Canadian Water Quality Guidelines for the Protection of Aquatic Life

CADMIUM

Cadmium occurs naturally in the environment. Its Chemical Abstract Service (CAS) number is 7440-43-9. It is a transition metal with a density of 8.642 $g \cdot cm^{-3}$ and a molecular weight of 112.40 $g \cdot mol^{-1}$. It is typically found in rock as a minor constituent in mineral sulphides, particularly zinc sulphides such as sphalerite and wurtzite (Nriagu 1980).

The two oxidation states of cadmium are the metallic (Cd^0) and divalent (Cd^{2+}). The metallic state is rare, and thus, the divalent state predominates in most natural deposits (NRCC 1979). While metallic cadmium is insoluble in water, several of its salts are freely soluble (Merck 1989).

Cadmium may exist as a variety of different chemical species in natural waters. Such chemical speciation is significant in relation to its geochemical and biochemical processes in the environment as well as toxicity. In the dissolved phase, cadmium may be present as hydrated ions, chloride salts, complexed with inorganic ligands, or chelated to form complexes with organic ligands (Raspor 1980). The main toxic form of Cd is the free Cd^{2+} ion; however other forms of cadmium, for example those bound to various ligands, may also cause adverse effects.

Analytical detection methods for environmental samples: Several methods such as flame atomic absorption (FAA), graphite furnace absorption (GFAA), direct current plasma emission (DCP) and inductively coupled plasma emission (ICP) or mass spectrometry (ICP-MS) are used to measure cadmium concentrations in environmental samples (Beaty and Kerber 2002).

Speciation of metals, including cadmium, in water is often related to the observed toxicity. However, most detection methods measure the total amount of cadmium in a sample, and provide little or no information on its speciation in water. Speciation of cadmium can be predicted using geochemical models, for example the Windermere Humic Aqueous Model (WHAM) (Tipping 1994; Vigneault and Campbell 2005). However, in most environmental monitoring and toxicity studies, cadmium concentrations are reported as total or dissolved cadmium, where "dissolved" is defined operationally as that Cd which passes through a 0.45 µm filter.

Production and uses: Of the approximately 77 active metal mines in Canada in 2007, only one was listed as a producer of cadmium. It is the Kidd Creek Mine (operated by Xstrata Copper Canada) which sends ores to Kidd Metallurgical Site, located in Timmins, Ontario (NRCan 2007). Cadmium production remained relatively constant through the late 1980s and 1990s but has been decreasing since 1999. Preliminary estimates for 2005 indicate that production is only 30-50% that seen in the mid-1990s, which was around 1 500 000 kg of cadmium. However, cadmium contamination can occur in areas where other metals, for example zinc, are mined, even if cadmium is not the primary metal being produced.

Cadmium is mainly recovered as a by-product from the smelting of zinc and other metal ores, and from precipitates obtained during the purification of zinc sulphate (Brown 1977). About 90% of Canadian production is exported, mostly to the United States and Japan (NRCan 2005). In 2004, 210 tonnes of cadmium were used in Canada (NRCan 2005). In 2004, the five major industrial uses of cadmium worldwide were nickel-cadmium batteries (79%), pigments (11%), coatings (7%), stabilizers in plastics and synthetic products (2%) and alloys (<1%) (NRCan 2005). Nickel-cadmium batteries are not manufactured in Canada (EC 1994).

Table 1. Canadian Water Quality Guidelines (CWQG) for the protection of aquatic life for cadmium.

	Long-term Exposure ($\mu g \cdot L^{-1}$)	**Short-term Exposure ($\mu g \cdot L^{-1}$)**
Freshwater	0.09[a]	1.0[b]
Marine	0.12[c]	NRG

NRG = no recommended guideline

[a] The long-term CWQG of 0.09 $\mu g \cdot L^{-1}$ is for waters of 50 mg $CaCO_3 \cdot L^{-1}$ hardness. At other hardness values, the CWQG can be calculated with the equation CWQG = $10^{\{0.83(\log[\text{hardness}]) - 2.46\}}$, valid for hardness between 17 and 280 mg $CaCO_3 \cdot L^{-1}$.

[b] The short-term benchmark concentration of 1.0 $\mu g \cdot L^{-1}$ is for waters of 50 mg $CaCO_3 \cdot L^{-1}$ hardness. At other hardness values, the benchmark can be calculated with the equation Benchmark = $10^{\{1.016(\log[\text{hardness}]) - 1.71\}}$, valid for hardness between 5.3 and 360 mg $CaCO_3 \cdot L^{-1}$.

[c] This value was not assessed as part of the present update; value is from CCME (1996).

