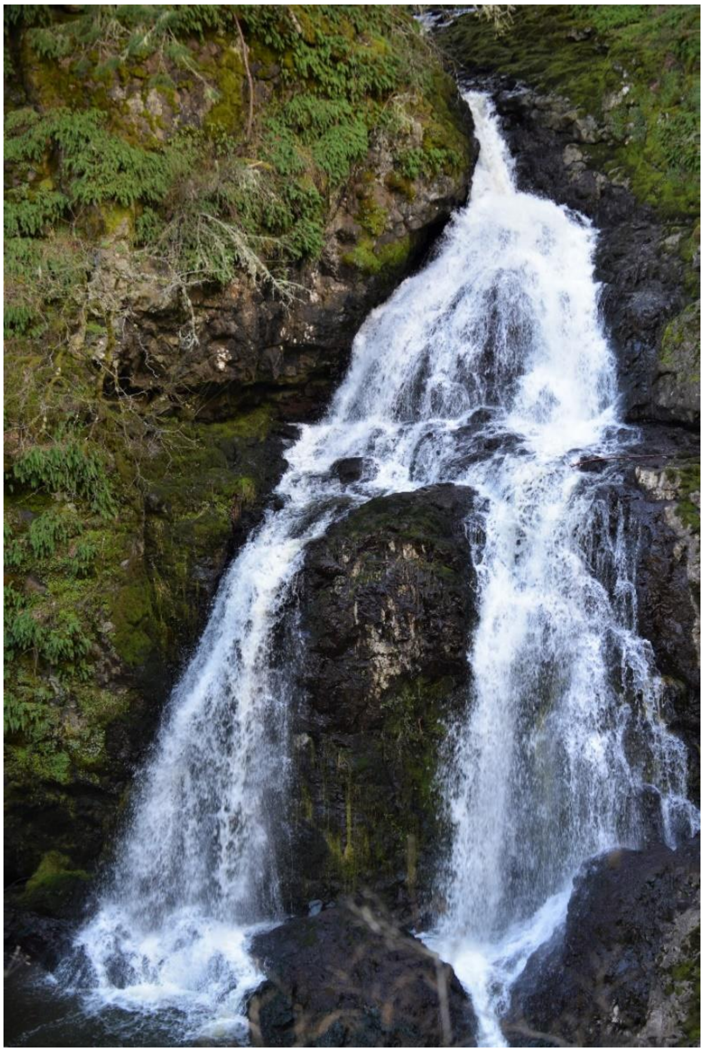
WATER QUALITY GUIDELINE SERIES

Zinc Water Quality Guidelines - Freshwater Aquatic Life

Ministry of Water, Land, and Resources Stewardship
Water Protection & Sustainability Branch



No. WQG-19-1

Erratum: Zinc Water Quality Guidelines – Freshwater Aquatic Life (2023)

Page 7 and Page 20, the 1997 guideline was denoted as dissolved zinc. This has been amended to reflect that the 1997 guideline was derived for total zinc.

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Page 21, Figure 9.1 compared dissolved zinc to the 1997 zinc water quality guideline. This has been amended to compare total zinc to the 1997 zinc water quality guideline.

The Water Quality Guideline Series is a collection of British Columbia (B.C.) Ministry of Environment and Climate Change Strategy water quality guidelines. Water quality guidelines are developed to protect a variety of water values and uses: aquatic life, drinking water sources, recreation, livestock watering, irrigation, and wildlife. The Water Quality Guideline Series focuses on publishing water quality guideline technical reports and guideline summaries using the best available science to aid in the management of B.C.'s water resources. For additional information on B.C.'s approved water quality parameter specific guidelines, visit:

http://www2.gov.B.C.ca/gov/content/environment/air-land-water/water/waterquality/water-quality-guidelines/approved-water-quality-guidelines

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Cover Photograph:

Location: Sitting Lady Falls, Vancouver Island, B.C.

EXECUTIVE SUMMARY

The British Columbia Ministry of Water, Land and Resource Stewardship (WLRS) develops province-wide ambient Water Quality Guidelines (WQGs) for substances or physical attributes that are important for managing both the fresh and marine surface waters of British Columbia (B.C.). WQGs provide a basis for water quality assessments and inform decision-making in the natural resource sector. WQGs may be created for the protection of designated values, including aquatic life, wildlife, agriculture, drinking water sources, and recreation. This document presents updated zinc (Zn) WQGs for the protection of freshwater aquatic life.

Elevated concentrations of Zn can adversely affect aquatic and terrestrial life. While background Zn concentrations in B.C. are generally lower than the threshold for adverse effects to biota, anthropogonic activities such as mining can increase Zn concentrations to levels that can be harmful.

In 2018, Canadian Council of Ministers of Environment (CCME) published Canadian WQGs for dissolved Zn for the protection of freshwater aquatic life. B.C. has adopted these guidelines with the addition of an assessment factor to account for the uncertainty of extrapolating laboratory studies to field conditions. While the previous B.C. WQG considered only hardness, the updated guidelines also consider dissolved organic carbon (DOC) and pH. When compared to background Zn concentrations across the province exceedances from the updated WQG were less than 10%.

WQGs for the protection of marine aquatic life, agriculture (irrigation and livestock watering) and wildlife were derived in 1999 and remain unchanged. These technical documents as well as the one for source drinking water WQGs can be found on the B.C. WQG website.

A summary of the WQGs is presented in Table E.1. As the calculation of the aquatic life guideline requires information on the site-specific water chemistry it is listed below as variable though it is generally much lower than WQGs for the other listed values. For example, for a waterbody with pH of 7.5, DOC of 0.5 mg/L, and hardness of 50 mg/L the freshwater aquatic life WQG is 3.5 µg/L.

Table E. 2.1. Summary of recommended water quality guidelines for Zinc.

Value	Guideline (µg/L)	Guideline Type
Freshwater Aquatic life	Variable	Long-term chronic
Marine Aquatic life	10	Long-term chronic
Livestock	2,000	Short-term acute
Irrigation	Soil pH < 6 1,000 Soil pH 6 to <7 2,000 Soil pH ≥ 7 5,000	Long-term chronic
Source drinking water	3,000	Maximum allowable concentration

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1. INTRODUCTION

The British Columbia Ministry of Water, Land, and Resource Stewardship (WLRS) develops province-wide ambient Water Quality Guidelines (WQGs) for substances or physical attributes that are important for managing both the fresh and marine surface waters of British Columbia (B.C.). WLRS defines a WQG as a scientifically derived numerical concentration or narrative statement considered to be protective of designated values in ambient conditions. WQGs provide a basis for water quality assessments and inform decision-making in the natural resource sector and may be derived for the protection of designated uses including aquatic life, wildlife, agriculture (livestock watering and irrigation), source drinking water, and recreation.

In B.C., WQGs are developed to protect the most sensitive endpoint associated with a given value (e.g., aquatic life, wildlife, livestock). For substances with sufficient toxicological data, both short-term acute and long-term chronic guidelines are developed. Interim WQGs are developed when the available toxicological data are insufficient (CCME, 1999; ENV, 2019).

WQGs are typically based on toxicological studies conducted under laboratory conditions. There are several uncertainties associated with applying WQGs to field conditions, including:

- Laboratory to field differences in exposure conditions,
- Single contaminant tests in laboratories vs exposure to multiple contaminants in the field that may demonstrate additive, synergistic, or antagonistic effects,
- Toxicity of metabolites,
- Intra- and inter-specific differences between test species used to derive the WQG and those found in the field,
- Indirect effects (e.g., behavioral responses, food web dynamics),
- Laboratory studies conducted on partial life cycle studies which may not include the most sensitive life stage,
- Delayed effects which may not occur within the life stage tested, or may occur across generations, and
- Exposure of organisms to cumulative effects of the various stressors, such as habitat loss and climate change.

Given these uncertainties, WQGs are a predicted no-effect concentration (i.e., no effects are expected if exposure concentrations are below the WQG). An exceedance of the WQGs presented in this document does not imply that unacceptable risks are present, but that the potential for adverse effects is increased and additional investigation and monitoring may be warranted. To that end, ongoing ecological monitoring is encouraged to ensure the WQG is indeed protective under field conditions.

