WATER QUALITY GUIDELINE SERIES

Lead Water Quality Guidelines – Freshwater Aquatic Life

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

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The Water Quality Guideline Series is a collection of British Columbia (B.C.) Ministry of Water, Land, and Resource Stewardship 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:

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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 lead (Pb) WQGs for the protection of aquatic life.

Elevated concentrations of lead can adversely affect aquatic and terrestrial life. While background Pb concentrations in B.C. vary across the province, atmospheric deposition, urban runoff, and industrial discharge can increase lead concentrations to levels that can be harmful.

Lead has no known biological function and is therefore considered a non-essential element. Its toxic mode of action for fish has been broadly investigated, while information is less available for invertebrates, aquatic plants, and algae. However, it appears that Pb^{2+} competes with Ca^{2+} at the uptake site in invertebrates.

In 2020, Environment and Climate Change Canada (ECCC) published a Federal Water Quality Guideline (FWQG) for dissolved lead for the protection of freshwater aquatic life. B.C. has adopted the lead FWQG (ECCC 2020) with the inclusion of an assessment factor to account for sources of uncertainty. This revised WQG for lead considers both hardness and dissolved organic carbon (DOC) whereas the previous B.C. WQG for Pb only considered hardness as a toxicity modifying factor and was for total Pb. There were no exceedances of the updated WQG when compared against ambient background Pb concentrations from across B.C.

WQGs for the protection of agriculture and wildlife were also derived in 1987 and remain unchanged. The technical document for the agriculture WQGs and the source drinking water WQGs can be found on the B.C. WQG website. A summary of the lead WQGs is presented in Table E.1 below. The aquatic life guideline is calculated using site-specific water chemistry (hardness and DOC) and, therefore, is listed below as variable. As an example, for a waterbody with DOC of 0.5 mg/L, and hardness of 50 mg/L the freshwater aquatic life WQG for dissolved Pb is 1.2 µg/L.

Table E.1. Summary of recommended water quality guidelines for lead.

Designated use	Guideline mg/L	Guideline Type
Freshwater aquatic life	Variable*	Long-term chronic dissolved Pb
Wildlife	0.1	Maximum total Pb
Livestock	0.1	Maximum total Pb
Irrigation (neutral and alkaline soils)	0.4	Maximum total Pb
Irrigation (all other soils)	0.2	Maximum allowable concentration

*The equation for the B.C. freshwater aquatic life lead WQG which includes hardness and DOC is provided in section 7.4.

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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), drinking water sources, and recreation.

In B.C., WQGs are developed to protect the most sensitive receptor and life stage 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,
- Cumulative effects of the various stressors, such as habitat loss and climate change, that organisms in the field are exposed to.

Given these uncertainties, WQGs are an estimate of a 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, however, 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 July 2020, Environment and Climate Change Canada (ECCC) published a Federal Water Quality Guidelines (FWQG) for lead (Pb) for the protection of freshwater aquatic life. B.C. has adopted this guideline with the addition of an assessment factor to account for the sources of uncertainty. This document provides information on ECCC'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 1987 lead water quality criteria for Marine, Agriculture, and Wildlife have not been updated and are available in a separate document on the B.C. WQG website (WLRS, 1987).

2. SUBSTANCE IDENTITY

Lead (Pb) is a highly toxic naturally occurring element (CAS Number 7439-92-1) found in bedrock, soils, tills, sediments, surface waters, groundwaters and seawater (Reimann and de Caritat 1998; Health Canada 2013). Lead is one of the most abundant metals in the earth's crust (Adriano 2001), is highly resistant to chemical corrosion, and has no known biological function (Mager 2012). It is a class B, post-transition metal with a density of 11.34 g/cm3 and a molecular weight of 207.2 g/mol. Lead has several oxidation states, but in nature the plumbous form predominates (ATSDR 2007). Lead can occur as stable organic compounds, such as tetraethyl lead, but this FWQG is for inorganic lead. Lead was one of the first substances added to the List of Toxic Substances (Schedule 1) of the Canadian Environmental Protection Act (CEPA), 1988 (GC 1988). It was determined that the scientific evidence of the adverse effects of lead on human health and the environment had been sufficiently demonstrated, and that determination of its adverse effects was consistent with the criteria set out in section 11 of CEPA 1988 (Health Canada 2013).

Canada is a major global producer and supplier of refined lead, ranked eighth in the world, producing 14,000 tonnes (t) of lead in concentrate and 277,000 t of refined lead production in 2017 (NRCan 2019). Canada operates two primary lead and four recycled lead smelters. Because of the significant recycling of lead-acid batteries, recycled lead accounted for 55% of Canada's total refined lead production. Canada exported 261,480 t of unwrought lead metal in 2017 and the majority of these exports were to the United States (NRCan 2019).

The primary use of lead is in the manufacturing of lead-acid batteries, but it is also used extensively in the manufacture of cable sheathing, circuit boards, lining for chemical baths and storage vessels, chemical transmission pipes, wheel weights, electrical components, polyvinyl chloride (as a chemical stabilizer) and radiation shielding (Health Canada 2013). Other uses include: lead used in ammunition and fishing sinkers and jigs. Historically, leaded gasoline and lead-based paints were important sources of lead, but these products have been phased out (Health Canada 2013).

Total lead emissions to air in Canada in 2014 were 136 t, representing an increase of 5% (about 7 t) from 2013, and 89% (1153 t) lower than in 1990 (ECCC 2016). Emissions to air decreased between 1990 and 2014 as a result of reduced emissions from many industrial sectors, most notably the non-ferrous smelting and refining industry and the mining industry. The national lead releases to water were 146 t of lead in 2014, more than 10 times the total releases reported in 2013, mainly due to 134.1 t released from the Mount Polley mine dam failure (ECCC 2016). Other categories contributing to most releases of lead to water were waste, accounting for approximately 5.1 t, followed by the pulp, paper and paperboard industry, representing 1.9 t of the national total. Further 500 t per year is released into aquatic environments from the unintentional loss of lead sinkers and jigs (Health Canada 2013). Historically, use of lead shot was a significant source of lead to aquatic environments. However, lead inputs from this source have declined in Canada since the 1997 national regulation prohibiting the use of lead shot for hunting migratory game birds (exempting American woodcock, mourning doves, and band-tailed pigeons) within 200 m of any watercourse and the 1999 extension of ban to include all areas of land and water nationwide (Stevenson et al. 2005). Not accounted by this regulation, lead ammunitions annually release about 5,200 t of lead into environment and this source represents the single most significant source of lead releases in Canada (GC 2018).

3. FATE, BEHAVIOUR, AND PARTITIONING IN THE ENVIRONMENT

Atmospheric deposition, urban runoff and industrial discharge are the major sources of lead in surface waters (Health Canada 2013; USEPA 2006). In surface waters lead is predominantly found as PbO or PbCO3. Fate, transport and the subsequent bioavailability of lead in both aquatic and terrestrial systems are primarily controlled by the solubility (USEPA 2013). In aquatic environments at a pH of ≥7, lead is readily complexed and, with the exception of nitrate, chlorate and chloride salts, most inorganic lead salts are poorly soluble, however, the solubility of lead salts greatly increases under acidic conditions (Mager 2012). Lead speciation in freshwater environments is largely driven by pH, alkalinity and dissolved organic matter (DOM) (Mager 2012). Lead concentrations in surface water are largely controlled by exchange with sediments, and the cycling of lead between water and sediments is governed by chemical, biological and mechanical processes that are affected by many factors, including salinity, organic complexation, oxidation-reduction potential, and pH (USEPA 2006).

The majority of lead in surface waters occurs in undissolved forms, as colloidal particles or undissolved particles of lead carbonate, lead hydroxide, or other lead compounds, which precipitate to the sediment bed (Getz et al. 1977; Eisler 1988). Concentrations of dissolved lead are generally small in surface and groundwaters because lead forms complexes with sulphates, hydroxides, phosphates, carbonates and other anions in the water. Lead can occur as surface coatings on sediment mineral particles, sorbed ions or within suspended organic matter, living or non-living (LDAI 2008). The ratio of lead in suspended solids to dissolved lead varies between 4:1 in rural streams and 27:1 in urban streams (Getz et al. 1977).