Anthropogenic sources to the environment: Global anthropogenic releases of cadmium into freshwater aquatic environments are estimated at 2100 to 17 000 tonnes per year, approximately 40% of which can be attributed to effluents from smelting and refining industries, and to atmospheric fallout (Nriagu and Pacyna 1988). In the marine environment, 2600 tonnes per year enter the world's oceans through atmospheric deposition, while 1500–2000 tonnes per year enter via river runoff (Yeats and Bewers 1987).

Environmental Concentrations: As a naturally occurring element, the presence of cadmium in water does not necessarily indicate pollution. As a result of geochemical processes, some areas naturally contain elevated concentrations of cadmium in underlying rock. The spatial and temporal variability in natural background concentrations of cadmium in water bodies is determined not only by the mineral composition of the surrounding environment, but also depends on abiotic processes such as weathering, climate, soil type, pH, dilution (e.g., due to rainfall, snowmelt, other seasonal variations), and redox potential (NRCan 2004). In other areas, anthropogenic activity may cause elevated concentrations of cadmium thereby exceeding the natural background levels.

Surface waters across Canada show a large range of cadmium concentrations. The Environmental Water Quality Database (1992) reported cadmium levels of <0.1 µg L^{-1} to 1.3 µg L^{-1} (mean = 0.1 µg L^{-1}) in the Yukon and <0.1 to 15.4 µg L^{-1} (mean = 0. 4 µg L^{-1}) in the Northwest Territories. It has also indicated that freshwater cadmium concentrations in British Columbia ranged from <0.1 to 8.6 µg L^{-1}, with a mean of 0.2 µg L^{-1} (ENVIRODAT 1992). Regarding the Prairie provinces, surface waters had cadmium concentrations ranging from <0.1 to 112 µg L^{-1} (an extreme value) (mean = 0.3 µg L^{-1}) in Alberta, from <0.1 to 0.4 µg L^{-1} (mean = 0.2 µg L^{-1}) in Saskatchewan, and from <0.1 to 2.2 µg L^{-1} (mean = 0.2 µg L^{-1}) in Manitoba (ENVIRODAT 1992). Dissolved and particulate concentrations of cadmium in surface waters from Ontario range from <0.001 to 4.78 µg L^{-1} (Allan and Ball 1990; Campbell and Evans 1991; Hinch and Stephenson 1987; Lum 1987; Stephenson and Mackie 1988). Data on surface water cadmium concentrations in Québec summarized from ENVIRODAT (1992) indicated a mean concentration of 0.3 µg L^{-1} (<0.1–10.8 µg L^{-1}). Surface water monitoring data from the Great Lakes reported cadmium concentrations range from below detection limits (<0.001 µg L^{-1}) to 0.098 µg L^{-1} (Lochner and Water Quality Monitoring and Surveillance 2008). Cadmium concentrations in surface water samples from various lakes and ponds in Nova Scotia had a median cadmium concentration of <0.6 µg L^{-1}, with a range of <0.6 to 2.9 µg L^{-1} (Nova Scotia Environment 2008). Data analyzed from Newfoundland and Labrador surface waters for total cadmium indicates a range of <0.001 to 2.3 ug/L (mean =0.1 ug/L) throughout the province (ENVIRODAT 1992).

Environmental fate and behaviour: The environmental fate and behaviour of cadmium is dependent on abiotic conditions, such as pH, hardness, and alkalinity, and natural organic matter. These factors influence the toxicity and mobility of cadmium by altering the speciation, or physiochemical forms, of cadmium in aquatic systems. Factors such as pH, oxidation/reduction potential (redox), and the type and abundance of organic ligands, hydroxides, and cations present could influence the speciation of cadmium in high pH conditions (Raspor 1980). Because cadmium has a high affinity for negatively charged particle surfaces such as hydroxides, carbonates, and organic matter, sorption and complexation processes could affect cadmium fate in waters containing high concentrations of organic and inorganic ligands (Callahan *et al.* 1979).

Mode of Action: Cadmium is a non-essential metal in aquatic organisms except for a marine diatom (*Thalassiosira weissflogii*) for which it is a minor nutrient at low concentrations (Lane and Morel 2000; Lee *et al.* 1995; Price and Morel 1990). Cadmium, at least in short-term exposures, exerts its toxic effects in aquatic organisms by blocking the uptake of calcium from water. Calcium (Ca^{2+}) is an essential element which is taken up by organisms from water via specialized calcium channels. However, when cadmium (Cd^{2+}) is present in water, this metal competes with calcium for binding sites, inhibiting calcium uptake and resulting in hypocalcaemia (Roch and Maly 1979).

Toxicity modifying factors: Water chemistry conditions can influence the toxicity of cadmium to aquatic organisms. The influence of hardness, alkalinity, pH, dissolved organic matter and temperature on cadmium toxicity was assessed. However, only hardness had sufficient data to demonstrate a clear relationship between water hardness and cadmium toxicity.