In 2018, Canadian Council of Ministers of the Environment (CCME) published an updated Canadian WQG for dissolved Zn for the protection of freshwater aquatic life. B.C. has adopted this guideline with the addition of an assessment factor to account for the uncertainty of extrapolating laboratory study results to field conditions. This document provides information on CCME's derivation of the aquatic life guideline (replicated here verbatim and highlighted grey) as well as a discussion of background concentrations in B.C. and the choice of assessment factor. The 1997 guidelines for marine aquatic life, wildlife, livestock watering, and irrigation (ENV, 1997) have not been updated and are available in a separate document on the B.C. WQG website.

2. SUBSTANCE IDENTITY

Zinc (Zn; CAS 7440-66-6) is an essential metal found widely in nature. Its predominant oxidation state in the natural environment is Zn^{2+}; the metallic form (Zn^0) is found only in highly reducing environments (Lindsay 1979). Zinc is able to form complexes with a variety of organic ligands and has a variety of salts (WHO 2001). Zinc metal is insoluble in water, but several of its salts are freely soluble (Budavari 1996; Lide 2006).

3. SOURCES AND USES

Canada is one of the largest producers and exporters of zinc. Zinc generally occurs in association with copper and lead; therefore, mining and milling operations usually recover these metals as co-products (NRCan 2007). Zinc is used mainly to coat iron and steel products such as pipes, wire and sheet metal, to render them resistant to corrosion and rust (NRCan 2007). Additionally, many zinc compounds are used in dentistry, medicine, the rubber industry, paint, cosmetics and household products (ATSDR 2007).

4. FATE, BEHAVIOUR, AND PARTITIONING IN THE ENVIRONMENT

Zinc can occur in both suspended and dissolved forms in natural aquatic environments, but most is partitioned into suspended and bottom sediments (Eisler 1993). Several processes control zinc concentrations and mobility in water, and thus its bioavailability to aquatic organisms. Several abiotic variables influence the speciation of zinc, and thus the predominance among zinc forms: most importantly pH, alkalinity, redox potential (Eh), dissolved organic matter and salinity. The most common dissolved zinc species in natural waters under aerobic conditions are $ZnOH^+$, Zn^{2+} and $ZnCO_3$ (Florence 1977; Stumm and Morgan 1981). Of all chemical species found in aquatic environments, the aqueous zinc ion (Zn^{2+}) is believed to be the most toxic (ANZECC 2000). Less soluble forms of zinc, such as zinc hydroxide ($Zn(OH)_2$) and zinc carbonate ($ZnCO_3$), are considered to be non-toxic (Cairns et al. 1971; Spear 1981). Changes in environmental conditions that influence zinc speciation can result in changes to zinc toxicity.

5. BACKGROUND CONCENTRATION OF ZINC IN BRITISH COLUMBIA

Zinc is a naturally occurring element in aquatic and terrestrial ecosystems, therefore, background concentrations must be considered when deriving provincial Zn WQGs.

5.1. Methods for Estimating Background Concentrations of Zinc in British Columbia Surface Waters

Background (i.e., from non-impacted sites) dissolved Zn concentrations vary across B.C. as a function of local geology and hydrology, therefore, a regional approach was used to estimate background concentrations. Zinc concentrations were estimated following methods used in recent WQG derivation documents (e.g., ENV, 2021). Only data from the B.C. Environmental Management System (EMS) database were used as the Canadian Aquatic Biomonitoring Network (CABIN) database did not contain data for dissolved Zn.

EMS does not identify reference stations, so the database was screened to create a sub-set of water quality stations known to be minimally impacted. To do this, “background” water quality sampling stations that were sampled at least three times over 20 years for any water quality parameter (1996/01/01 to 2017/05/03) were extracted. Next, the list of stations with location information was given to ENV environmental impact assessment biologists to identify sites that they considered minimally impacted by human activities. No strict definition of ‘minimally impacted’ was given to the biologists and station selection was left to their professional judgement.

The list of minimally impacted stations was then used to extract Zn data from the EMS database within the following date range: 2000/01/01 to 2023/05/24.

The dataset underwent several additional automated and manual data cleaning steps summarized below:

- Where lake samples were available at multiple depths, only surface samples were included;
- non-detect results with a method detection limit (MDL) ≥5 µg/L were removed as these would influence the results of the analysis; and
- samples were excluded where results were missing or reported as 0.

Arithmetic means were calculated for laboratory replicates (analytical replicates taken from one field sample) with the MDL substituted for values below detection. All field replicates were included as independent samples. The final data set consisted of 159 stations with 3603 samples.

Table 5.1. Statistical approach used to calculate station means.

Group	Conditions	Approach	Total Stations	Total Samples
1	% non-detects = 100	½ of minimum station MDL	6	107
2	0 < % non-detects < 100 AND # detects < 3	Substitute ½ MDL for non-detects and calculate arithmetic mean for all samples	13	36
3	0 < % non-detects < 100 AND # detects ≥ 3	Regression on order statistics	81	399
4	% non-detects = 0	Arithmetic mean	59	3061

5.2. Background Concentration Results

The distribution of dissolved Zn concentrations by ENV administrative region is summarized in Table 5.2 and Figure 5.1. The median of station means ranged from 0.5 µg/L (Skeena) to 3.3 µg/L (Omineca). Of the 159 stations, 62 stations were on lakes and 97 were on rivers. The median of the distribution of station means in lakes (0.5 µg/L) was similar to that of rivers (0.4 µg/L).

Table 5.2. Summary statistics for station mean dissolved Zn at minimally impacted stations in British Columbia.

Region	Number of Stations	Number of Samples	Date Range	Concentration Range Across all Samples (µg/L)	MDL Range Across all Samples	% Samples < MDL	Distribution of Station Means (µg/L)		
							Median	10th Percentile	90th Percentile
Cariboo	51	1037	2000 – 2022	0.1 – 45.1	0.1 – 3	57	0.8	0.2	1.8
Kootenay	11	127	2001 – 2022	0.1 –19	1 – 1	40	1.9	0.8	16.0
Lower Mainland	3	19	2002 – 2005	0.4 – 2	0.1 – 0.1	11	1.2	0.4	1.3
Okanagan	7	1176	2000 – 2022	0.1 – 88	0.1 – 3	59	0.9	0.4	1.3
Omineca	7	12	2005 – 2018	0.1 – 6	0.1-0.2	NA	3.3	0.6	6.0
Peace	4	44	2012 – 2018	0.1 – 2	0-1 – 0.1	NA	1.6	0.7	2.0
Skeena	28	390	2000 – 2022	0.1 – 18	0.1 – 2	42	0.5	0.2	2.7
Thompson	5	215	2001 – 2018	0.2 – 60	0.1 – 1	NA	0.6	0.4	6.9
Vancouver Island	43	584	2001 – 2022	0.1 – 152	0.1 – 4	21	0.7	0.3	2.9