The bioavailability of lead to freshwater aquatic organisms is influenced by a variety of water chemistry parameters (Van Sprang et al. 2016). It is generally assumed that the free Pb ion (i.e., Pb2+) is the most toxic form of lead, although it still needs to be determined whether other chemical species (e.g., PbOH+) are also important contributors to lead toxicity (Mager 2012). As low pH favours a greater proportion of Pb2+, lead toxicity tends to be greater at low pH (although the higher concentration of protons [H+] at low pH can also compete with Pb2+ for uptake by aquatic organisms) (Mager 2012). Conversely, as pH increases, an increasing proportion of lead binds to carbonate and hydroxide ions, which are less bioavailable forms of lead. Very high hardness may also reduce lead solubility, but pH appears to be an important factor in determining lead solubility for the range of water chemistries typically used in toxicity testing (Mager 2012). In addition to pH, DOM is another water quality variable that strongly influences the bioavailability of lead to aquatic organisms (Mager et al. 2010). DOM can complex the majority of lead under most environmentally-relevant conditions, although the quality of the DOM also has an important influence on its binding capacity (Richards et al. 2001; Mager 2012). Finally, several water chemistry parameters co-vary, which can make it difficult to elucidate the relative influence of each water chemistry parameter on lead bioavailability. For example, hardness and pH often co-vary with alkalinity and it can be difficult to determine the relative influence of each (Mager 2012).

In general lead is relatively stable in sediments, with long residence times and limited mobility (Das et al. 2008). However, lead-containing sediment particles can be remobilized into the water column. As a result, trends in sediment concentration tend to follow those in overlying waters (LDAI 2008). Desorption, dissolution, precipitation, sorption and complexation processes can all occur concurrently and continuously, leading to transformations and redistribution of lead (USEPA 2013).

Lead is typically bound to organic matter and soil in terrestrial systems and the most important factors determining its solubility in soils are pH and cation exchange capacity (Smolders et al. 2009). Iron and manganese oxides are also known to play an important role in lead sequestration in soils (USEPA 2013). Because lead is strongly adsorbed to soil, it generally is retained in the upper layers of soil and does not leach appreciably into the subsoil and groundwater (ATSDR 2007). Organic matter decreases bioavailability of lead, but over time as it is broken down, pedogenic minerals become more important in sequestration of lead (Schroth et al. 2008). The binding of lead to organic matter is relatively weak and as the organic matter is broken down the lead may be released into soil solution (USEPA 2013). However, as lead ages in soils, through its incorporation into particulate solid-phase of the soil, the bioavailability of lead is reduced to plants and soil organisms.

4. BACKGROUND CONCENTRATIONS OF LEAD IN BRITISH COLUMBIA

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

4.1 Methods for Estimating Background Concentrations of Lead in British Columbia Surface Waters

Background (i.e., from non-impacted sites) dissolved lead concentrations vary across B.C. as a function of local geology and hydrology. Therefore, a regional approach was used to estimate background lead concentrations in aquatic environments following methods used in recent WQG derivation documents (e.g., ENV, 2021). Data were obtained from two sources: the B.C. Environmental Management System (EMS) database and the Canadian Aquatic Biomonitoring Network (CABIN) database; however, the CABIN database did not contain any dissolved concentrations for lead.

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 the last 23 years for any water quality parameter (2000/01/01 to 2023/05/24) 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 lead data from the EMS database.

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) ≥ the upper 95th percentile of the dataset 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 107 stations with 614 samples.

The results from each station were given equal weight within an ENV administrative region by calculating the mean lead concentrations for each station. Station means were calculated using four different approaches depending on the number of samples above (detects) and below (non-detects) the MDL (Table 4.1). A value of ½ the minimum MDL was used to represent station means when all samples were below the MDL (Group 1). The minimum MDL was chosen to account for decreasing MDLs over time. For stations with less than three detects, ½ of the MDL was substituted for non-detect values and the arithmetic mean of all station results was calculated (Group 2). Regression on order statistics (ROS) was used to calculate an estimate of the mean for stations that had a mixture of non-detects and detects with at least three detected values (Huston and Juarez-Colunga, 2009; Group 3). Although Huston and Juarez-Colunga (2009) state that ROS can be used on sample sizes >0, a minimum of three detects is required to calculate a valid regression using the NADA package (Lee, 2017) in R (R Core Team, 2022). The arithmetic mean was calculated for stations where all samples were above the MDL (Group 4). Statistics to summarize the distribution of station means (median, the 10th and 90th percentile) were calculated for each ENV region.

Table 4.1. Statistical approach used to calculate station means.

Group	Conditions	Approach	Total Stations	Total Samples
1	% non-detects = 100	½ of minimum station MDL	29	104
2	0 < % non-detects < 100 AND # detects < 3	Substitute ½ MDL for non-detects and calculate arithmetic mean for all samples	29	149
3	0 < % non-detects < 100 AND # detects ≥ 3	Regression on order statistics	19	294
4	% non-detects = 0	Arithmetic mean	30	67

4.2 Background Concentration Results

The distribution of dissolved lead concentrations by ENV administrative region and the summary statistics for station mean values are summarized in Figure 4.1 and Table 4.2. Summary statistics for station mean dissolved lead at minimally impacted stations in British Columbia The median of station means ranged from 0.008 µg/L (Northeast) to 0.276 µg/L (Omineca). There were no data in EMS for dissolved lead concentrations at background sites in the Lower Mainland. Of the 107 stations, 31 were on lakes and 76 were on rivers. The median of the distribution of station means was 0.025 µg/L in both lakes and rivers (Figure 4.2).

Table 4.2. Summary statistics for station mean dissolved lead at minimally impacted stations in British Columbia.

Region	Number of Stations	Number of Samples	Date Range	% Samples < MDL	MDL Range Across all Samples (µg/L)	Concentration Range Across all Samples (µg/L)	Distribution of Station Means (µg/L)		
							Median	10th Percentile	90th Percentile
Cariboo	43	224	2000 – 2023	64%	0.005 - 1	<0.005 - 1	0.025	0.006	0.100
Kootenay-Boundary	7	29	2008 – 2023	69%	0.05 - 0.2	<0.05 - 0.7	0.086	0.025	0.148
Lower Mainland	0	0	NA	NA	NA	NA	NA	NA	NA
Northeast	1	2	2012 - 2013	0%	NA	0.007 – 0.0081	0.008	0.008	0.008
Omineca	1	16	2010 – 2023	13%	0.01 – 0.2	<0.01 – 2.36	0.276	0.276	0.276
Skeena	20	79	2000 – 2023	67%	0.005 - 0.25	<0.005 – 0.8	0.020	0.005	0.058
South Coast	2	7	2004 - 2023	0%	NA	0.0193 – 0.12	0.060	0.044	0.076
Thompson-Okanagan	8	173	2005 – 2023	83%	0.005 - 1	<0.005 - 5	0.018	0.003	0.115
West Coast	25	82	2001 – 2023	34%	0.005 - 0.2	<0.005 – 0.57	0.020	0.005	0.061