Hardness is defined as the sum of polyvalent cations, primarily calcium (Ca^{2+}) and magnesium (Mg^{2+}) cations in solution. Water hardness strongly influences the toxicity of cadmium to aquatic organisms. Higher water hardness generally reduces the toxicity of cadmium to aquatic organisms. Since cadmium toxicity in aquatic organisms is caused by calcium deficiency, higher water hardness (particularly calcium hardness) reduces cadmium toxicity because the calcium ions compete more successfully with cadmium for uptake sites (Niyogi and Wood 2004).

Of water quality parameters that could potentially influence the cadmium uptake (hardness, pH, alkalinity, and dissolved organic matter), hardness is the major factor influencing cadmium toxicity (Calamari *et al.* 1980;

Hansen *et al.* 2002; Hollis *et al.* 1997; Hollis *et al.* 2000a; Hollis *et al.* 2000b; Penttinen *et al.* 1998). Empirical relationships have been derived (for both short-term and long-term studies) to convert these data to a standardized hardness, and these relationships were then used in deriving this CWQG for cadmium. First, this relationship was used to adjust toxicity endpoints to a common hardness of 50 mg·L^{-1} as $CaCO_3$ in order to compare cadmium toxicity data from different studies for all species used in derivation of the CWQGs. Those hardness-toxicity slopes were also incorporated into the CWQGs which are presented as equations rather than single values, allowing the user to derive a cadmium guideline based on the water hardness of the site under consideration.

The CWQG equations were derived based on the methods established by Stephan *et al.* (1985) by investigating the log-log relationships and deriving a pooled slope based on an analysis of covariance. This relationship was established by selecting those freshwater aquatic species for which acute toxicity data were available over a wide range of hardness. In order for a species to be included, definitive acute values had to be available over a range of hardness such that the highest hardness was at least three times the lowest, and such that the highest was at least 100 mg·L^{-1} higher than the lowest (U.S. EPA 2001). Thirteen species met these criteria for short-term data (Table 2) while seven species were used for the long-term hardness-toxicity slope derivation (Table 3). The selected data were plotted into a regression of logarithm (log base 10) of toxicant concentration as the dependent variable against the log of hardness as the independent variable. A slope of the hardness-toxicity relationship was calculated for each of these fish and invertebrate species for short-term and long-term separately. An F-test showed that the slopes for all species were not significantly different from each other. An analysis of covariance was performed to calculate the pooled slope for hardness using the logarithm of toxicity values as the dependant variable, species as the treatment or grouping variable, and the logarithm of hardness as the covariate or independent variable. The pooled slope is thus equivalent to a regression slope from a pooled data set, where every variable is adjusted relative to its mean (U.S. EPA 2001). Species individual slopes and pooled slopes for short-term and long-term hardness toxicity relationships are reported in Table 2 and 3 respectively.

Table 2. Short-term hardness-toxicity individual regression slope for each species and the overall pooled regression slope.

Species	n	Slope	R^2
Carassius auratus	3	1.729	0.619
Ceriodaphnia reticulata	3	0.293	0.504
Daphnia magna	5	1.179[a]	0.909
Daphnia pulex	4	1.473[a]	0.975
Hyalella azteca	3	0.629	0.988
Lepomis cyanellus	3	1.037	0.938
Morone saxatilis	2	0.467	-
Oncorhynchus mykiss	21	1.197[a]	0.53
Oncorhynchus tshawytscha	4	1.329[a]	0.993
Pimephales promelas	11	1.27[a]	0.814
Salmo trutta	4	1.37[a]	0.96
Tubifex tubifex	3	0.418	0.9
Danio rerio	2	0.917	-
Pooled slope for all species	68	1.016[a,b]	0.966

[a] Slope is significantly different than 0 ($p<0.05$).
[b] Individual slopes not significantly different ($p = 0.286$).

Table 3. Long-term hardness-toxicity individual regression slope for each species and the overall pooled regression slope.

Species	n	Slope	R^2
Salmo trutta	3	1.234[a]	0.995
Daphnia magna	3	1.123	0.903
Hyalella azteca	4	0.799[a]	0.93
Aeolosoma headleyi	3	0.749	0.786
Daphnia pulex	4	0.504	0.617
Salvelinus fontinalis	4	0.619[a]	0.98
Pimephales promelas	2	0.891	-
Pooled slope for all species	23	0.83 [a,b]	0.985

[a] Slope is significantly different than 0 ($p<0.05$).
[b] Individual slopes not significantly different ($p = 0.397$).