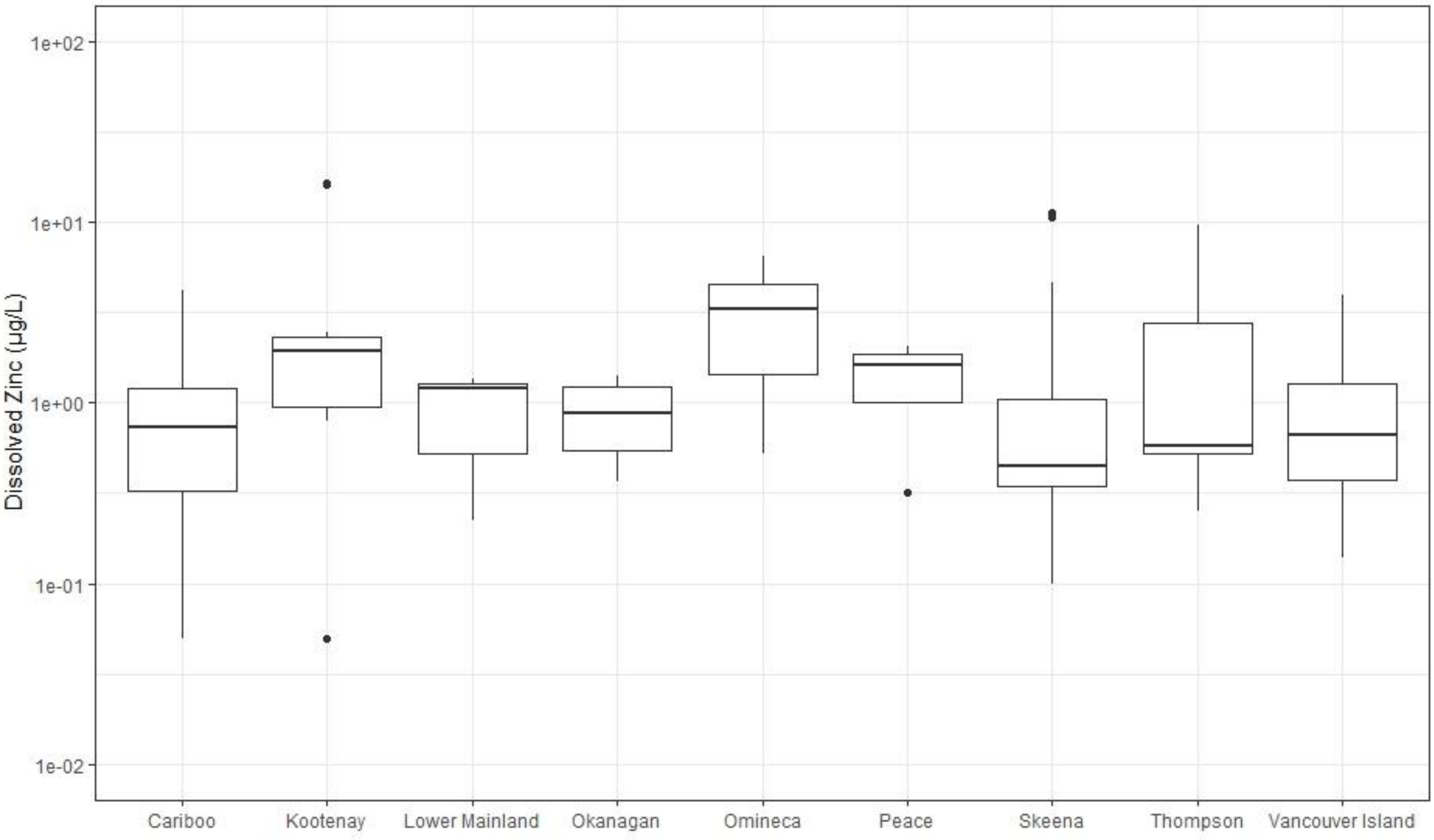

Figure 5.1. Distribution of station mean dissolved Zn at background stations in British Columbia by region. Solid horizontal bar and the lower and higher whiskers represent median, 10th and 90th percentile of station means.

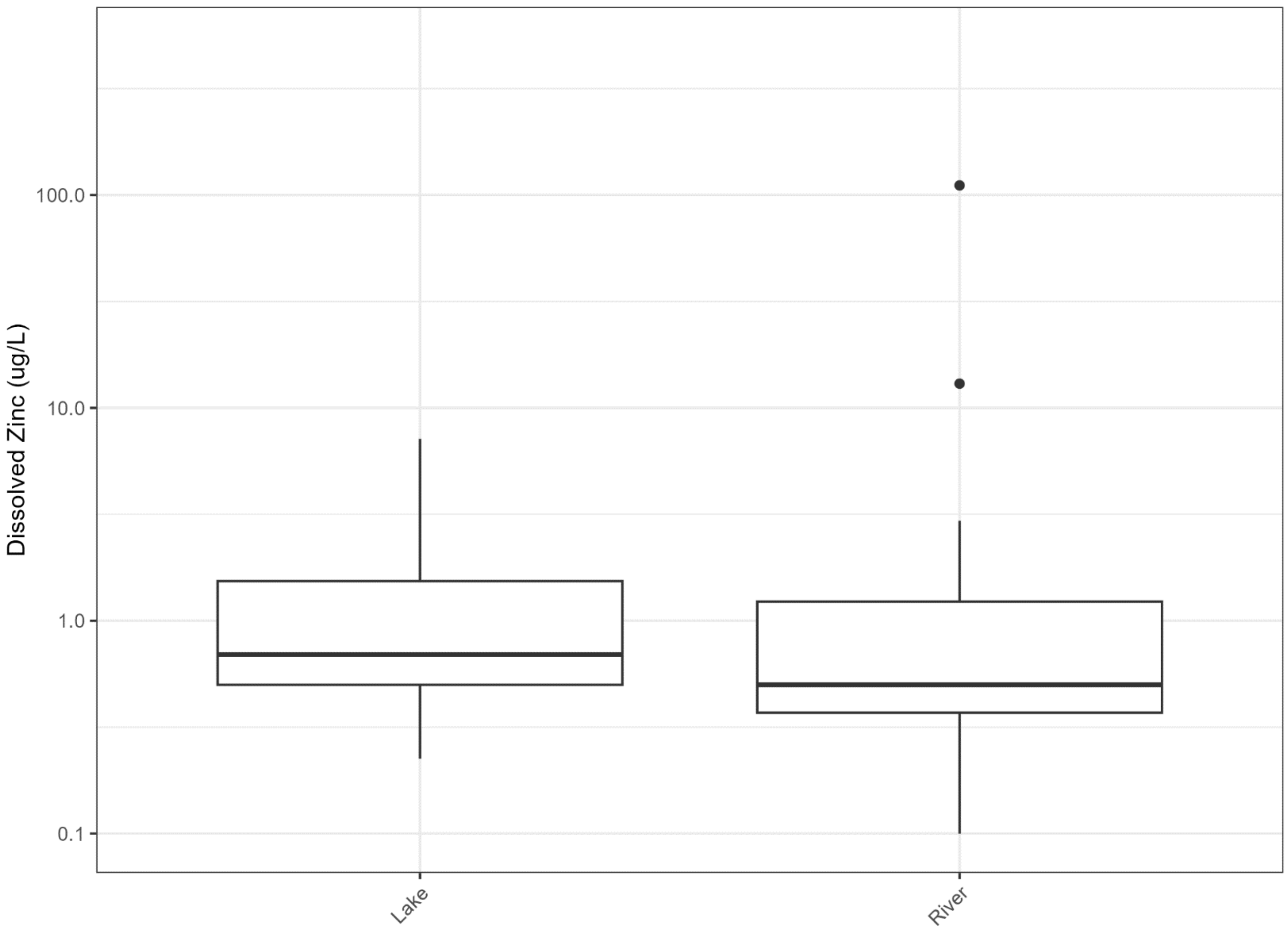

Figure 4.2. Distribution of station mean dissolved Zn at background stations in British Columbia by waterbody type. Solid horizontal bar and the lower and higher whiskers represent median, 10th and 90th percentile of station means.

6. EFFECTS ON AQUATIC LIFE

6.1. Effects

Zinc is an essential element for numerous biological functions. Environmental concentrations that are well below a species' optimal concentration range can disrupt homeostasis, and deficiencies have observable effects (Muyssen and Janssen 2002). At higher concentrations, however, zinc produces adverse chronic and acute effects on reproduction, biochemical and physiochemical reactions, and behavioural effects in aquatic organisms (WHO 2001). In fish, zinc interferes with gill uptake of calcium (Hogstrand et al. 1994; Spry and Wood 1985). Because calcium is also an essential element, this reduction in uptake causes calcium deficiency (Spry and Wood 1985). Zinc also disrupts calcium homeostasis in invertebrates (Muyssen et al. 2006) due to competition between zinc and calcium for the same uptake sites on the gill epithelium (Hogstrand et al. 1994; Hogstrand et al. 1998). Zinc also disturbs, to a lesser extent, sodium and chloride fluxes (Spry and Wood 1985). At higher zinc concentrations, lethal toxicity of zinc to aquatic organisms is caused by the irreversible destruction of the gill epithelium, which causes tissue hypoxia, osmoregulatory failure, acidosis and low oxygen tensions in the arterial blood (Hiltibran 1971; Skidmore 1970; Skidmore and Tovell 1972). In general, salmonids were found to be more sensitive than other types of fish in short-term studies.

7. CRITERIA FROM OTHER JURISDICTIONS

Zinc WQGs/criteria from eight provincial and national jurisdictions are summarized in Table 7.1. Three types of guidelines are used: a static number, a hardness-based equation, and MLR taking the influence of pH, hardness, and DOC into account. In general, most of the older WQGs are static, while more recent WQGs are calculated using MLR. While older guidelines exist for total Zn, more recent guidelines are based on dissolved Zn.

7.1. British Columbia

The B.C. Ministry of Environments, Land and Parks established a hardness-based Zn WQG in 1997 (ENV, 1997) for freshwater aquatic life. This guideline was for total Zn, is based on hardness, and provides both chronic and acute WQGS.