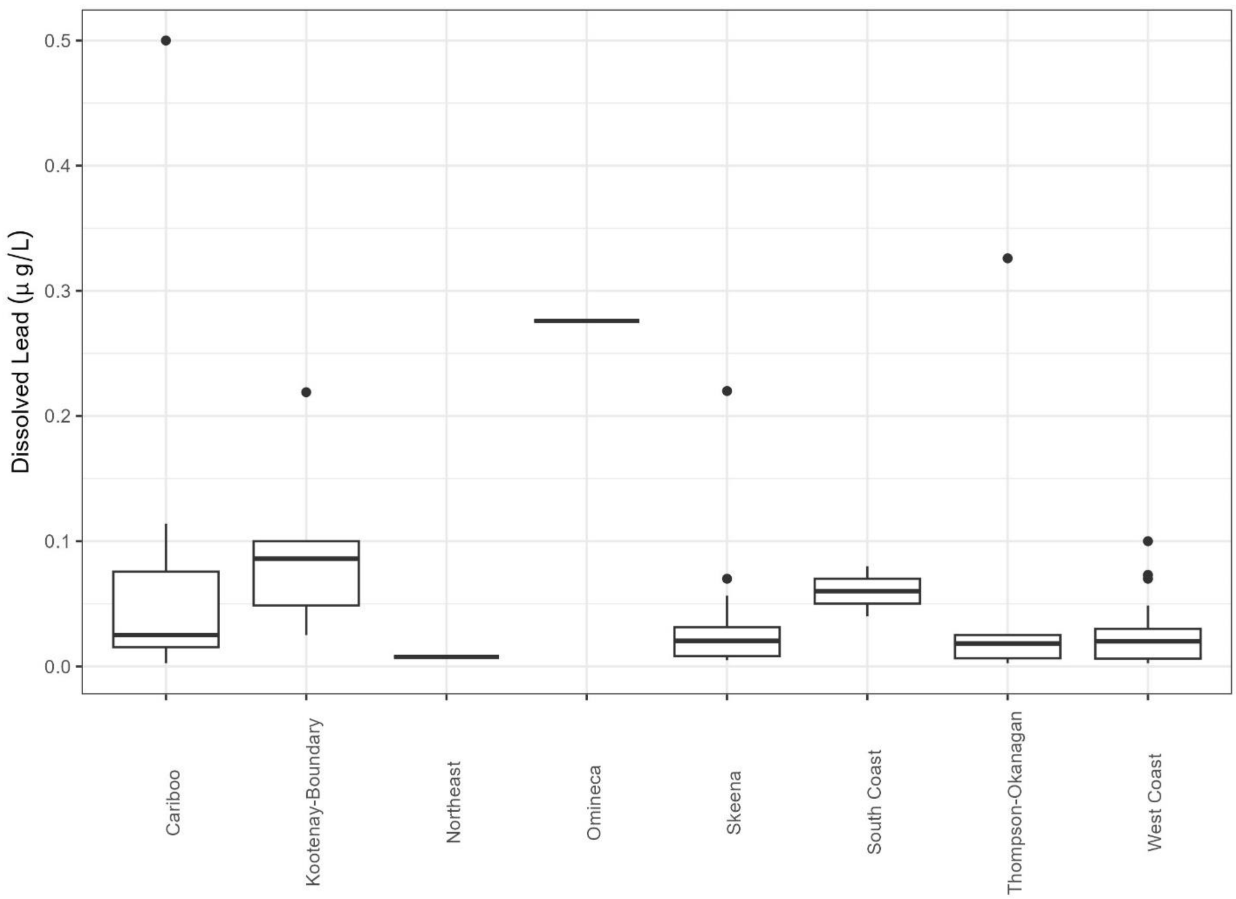

Figure 4.1. Distribution of station mean values for regions in British Columbia. Note: There were no data available in EMS for dissolved lead concentrations at background sites in the Lower Mainland.

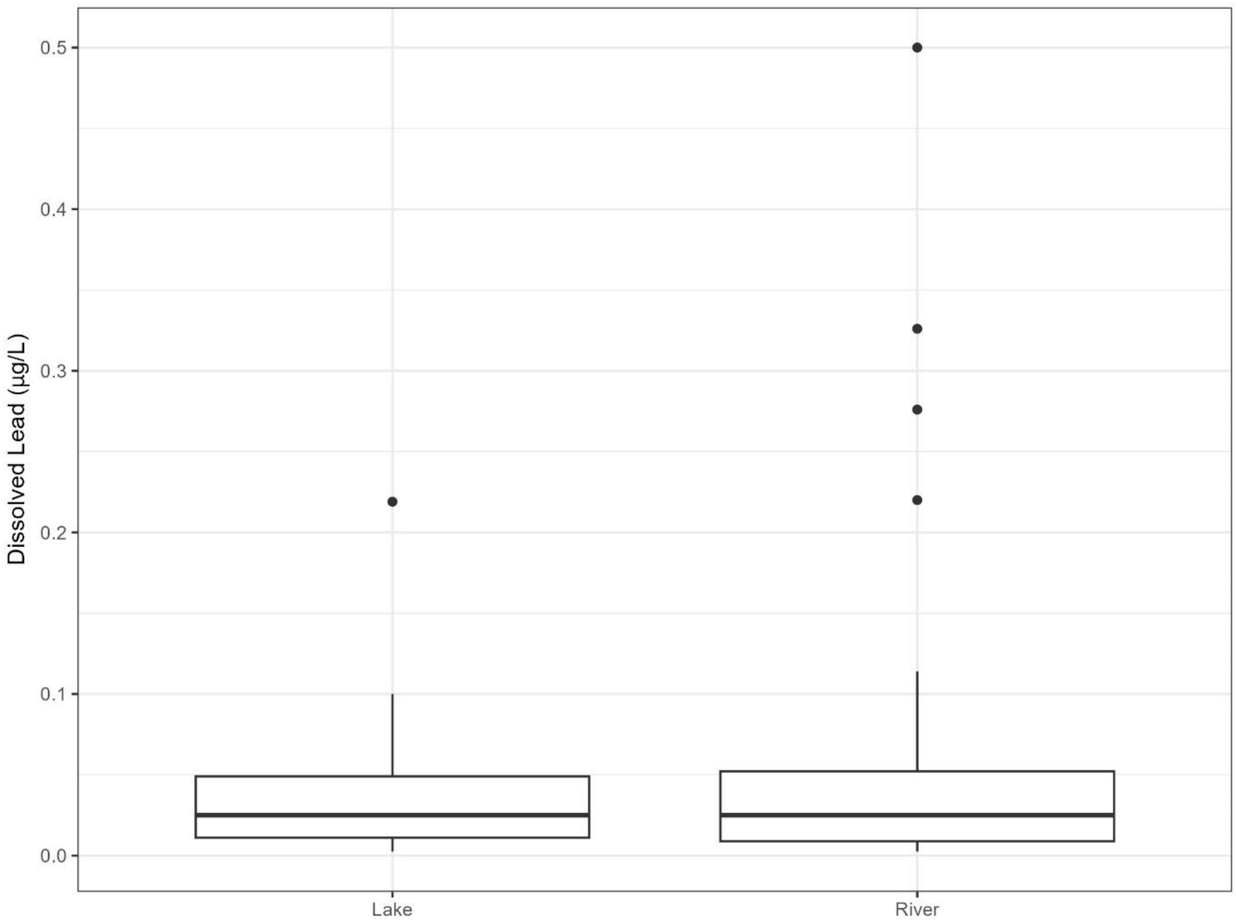

Figure 4.2. Distribution of station means for lakes and rivers for dissolved lead. Solid horizontal bar and the lower and higher whiskers represent median, 10^{th} and 90^{th} percentile of station means.

5. MODE OF ACTION

Mechanisms of acute lead toxicity in fish include a smothering effect at very high lead concentrations (e.g., 20 to >100 mg/L) and an ionoregulatory effect at lower lead concentrations that may be more typically observed in the environment (Mager 2012). As demonstrated in a series of studies with rainbow trout (*Oncorhynchus mykiss*), acute lead exposures can result in the disruption of Ca2+, Na+, and Cl- homeostasis, with hypocalcemia being the primary cause of lead toxicity in fish (Rogers et al. 2003, 2005; Rogers and Wood 2004). In chronic lead exposures to fish, lead can adversely affect the growth and development of fish, including spinal deformity (Davies et al. 1976; Holcombe et al. 1976; Hodson et al. 1978). Although the mechanisms of how lead may affect growth in fish are not fully understood, it could be related to reduced feeding ability or appetite due to neurological effects of lead (Mager 2012).

The mechanisms of lead toxicity in invertebrates are less understood than in fish. However, where Pb2+ competes with Ca2+ at a common uptake site, it appears, at least for the sensitive cladoceran *C. dubia* at low aqueous lead concentrations, that Pb2+ is taken up via a channel or transporter that has a low affinity for Ca2+ (Mager et al. 2011a,b). For the snail *L. stagnalis*, also a chronically-sensitive species to lead, Ca2+ homeostasis can be affected by lead exposure, but this appears to be a secondary effect and does not explain the sensitivity of snail to lead (Brix et al. 2012). In plants, excess lead can lead to reduced mitosis, photosynthesis and water absorption, as well as growth inhibition (Eisler 1988).

6. CRITERIA FROM OTHER JURISDICTIONS

Lead WQGs from six provincial and national jurisdictions are summarized in Table 6.1. Three types of guidelines are used: a static number for different hardness values, hardness-based equations, and multiple linear regression (MLR) that considers the toxicity modifying effects of pH, hardness, and dissolved organic carbon (DOC). In general, most of the WQGs are derived from hardness-based equations.

6.1 British Columbia

In B.C., a hardness-based lead WQG was established in 1987 (ENV, 1987) for freshwater aquatic life (Table 6.1). The guideline is calculated based on a an average concentration of total lead in water over a 30-day period (based on a minimum of 5 weekly samples), and an average hardness of water >8 mg/L $CaCO_3$, using the following equation: 3.31 + exp(1.273 [ln (average hardness)] -4.705).

6.2 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 for long term exposure to total lead is related to water hardness (as $CaCO_3$) and is presented in (Table 6.1). When hardness is 0 to ≤ 60 mg/L CaCO3, the CCME WQG is 1 µg/L. However, at hardness >60 to ≤ 180 mg/L CaCO3, the WQG is calculated using the following equation: exp(1.273 [ln(hardness)] -4.405) (CCREM 1987, CCME 1999).

6.3 Environment and Climate Change Canada (ECCC)

Environment and Climate Change Canada published a WQG for dissolved lead in 2020 which uses an MLR approach with DOC and hardness to derive a chronic Federal Water Quality Guideline (FWQG) (ECCC, 2020). The equation to derive the Federal Water Quality Guideline (FWQG) is as follows: exp(0.514 [ln(DOC)] + 0.214 [ln (hardness)] + 0.4354).