Toxicity to freshwater organisms: Toxicity of cadmium to aquatic life is affected by ambient water quality. The following section summarizes the most sensitive and least sensitive species in each taxonomic group in both short- and long-term studies. Note that this section relates only to those data selected for inclusion in the species sensitivity distribution (SSD). Toxicity values described in this section that have been adjusted to 50 mg·L^{-1} hardness (as $CaCO_3$ equivalents) have been identified using the term “hardness-adjusted”.

The most sensitive fish species was the rainbow trout (*Oncorhynchus mykiss*) with a hardness-adjusted 96-h LC_{50} value of 0.47 µg·L^{-1} (Hollis *et al.* 2000b) and a hardness-adjusted 62-d EC_{10} for weight in the early life stage of *O. mykiss* of 0.23 µg·L^{-1} (Mebane *et al.* 2008). The least sensitive fish in short-term experiments was the grass carp (*Ctenopharyngodon idellus*) which had a 96-h LC_{50} of 9420 µg·L^{-1} (Yorulmazlar and Gül 2003). The least sensitive long-term endpoint for fish was a hardness-adjusted 35-d MATC of 8.03 µg·L^{-1} for decrease in biomass for embryos of the Northern pike (*Esox lucius*) (Eaton *et al.* 1978).

For invertebrates, the most sensitive were the cladocerans (water fleas, daphnids), amphipods (e.g., *Hyalella sp.*), and hydras in both short- and long-term exposure. The most sensitive short-term invertebrate endpoint was for *Hyalella azteca*, with a hardness-adjusted 96-h LC_{50} of 0.84 µg·L^{-1} (Schubauer-Berigan *et al.* 1993). The most sensitive long-term endpoint was a hardness-adjusted 7-d EC_{10} value (for both reproduction and feeding inhibition) for *Daphnia magna* of 0.045 µg·L^{-1} (Barata and Baird 2000). The least sensitive species to short-term exposure was the damselfly (*Enallagma sp.*), with a hardness-adjusted 96-h LC_{50} value of 28900 µg·L^{-1} (Mackie 1989). Of all long-term data, the least sensitive endpoint was a hardness-adjusted 7-day MATC for the survival of a dragonfly, *Pachydiplax longipennis*, with a value of 76500 µg·L^{-1} (Tollett *et al.* 2009).

The most sensitive amphibian species was the Northwestern salamander (*Ambystoma gracile*) with a hardness-adjusted 96-h LC_{50} value of 521 µg·L^{-1} and a hardness-adjusted 24-d MATC of 106 µg·L^{-1} (Nebeker *et al.* 1995). The least sensitive species was the Argentine toad (*Bufo arenarum*) with a hardness-adjusted 96-h LC_{50} value of 1360 µg·L^{-1} (Ferrari *et al.* 1993).

Due to the rapid growth and turnover of algal/aquatic plant species, it is difficult to obtain short-term data. Most toxicity studies are carried out over a period of 1-4 days, which would be classified as long-term relative to the lifespan of many algae/plants. Thus, no suitable short-term toxicity data were obtained for algae/plants. In long-term experiments, the most sensitive species was the green alga *Ankistrodesmus falcatus*, with a hardness-adjusted 96-h no observable effect concentration (NOEC) for growth of 4.9 µg·L^{-1} (Baer *et al.* 1999). The least sensitive species was a duckweed, *Lemna minor*, with a hardness-adjusted 7-d EC_{50} for growth of 79.0 µg·L^{-1} (Drost *et al.* 2007).

Water quality guideline derivation: The short and long-term freshwater CWQGs for cadmium for the protection of aquatic life were developed based on the CCME protocol (CCME 2007) using the statistical (Type A) approach.

Short-term freshwater benchmark concentration: Short-term exposure benchmark concentrations are derived using severe-effects data (such as lethality) of defined short-term exposure periods (24-96h). These benchmarks identify estimators of severe effects to the aquatic ecosystem and are intended to give guidance on the impacts of severe, but transient, situations (e.g., spill events to aquatic receiving environments and infrequent releases of short-lived/nonpersistent substances). Short-term benchmark concentrations *do not* provide guidance on protective levels of a substance in the aquatic environment, as short-term benchmarks are levels which *do not* protect against adverse effects.

The minimum data requirements for the Type A guideline approach were met, and a total of 62 data points were used in the derivation of the short-term benchmark concentration. Toxicity studies meeting the requirements for primary and secondary data, according to CCME (2007) protocol, were considered in the derivation of the short-term SSD. Each species for which appropriate short-term toxicity was available was ranked according to effect concentration, and its position on the SSD (proportion of species affected) was determined using the Hazen plotting position (estimate of the cumulative probability of a data point). When more than one endpoint was available for a species, a geometric mean of the values was taken if the endpoints had the same life stage, duration, effect and experimental conditions. All "effect" concentrations were adjusted to a hardness of 50 mg·L^{-1} $CaCO_3$ where possible using the short-term slope of the hardness-toxicity relationship. Table 4 presents the final dataset that was used to generate the short-term fitted SSD for cadmium.