7.2. Canadian Council of Ministers of the Environment (CCME)

The CCME develops national WQGs for the protection of aquatic life and other values. The CCME aquatic life WQG is for dissolved Zn and is calculated using MLR. The short-term WQG takes hardness and DOC into account for guideline calculation (Table 7.1) whereas for the calculation of the long-term WQG pH, hardness and DOC are needed.

7.3. Provincial Water Quality Guidelines

Canadian provinces typically develop or adopt WQGs from another jurisdiction. Manitoba and Quebec have adopted the USEPA 1995 WQC (MWS, 2011; MDDEFP 2013;) and Alberta and Saskatchewan have adopted the previous CCME WQGS of 35 µg/L (Water Security Agency, 2015; AEP, 2018).

7.4. USEPA Water Quality Criteria

The USEPA developed a national WQC for the protection of aquatic life based on dissolved Zn (USEPA, 1995). The USEPA Zn WQC is hardness-based and has identical values for chronic and acute criteria and is calculated using the equation presented in Table 7.1.

7.5. European Union

The European union has derived a predicted no effect concentration (PNEC) of 3.1 µg/L for waters with low hardness (less than 24 mg/l) and a PNEC of 7.8 µg/L for water with high hardness (more than 24 mg/l) and is for dissolved Zn (EU, 2006).

7.6. Australia and New Zealand

Australia and New Zealand have joint WQGs, described as trigger values, that invoke a response if exceeded (ANZECC, 2000a; 2000b). Although four trigger values have been calculated to provide various levels of protection (i.e., 80-99% of species), ANZECC (2000a) recommends application of the 80%, 95% and 99% protection levels to protect highly disturbed ecosystems, slightly-moderately disturbed ecosystems, and high conservation/ecological value ecosystems, respectively (ANZECC, 2000a). The Zn trigger value is dependant on the site-specific hardness.

Table 7.1. Summary of freshwater aquatic life water quality guidelines for Zn by jurisdiction.

Jurisdiction	**Chronic (µg/L)**	**Acute (µg/L)**	**Total/ dissolved**	**Year published**
British Columbia	7.5 + 0.75 (water hardness-90)	33 + 0.75 (water hardness-90)	Total	1997
CCME	$\exp^{(0.947[\ln(\text{hardness})] - 0.815[\text{pH}] + 0.398[\ln(\text{DOC})] + 4.625)}$	$\exp^{(0.833[\ln(\text{hardness})] + 0.240[\ln(\text{DOC})] + 0.526)}$	Dissolved	2018
Alberta	30	NA	Total	2018
Ontario	30	NA	Total	1994
Saskatchewan	30	NA	Total	2015
USEPA	$e^{(0.8473\ [\ln(\text{hardness})] + 0.884)} * 0.986$	$e^{(0.8473\ [\ln(\text{hardness})] + 0.884)} * 0.986$	Dissolved	1995
European Union	Hardness <24 3.1 Hardness ≥24 7.6	NA	Dissolved	2006
Australia/ New Zealand	NA	$a^* \times TV^*(\text{hardness}/30)^{0.85}$	Dissolved	2000

TV*: trigger value varies depending on intended level of protection.

a*: constant varies based on hardness.

8. RECOMMENDED GUIDELINE

8.1. CCME Zinc Water Quality Guidelines

8.1.1. Toxicity Data

All zinc toxicity data were evaluated for scientific acceptability before being considered for or used in the derivation of the short-term benchmark concentration and CWQG. Data from toxicity studies were ranked as primary, secondary or unacceptable in terms of acceptability for guideline derivation. The ranking criteria are described fully in the CCME 2007 protocol and are briefly outlined here.

In order for a toxicity value to be considered primary, the concentration of the toxic substance must be measured at the beginning and end of the exposure period, and the measurement of water quality parameters (hardness, pH, temperature, etc.) must be reported. Adequate replication must be performed, suitable statistical procedures should be used and control mortality should be low (typically less than 10%). Secondary data are those that originate from studies where primary data cannot be generated but are still of acceptable quality and documentation. For example, a study may use calculated (rather than measured) substance concentrations, but the most relevant water quality parameters must be reported. Appropriate test replication is still necessary, but pseudo replication may be acceptable for secondary studies (e.g., all test organisms in only one aquarium per concentration). Unacceptable data are those that do not meet the criteria of primary or secondary data.

8.1.2. Toxicity-Modifying Factors

Water chemistry conditions influence how toxic Zn is to aquatic organisms by affecting its environmental fate, behaviour and bioavailability. Water hardness, dissolved organic carbon (DOC), and pH are the most important variables. Complete details of the assessment are available in the scientific criteria document (CCME 2018).

In general, increased hardness is protective (i.e., zinc is less toxic in harder waters), likely due to competitive interactions with Ca^{2+} and Mg^{2+} at binding sites. The effect of pH is not as clear. Authors report that toxicity to fish and algae increases with increasing pH in natural waters, but there are no consistent patterns for invertebrates (CCME 2018). Increased bioavailability of zinc is possible at high pH due to decreased binding by organic ligands. Dissolved organic matter is an important complexing agent for zinc; therefore, increased organic matter (measured as DOC) tends to have a protective effect. The toxicity modifying factors are described more fully in CCME (2018).

It is important to account for exposure and toxicity-modifying factors when deriving guidelines (CCME 2007). This can be done through single- or multi-factor equations, matrices or models. In this case, CCME used multiple linear regression (MLR) analysis to account for the simultaneous effects of water hardness, DOC and pH on zinc toxicity.

CCME derived empirical relationships for short-term and long-term exposure using forward stepwise MLR. The analysis identified which water chemistry variables explained a significant portion of variability in zinc toxicity. MLR analyses were conducted species by species. The best species model was selected based on how well it predicted toxicity, how well it explained variability in the dataset and, in the case of the long-term guideline, the protectiveness of the values calculated by the model.

For the short-term benchmark, hardness and DOC were both significant factors. For the long-term Canadian Water Quality Guideline (CWQG), hardness, pH and DOC all explained a significant portion of the variation and were used to derive the CWQG equation. CCME's short-term benchmark equation is based on a pooled Daphnia magna and *D. pulex* model containing variables for hardness and DOC. The long-term CWQG equation is based on an Oncorhynchus mykiss model containing variables for hardness, pH and DOC. Accordingly, the CWQG and short-term benchmark for freshwater exposure to zinc are presented as multivariable equations that are a function of water hardness, DOC and pH and allow users to derive guidelines and benchmarks based on the water chemistry of the site under consideration.

8.1.3. Water Quality Guideline Derivation

For the derivation of the short-term guideline, effect concentrations were normalized to a hardness of 50 mg·L−1 as CaCO3 and a DOC concentration of 0.5 mg·L−1 using the pooled *Daphnia* MLR equation. For the derivation of the long-term guideline, effect concentrations were normalized to a hardness of 50 mg·L−1 as CaCO3 and a DOC concentration of 0.5 mg·L−1 and pH of 7.5 using the O. mykiss MLR. Total zinc concentrations were converted to dissolved using a conversion factor for laboratory toxicity data of 0.978 for the short-term guideline and 0.986 for the long-term guideline (USEPA 1996) and plotted (see Figures 1 and 2). For details and references regarding the data included in the SSDs, see the scientific criteria document for the CWQG for zinc and its spreadsheet appendix (CCME 2018).

8.1.3.1. Long-term Water Quality Guidelines

Long-term exposure guidelines identify waterborne concentrations 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 29 data points were used to derive the guideline (Table 6). Each species for which appropriate long-term toxicity data were available was ranked according to sensitivity.

No data points fell below the fifth percentile value on the long-term SSD curve. CCME assessed the CWQG for zinc for protectiveness and found it achieved the intended level of protection as per CCME 2007 and 2018). Because the analysis of the long-term data found that water hardness, pH and DOC were significant toxicity-modifying factors, the CWQG is expressed as an equation into which the local water hardness, pH and DOC must be entered in order to produce an appropriate site-specific CWQG.

Equation 2.

$$\text{CWQG} = \exp^{(0.947[\ln(\text{hardness})] - 0.815[\text{pH}] + 0.398[\ln(\text{DOC})] + 4.625)}$$

Where the CWQG is expressed in dissolved zinc concentration ($\mu g \cdot L^{-1}$), hardness is measured as CaCO3 equivalents in $mg \cdot L^{-1}$, pH is in standard units and DOC is in $mg \cdot L^{-1}$.