6.4 Provincial Water Quality Guidelines

Canadian provinces typically develop their own WQGs or adopt WQGs from another jurisdiction (e.g., CCME). The Ontario Ministry of Environment sets policies to manage Ontario's water resources, including providing Provincial Water Quality Objectives (PWQOs) for surface water to protect aquatic life (OMOEE, 1994). The interim chronic PWQO for total lead is based on hardness (as $CaCO_3$ mg/L) in three categories: hardness <30 mg/L: PWQO = 1 µg/L lead; hardness 30 mg/L to 80 mg/L: PWQO = 3 µg/L lead; and hardness >80 mg/L: PWQO = 5 µg/L lead (OMOEE, 1994).

Government of Alberta adopted the 1987 CCME guideline for lead (Government of Alberta 2018). Saskatchewan adopted the chronic CCME WQG as an interim surface water quality objective with some modifications (Water Security Agency, 2015). Manitoba has adopted the US EPA acute and chronic Water Quality Criteria (WQC) published in 1985 (see below; MWS, 2011).

6.5 USEPA Water Quality Criteria

The USEPA developed acute (i.e., short-term) and chronic (i.e., long-term) national water quality criteria (WQC) for the protection of aquatic life based on dissolved lead and site-specific hardness (as $CaCO_3$ mg/L; USEPA, 1985). For chronic exposure, the four-day average dissolved lead should not exceed the WQC from the following equation: exp(1.273 [ln(hardness)] -4.705) more than once every three years (USEPA, 1985). The acute WQC specifies that the 1-hour average of dissolved lead (µg/L) should not exceed the WQC derived from the following equation: exp (1.273 [ln(hardness)] -1.460) more than once every three years (USEPA, 1985).

6.6 Australia and New Zealand

Australia and New Zealand have joint WQGs, described as trigger values, where the protection level signifies the percentage of species expected to be protected (ANZECC, 2000a; 2000b). Although four trigger values have been calculated to provide various levels of protection (i.e., 80-99% of species), ANZECC (2000) recommends application of the 80%, 95% and 99% protection levels to protect highly disturbed ecosystems, moderately disturbed ecosystems, and high conservation/ecological value ecosystems, respectively (ANZECC, 2000). The lead trigger value was derived based on a hardness of 30 mg/L (as $CaCO_3$ mg/L). For example, to protect 95% of aquatic life, ANZECC (2000) developed a trigger value for total lead of 3.4 µg/L for water with a hardness of 30 mg/L $CaCO_3$ (Table 6.1). However, to calculate the trigger value with a site specific hardness, an equation is provided to calculate the hardness modified trigger value (HMTV) using the following equation: $HMTV = TV(hardness/30)^{1.27}$.

Table 6.1. Summary of Lead Freshwater Aquatic Guidelines in Different Jurisdictions

Jurisdiction (Year Published)	Conditions	Guideline (µg/L)	Fraction
		Chronic Guidelines	
British Columbia (1987)	$CaCO_3$ > 8 mg/L	3.31+exp(1.273 ln (mean hardness)-4.705)1[1]	Total
CCME (1987)	0 to ≤60 mg/L $CaCO_3$	1	Total
	>60 to >180 mg/L $CaCO_3$	exp(1.273[ln(hardness)]-4.705	
	>180 mg/L $CaCO_3$	7	
ECCC (2020)	N/A	exp(0.514[ln(DOC)] + 0.214[ln (hardness)] + 0.4354)	Dissolved
Ontario (1994)	<30 mg/L $CaCO_3$	1	Total
	30 to 80 mg/L $CaCO_3$	3	
	>80 mg/L $CaCO_3$	5	
USEPA (1984)	N/A	exp(1.273[ln(hardness)]-4.705)	Dissolved
Australia/New Zealand (2000)	30 mg/L $CaCO_3$	3.4	Total
		Acute Guidelines	
British Columbia (1987)	$CaCO_3$ ≤8 mg/L	3	Total
	$CaCO_3$ >8 mg/L	exp(1.273 ln(hardness)-1.460)	
USEPA (1984)	N/A	exp(1.273[ln(hardness)]-1.460)	Dissolved

[1] The B.C. chronic WQG is compared to the lead average concentration over a 30-day period, based on a minimum of 5 weekly samples. In addition, not more than 20% (i.e., 1 in 5) of the values in a 30-day period should exceed 1.5 times the 30-day average criterion.

7. RECOMMENDED GUIDELINE

7.1 Aquatic Toxicity Data

A detailed review of studies was performed following the CCME (2007) guidance for data quality. Determinants of test acceptability included, but were not limited to, exposure duration, analytical determination of lead exposure concentrations and other water quality parameters, documentation of the control response, the use of suitable biological endpoints and the inclusion of appropriate statistical analyses of the data collected in the study.

The chronic freshwater toxicity studies for lead were identified from existing data compilations (ECCC 2020). It is now generally accepted that the dissolved rather than the total recoverable fraction of most metals, including lead, reflects the fraction that is potentially bioavailable to aquatic organisms (Reiley et al. 2003). As summarized in Diamond et al. (1997), the relationship between total recoverable and dissolved lead is variable because it is heavily influenced by the amount of carbonate and hence alkalinity (Davies et al. 1976; Sprague 1995). Van Sprang et al. (2016) assessed dissolved versus total lead measurements in toxicity studies and concluded that in all studies they examined estimated inorganic lead concentration was lower than the inorganic solubility limit, and therefore precipitation was considered unlikely to have occurred in studies where only total lead concentrations were reported. Therefore, the dissolved lead concentration was assumed to be equal to the total lead concentration.

Acceptable chronic toxicity data were available for 28 species (11 fish, 13 invertebrates and 4 plants/algae) (ECCC 2020) and the dataset met the CCME's (2007) minimum data requirements for developing the SSD-based guideline (i.e., Type A guideline). Within the acceptable dataset, several studies evaluated the influence of varying water chemistry on the bioavailability of lead and related chronic toxicity to aquatic species. The toxicity data for these species were used to evaluate toxicity modifying factors (TMFs) to develop FWQGs for lead that could be adjusted for the site-specific water chemistry (ECCC 2020).

7.2 Toxicity Modifying Factors

The CCME (2007) protocol states that, where possible, it is important to account for exposure and toxicity modifying factors in guideline derivation. This may be done through single or multi-factor equations, matrices or models (CCME 2007). Multiple linear regression (MLR) analysis was explored as an approach to account for the simultaneous effect of multiple water chemistry variables on lead toxicity. In conducting forward step-wise MLR (e.g., Neter et al. 1990), the independent variable (in this case water hardness, DOC or pH) that explains the greatest amount of the variability in the dependent variable (in this case lead toxicity) is entered first. If the relationship between this independent variable and the dependent variable is not significant, the modelling process would be considered complete (that no MLR model could be developed). If the relationship is significant, the variable is retained and the independent variable that explains the greatest proportion of the remaining variability is entered next. If this second variable does not explain a significant additional percentage of the variability, the second variable is removed and the final model contains only the first independent variable that was entered. If the relationship is significant, the second variable is retained, and the independent variable explaining the next highest proportion of the remaining variability is entered, and so on.

The increased understanding of how various factors influence the bioavailability of metals has led to the development of the biotic ligand model (BLM) (Di Toro et al. 2001; Santore et al. 2001; Paquin et al. 2002).

The BLM is a mechanistic model that predicts metal bioavailability to aquatic organisms by considering competition for metal ions at the "biotic ligand" of the organism (e.g., fish gills) and other ligands in the water (e.g., DOC), as well as competition between uptake of metals and other cations in the water (e.g., calcium) (Di Toro et al. 2001). The BLM has been used to develop water quality criteria/guidelines (USEPA 2007; EU 2008a,b,c, 2010; DeForest et al 2017). The BLM for lead and other metals served as an important basis for identifying the key variables considered in the MLR-based approach considered in the current evaluation.

Multiple linear regression analysis was evaluated as a potential tool for deriving the FWQG for two primary reasons. First, MLR models are reliable tool for predicting metal toxicity (DeForest et al. 2018), including lead toxicity (Esbaugh et al. 2011, 2012) over a range of water chemistries. Second, it is a linear model that is conceptually similar to the already accepted hardness-based model. As such, the procedure for developing potential MLR-based WQGs would follow the same basic steps that have already been accepted for developing hardness-based WQGs (CCME 2007) and the resulting equation would have the same basic structure as a hardness-based WQG, but instead of just a hardness slope it may, for example, contain slopes for hardness, DOC and pH. For several metals (e.g., aluminium, lead, nickel, zinc), it has been observed that MLR models are able to predict toxicity as well as BLMs (Esbaugh et al. 2012; Brix et al. 2017; DeForest et al. 2018; USEPA 2018).

