphnia similis*	Water flea	48-h EC_{50} (immobility)	14840 (Geomean)	Total	Egler et al. 2023
Invertebrate	*Hyalella azteca*	Lawn shrimp	96-h LC_{50}	18900	Total	EGLE 2024
Invertebrate	*Tetrahymena shanghaiensis*	Ciliated protozoan	24-h IC_{50} (cell count)	277810	Nominal	Wang et al. 2000

EC – effect concentration, h – hour, IC – inhibition concentration, LC – lethal concentration

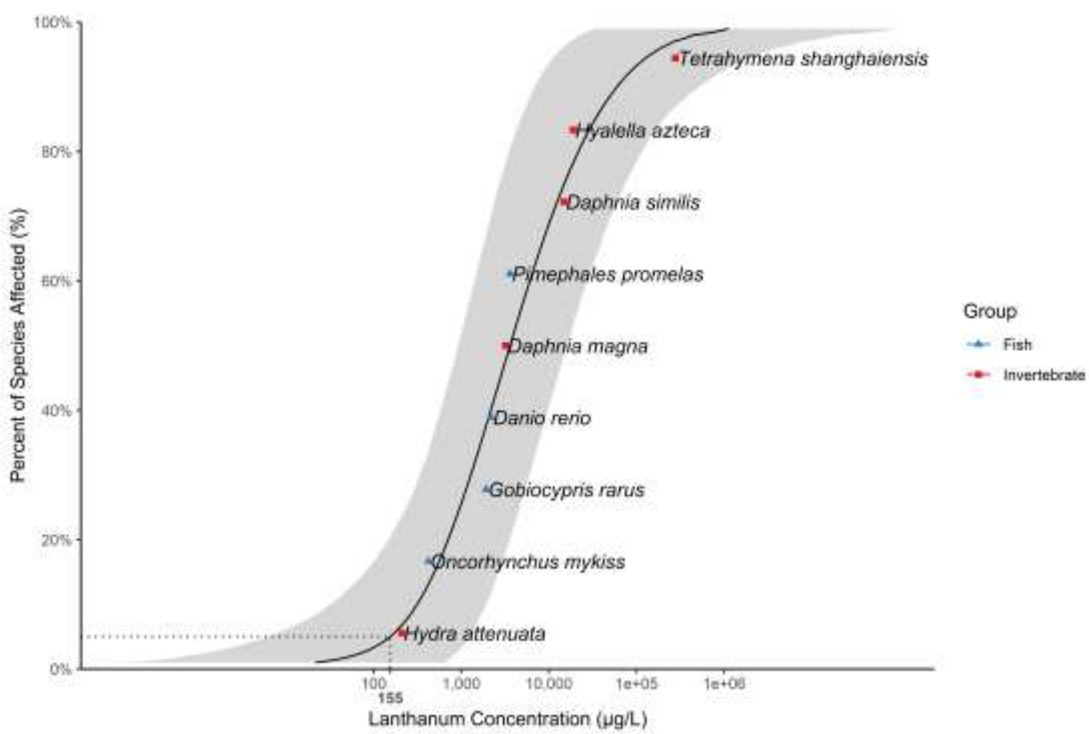

Figure 3. Species sensitivity distribution (SSD) for the acute toxicity of lanthanum in freshwater. The HC_5 (dotted line) is 160 µg La/L (rounded to two significant figures), and the shaded area shows the confidence intervals.

Long-term guideline

The acceptable chronic dataset for lanthanum met CCME minimum data requirements for a long-term freshwater guideline following a Type A approach (CCME 2007). Toxicity data for 13 species (three fish, six invertebrates and four plants) were selected for the lanthanum guideline (Table 7). Plant species

Chlorella vulgaris (72-h IC_{10} of 3.59 µg La/L) and invertebrate *Neocloeon triangulifer* (14-d IC_{10} of 1040 µg La/L) were the most and least sensitive species, respectively. The HC_5 from the SSD (Figure 4) represents the long-term lanthanum guideline in fresh water and is 2.4 µg La/L. As the chronic lanthanum dataset was comprised mostly of dissolved concentrations, the long-term guideline applies to dissolved concentrations of lanthanum sampled in water. A sensitivity analysis demonstrated that exclusion of the *L. minor* nominal endpoint from the dataset had minimal effect on the guideline value, and therefore it was retained to increase species representation.

Table 10. Chronic freshwater toxicity data for deriving the long-term guideline for lanthanum.