Table 8.1. Endpoints Used to Determine the Long-term Freshwater CWQG for Dissolved Zinc (from CCME 2018).

Species sensitivity distribution rank	Species	Endpoint	Normalized effect concentration [a] (µg dissolved
1	*Chironomus riparius* (chironomid)	11-w LOEC (development)	9.89
2	*Ceriodaphnia dubia* (water flea)	7-d MATC (reproduction)	11.3
3	*Pseudokirchneriella subcapitata (green algae)*	72-h EC_{10} (growth rate)	13.8
4	*Daphnia magna* (cladoceran)	21-d EC_{10} (reproduction)	15.0
5	*Potamopyrgus jenkinsi* (snail)	12-w MATC (growth)	19.1
6	*Jordanella floridae* (flagfish)	100-d MATC (growth)	27.9
7	*Cottus bairdi* (mottled sculpin)	30-d EC_{10} (mortality)	31.5
8	*Brachionus havanaensis* (rotifer)	18-d EC_{10} (population growth inhibition)	36.5
9	*Phoxinus phoxinus* (Eurasian minnow)	150-d LC_{10} (mortality)	51.0
10	*Dreissena polymorpha* (zebra mussel)	10-w LC_{10} (mortality)	51.1
11	*Pimephales promelas* (fathead minnow)	7-d IC_{10} (growth)	68.2
12	*Brachionus calyciflorus* (rotifer)	48-h EC_{10} (intrinsic rate of population increase)	73.0
13	*Oncorhynchus mykiss* (rainbow trout)	30-d LC_{10} (mortality)	101
14	*Lampsilis siliquoidea* (fatmucket)	28-d IC_{10} (length)	104
15	*Bufo boreas* (boreal toad)	4-w MATC (development)	108
16	*Lymnaea stagnalis* (snail)	28-d EC_{10} (growth)	113
17	*Salmo trutta* (brown trout)	58-d MATC (weight)	130
18	*Prosopium williamsoni* (mountain white fish)	90-d IC_{10} (biomass)	133
19	*Salvelinus fontinalis* (brook trout)	24-w IC_{10} (egg fragility)	161
20	*Oncorhynchus clarkii pleuriticus* (cutthroat trout)	30-d MATC (biomass)	169
21	*Chlorella* sp. (green algae)	48-h IC_{50} (growth rate)	225
22	*Physa gyrina* (snail)	30-d NOEC/L (mortality)	344
23	*Lemna minor* (duckweed)	7-d EC_{10} (growth)	400
24	*Lyngbya* sp. (cyanobacteria)	18-d EC_{10} (growth rate)	415
25	*Cyclotella meneghiniana* (diatom)	5-d EC_{10} (growth rate)	477
26	*Ceratophyllum demersum* (hornwort)	15-d LOEC (chlorophyll content and biomass)	1116
27	*Chlamydomonas* sp. (green algae)	10-d EC_{10} (growth rate)	1428
28	*Scenedesmus quadricauda* (green	5-d EC_{10} (growth rate)	1628
29	*Rhithrogena hageni* (mayfly)	10-d EC_{10} (mortality)	1696

[a] Normalized for hardness and dissolved organic carbon—see text for details.

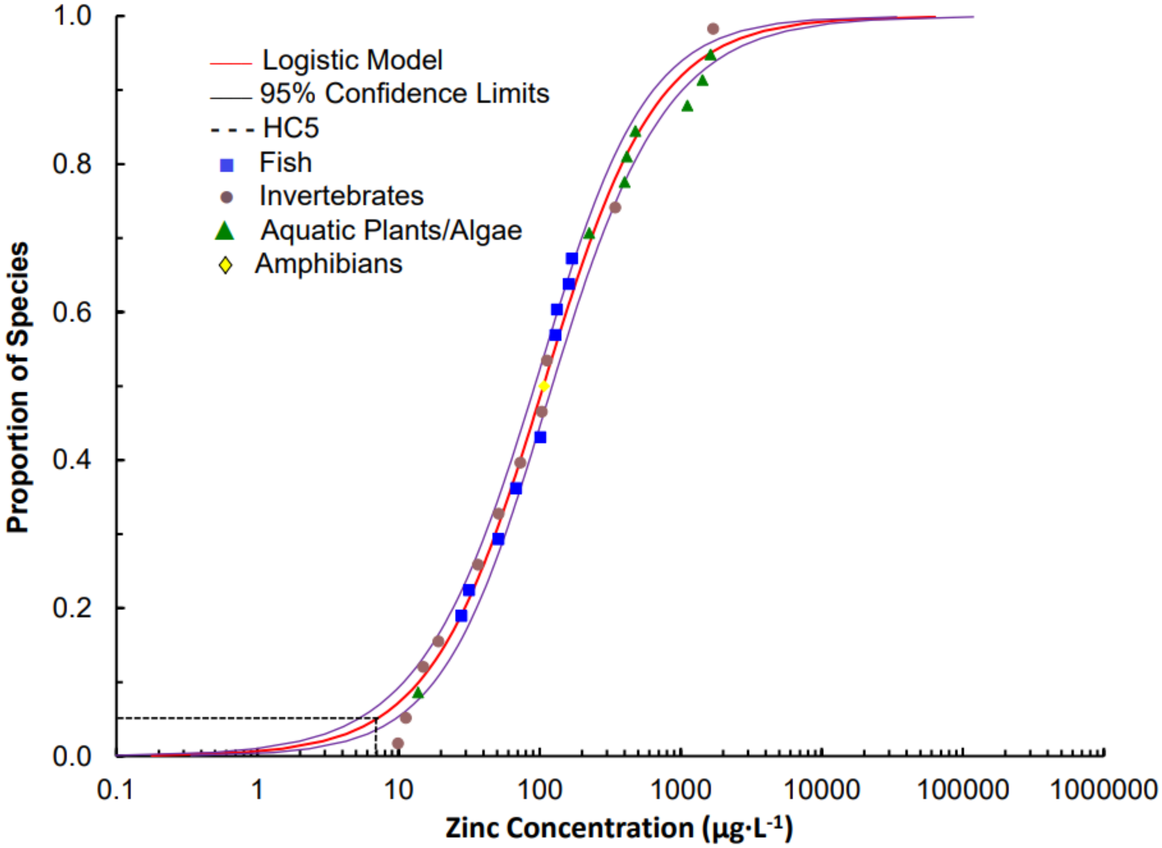

Figure 8.1. Long-term species sensitivity distribution (SSD) for dissolved zinc in fresh water, derived by fitting the logistic model to the long-term endpoints of 29 aquatic species. Data were normalized to hardness, dissolved organic carbon and pH, and converted to dissolved concentrations. The fifth percentile on the long-term SSD is 7.0 μg·L^{-1}.

8.1.3.2. Short-term Water Quality Guidelines

CCME derives short-term benchmark concentrations using severe effects data (such as lethality) for defined short-term exposure periods. These benchmarks are estimators of severe effects to the aquatic ecosystem and are intended to give guidance on the impacts of severe but transient situations, such as spill events and infrequent releases of short-lived or non-persistent substances. Short-term benchmark concentrations do not provide guidance for protective levels of a substance in the aquatic environment, as they are levels that do not protect against adverse effects. The minimum data requirements for the Type A guideline approach were met and CCME used a total of 81 data points to derive the benchmark concentration (Table 4). Each species was ranked according to sensitivity.

Because water hardness and DOC were significant toxicity-modifying factors in the short-term analysis, CCME expresses the short-term benchmark as an equation into which the local water hardness and DOC must be entered in order to produce an appropriate site-specific benchmark concentration. Full details of the derivation are provided in CCME (2018). See Table 5 for examples.

Equation 1.

$$\text{Short-term benchmark} = \exp^{(0.833[\ln(\text{hardness})] + 0.240[\ln(\text{DOC})] + 0.526)}$$

where the benchmark is expressed in dissolved zinc concentration ($\mu g \cdot L^{-1}$), hardness is measured as CaCO3 equivalents in mg·L−1 and DOC is measured in mg·L−1 .

Table 8.2. Endpoints Used to Determine the Short-term Freshwater Benchmark Concentration for Dissolved Zinc[a].