Forward stepwise multiple linear regression (MLR) analyses were conducted using SYSTAT (Version 13) statistical software. The MLR analyses determines whether a significant portion of variability in toxicity could be explained by hardness, pH and/or DOC. MLR analysis was conducted for a given species if toxicity data were available from tests in which the range of hardness exceeded 100 mg $CaCO_3$/L (with the highest hardness being three times the lowest), the range of DOC exceeded 5 mg/L (with the highest DOC being three times the lowest) and the range of pH spanned at least 1.5 units. The acceptable toxicity data could include data combined from multiple studies for the same species. MLR analyses were conducted on a species-by-species basis, whereby toxicity values for a given species were the dependent variables and the water chemistry values were the independent variables. Individual species MLRs were conducted for the following species: *Brachionus calyciflorus*, *Ceriodaphnia dubia*, *Lymnaea stagnalis*, *Pimephales promelas*, *Pseudokirchneriella subcapitata* (Grosell et al. 2006; Nys et al. 2016; Cooper et al. 2009; Mager et al. 2011b; Esbaugh et al. 2012; Parametrix 2010a,b; De Schamphelaere et al. 2014). A pooled MLR analyses was also conducted including the invertebrates and fish stated previously with the addition of *Philodina rapida*. *Philodina rapida* was not included in the individual species MLR analyses because the range of pH did not meet the minimum requirement but was included in the pooled MLR since it has been tested over a wide range of DOC and hardness conditions. The green algae *P. subcapitata* could not be included in the pooled MLR since the MLR analyses indicated the TMF relationships were significantly different compared with the fish and invertebrates. All MLR models were derived using EC10 effect concentrations.

The results of MLR analysis are presented in Table 7.1 None of the variables were significant for *B. calyciflorus*. The *P. subcapitata* MLR was the only MLR to retain pH. Both DOC and hardness were significant in the MLR analysis for the pooled invertebrate and fish model, whereas pH was not significant. These MLR relationships are referred to as MLR models hereon in this factsheet.

Table 7.1. Summary results of MLR analysis.

Species	n	r^2	Ln DOC*	pH*	Ln Hardness*	Intercept*
Brachionus calyciflorus	18	0	-	-	-	-
Ceriodaphnia dubia	28	0.2	0.682	-	-	2.649
Pimephales promelas	8	0.68	-	-	0.984	1.989
Lymnaea stagnalis	6	0.69	1.259	-	-	-0.229
Pseudokirchneriella subcapitata	15	0.81	0.473	-1.542	-	12.629
Pooled (invertebrates and fish)[a]	66	0.72	0.514	-	0.214	2.156

* Model coefficents

[a] Includes data from 5 species (*B. calyciflorus*, *C. dubia*, *P. promelas*, *L. stagnalis,* and *P. rapida*). *P. rapida* was not included in the individual species MLR analyses because the range of pH did not meet the minimum requirement but was included in the pooled MLR because it has been tested over a wide range of DOC and hardness conditions.

The pooled MLR model incorporates 66 data points from 5 different species, retained both DOC and hardness variables with r2 value of 0.72 and wide water chemistry ranges (DOC range 0.5- 31.5 mg/L and hardness range 4.7-511 mg/L). The pooled (invertebrate and fish) MLR model was therefore chosen for deriving the guideline.

7.3 Federal Water Quality Guideline Derivation

Federal Water Quality Guidelines (FWQGs) are preferably developed using the CCME (2007) protocol. In the case of lead, there were sufficient acceptable chronic toxicity data to meet the minimum data requirements for the preferred CCME Type A approach. A Type A guideline is a statistical approach that uses species sensitivity distributions (SSD) to calculate a hazard concentration of 5% of species (HC_5), which in turn is the final guideline value (CCME 2007).

The first step in developing the FWQG for lead was to normalize the toxicity values to a common water chemistry using the pooled MLR. The chronic toxicity data for all 28 species were normalized to water with a DOC concentration of 0.5 mg/L and hardness of 50 mg/L. All data in the toxicity dataset were within the acceptable ranges of the pooled MLR (DOC range 0.5- 31.5 mg/L and hardness range 4.7-511 mg/L) and therefore were able to be considered in guideline derivation. Where multiple comparable endpoints were available for the same species, effect, life stage and exposure duration, a geometric mean was calculated. In an effort to include data for preferred endpoints, if studies did not report an EC_{10}, but reported sufficient information to develop a concentration-response curve, EC_{10} values were calculated using the USEPA Toxicity Relationship Analysis Program (TRAP v. 1.3) (USEPA 2015).

The most sensitive and preferred endpoint (or geometric mean) was then selected for each species following CCME (2007). A total of 82 endpoints (79 EC_{10}s, 1 EC_{20}, 1 NOEC and 1 MATC) for 28 species were included in the SSD dataset and summarized in Table 7.2. *Lymnaea stagnalis* was the most sensitive species with a normalized species mean toxicity value of 1.8 µg/L and smallmouth bass (*Micropterus dolomieui*) was the least sensitive species with a normalized effect concentration of 376.4 µg/L.

Table 7.2. Pooled multiple linear regression based normalized chronic lead toxicity endpoints for toxicity data used in deriving the FWQG for lead.

Species	Group	Endpoint	Effect Concentration (µg/L)	Normalized Effect Concentration (µg/L)[a]	Reference
Lymnaea stagnalis (great pond snail)	Invertebrate	14-d EC10 (growth)	Geomean (n=6)	1.8	Esbaugh et al. 2012; personal communication
Philodina rapida (rotifer)	Invertebrate	4-d EC10 (population growth)	Geomean (n=6)	3.8	Esbaugh et al. 2012
Ceriodaphnia dubia (cladoceran)	Invertebrate	6-d EC10 (survival and reproduction)	Geomean (n=3)	4.1	AquaTox 2012
Hyalella azteca (amphipod)	Invertebrate	42-d EC10 (survival, growth and reproduction)	5	4.1	Besser et al. 2016
Pseudokirchneriella subcapitata (alga)	Plant	72-h EC10 (Mean growth rate)	Geomean (n=15)	5.9	De Schamphelaere et al. 2014
Lampsilis siliquoidea (fatmucket)	Invertebrate	28-d EC10 (survival and growth)	6	6.5	Wang et al. 2010
Oncorhynchus mykiss (rainbow trout)	Fish	62-d EC10 (weight)	7	7.0	Mebane et al. 2008; personal communication
Lymnaea palustris (marsh snail)	Invertebrate	120-d EC20 (survival and growth)	23	10.2	Borgmann et al. 1978; Van Sprang et al. 2016
Diaphanosoma birgei (cladoceran)	Invertebrate	25-d EC10 (net reproductive rate)	13	11.9	Garcia-Garcia et al. 2006; Van Sprang et al. 2016
Chironomus dilutus (midge)	Invertebrate	21-d EC10 (emergence)	15	15.0	Mebane et al. 2008; personal communication

Daphnia magna (cladoceran)	Invertebrate	21-d EC10 (survival and reproduction)	Geomean (n=3)	15.4	Chapman et al. 1980
Acipenser transmontanus (white sturgeon)	Fish	53-d EC10 (survival)	26	25.0	Ingersoll and Mebane 2014
Alona rectangula (cladoceran)	Invertebrate	25-d EC10 (gross reproductive rate)	40	35.9	Garcia-Garcia et al. 2006; Van Sprang et al. 2016
Pimephales promelas (fathead minnow)	Fish	30-d EC10 (survival and growth)	Geomean (n=3)	36.0	Mager et al. 2011b
Baetis tricaudatus (mayfly)	Invertebrate	10-d EC10 (molting)	37	40.9	Mebane et al. 2008; personal communication
Brachionus calyciflorus (rotifer)	Invertebrate	2-d EC10 (population size)	Geomean (n=18)	43.1	Nys et al. 2016
Chlaydomonas reinhardtii (green alga)	Plant	48-h EC10 (growth rate)	82	45.7	De Schamphelaere et al. 2014
Salvelinus namaycush (lake trout)	Fish	60-d EC10 (weight)	50	54.7	Sauter et al. 1976
Lemna minor (duckweed)	Plant	7-d EC10 (root growth)	Geomean (n=7)	58.3	Antunes and Kreager 2014
Lepomis macrochirus (bluegill)	Fish	60-d EC10 (survival)	57	59.1	Sauter et al. 1976
Salvelinus fontinalis (brook trout)	Fish	12-wk EC10 (growth)	88	60.2	Holcombe et al. 1976
Chlorella kesslerii (green alga)	Plant	48-h EC10 (growth rate)	120	66.6	De Schamphelaere et al. 2014
Chironomus riparius (midge)	Invertebrate	14-d EC10 (survival and growth)	Geomean (n=2)	76.5	Nguyen et al. 2012