Group	Species Latin Name	Species Common Name	Endpoint	Effect Concentration (µg La/L)	Concentration Type	Reference
Algae/Plant	*Chlorella vulgaris*	Green alga	72-h IC_{10} (cell yield)	3.59	Dissolved	NRCan 2021a
Fish	*Salmo trutta*	Brown trout	28-d IC_{10} (dry weight)	7.24	Dissolved	NRCan 2017
Algae/Plant	*Raphidocelis subcapitata*	Green alga	72-h IC_{10} (cell yield)	9.57	Dissolved	NRCan 2021a
Invertebrate	*Ceriodaphnia dubia*	Water flea	7-d IC_{10} (reproduction)	9.79	Dissolved	NRCan 2018
Fish	*Pimephales promelas*	Fathead minnow	7-d IC_{10} (biomass)	19.8	Dissolved	NRCan 2017
Algae/Plant	*Chlorella fusca*	Green alga	5-d EC_{20} (growth)	31.95	Total dissolved[a]	Aharchaou et al. 2020
Invertebrate	*Hyalella azteca*	Lawn shrimp	14-d IC_{10} (dry weight)	71.7	Dissolved	NRCan 2018
Invertebrate	*Daphnia magna*	Water flea	21-d MATC (body length/ mean brood size)	80.11	Dissolved	Shu et al. 2023
Fish	*Oncorhynchus kisutch*	Coho salmon	35-d EC_{10} (survival)	206.5	Dissolved	NRCan 2018
Invertebrate	*Sphaerium sp.*	Fingernail clam	28-d IC_{10} (dry weight)	360	Dissolved	NRCan 2019b
Algae/Plant	*Lemna minor*	Common duckweed	7-d IC_{10} (dry weight)	538.78	Nominal	NRCan 2021a
Invertebrate	*Chironomus dilutus*	Midge	10-d IC_{10} (dry weight)	750	Dissolved	NRCan 2019b
Invertebrate	*Neocloeon triangulifer*	Mayfly	14-d IC_{10} (dry weight)	1040	Dissolved	NRCan 2019b

[a] Samples were filtered through two superimposed 2µm filters.

d – days, EC – effect concentration, h – hour, IC – inhibition concentration, MATC – maximum acceptable toxicant concentration

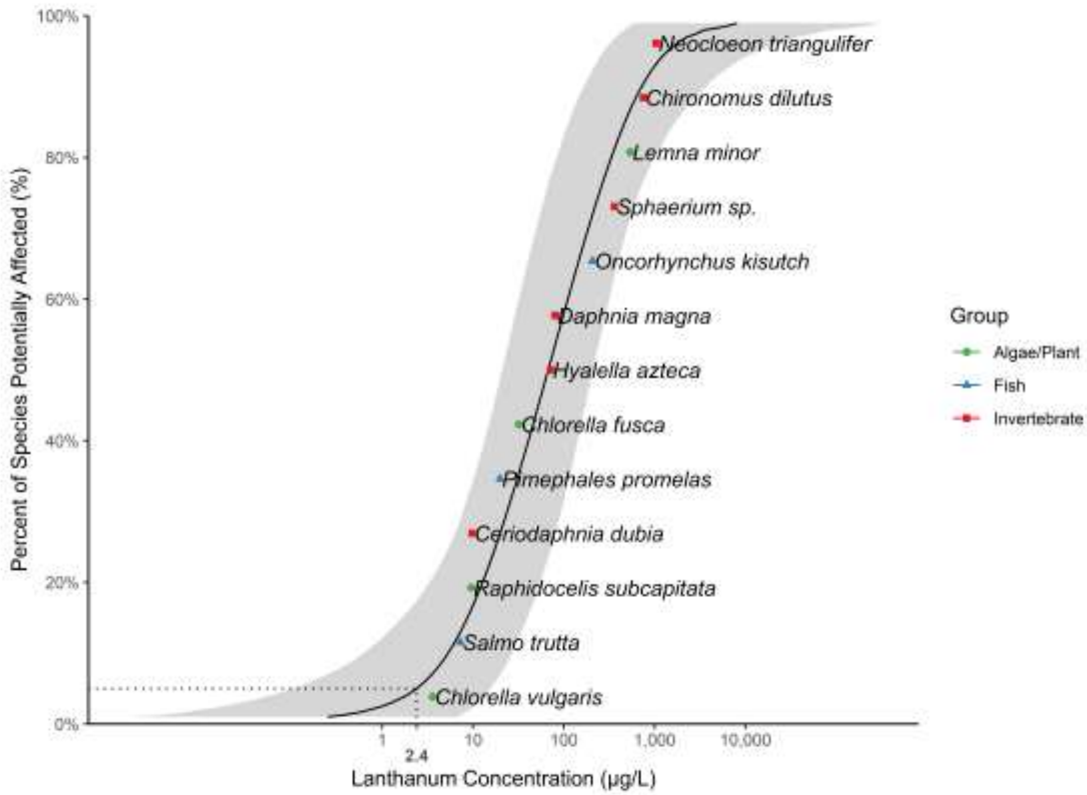

Figure 4. Species sensitivity distribution (SSD) for the chronic toxicity of lanthanum in fresh water. The HC_5 (dotted line) is 2.4 µg La/L, and the shaded area shows the confidence intervals.