Table 4. Endpoints used to determine the short-term freshwater benchmark concentration for cadmium.

Species	Endpoint	Concentration (μg Cd·L^{-1})
Fish		
Oncorhynchus mykiss	96 h LC50	0.47
Salmo trutta	96 h LC50	1.61
Morone saxatilis	96 h LC50	1.71
Cottus bairdi	96 h LC50	1.74
Salvenlinus confluentus	96 h LC50	1.97*
Oncorhynchus tshawytscha	96 h LC50	3.96
Oncorhynchus kisutch	96 h LC50	4.16
Thymallus arcticus	96 h LC50	4.89
Prosopium williamsoni	96 h LC50	4.92
Pimephales promelas	96 h LC50	10.1
Danio rerio	96 h LC50	603
Carassius auratus	96 h LC50	844
Catostomus commersoni	96 h LC50	3130
Lebistes reticulatus	96 h LC50	3220
Perca flavescens	96 h LC50	3350
Lepomis macrochirus	96 h LC50	4920
Ictalurus punctatus	96 h LC50	5050
Lepomis cyanellus	96 h LC50	7210
Ctenopharyngodon idellus	96 h LC50	9420
Invertebrates		
Hyalella azteca	96 h LC50	0.84
Daphnia magna	72 h LC50	0.91
Hydra viridissima	96 h LC50	7.81
Daphnia ambigua	48 h LC50	10.1
Lampsilis rafinesqueana	96 h EC50	22.8
Simocephalus serrulatus	48 h LC50	28.2
Daphnia pulex	96 h LC50	30.3
Ceriodaphnia dubia	48 h LC50	31.5
Ceriodaphnia reticulata	48 h LC50	37.4
Gammarus pseudolimnaeus	96 h LC50	40.4
Lampsilis siliquoidea	48 h EC50	44.6*
Hydra vulgaris	96 h LC50	54.9
Simocephalus vetulus	48 h LC50	66.3
Aplexa hypnorum	96 h LC50	104.9
Lumbriculus variegatus	96 h LC50	131
Tubifex tubifex	96 h LC50	250
Chironomus plumosus	96 h LC50	300
Paraleptophlebia praepedita	96 h LC50	334
Procambarus acutus	96 h LC50	414
Orconectes placidus	96 h LC50	553
Procambarus clarkii	96 h LC50	589
Chironomus tentans	96 h LC50	727
Chironomus riparius	96 h LC50	762
Limnodrilus hoffmeisteri	96 h LC50	1660
Brachiura sowerbyi	96 h LC50	2350
Pisidium casertanum	96 h LC50	2570*
Pisidium compressum	96 h LC50	2690*
Orconectes juvenilis	96 h LC50	2770
Quistadrilus multisetosus	96 h LC50	3130
Procambarus alleni	96 h LC50	3360
Spirosperma ferox	96 h LC50	3420
Varichaeta pacifica	96 h LC50	3720
Orconectes virilis	96 h LC50	3890
Spirosperma nikolskyi	96 h LC50	4400
Stylodrilus heringianus	96 h LC50	5380
Rhyacodrilus montana	96 h LC50	6160
Potamopyrgus antipodarum	48 h LC50	7200
Rhithrogena hageni	96 h LC50	10900
Orconectes immunis	96 h LC50	11 500
Amnicola limosa	96 h LC50	13 400*
Enallagma sp.	96 h LC50	28 900*
Amphibians		
Ambystoma gracile	96 h LC50	521
Bufo arenarum	96 h LC50	1360

*Value shown is the geometric mean of comparable values.

The log-normal model provided the best fit of the models tested (Anderson-Darling statistic (A^2) = 1.5). The equation of the model is on the form:

$$f(x) = \frac{1}{2}\left(1 + erf\left(\frac{x-\mu}{\sigma\sqrt{2}}\right)\right)$$

Where, for the fitted model: x = log (concentration), μ = 2.52 and σ = 1.52 are the location and scale parameters, and f(x) is the proportion of taxa affected. The short-term SSD is shown in Figure 1. Summary statistics for the short-term SSD are presented in Table 5. The 5th percentile on the short-term SSD is 1.0 μg·L^{-1} cadmium.

Table 5. Short-term benchmark concentration for cadmium derived using the SSD method. (LFL = lower fiducial limit; UFL = upper fiducial limit).