Ictalurus punctatus (channel catfish)	Fish	60-d EC10 (survival)	76	81.3	Sauter et al. 1976
Catostomus commersoni (white sucker)	Fish	60-d EC10 (weight)	101	107.4	Sauter et al. 1976
Stizostedion vitreum (walley)	Fish	30-d EC10 (survival)	148.62	158.0	Sauter et al. 1976
Micropterus dolomieui (smallmouth bass)	Fish	90-d NOEC (growth)	308	242.4	Coughlan et al. 1986
Esox lucius (Northern pike)	Fish	20- d MATC (survival)	349.5697355	376.4	Sauter et al. 1976

[a]Normalized to a hardness of 50 mg/L and DOC of 0.5 mg/L using the pooled invertebrate and fish MLR

The R package (R version 3.4.2) 'ssdtools' (version 0.0.3) (Thorley and Schwarz 2018) as well as the corresponding user friendly "Shiny App" (Dalgarno 2018) were used to create SSDs from the dataset. The package fit several CDFs (log-normal, log-logistic, log-Gumbel, gamma and Weibull) to the data using maximum likelihood estimation (MLE) as the regression method. Akaike information criterion (AIC), which is a measure of the relative quality of fit to the data set, was calculated for each distribution (Burnham and Anderson 2002). Using AIC, AIC corrected for small sample size, a model averaged HC5 can be established. The smaller the AIC the better the distribution fits the data set. Each model was then weighted, models with high value weight fit the data well compared to the others. The SSD and accompanying summary statistics at water hardness 50 mg/L and DOC 0.5 mg/L are presented in Figure 7.1 and Table 7.3, respectively.

Table 7.3. SSD summary statistics at 50 mg/L hardness and 0.5 mg/L DOC

Distribution	AICc	Predicted HC_5 (µg/L)	95% LCL and UCL (µg/L)	Weight	Weighted HC_5 (µg/L)	Weighted 95% LCL and UCL (µg/L)
Log-normal	-46.9	3.04	(1.49-6.64)	0.4	1.22	(0.6-2.67)
Log-logistic	-45.2	2.81	(1.15-6.83)	0.17	0.49	(0.2-1.18)
Log-Gumbel	-42.9	3.38	(2.11-6.34)	0.06	0.19	(0.12-0.35)
Log-normal_Log-normal	-42.6	3.06	(1.92-5.91)	0.05	0.15	(0.09-0.29)
Gamma	-44.6	1.45	(0.292-6.2)	0.13	0.19	(0.04-0.81)
Weibull	-45.4	1.42	(0.402-4.89)	0.19	0.27	(0.08-0.94)
				Guideline =	2.5	(1.13-6.33)

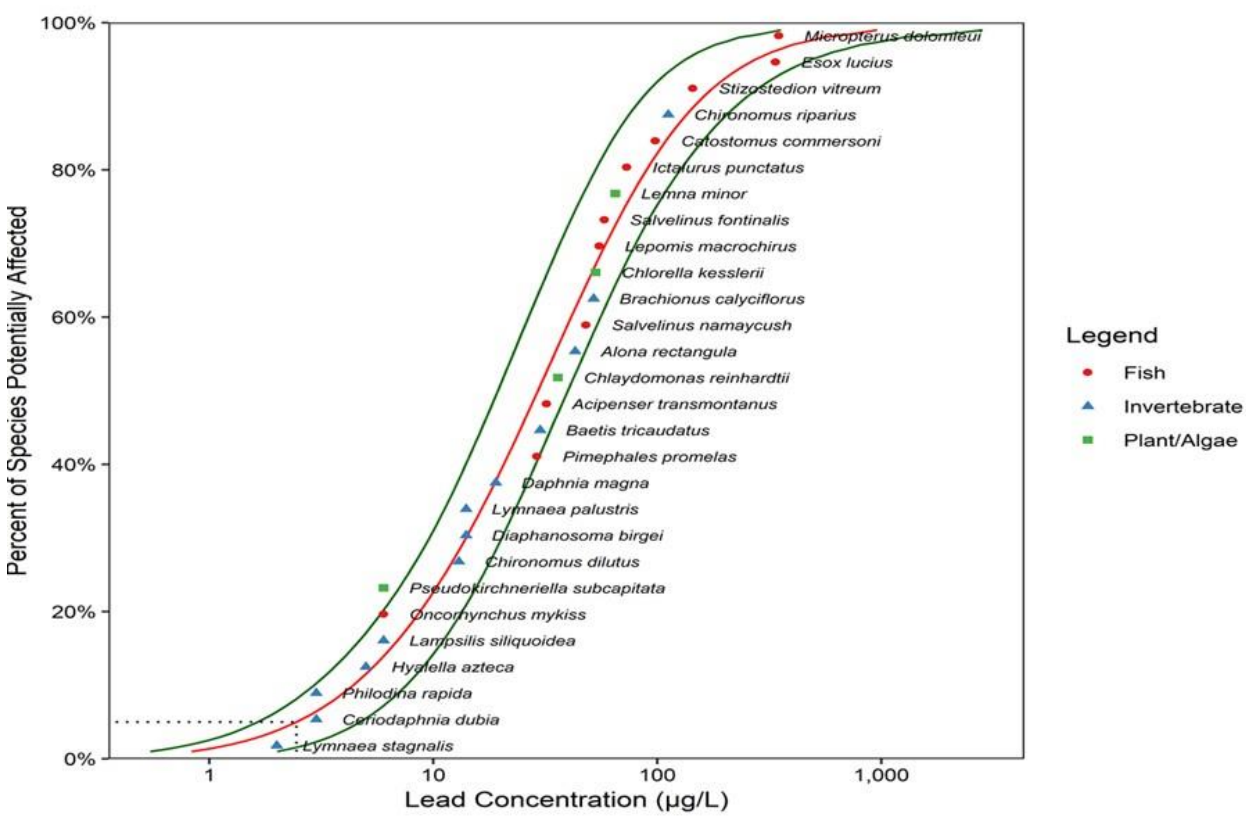

Figure 7.1. Species sensitivity distribution (SSD) for the chronic toxicity of lead at DOC of 0.5 mg/L and hardness of 50 mg/L. The HC5 is 2.5 µg/L.

The normalized chronic toxicity data for 28 fish, invertebrate and plant species are plotted in a species sensitivity distribution along with the confidence intervals. The 5th percentile value of the plot is 2.5 µg/L. This value is the site-specific federal water quality guideline for the site water that has the DOC concentration of 0.5 mg/L and hardness of 50 mg/L. The guideline value represents the concentration below which one would expect either no, or only a low likelihood of, adverse effects on aquatic life.

Because DOC and hardness were identified as significant toxicity modifying factors, the FWQG is expressed as an equation where the local water DOC and hardness are entered in order to calculate a site-specific FWQG. The equation is based on the pooled MLR model slopes of 0.514 and 0.214, respectively, and the 5th percentile value of 2.5 µg/L derived from the SSD at DOC of 0.5 mg/L and hardness of 50 mg/L.

Based on the pooled MLR model and the HC5 from the SSD, the equation to derive FWQG for lead is:

$$\begin{aligned}\text{y-intercept} &= \ln(\text{5th percentile}) - [\text{DOC slope} \times \ln(\text{DOC})] - [\text{hardness slope} \times \ln(\text{hardness})]\\ &= \ln(2.45) - [0.514 \times \ln(0.5)] - [0.214 \times \ln(50)]\\ &= 0.4354\end{aligned}$$

$$\text{FWQG } (\mu g/L) = \exp(0.514\,[\ln(\text{DOC})] + 0.214[\ln(\text{hardness})] + 0.\,4354)$$

The FWQG equation was derived for dissolved lead and is found by using the equation above or by using the FWQG calculator (Appendix). Users can input site-specific DOC and hardness measurements to calculate a FWQG for the specific water chemistry. The FWQG equation is valid between DOC 0.5 and 31.5 mg/L and hardness 4.7 and 511 mg/L, which are the ranges of data used to derive the MLR slopes. Only values within these DOC and hardness ranges should be entered into the guideline equation to ensure the equation is accurate and the FWQG is protective. Users should be extremely cautious if extrapolating beyond the recommended ranges of DOC and hardness and should contact their local authority for advice. Although the hardness is regularly measured during monitoring, DOC may not always be routinely measured. In the absence of site-specific data, a DOC concentration of 0.5 mg/L and a hardness concentration of 4.7 mg/L may be assumed, which are the lower limits of the FWQG equation. For water bodies where lead concentrations are potentially of concern, it is recommended that both DOC and hardness be measured. It is to be also noted that the FWQG for lead is for dissolved concentration of lead. When guideline users only have total lead concentrations for their site, it is recommended that they first compare their total lead concentration to dissolved lead guideline, and where there is an exceedance, re-sample the waterbody for the dissolved lead. Examples of FWQGs for lead for selected DOC and hardness values are given in Table 7.4.