Neodymium

Short-term benchmark

Minimum CCME data requirements were met for a Type B2 approach (CCME 2007) for acute freshwater exposure to neodymium, including acceptable LC_{50} or equivalent endpoints for two fish and five invertebrate species. Table 8 contains the most sensitive LC_{50} or equivalent endpoint for each species in the acceptable acute toxicity dataset. The *O. mykiss* endpoint is an unbounded value, for which effects were not seen at the highest concentration level in the study. Because the endpoint was not directly used to derive the guideline value following a Type B2 approach, and because the study showed the species to be insensitive to the concentrations tested, the endpoint was considered acceptable to meet minimum data requirements. The lowest endpoint was a 48-h EC_{50} of 227.2 µg Nd/L for mortality of *Daphnia pulex*. Following CCME protocol, the most sensitive LC_{50} or equivalent endpoint from an acute exposure study is the critical study to which a safety factor of 10 is applied to derive the short-term exposure Type B2 guideline. The safety factor of 10 accounts for differences in sensitivity to a chemical due to differences in species, exposure conditions, and test endpoints, as well as a paucity of toxicological data (CCME 2007). Therefore, the short-term freshwater benchmark for neodymium is 23 µg Nd/L. Because the critical endpoint was for a dissolved measurement, the short-term neodymium benchmark applies to dissolved concentrations.

Table 11. Acute freshwater toxicity data for deriving the short-term benchmark for neodymium.

Group	Species Latin Name	Species Common Name	Endpoint	Effect Concentration (µg Nd/L)	Concentration Type	Reference
Invertebrate	*Daphnia pulex*	Water flea	48-h EC_{50} (mortality)	227.2	Dissolved	King et al. 2005

Group	Species Latin Name	Species Common Name	Endpoint	Effect Concentration (µg Nd/L)	Concentration Type	Reference
Invertebrate	*Hydra attenuata*	Hydra	96-h LC_{50}	310	Nominal	Blaise et al. 2018
Invertebrate	*Daphnia magna*	Water flea	48-h EC_{50} (immobility)	332	Dissolved	Do 2024
Invertebrate	*Daphnia similis*	Water flea	48-h EC_{50} (immobility)	9190	Total	Egler et al. 2023
Fish	*Danio rerio*	Zebrafish	96-h LC_{50}	55580	Measured[a]	Lora-Benitez et al. 2024
Invertebrate	*Caenorhabditis elegans*	Round worm	48-h LC_{50}	57503	Nominal	Xu et al. 2017
Fish	*Oncorhynchus mykiss*	Rainbow trout	96-h LC_{50}	> 40000	Nominal	Dubé et al. 2019

[a] Measured concentration not specified in data source as total or dissolved
EC – effect concentration, h – hour, LC – lethal concentration

Long-term guideline

The acceptable chronic dataset for neodymium met minimum requirements for a Type A approach (CCME 2007). Toxicity data for 13 species, including three fish, six invertebrate and four plant/algal species, were selected for deriving the neodymium guideline (Table 9). *Lymnaea stagnalis* was the most sensitive (28-d EC_{10} 1.6 µg Nd/L), while *Spirodela polyrhiza* was the least sensitive species (10-d IC_{10} 6965 µg Nd/L). The HC_5 from the chronic SSD (Figure 5) represents the long-term guideline for neodymium and is 1.1 µg Nd/L. As the chronic neodymium dataset was comprised mostly of dissolved concentrations, the long-term guideline applies to dissolved concentrations of neodymium sampled in water. A sensitivity analysis demonstrated that exclusion of the nominal endpoints from the dataset resulted in a higher guideline value, therefore those endpoints were retained to err on the side of conservatism and increase species representation in the dataset.

Table 12. Chronic freshwater toxicity data for deriving the long-term guideline for neodymium.

Group	Species Latin Name	Species Common Name	Endpoint	Effect Concentration (µg Nd/L)	Concentration Type	Reference
Invertebrate	*Lymnaea stagnalis*	Great pond snail	28-d EC_{10} (embryo hatching success)	1.6	Nominal	Casey et al. 2019
Algae/Plant	*Chlorella vulgaris*	Green alga	72-h IC_{10} (cell yield)	2.49	Dissolved	NRCan 2021a
Algae/Plant	*Raphidocelis subcapitata*	Green alga	72-h IC_{10} (cell yield)	8.22	Dissolved	NRCan 2021a
Invertebrate	*Ceriodaphnia dubia*	Water flea	7-d IC_{10} (reproduction)	20.77	Dissolved	NRCan 2018
Fish	*Salmo trutta*	Brown trout	28-d IC_{10} (dry weight)	21.13	Dissolved	NRCan 2017
Fish	*Pimephales promelas*	Fathead minnow	7-d larval IC_{10} (biomass)	27.93	Dissolved	NRCan 2017
Fish	*Oncorhynchus kisutch*	Coho salmon	35-d IC_{10} (dry weight)	291.1	Dissolved	NRCan 2018
Invertebrate	*Hyalella azteca*	Lawn shrimp	14-d IC_{10} (dry weight)	306.9	Dissolved	NRCan 2018
Algae/Plant	*Lemna minor*	Common duckweed	7-d IC_{10} (frond count)	669.61	Nominal	NRCan 2021a
Invertebrate	*Chironomus dilutus*	Midge	10-d IC_{10} (dry weight)	680	Dissolved	NRCan 2019b
Invertebrate	*Sphaerium sp.*	Fingernail clam	28-d LC_{10}	710	Dissolved	NRCan 2019b
Invertebrate	*Neocloeon triangulifer*	Mayfly	14-d IC_{10} (dry weight)	1050	Dissolved	NRCan 2019b
Algae/Plant	*Spirodela polyrhiza*	Common duckmeat	10-d IC_{10} (frond yield)	6965	Nominal	Carpenter et al. 2019

d – days, EC – effect concentration, h – hour, IC – inhibition concentration, LC – lethal concentration