Species sensitivity distribution rank	Species	Endpoint	Normalized effect concentration [a] (µg dissolved Zn·L^{-1})
1	*Daphnia magna* (water flea)	96-h LC_{50}	22.7
2	*Ceriodaphnia dubia* (water flea)	48-h LC_{50}	34.0
3	*Pseudokirchneriella subcapitata* (green algae)	4-h EC_{50} (growth)	36.2
4	*Ceriodaphnia reticulata* (water flea)	48-h LC_{50}	67.2
5	*Chlorella pyrenoidosa* (green algae)	24-h EC_{50} (growth)	76.3
6	*Oncorhynchus mykiss* (rainbow trout)	5-d LC_{50}	84.9
7	*Daphnia pulex* (water flea)	48-h LC_{50}	94.6
8	*Oncorhynchus tshawytscha* (Chinook	96-h LC_{50}	99.6
9	*Oncorhynchus clarkii virginalis* (Rio Grande cutthroat trout	96-h LC_{50}	120
10	*Cottus bairdi* (mottled sculpin)	96-h LC_{50}	121
11	*Salvelinus confluentus* (bull trout)	5-d LC_{50}	123
12	*Morone saxatilis* (striped bass)	96-h LC_{50}	141
13	*Salmo trutta* (sea trout)	96-h LC_{50}	147
14	*Daphnia ambigua* (cladoceran)	48-h LC_{50}	150
15	*Rhinichthys chrysogaster* (longfin dace)	96-h LC_{50}	152
16	*Thymallus arcticus* (Arctic grayling)	96-h LC_{50}	171
17	*Lampsilis rafinesqueana* (Neosho mucket)	48-h EC_{50} (survival)	175
18	*Pimephales promelas* (fathead minnow)	96-h TLM	194
19	*Daphnia longispina* (cladoceran)	48-h EC_{50} (immobility)	210
20	*Daphnia carinata* (cladoceran)	48-h LC50	224
21	*Oncorhynchus clarkii pleuriticus* (Colorado River cutthroat trout	96-h LC50	245
22	*Simocephalus vetulus* (cladoceran)	48-h EC_{50} (immobility)	246
23	*Daphnia galeata* (cladoceran)	48-h EC_{50} (immobility)	262
24	*Simocephalus exspinosus* (cladoceran)	48-h EC_{50} (immobility)	307
25	*Prosopium williamsoni* (mountain whitefish)	96-h LC_{50}	327
26	*Oncorhynchus clarkii stomias* (greenback cutthroat trout	96-h LC_{50}	328
27	*Acroperus elongatus* (cladoceran)	48-h EC_{50} (immobility)	423
28	*Chydorus ovalis* (cladoceran)	48-h EC_{50} (immobility)	426
29	*Ceriodaphnia pulchella* (cladoceran)	48-h EC_{50} (immobility)	443
30	*Lampsilis siliquoidea* (fatmucket)	96-h LC_{50} (survival)	470
31	*Chydorus sphaericus* (cladoceran)	48-h EC_{50} (immobility)	516

Species sensitivity distribution rank	Species	Endpoint	Normalized effect concentration [a] (µg dissolved $Zn\cdot L^{-1}$)
32	*Ptychocheilus lucius* (Colorado pikeminnow)	96-h LC$_{50}$	533
33	*Bufo boreas* (boreal toad)	96-h LC$_{50}$	535
34	*Oncorhynchus nerka* (sockeye salmon)	115-h LC$_{50}$	717
35	*Oncorhynchus kisutch* (coho salmon)	96-h LC$_{50}$	834
36	*Culicoides furens* (midge)	96-h LC$_{50}$	888
37	*Chironomus plumosus* (midge)	96-h LC$_{50}$	999
38	*Physa heterostropha* (snail)	96-h LC$_{50}$	1021
39	*Moina macrocopa* (cladoceran)	48-h LC$_{50}$	1144
40	*Tubifex tubifex* (worm)	96-h LC$_{50}$	1245
41	*Xyrauchen texanus* (razorback sucker)	96-h LC$_{50}$	1286
42	*Physa gyrina* (snail)	96-h LC$_{50}$	1356
43	*Rhinichthys cataractae* (longnose dace)	96-h LC$_{50}$	1382
44	*Brachionus havanaensis* (rotifer)	24-h LC$_{50}$	1428
45	*Gila elegans* (bonytail)	96-h LC$_{50}$	1505
46	*Lymnaea luteola* (snail)	96-h LC$_{50}$	1542
47	*Salvelinus fontinalis* (brook trout)	96-h LC$_{50}$	1712
48	*Platygobio gracilis* (flathead chub)	96-h LC$_{50}$	1809
49	*Hydra viridissima* (green hydra)	96-h LC$_{50}$	2003
50	*Lirceus alabamae* (isopode)	96-h LC$_{50}$	2077
51	*Cyprinus carpio* (carp)	96-h LC$_{50}$	2496
52	*Spirodela polyrrhiza* (greater duckweed)	4-d IC$_{50}$ (growth)	2505
53	*Azolla pinnata* (mosquito fern)	4-d IC$_{50}$ (growth)	2540
54	*Catostomus commersoni* (white sucker)	96-h LC$_{50}$	2688
55	*Lepomis macrochirus* (bluegill)	96-h LC$_{50}$	3155
56	*Catostomus latipinnis* (flannelmouth sucker)	24-h LC$_{50}$	3604
57	*Corbicula fluminea* (bivalve)	96-h LC$_{50}$	3696
58	*Brachydanio rerio* (zebrafish)	96-h LC$_{50}$	3761
59	*Caecidotea bicrenata* (isopode)	96-h LC$_{50}$	3897
60	*Gambusia holbrooki* (eastern mosquitofish)	96-h LC$_{50}$	4192
61	*Rana hexadactyla* (green pond frog)	96-h LC$_{50}$	4404
62	*Hydra vulgaris* (pink hydra)	96-h LC$_{50}$	4928
63	*Bufo melanostictus* (Asian toad)	96-h LC$_{50}$	4945
64	*Morone americana* (white perch)	48-h TLm	5253
65	*Daphnia magna* (water flea)	96-h LC$_{50}$	5420
66	*Ceriodaphnia dubia* (water flea)	72-h LC$_{50}$	5928
67	*Pseudokirchneriella subcapitata* (green	96-h LC$_{50}$	7293

Species sensitivity distribution rank	Species	Endpoint	Normalized effect concentration [a] (µg dissolved Zn·L^{-1})
68	*Ceriodaphnia reticulata* (water flea)	96-h TLm	7542
69	*Chlorella pyrenoidosa* (green algae)	24-h LC$_{50}$	7666
70	*Oncorhynchus mykiss* (rainbow trout)	96-h LC$_{50}$	8429
71	*Daphnia pulex* (water flea)	96-h TLm	9987
72	*Oncorhynchus tshawytscha* (Chinook	96-h TLm	10455
73	*Oncorhynchus clarkii virginalis* (Rio Grande cutthroat trout	48-h LC$_{50}$	11076
74	*Xenopus laevis* (African clawed frog)	4-d LC$_{50}$	18947
75	*Lepidostoma* sp. (caddisfly)	96-h LC$_{50}$	35215
76	*Carassius auratus* (goldfish)	24-h LC$_{50}$	39517
77	*Rhithrogena hageni* (mayfly)	96-h LC$_{50}$	40479
78	*Drunella doddsi* (mayfly)	96-h LC$_{50}$	46625
79	*Chloroperlidae* (stonefly)	96-h LC$_{50}$	49058
80	*Cinygmula* sp. (mayfly)	96-h LC$_{50}$	49058
81	*Ephemerella* sp. (mayfly)	96-h LC$_{50}$	49058

[a] Normalized for hardness and dissolved organic carbon—see text for details.