	Concentration (μg Cd·L^{-1})
SSD 5th percentile	1.0
SSD 5th percentile, LFL (5%)	0.86
SSD 5th percentile, UFL (95%)	1.3

Because water hardness decreases cadmium toxicity to freshwater aquatic organisms, the freshwater guideline is expressed as an equation into which the local water hardness must be entered in order to produce an appropriate site-specific benchmark concentration. The short-term benchmark equation is based on the short-term toxicity-hardness relationship with a slope value of 1.016 and the short-term cadmium 5th percentile value at 50 mg·L^{-1} hardness of 1.0 μg Cd·L^{-1}. The general equation describing this linear regression and therefore, the **equation to derive the short-term freshwater benchmark concentration** is the following:

$$\boxed{\text{Benchmark} = 10^{\{1.016(\log[\text{hardness}]) - 1.71\}}}$$

where the benchmark is expressed in total cadmium concentration (μg·L^{-1}) and hardness is measured as $CaCO_3$ equivalents in mg·L^{-1}.

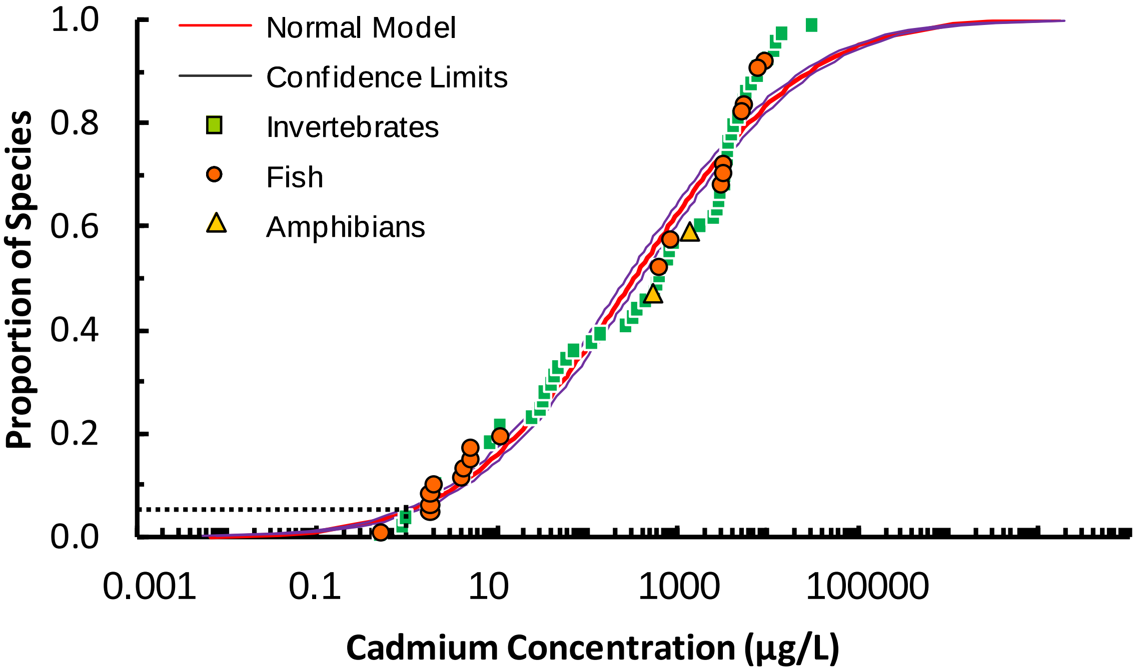

Figure 1. Short-term species sensitivity distribution (SSD) for cadmium in freshwater derived by fitting the log-normal model to the short-term LC_{50}s of 62 aquatic species.

Long-term freshwater quality guideline: Long-term exposure guidelines identify benchmarks in the aquatic ecosystem that are intended to protect all forms of aquatic life for indefinite exposure periods. The minimum data requirements for the Type A guideline approach were met, and a total of 36 data points were used in the derivation of the guideline. Toxicity studies meeting the requirements for primary and secondary data, according to CCME (2007) protocol, were considered in the derivation of the long-term SSD. Each species for which appropriate long-term toxicity was available was ranked according to effect concentration and its position on the SSD (proportion of species affected) was determined using Hazen plotting positions. When more than one endpoint was available for a species, a geometric mean of the values was taken if the endpoints had the same life stage, duration, effect and experimental conditions. All cadmium effect values were adjusted to a hardness of 50 mg·L^{-1} as $CaCO_3$ using the long-term slope of the hardness-toxicity relationship. Table 6 presents the final dataset that was used to generate the fitted SSD for cadmium.

Table 6. Endpoints used to determine the long-term CWQG for cadmium.