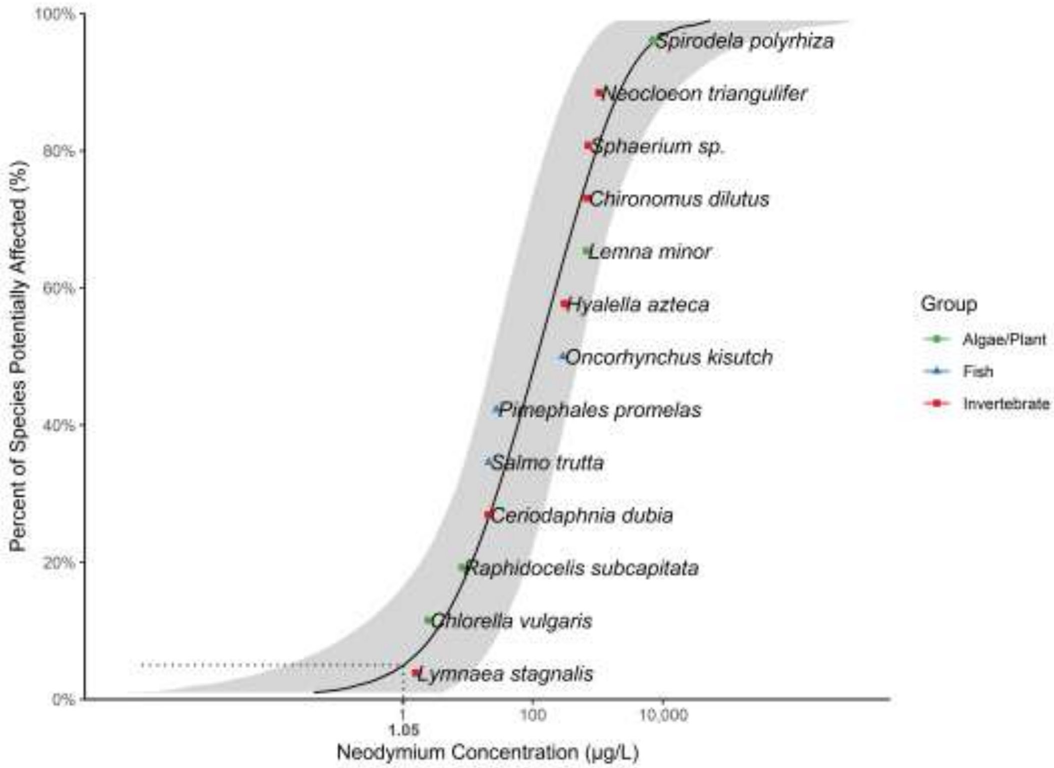

Figure 5. Species sensitivity distribution (SSD) for the chronic toxicity of neodymium in freshwater. The HC_5 (dotted line) is 1.1 µg Nd/L (rounded to two significant figures), and the shaded area shows the confidence intervals.

Yttrium

Short-term benchmark

Minimum CCME data requirements were met for a Type B2 approach (CCME 2007) for acute freshwater exposure to yttrium, including two fish and three invertebrate species. Table 10 contains the most sensitive LC_{50} or equivalent endpoint for each species in the acceptable acute toxicity dataset. The lowest endpoint was a 48-h EC_{50} of 217 µg Y/L for immobility of *Daphnia magna*. Following CCME protocol, the most sensitive LC_{50} or equivalent endpoint from an acute exposure study is the critical study to which a safety factor of 10 is applied to derive the short-term Type B2 benchmark. The safety factor of 10 accounts for differences in sensitivity to a chemical due to differences in species, exposure conditions, and test endpoints, as well as a paucity of toxicological data (CCME 2007). Therefore, the short-term freshwater benchmark for yttrium is 22 µg Y/L. Because the critical endpoint was for a dissolved measurement, the short-term yttrium benchmark applies to dissolved concentrations.

Table 13. Acute freshwater toxicity dataset for deriving the short-term benchmark for yttrium.