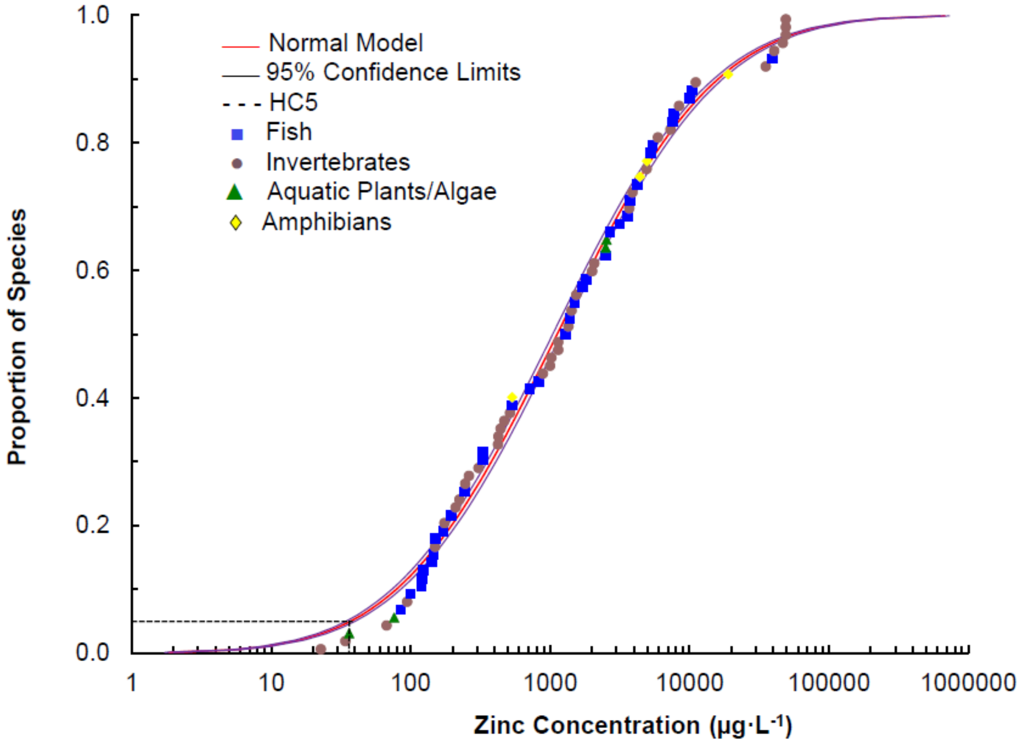

Figure 8.2. Short-term species sensitivity distribution (SSD) for dissolved zinc in fresh water. Derived by fitting the log-normal model to the short-term LC/EC50 values of 81 aquatic species. Data were normalized to hardness and

dissolved organic carbon and converted to dissolved concentrations. The fifth percentile on the short-term SSD is 37 $\mu g \cdot L^{-1}$.

8.2. B.C. Zinc Water Quality Guidelines

The CCME Zn WQGs are based on SSDs that use an MLR approach to incorporate the toxicity modifying factors of pH, hardness, and DOC in the calculation of the WQG (CCME, 2018). In the sections below the chronic and acute CCME WQGs are reviewed and the selected assessment factor is discussed.

8.2.1. Chronic long-term water quality guidelines

The toxicity dataset used to derive the Zn long-term WQG consists of data for one bacterium, one diatom, six plants, 11 invertebrates, nine fishes, and one amphibian, the boreal toad (*Bufo boreas*) which is native to Canada. The chronic dataset used for the Zn FEQG fulfills the minimum number of species required for a type A2 guideline (ENV, 2019). It should be noted that of the 29 species with chronic data for Zn, four are not native to Canada. However, the minimum data requirement using data for only Canadian species.

The CCME Zn WQG meets the conditions specified by the B.C. derivation protocol for Type A2 WQG. However, to account for the sources of uncertainty associated with WQG derivation, an assessment factor (AF) must be applied to the calculated HC5 (ENV, 2019). The minimum AF to be applied to Type A WQGs is 2 which accounts for the extrapolation of lab results to field conditions and the cumulative effects of other environmental stressors. Considering that the database has data on a relatively large number of species including amphibians and important benthic invertebrates (i.e., Ephemeroptera, Plecoptera, Tricoptera or EPT), and data are available on all endpoints (e.g., survival, growth, and reproduction) the minimum AF of 2 was applied to the calculated HC_5.

The chronic long-term WQG for dissolved zinc for the protection of freshwater aquatic life is calculated using the equation:

$$\text{Chronic long-term WQG } (\mu g\ L^{-1}) = \frac{\exp(0.947[\ln(\text{hardness})] - 0.815[\text{pH}] + 0.398[\ln(\text{DOC})] + 4.625)}{2}$$

The equation is valid between hardness 23.4 and 399 mg CaCO3$\cdot L^{-1}$, pH 6.5 and 8.13 and DOC 0.3 to 22.9 mg$\cdot L^{-1}$.

Table 8.3. BC long term chronic WQGs for dissolved Zn (µg/L) at various levels of DOC (farthest left column), pH (separate blocks), and hardness (values ranging from 25 to 399 across the top; adapted from CCME 2018).

pH 6.5	**Hardness (mg CaCO3·L^{-1})**					
DOC (mg/L)	**25**	**50**	**75**	**100**	**200**	**399***
0.5	4.1	7.9	11	15	29	56
2.0	7.1	13	20	26	51	97
5.0	10	19	29	34	73	140
10.0	13	26	38	50	96	185
22.9*	18	36	53	70	134	258

pH 7.0

	25	**50**	**75**	**100**	**200**	**399***
0.5	2.7	5.2	7.7	10	19	37
2.0	4.7	9.1	13	17	34	65
5.0	6.8	13	19	25	48	93
10.0	8.9	17	25	33	64	123
22.9*	12	24	35	46	89	171

pH 7.5

	25	**50**	**75**	**100**	**200**	**399***
0.5	1.8	3.5	5.1	6.7	13	25
2.0	3.1	6.1	8.9	11	22	43
5.0	4.5	8.7	13	17	32	62
10.0	5.9	11	17	22	42	82
22.9*	8.3	16	23	31	59	114

pH 8.0

	25	**50**	**75**	**100**	**200**	**399***
0.5	1.2	2.3	3.4	4.5	8.6	17
2.0	2.1	4.0	5.9	7.8	15	29
5.0	3.0	5.8	8.5	11	21	41
10.0	3.9	7.6	11	14	28	54
22.9*	5.5	10	15	20	39	76

*The B.C. WQG equation is valid between hardness 23.4 and 399 (mg CaCO3/L), pH 6.5 and 8.13 and DOC of 0.3 to 22.9 (mg/L).

8.2.2. Acute short-term water quality guidelines

The CCME acute WQG also used MLR to account for toxicity modifying factors, however, only hardness and DOC were included in the multiple linear regression model. The toxicity dataset used to derive the CCME short-term WQG for dissolved Zn consists of data for four plants, 40 invertebrates, 34 fishes, and four amphibians. The acute dataset consists of Canadian and non-Canadian species, however if only the Canadian species are considered, the database fulfills the minimum number of species required for a B.C. Type A2 guideline (ENV, 2019).

Considering the large number of species in the data including data on all aquatic taxa (e.g., amphibians, EPT, and plants), the minimum AF of 2 is sufficient.

The B.C. short term WQG for dissolved Zn is calculated using the following equation:

$$\text{Acute short-term WQG } (\mu\text{g L}^{-1}) = \frac{\exp(0.833[\ln(\text{hardness})] + 0.240[\ln(\text{DOC})] + 0.526)}{2}$$

The equation is valid between hardness 13.8 and 250.5 mg CaCO3·L^{-1} and DOC 0.3 and 17.3 mg·L^{-1}

Table 8.4. Examples of short-term WQG (µg/l) for dissolved Zn in freshwater at various levels of hardness and DOC.

	Hardness (mg CaCO3·L^{-1})							
DOC (mg/L)	**15**	**25**	**50**	**75**	**100**	**150***	**200**	**250.5***
0.5	7	10.5	18.5	26	33	46.5	59	71.5
2.0	9.5	14.5	26	36.5	46.5	65	82.5	99.5
5.0	12	18	32.5	45.5	57.5	81	103	124
10.0	14	22.5	38.5	53.5	68	95.5	122.5	146.5
17.3*	16	25.5	43.5	61	77.5	109	138.5	167

* The short-term benchmark equation is valid between hardness 13.8 and 250.5 (mg CaCO3/L) and from DOC 0.3 to 17.3 (mg/L).

9. COMPARISON OF AMBIENT ZINC CONCENTRATIONS TO WATER QUALITY GUIDELINES

Water quality guidelines are commonly used to determine the potential risk of toxicity to aquatic life from a given substance in ambient conditions. In general, if ambient concentrations are below the WQG the risk is assumed to be low. It is important to understand how the assessment of risk to aquatic life will change with the updated Zn WQG. To answer this question, water quality data (dissolved Zn, pH, DOC, and hardness) collected over the past 22 years from freshwater sites were extracted from the EMS database. Non-detect data for Zn were not included if the MDL was greater than 5 µg/L. Non-detect data for DOC were not included if the MDL was greater than 0.5 mg/l. Results reported as "<MDL", were given the value of the MDL. A total of 722 records were retrieved to calculate the 1997 WQG (i.e., hardness and total Zn) and a total of 6,913 records were retrieved to calculate 2023 WQG (i.e., pH, hardness, DOC, and dissolved Zn).