Table 7.4. FWQGs (µg/L) for lead for the protection of aquatic life for selected DOC and hardness values.

DOC (mg/L)	50 *	100*	200*	300*	400*	500*
0.5	2.5	2.9	3.4	3.7	3.9	4.1
2	5.1	5.9	6.9	7.5	8.0	8.3
5	8.2	9.5	11.0	12.0	12.7	13.4
10	11.7	13.5	15.7	17.1	18.2	19.1
20	16.6	19.3	22.4	24.4	26.0	27.3
30	20.5	23.8	27.6	30.1	32.0	33.6

*Hardness (mg/L)

7.3.1 *Protectiveness Assessment*

To assess whether the FWQG for lead is sufficiently protective, a protectiveness assessment was conducted following CCME (2007). FWQGs were calculated for each of the 134 acceptable endpoints in the toxicity dataset. The FWQGs were then compared to measured toxicity values at their associated water chemistry (Figure 7.2). Values that plot above the 1 to 1 line indicate that the FWQG is protective of the toxicity value in that particular test, while values below the 1 to 1 line indicate that the FWQG is lower than the observed toxicity, and hence may require further evaluation. This protectiveness assessment resulted in 11 out of 134 (92%) acceptable toxicity data points being above the site-specific guideline. These 11 endpoints include 8 endpoints for invertebrates (3 for *C. dubia*, 4 for *L. stagnalis*, 1 for *Philodina rapida*) and 3 endpoints for plant species *P. subcapitata*. It is important to note that an equal or greater number of endpoints for these 4 species were above the 1 to 1 line (31 for *C. dubia*; 4 for *L. stagnalis*, 5 for *Philodina rapida* and 12 for *P. subcapitata*. None of the endpoints below the guideline were for a species at risk, or for lethal effects equal to or above a level of 15% (CCME 2007). Overall examination of the available data suggests the lead FWQG is protective.

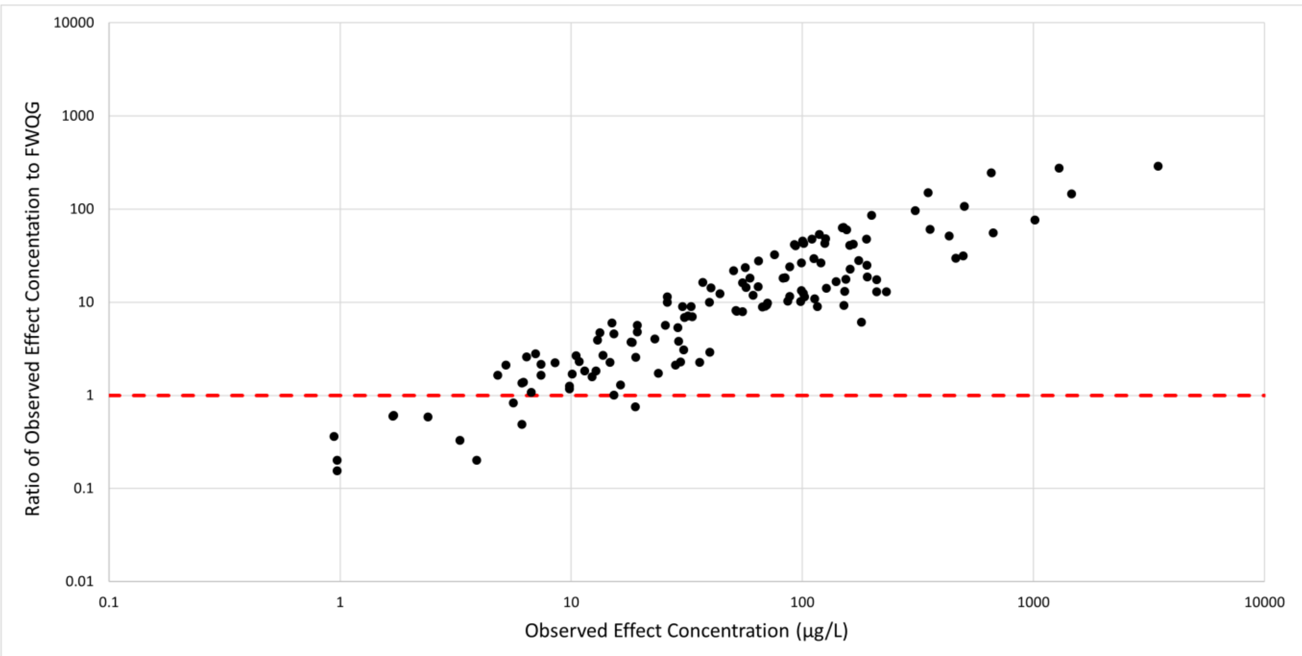

Figure 7.2. Ratio of chronic effect concentration for lead to FWQG calculated using the 5 species pooled MLR model containing hardness and DOC.

7.4 B.C. Chronic Lead Water Quality Guideline

The FWQG is based on an SSD and uses a MLR approach to incorporate the toxicity modifying factors of hardness and DOC in the calculation of the WQG (ECCC 2020). The chronic toxicity dataset consists of data for 28 species: 11 fish, 13 invertebrates, and 4 plants/algae (ECCC 2020) and fulfills the minimum number of species required for a Type A2 guideline (ENV, 2019). Of the 11 fish species, all but two are Canadian species (i.e., bluegill, [*Lepomis macrochirus]*, and channel catfish [*Ictalurus punctatus*]). Of the 13 invertebrate species, all but one are Canadian species (*Philodina rapida*). The invertebrates are the most sensitive species to lead, with *Lymnaea stagnalis*, the most sensitive species on the SSD, followed by *Ceriodaphnia dubia*, *Philodina rapida*, and *Hyalella azteca* (ECCC, 2020).

To account for the sources of uncertainty associated with WQG derivation, an assessment factor (AF) must be applied to the calculated HC_5 (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. Sources of uncertainty specific to the dataset include the lack of data for Canadian amphibians, and the lack of data for reproduction in fish. Given these sources of uncertainty, an AF of 2 was applied to the calculated HC_5.

The B.C. chronic lead (Pb) WQG for dissolved lead is calculated using the following equation:

$$\text{Dissolved lead (Pb) WQG } (\mu g/L) = \frac{e^{(0.514[\ln(DOC)] + 0.214\,[\ln(hardness)] + 0.4354)}}{2}$$

Table 7.5 provides examples of B.C. chronic dissolved lead WQGs in various water chemistry scenarios. For other water chemistry scenarios, a lead WQG calculator in Excel is available on the approved WQG website[2]. The B.C. WQG equation is valid for hardness concentrations from 4.7 mg/L to 511 mg/L, and DOC from 0.5 mg/L and 31.5 mg/L, which are the ranges of data used to derive the MLR slopes (ECCC, 2020; Table 7.5). Any user inputs into the B.C. lead WQG calculator that are outside of these ranges are automatically rounded to the upper or lower bounds. If site-specific water hardness or dissolved organic carbon (DOC) is not known, the corresponding lower limits can be used (the B.C. lead WQG calculator will do this automatically).

The protectiveness of the chronic lead WQG (Table 7.5) has been shown only within the ranges of the water chemistry parameters of the MLR model. When water chemistry parameters are outside of these bounds for a specific water body, and the dissolved lead concentration is lower than the WQG generated by the B.C. lead WQG calculator (i.e., using the bounds of the model), then the risk should be minimal. However, if the site dissolved lead concentration is higher than the WQG generated by the B.C. lead WQG calculator using the bounds of the model, then a site-specific assessment may be required to assess potential risks to aquatic life.

Table 7.5. BC chronic dissolved Pb WQGs (µg/L) at various levels of dissolved organic carbon and hardness levels (adapted from ECCC, 2020).

	Hardness (mg/L)					
DOC (mg/L)	**50**	**100**	**200**	**300**	**400**	**500**
0.5	1.3	1.4	1.7	1.8	2.0	2.0
2	2.5	3.0	3.4	3.7	4.0	4.2
5	4.1	4.7	5.5	6.0	6.4	6.7
10	5.8	6.8	7.8	8.6	9.1	9.5
20	8.3	9.7	11.2	12.2	13.0	13.6
30	10.3	11.9	13.8	15.0	16.0	16.8

[2] https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/water-quality/water-quality-guidelines/approved-water-quality-guidelines

8. COMPARISON OF AMBIENT LEAD 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 lead WQG. To answer this question, water quality data (dissolved lead, total lead, DOC, and hardness) from freshwater sites were extracted from the EMS database and ambient levels compared to the 1987 WQG and the 2024 WQG.