Group	Species Latin Name	Species Common Name	Endpoint	Effect Concentration (µg Y/L)	Concentration Type	Reference
Invertebrate	*Daphnia magna*	Water flea	48-h EC_{50} (immobility)	217	Dissolved	Shah 2022
Invertebrate	*Hydra attenuata*	Hydra	96-h LC_{50}	220	Nominal	Blaise et al. 2018
Fish	*Oncorhynchus mykiss*	Rainbow trout	96-h LC_{50}	700	Nominal	Dubé et al. 2019

Fish	*Danio rerio*	Zebrafish	96-h LC_{50}	45610	Measured[a]	Lora-Benitez et al. 2024
Invertebrate	*Tetrahymena shanghaiensis*	Ciliated protozoan	24-h IC_{50} (cell count)	73791	Nominal	Wang et al. 2000

[a] Measured concentration not specified in data source as total or dissolved
EC – effect concentration, h – hour, IC – inhibition concentration, LC – lethal concentration

Long-term guideline

Minimum CCME data requirements were met for a long-term yttrium guideline following a Type A approach (CCME 2007). The yttrium SSD dataset (Table 11) contained 12 endpoints, including four fish, five invertebrates, and three plant/algal species. *Chlorella vulgaris* was the most sensitive (72-h IC_{10} of 2.685 µg Y/L), while *Chironomus dilutus* was the least sensitive species (10-d IC_{10} of 830 µg Y/L). The HC_5 from the chronic SSD (Figure 6) represents the long-term guideline for yttrium and is 1.9 µg Y/L. The yttrium chronic dataset is mostly composed of endpoints for dissolved concentrations; therefore, the long-term guideline applies to the dissolved fraction of yttrium in water samples. The endpoint for *C. dubia* was not specified as a measurement for dissolved or total fraction, however, the endpoint was lower than dissolved endpoints for the same species from another study and was therefore included to err on the side of conservatism. A sensitivity analysis whereby the nominal endpoint for *L. minor* was excluded demonstrated minimal effect on the guideline value, and therefore the endpoint was retained to increase species representation.

Table 14. Chronic freshwater toxicity data for deriving the long-term guideline for yttrium.

Group	Species Latin Name	Species Common Name	Endpoint	Effect Concentration (µg Y/L)	Concentration Type	Reference
Algae/Plant	*Chlorella vulgaris*	Green alga	72-h IC_{10} (cell yield)	2.69	Dissolved	NRCan 2021a
Algae/Plant	*Raphidocelis subcapitata*	Green alga	72-h IC_{10} (cell yield)	5.67	Dissolved	NRCan 2021a
Invertebrate	*Ceriodaphnia dubia*	Water flea	7-d IC_{10} (mortality/ reproduction)	6.7	Measured[a]	Okamoto et al. 2021
Fish	*Pimephales promelas*	Fathead minnow	7-d larval IC_{10} (biomass)	12.9	Dissolved	NRCan 2017
Invertebrate	*Daphnia magna*	Water flea	21-d EC_{10} (growth)	19.80 (Geomean)	Dissolved	Do 2024
Invertebrate	*Hyalella azteca*	Lawn shrimp	14-d IC_{10} (dry weight)	25.98	Dissolved	NRCan 2018
Fish	*Oncorhynchus mykiss*	Rainbow trout	28-d MATC (wet weight)	53.33	Dissolved	Cardon et al 2019
Fish	*Salmo trutta*	Brown trout	28-d IC_{10} (dry weight)	90.88	Dissolved	NRCan 2017
Algae/Plant	*Lemna minor*	Common duckweed	7-d IC_{10} (dry weight)	226.13	Nominal	NRCan 2021a
Fish	*Oncorhynchus kisutch*	Coho salmon	35-d IC_{10} (length)	291.1	Dissolved	NRCan 2018
Invertebrate	*Neocloeon triangulifer*	Mayfly	14-d IC_{10} (dry weight)	690	Dissolved	NRCan 2019b
Invertebrate	*Chironomus dilutus*	Midge	10-d IC_{10} (dry weight)	830	Dissolved	NRCan 2019b

[a] Measured concentration not specified in data source as total or dissolved
d – days, EC – effect concentration, h – hour, IC – inhibition concentration, MATC – maximum acceptable toxicant concentration