Species	Endpoint	Concentration (µg Cd·L^{-1})
Fish		
Oncorhynchus mykiss	62 d EC10 Weight	0.233
Salvelinus confluentus	55 d MATC Growth	0.825
Cottus bairdi	21 d EC50 Biomass	0.964
Salmo salar	496 d MATC Biomass	0.987
Acipenser transmontanus	58 d LC20 Mortality	1.14
Prosopium williamsoni	90 d IC10 Weight, biomass	1.25
Salmo trutta	30 d IC20 Biomass	1.36
Salvelinus fontinalis	126 d MATC Biomass	2.23
Oncorhynchus tshawytscha	8 d LC10 Mortality	2.29
Pimephales promelas	7 d MATC Mortality	2.36
Catostomus commersoni	40 d MATC Biomass	7.75
Oncorhynchus kisutch	62 d MATC Biomass	7.81
Salvelinus namaycush	64 d MATC Biomass	8.03
Esox lucius	35 d MATC Biomass	8.03
Invertebrates		
Daphnia magna	7 d EC10 Feeding inhibition	0.045
Ceriodaphnia reticulata	7 d MATC Reproduction	0.117
Hyalella azteca	28 d IC25 Biomass	0.122
Hydra viridissima	7 d NOEC/L Population growth	0.874
Chironomus tentans	60 d IC25 Hatching success	0.957
Echinogammarus meridionalis	6 d MATC Feeding inhibition	1.30
Atyaephyra desmarestii	6 d MATC Feeding inhibition	1.32
Gammarus pulex	7 d NOEL/L Feeding inhibition	1.86
Daphnia pulex	42 d MATC Reproduction	2.07
Ceriodaphnia dubia	14 d MATC Reproduction	4.90
Lampsilis siliquoidea	28 d IC10 Length	5.12
Aeolosoma headleyi	14 d MATC Population growth	14.7
Lymnaea stagnalis	4 wk NOEC/L Growth	18.9
Chironomus riparius	17 d MATC Mortality	27.1
Lymnaea palustris	4 wk EC50 Growth	58.2
Rhithrogena hageni	10 d EC10 Mortality	2659
Erythemis simplicicollis	7 d NOEC/L Survival	48 400
Pachydiplax longipennis	7 d MATC Survival	76 500
Amphibians		
Ambystoma gracile	24 d MATC Weight	106
Plants/Algae		
Ankistrodesmus falcatus	96 h NOEC/L Growth	4.9
Pseudokirchneriella subcapitata	72 h EC10 Growth rate	19.8*
Lemna minor	7 d EC50 Growth rate	79.0

*Value shown is the geometric mean of comparable values.

The log-logistic model provided the best fit of the models tested (Anderson-Darling Statistic (A^2) = 1.07). The equation of the logistic model is on the form:

$$f(x) = \frac{1}{1+e^{-(x-\mu)/s}}$$

Where, in the case of the fitted model, x = log (concentration), μ = 0.55, and s = 0.54 are the location and scale parameters, and f(x) is the proportion of taxa affected. The long-term SSD is shown in Figure 2. Summary statistics for the long-term SSD are presented in Table 7. The 5th percentile on the long-term SSD is 0.09 µg·L^{-1}.