Total Zn exceeded the 1997 WQGs (based on total Zn) concentrations 4.1% of the time (30/722) (Figure 9.1) and dissolved zinc exceeded the updated WQG 8.6% of the time (596/6913) (Figure 9.2). The higher rate of exceedance of the updated WQG compared to the 1997 WQG is mainly because the updated WQG could be as low as 1.35 µg/L when pH is high and DOC and hardness are low, whereas the lowest value for 1997 WQG is 7.5 µg/L. In addition, some of the exceedances from the updated WQG are due to the non detect data that were replaced with the MDL of 5 ug/L (the horizontal dots at 5 ug/L in Figure 9.2)

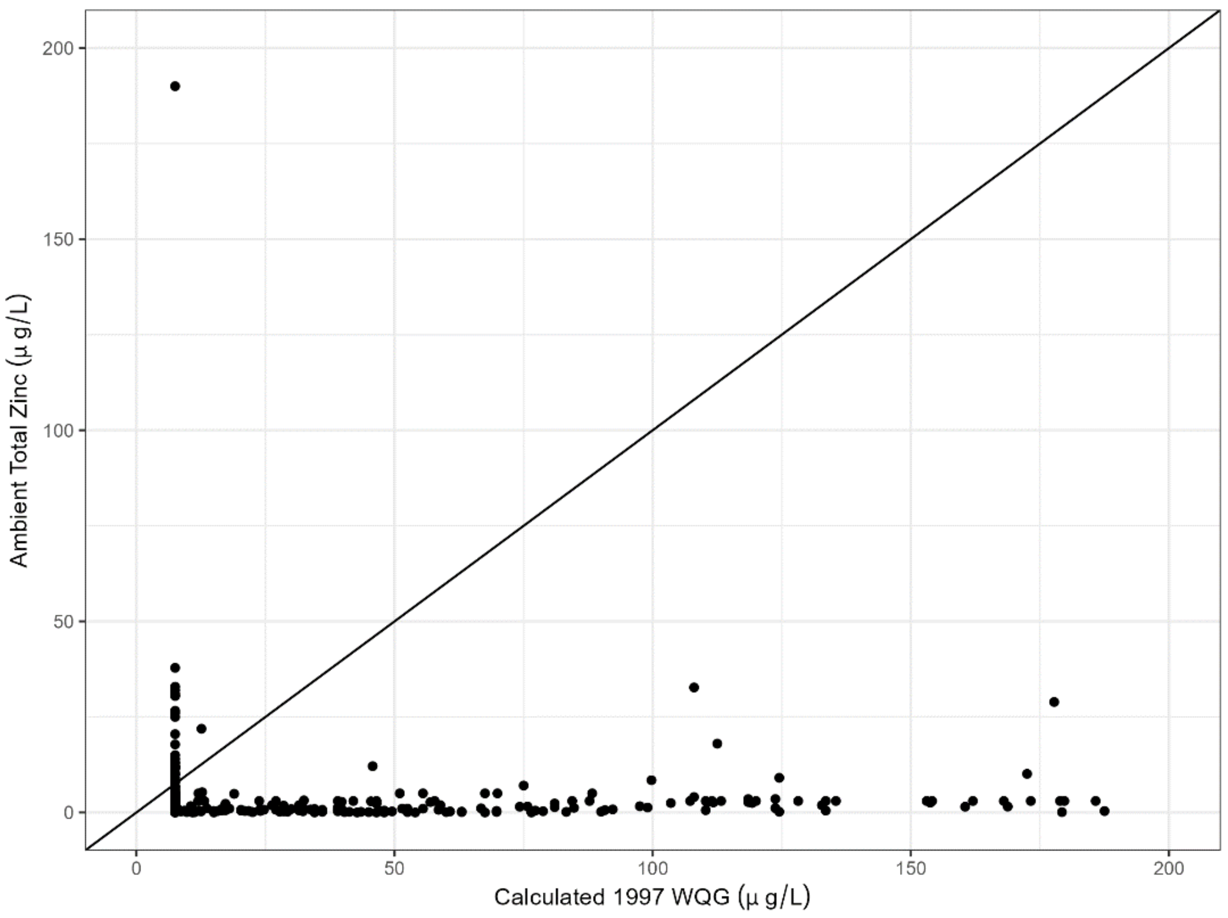

Figure 9.1. Ambient Zn concentrations compared to the 1997 chronic total Zn WQGs. Points above the solid 1:1 line represent exceedances. The minimum and maximum values for the 1997 chronic WQG are 7.5 and 187.5 µg/L respectively.

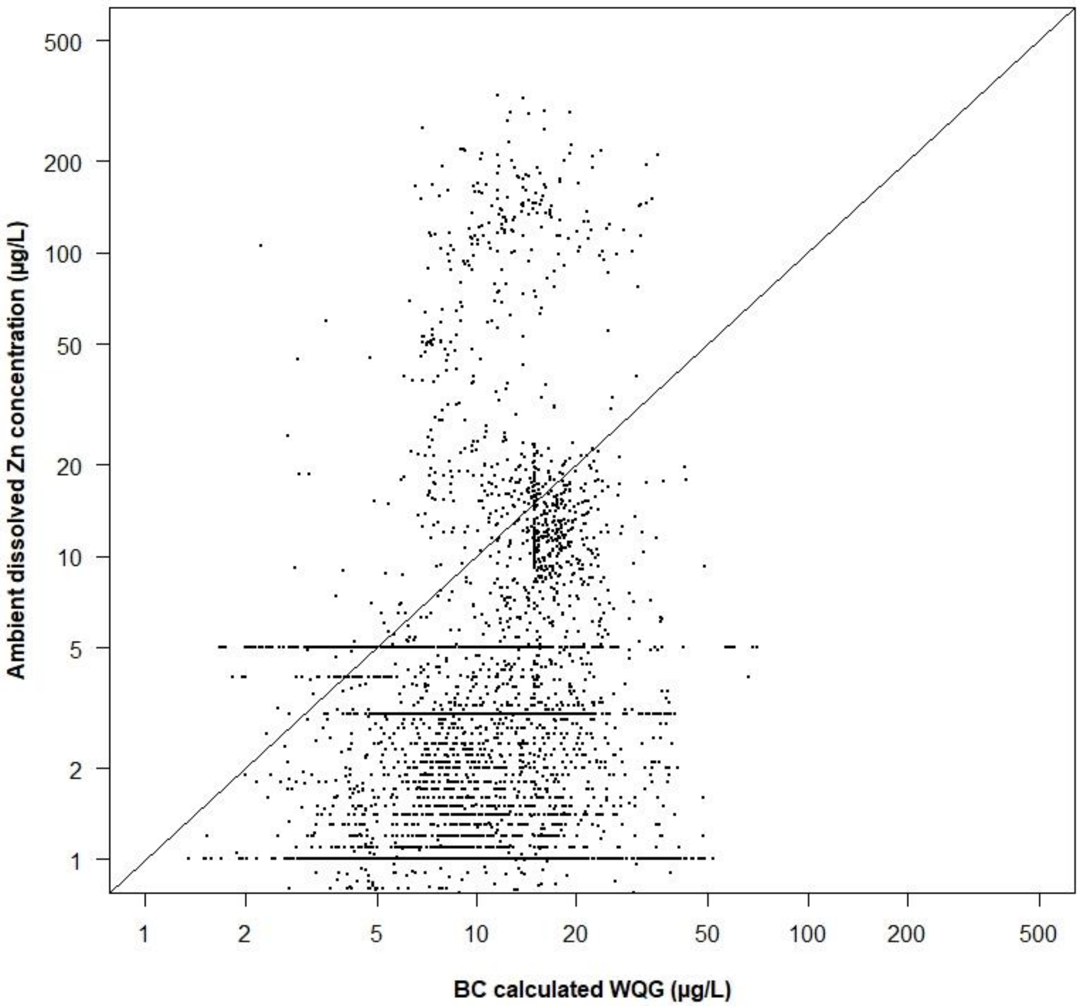

Figure 9.2. Ambient Zn concentrations compared to the 2023 chronic dissolved Zn WQGs. Points above the solid 1:1 line represent exceedances.

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