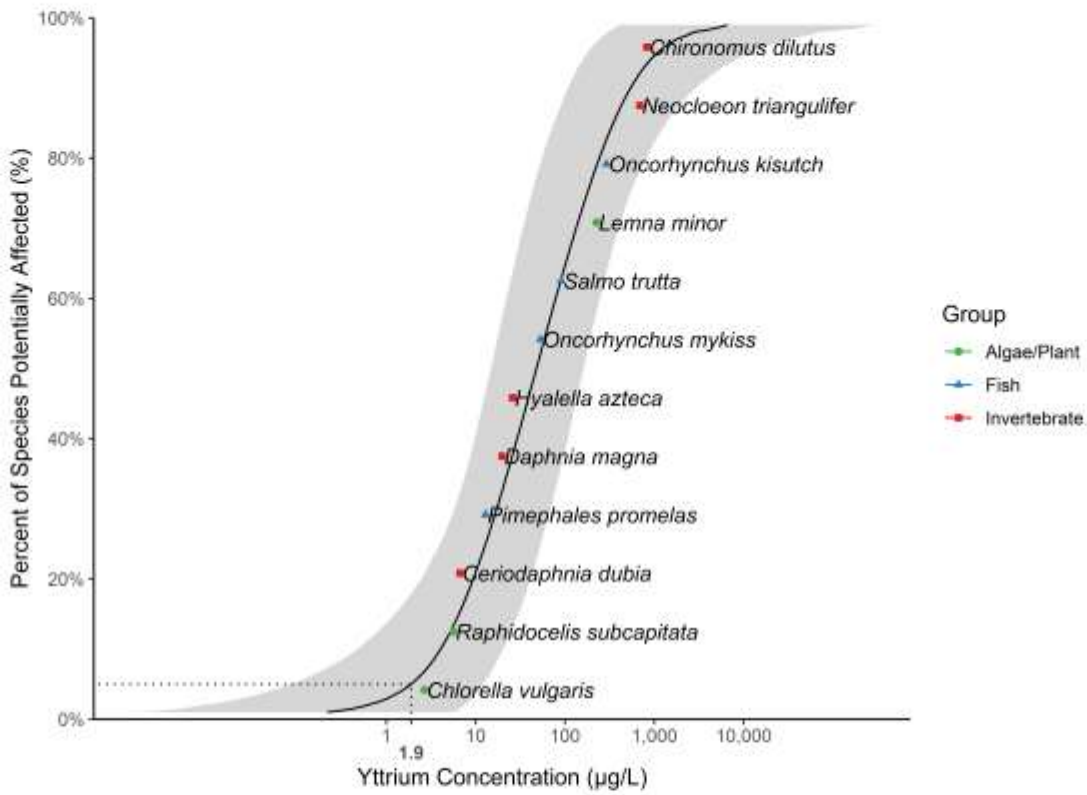

Figure 6. Species sensitivity distribution (SSD) for the chronic toxicity of yttrium in freshwater. The HC_5 (dotted line) is 1.9 µg Y/L, and the shaded area shows the confidence intervals.

Protectiveness assessment

To determine whether the long-term FWQGs for REEs are sufficiently protective and meet CCME's guiding principle (CCME 2007), a protectiveness assessment was completed using results of acceptable aquatic toxicity studies (that is, all acceptable acute and chronic toxicity data where organisms were exposed via an aqueous exposure (see Appendices A-D) were compared to the long-term guideline values). Any toxic effects observed at concentrations below the REE FWQGs for chronic exposure were examined to determine if the protection clause was applicable (CCME 2007). Note that only laboratory-derived data were used in this assessment. Assessing the protectiveness of the guidelines using data from natural ecosystems is beyond the scope of this document. No endpoints in the acceptable acute and chronic water toxicity datasets were below long-term guideline values for lanthanum, neodymium or yttrium. For cerium, there was one endpoint for *Daphnia magna* below the long-term cerium guideline (48-h EC_{50} for immobility of 0.91 µg Ce^{3+}/L as compared to the guideline of 1.6 µg dissolved Ce/L). However, this endpoint was for the free-ion concentration of cerium calculated using models and cannot be directly compared to measured dissolved or total concentrations. The dissolved measured concentration associated with that same EC_{50} endpoint from the same study and test conditions was well-above the guideline value. Additionally, there were 145 other acceptable endpoints for *Daphnia magna* in the cerium acute and chronic datasets for dissolved, total and free ion concentrations that were all above the long-term guideline (of which 140 endpoints were also EC_{50} values for immobility). Overall examination of the available data suggests the long-term FWQGs for cerium, lanthanum, neodymium and yttrium are consistent with the CCME guiding principle and are therefore intended to protect all forms of freshwater aquatic life for indefinite exposure periods.

Marine exposure

Minimum data requirements were not met for any approach to derive acute or chronic water guidelines for marine environments for cerium, lanthanum, neodymium or yttrium (see Appendices A-D). No acceptable marine data were available for cerium. Acceptable marine data for lanthanum were limited to a 72-h EC_{50} for developmental effects to *Arbacia lixula* of 2153 µg nominal La/L (Trifuoggi et al. 2017). For neodymium, acceptable data included 72-h LOEC (144 µg nominal Nd/L) and EC_{50} (216 µg nominal Nd/L) values for developmental effects to *A. lixula* (Trifuoggi et al. 2017) and a 48-h EC_{50} of 46,660 µg nominal Nd/L for immobility for *Artemia salina* (Bergsten-Torralba et al. 2020). Acceptable marine data for yttrium were limited to a 72-h LOEC (89 µg nominal Y/L) and EC_{50} (356 µg nominal Y/L) for developmental effects to *A. lixula* (Trifuoggi et al. 2017). It is not appropriate to apply the freshwater REE guidelines to marine or estuarine environments due to uncertainty in the relative toxicity of REEs in fresh water compared to saltwater.