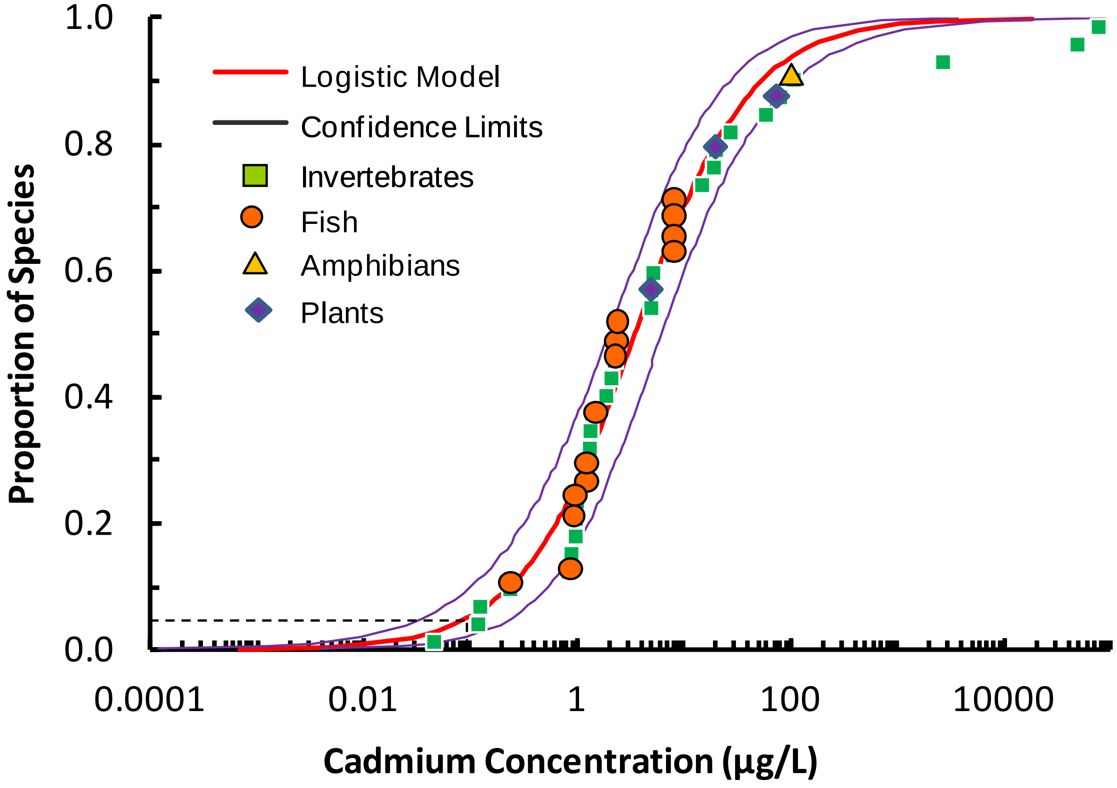

Figure 2. Long-term species sensitivity distribution (SSD) for cadmium in freshwater derived by fitting the log-logistic model to the long-term endpoints of 36 aquatic species.

Table 7. Long-term CWQG for cadmium derived using the SSD method. (LFL = lower fiducial limit; UFL = upper fiducial limit).

	Concentration ($\mu g\ Cd \cdot L^{-1}$)
SSD 5th percentile	0.09
SSD 5th percentile, LFL (5%)	0.04
SSD 5th percentile, UFL (95%)	0.24

The long-term guideline is expressed as an equation into which the local water hardness must be entered in order to produce an appropriate site-specific CWQG. The long-term CWQG equation is based on the long-term toxicity-hardness relationship with a slope value of 0.83 and the long-term cadmium 5th percentile value at 50 $mg \cdot L^{-1}$ hardness of 0.09 $\mu g\ Cd \cdot L^{-1}$. The general equation describing this linear regression and therefore, the **equation to derive the long-term CWQG to protect freshwater life** is the following:

$$\boxed{\text{CWQG} = 10^{\{0.83(\log[\text{hardness}]) - 2.46\}}}$$

where the CWQG is expressed in total cadmium concentration ($\mu g \cdot L^{-1}$) and hardness is measured as $CaCO_3$ equivalents in $mg \cdot L^{-1}$.

Table 8 below provides examples of the guideline values that would apply to freshwaters of varying hardness, which were calculated using the freshwater hardness equations.

Table 8. CWQGs for cadmium in fresh water at various levels of water hardness.

Hardness	**Guideline value ($\mu g\ Cd \cdot L^{-1}$)**	
($mg \cdot L^{-1}$ $CaCO_3$)	**Short-term**	**Long-term**
Lower limit*	0.11	0.04
Soft (60)	1.2	0.10
Medium (120)	2.5	0.18
Hard (180)	3.8	0.26
Upper limit**	7.7	0.37

Lower and upper limits for hardness reflect the minimum and maximum hardness values, respectively, that were used in the derivation of hardness slopes, beyond which values should not be extrapolated.

*A lower limit of 0.11 $\mu g \cdot L^{-1}$ is the short-term benchmark that applies to all waters of hardness below 5.3 mg $CaCO_3 \cdot L^{-1}$. A lower limit of 0.04 $\mu g \cdot L^{-1}$ is the long-term guideline value that applies to all waters of hardness below 17 mg $CaCO_3 \cdot L^{-1}$.

**An upper limit of 7.7 $\mu g \cdot L^{-1}$ is the short-term benchmark that applies to all waters of hardness above 360 mg $CaCO_3 \cdot L^{-1}$. An upper limit of 0.37 $\mu g \cdot L^{-1}$ is the long-term guideline that applies to all waters of hardness above 280 mg $CaCO_3 \cdot L^{-1}$.

Marine water quality guideline: No marine water quality guidelines for cadmium were derived at this time so the previously derived value of 0.12 $\mu g \cdot L^{-1}$is retained.

Considerations in guideline derivation: The natural background concentration of naturally-occurring substances is a very site-specific matter. Naturally elevated levels of such a substance may lead to specific, locally-adapted ecological communities, which may respond differently to anthropogenic releases of this substance when compared to non-adapted communities. This aspect cannot be incorporated into a nationally-applicable guideline value. Therefore, in some situations, such as when the recommended national guideline value falls below (or outside) the natural background concentration, it may be necessary or advantageous to derive a site-specific guideline (or objective). These national guidelines should thus be used as a basis for the derivation of site-specific guidelines and objectives when needed. For more information on site-specific WQG derivation procedure, please refer to CCME guidance document (2003).

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Excerpt from Publication No. 1299; ISBN 1-896997-34-1