Data from minimally disturbed sites included a total of 649 records with hardness and total lead data to calculate the 1987 WQG and a total of 176 records with hardness, DOC, and dissolved lead to calculate the 2024 WQG[3].

Total lead exceeded the 1987 WQGs concentrations 0.6% of the time (4/649) (Figure 8.1) and dissolved lead exceeded the 2024 WQG 0% of the time (0/176) (Figure 8.2). The higher rate of exceedance of the old 1987 WQG compared to the new WQG is mainly because the updated WQG uses dissolved lead and is being compared to dissolved ambient lead concentrations. However, the updated WQG was shown to be protective, with no ambient lead concentrations at minimally disturbed sites exceeding the 2024 WQG.

[3] Non-detect data were replaced by the method detection limit (MDL), but MDL that were greater than 5 µg/L for either form of lead and greater than 0.5 mg/L for DOC were excluded.

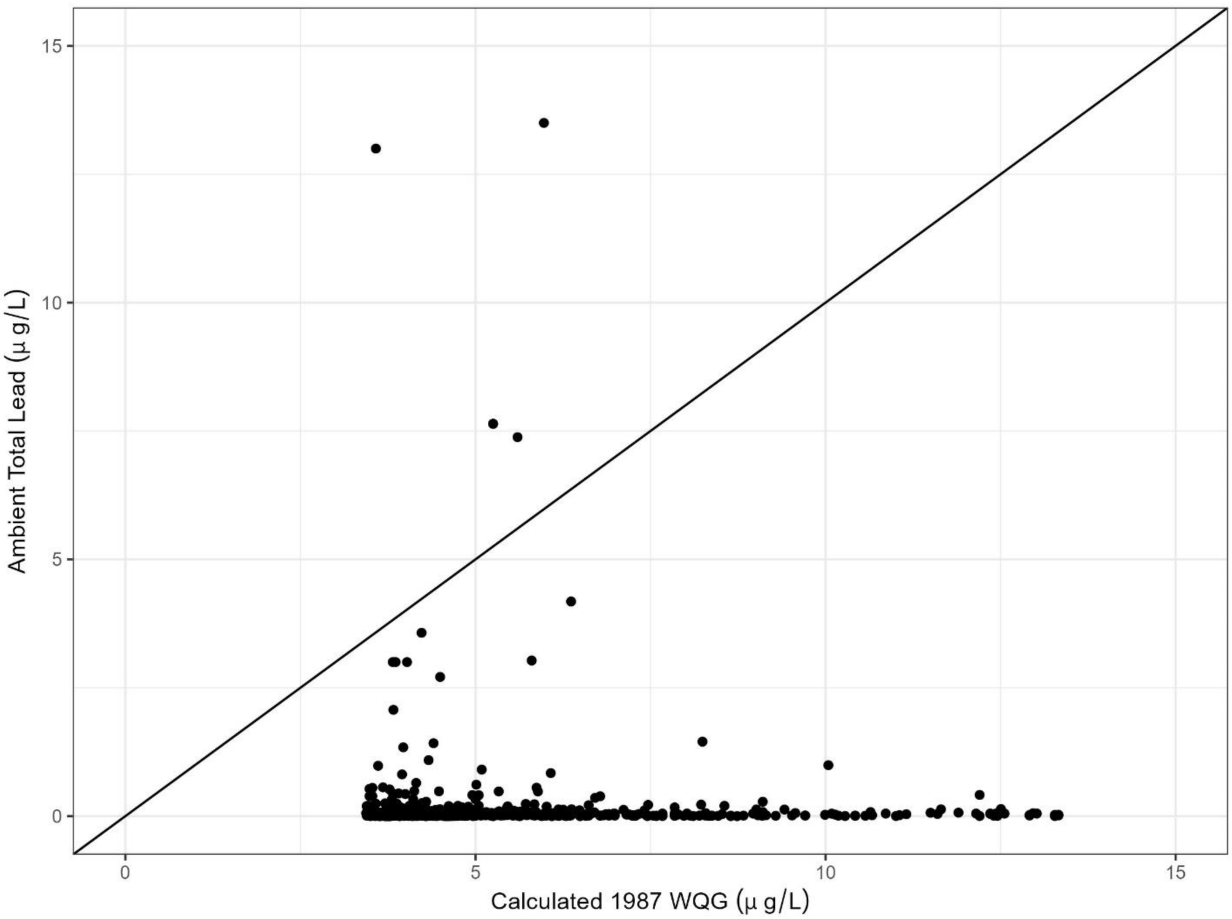

Figure 8.1: Ambient lead concentrations compared to the 1987 chronic total lead WQGs. Points above the 1:1 line represent exceedances.

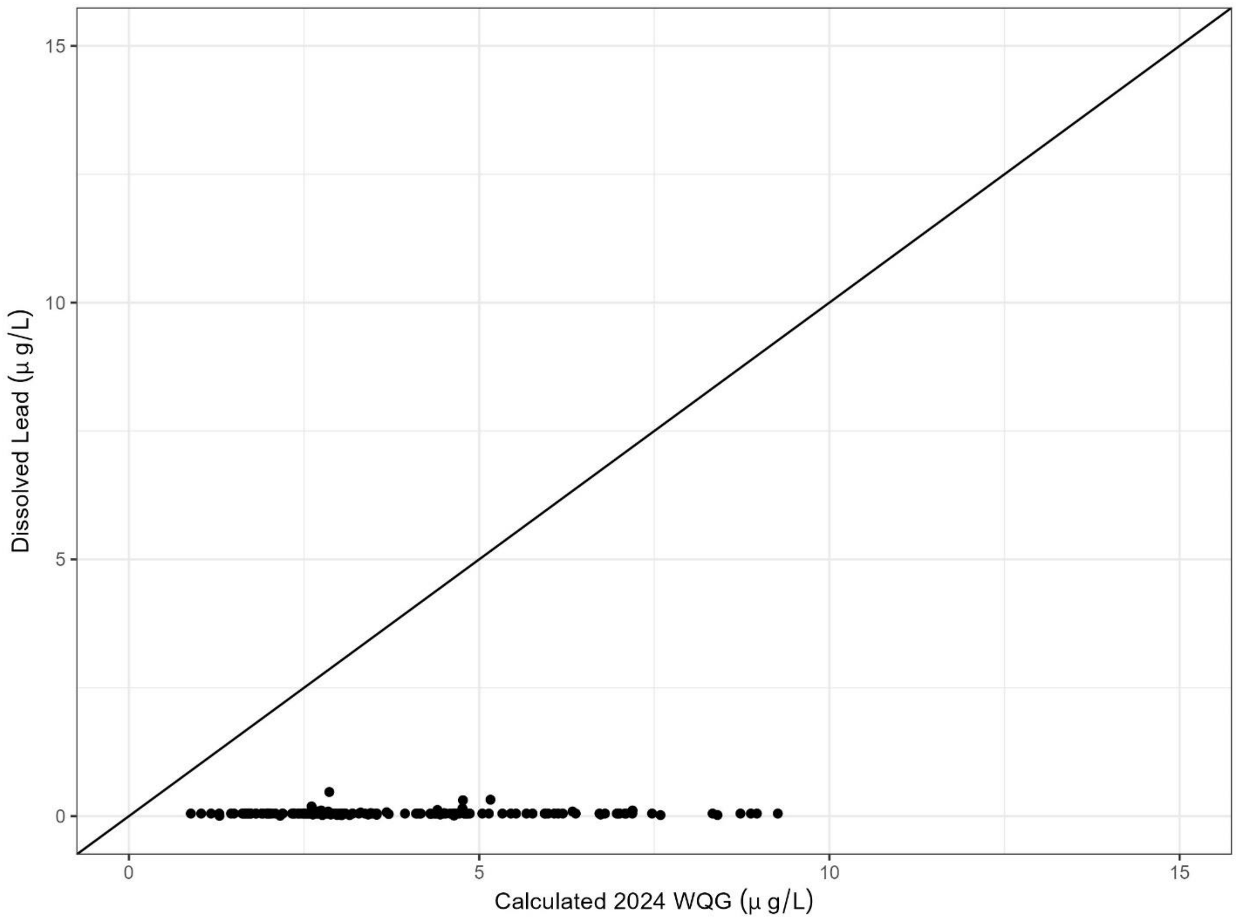

Figure 8.2: Ambient lead concentrations compared to the 2024 chronic dissolved lead WQGs. Points above the solid 1:1 line represent exceedances.

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