Sediment Toxicity

Testing with sediment collected from an area in Quebec naturally enriched in light REEs found physiochemical properties of sediment were important factors for REE availability and toxicity. A positive correlation was found with total REEs and fine grain size, base saturation, Fe and Al, and carbonate content (that is, greater availability and toxicity observed), while a negative correlation was found with sand, coarse silt, organic carbon and cation exchange capacity (that is, lower availability and toxicity observed) (Romero-Freire et al. 2018). Other tests conducted with sediment naturally enriched with REEs from a prospective mining area in Northern Quebec (∑REE concentration 118 mg/kg dw) demonstrated decreased locomotor activity and impaired osmoregulation in acute exposures and reproductive effects in chronic exposures with the amphipod *Gammarus fossarum* (Mehennaoui et al. 2024). Data from studies using naturally enriched sediment were not considered appropriate for guideline derivation due to the presence of multiple REEs.

Data on sediment-dwelling organisms using spiked-sediment toxicity testing were available for several species and demonstrated adverse effects on survival and growth for some species of benthic plant and invertebrates (see Appendices E-H). Laboratory data using spiked-sediment toxicity testing with a single REE per exposure were considered for derivation of sediment quality guidelines. The sediment toxicity data in this factsheet are current to July 2024. The majority of the available sediment toxicity data were derived from tests commissioned by NRCan.

Federal Sediment Quality Guidelines

Federal Sediment Quality Guidelines (FSeQGs) are intended to protect sediment-dwelling biota. The guidelines apply to indefinite exposure periods to sediments and specify the concentration found in bulk sediment (dry weight) not expected to result in adverse effects. REEs are likely to bind to sediment particles (Weltje et al. 2002b; Hermann et al. 2016), thus highlighting the relevance of sediment quality guidelines for REEs.

Sediment quality guidelines can be developed according to two approaches (CCME 1995): (i) the National Status and Trends Program (NSTP) or (ii) the Spiked-Sediment Toxicity Test (SSTT). Since there were insufficient sediment data for the former, the NSTP approach was not considered further. For SSTT, low-effect endpoints are the preferred endpoint type for guideline derivation following CCME protocol (1995). Specifically, four studies (two of which must be partial or full life-cycle tests) are required on two or more sediment-dwelling North American invertebrate species (including one arthropod and one crustacean). Minimum data requirements for the SSTT approach were not strictly met, as only two studies were available for each element rather than the required four studies (see full sediment toxicity dataset in Appendices E-H).

NRCan (2019a) commissioned spiked sediment toxicity tests for the freshwater larval midge (*Chironomus dilutus*) and an amphipod (*Hyalella azteca*) for cerium, lanthanum, neodymium and yttrium, following the standardized sediment test methods of Environment Canada (1997, 2017). No adverse effects were observed for *C. dilutus*, whereas reduced survival was observed for *H. azteca* resulting in LC_{50} values of 342 mg Ce/kg dw, 375 mg La/kg dw, >391 mg Nd/kg dw and 243 mg Y/kg dw (see Appendices E-H). The growth of *H. azteca* was also reduced at the higher concentrations of these REEs, resulting in IC_{20} values of 211 mg Ce/kg dw, 225 mg La/kg dw, 323 mg Nd/kg dw and 206 mg Y/kg dw (Table 12, Appendices E-H). These sediment toxicity results are consistent with the water-based toxicity tests where *C. dilutus* was found to be less sensitive to REEs than *H. azteca* (NRCan 2018, 2019a, b). Sediment toxicity data from peer-reviewed journals were included as available. Data for the aquatic macrophyte *Myriophyllum aquaticum* demonstrated less sensitivity compared to *H. azteca* (10-d LOEC of 500 mg/kg lanthanum dw (Table 12); NOEC >500 mg/kg dw for cerium and neodymium (Appendices E-G)). For the derivation of the FSeQGs, IC/EC_{20} values were selected as the preferred endpoint to represent a low-effect level, consistent with CCME's aquatic life protocol (CCME 2007). The preferred low-effect endpoint for each species and element can be found in Table 12, while the full sediment toxicity dataset can be found in Appendices E-H.

Table 15. Sediment toxicity endpoints for organisms exposed to cerium, lanthanum, neodymium and yttrium and the respective Federal Sediment Quality Guidelines (FSeQGs).

Element	Species Latin Name	Species Common Name	Endpoint	Effect Concentration (mg/kg dw)[a]	OC-adjusted Effect Concentration (mg/kg dw)[b]	Reference	FSeQG (mg/kg dw)[c]
Cerium	*Hyalella azteca*	Lawn shrimp	14-d IC_{20} (growth)	211	248	NRCan 2019a	25
Cerium	*Chironomus dilutus*	Midge	10-d IC_{20} (growth)	>857	>1008	NRCan 2019a	-
Lanthanum	*Hyalella azteca*	Lawn shrimp	14-d IC_{20} (growth)	225	265	NRCan 2019a	27
Lanthanum	*Myriophyllum aquaticum*	Eurasian watermil-foil	10-d LOEC (growth)	500[d]	N/A	Gjata et al. 2024	-
Lanthanum	*Chironomus dilutus*	Midge	10-d IC_{20} (growth)	>844	>993	NRCan 2019a	-
Neodymium	*Hyalella azteca*	Lawn shrimp	14-d IC_{20} (survival)	244	287	NRCan 2019a	29
Neodymium	*Chironomus dilutus*	Midge	10-d IC_{20} (growth)	>391	>460	NRCan 2019a	-
Yttrium	*Hyalella azteca*	Lawn shrimp	14-d IC_{20} (growth)	206	242	NRCan 2019a	24
Yttrium	*Chironomus dilutus*	Midge	10-d IC_{20} (growth)	>536	>631	NRCan 2019a	-

[a] Tests performed in 0.85% organic carbon (OC) sediment unless otherwise noted.
[b] Concentration adjusted to 1% organic carbon sediment.
[c] Final guideline values are rounded to two significant figures.
[d] Percent organic carbon in sediment not reported in study.
IC – inhibition concentration, LOEC – lowest observed effect concentration, N/A – not available, '-' – not applicable

Toxicity values were normalized to 1% organic carbon (OC) sediment because FSeQGs are typically derived for 1% OC sediment to provide a conservative benchmark for which to compare monitoring data. A safety factor of 10 was applied to OC-normalized IC_{20} values to yield sediment quality guidelines of 25, 27, 29 and 24 mg/kg dw for cerium, lanthanum, neodymium and yttrium, respectively (Table 12). The safety factor of 10 was chosen for lab to field extrapolation and because of limitations in the dataset (that is, four toxicity studies were not available as per minimum data requirements; CCME 1995). The FSeQG applies to freshwater sediments only. While making comparisons to the FSeQG, monitoring data should be normalized to 1% OC to assess whether the guideline value is exceeded.

Additional Considerations

In the case of the water quality guidelines for REEs that apply to dissolved concentrations, these should be compared to monitoring data for dissolved samples. If guideline users only have total concentrations for their site, it is recommended that they first compare their total concentration to the dissolved REE guideline, and where there is an exceedance, re-sample the waterbody for the dissolved concentrations. In the case of the REE guidelines that apply to total concentrations (that is, short-term benchmarks for cerium and lanthanum), these should be compared to monitoring data based on total concentrations.

Because REEs are naturally occurring elements in the environment, consideration can be given to natural background concentrations at sites with guideline exceedances. There may be cases where natural background concentrations exceed the guideline without apparent effects on aquatic organisms (for example, if the substance is not present in a bioavailable form). Under these circumstances, it may be necessary to modify water quality guidelines to account for conditions that occur at the site. CCME (2003) provides guidance on two methods for establishing site-specific water quality objectives, which can be: 1) slightly above the natural background level, or 2) at the upper limit of natural background concentrations. To define natural background levels, it is recommended that research is conducted into historical records of elevated REE concentrations with historical land uses (that is, before and after human activity, and analysis of REE concentration trends). An extensive dataset of water parameters over several consecutive years for each site is required to estimate natural background levels.

Lastly, Jreije et al. (2022) found that the use of different membrane filter types, all with the same pore size of 0.45 µM, greatly affected the recovery of total and dissolved cerium from laboratory-prepared solutions, as well as for those sampled from rain and river water. Although the research is still ongoing, filter type appears to be an important consideration when working with REEs and should be noted in future studies to better account for its potential confounding effects.

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List of Acronyms and Abbreviations

AICc – Akaike information criterion corrected for small sample size
BAF – bioaccumulation factor
BC EMS - British Columbia Environmental Monitoring System
BCF – bioconcentration factor
BQMA - Banque de données sur la Qualité du Milieu Aquatique
CAS RN – Chemical Abstracts Service registry number
CCME – Canadian Council of Ministers of the Environment
CEPA – Canadian Environmental Protection Act
CETIS – Comprehensive Environmental Toxicity Information System
CMP – Chemicals Management Plan
CREEN – Canadian Rare Earth Elements Network
DOM – dissolved organic matter
dw – dry weight
ECCC – Environment and Climate Change Canada
EC_x – effect concentration to x% of test species
ECHA – European Chemicals Agency
FEQG – Federal Environmental Quality Guideline
FSeQG – Federal Sediment Quality Guideline
FWQG – Federal Water Quality Guideline
GC – Government of Canada
GM – geometric mean
HC_5 – hazard concentration at the 5^{th} percentile
HREE – heavy rare earth elements
IC_x – concentration that causes x% inhibition in test species
LCD – liquid-crystal display
LC_x – lethal concentration to x% of test species
Log $Kp_{(sed/wat)}$ – Sediment-water partition coefficient
LOEC – lowest observed effect concentration
LREE – light rare earth elements
MATC – maximum acceptable toxicant concentration (geometric mean of the NOEC and LOEC)
MELCC - Ministère de l'Environnement et de la Lutte contre les changements climatiques
MITE – Metals in the Environment
NLTWQM - National Long Term Water Quality Monitoring
NOEC– no observed effect concentration
NRCan – Natural Resources Canada
NSTP – National Status and Trends Program
OC – organic carbon
REACH - Registration, Evaluation, Authorisation, and Restriction of Chemicals
REE – rare earth elements
RSS – robust study summary
SSD – species sensitivity distribution
SSTT – Spiked-Sediment Toxicity Test
TMF – toxicity modifying factor
ww – wet weight