WATER QUALITY GUIDELINE SERIES

Aluminum Water Quality Guidelines – Freshwater Aquatic Life

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

BRITISH COLUMBIA

No. WQG-09-1

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:

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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 aluminum (Al) WQGs for the protection of aquatic life.

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

Aluminum has no known biological function and is therefore considered a non-essential element. Its toxic mode of action for fish has been widely investigated, however information is less available for invertebrates, aquatic plants, and algae. Elevated Al has also been demonstrated to have adverse effects on the growth and reproductivity of terrestrial plants and on terrestrial animals.

In 2022, Environment and Climate Change Canada (ECCC) published an updated Federal Water Quality Guideline (FWQG) for Al 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. While the previous B.C. WQG was based on dissolved Al, the adopted FWQG is based on total Al as the total Al corresponds better with Al toxicity. In addition, where the previous B.C. Al guideline considered only pH in the calculations of site-specific guidelines, the updated guideline also takes into account dissolved organic carbon (DOC) and hardness. This updated guideline is generally higher in comparison to the previous guideline due to the inclusion of more ameliorating water quality parameters. When compared to background Al concentrations across the province, fewer exceedances from the updated WQG were observed compared to the 1988 WQG (8.9 % vs 18.3 %).

WQGs for the protection of agriculture (irrigation and livestock watering) and wildlife were derived in 1988 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 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 0.055 mg/L.

Table E.1. Summary of recommended water quality guidelines for total aluminum.

Designated use	Guideline mg/L	Guideline Type
Freshwater Aquatic life	Variable*	Long-term chronic
Wildlife	5	Short-term acute
Livestock	5	Short-term acute
Irrigation	5	Short-term acute
Source drinking water	9.5	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), drinking water sources, 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,
- 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 2022, Environment and Climate Change Canada (ECCC) published an updated Federal Water Quality Guidelines (FWQG) for Al 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 1988 guidelines for wildlife, livestock watering, and irrigation (ENV, 1988) have not been updated and are available in a separate document on the B.C. WQG website.

2. SUBSTANCE IDENTITY

Aluminum (Al; CAS RN 7429-90-5; molar mass 26.98 g/mol) is the third most abundant element and the most common metal in the Earth's crust (USEPA, 2018). Aluminum is often found combined with other elements, typically complexed with oxygen as oxides and silica as silicates, but rarely in the elemental state (ATSDR, 2008; USEPA, 2018).

Aluminum is commonly found in rocks, particularly in aluminosilicate minerals where it is considered toxicologically irrelevant (i.e., essentially inert, not bioavailable). When these minerals weather they slowly release potentially toxic forms of Al to the environment (i.e., Al^{3+}, Al hydroxides, etc.) (GC, 2010; USEPA, 2018). The most common ore for Al metal is the mineral bauxite (ATSDR, 2008). Aluminum metal is light-weight, ductile, and silvery-white in appearance. It is considered a non-essential element because it plays no important biological function and offers no beneficial properties to life. The speciation and solubility of Al in surface waters are greatly affected by various water quality parameters, most importantly pH (Cardwell et al., 2018). In the water column, Al may be present as dissolved complexes (both organic and inorganic), as a free ion (Al^{3+}), in association with particles, as colloids, or as solids precipitating to the sediment (GC, 2010). Aluminum is commonly found in aquatic systems from both natural and anthropogenic inputs. Elevated levels in surface waters can cause toxic effects to aquatic organisms.

3. SOURCES AND USES

Aluminum metal and Al compounds are used in a variety of applications in Canada and worldwide. Aluminum sulfate and chloride salts are primarily used in municipal drinking water and wastewater treatment as flocculating agents to help remove suspended particles and bacteria from the water (ATSDR, 2008; GC, 2010). They are also used as an additive in the pulp and paper industry for paper sizing (GC, 2010). Consumer products containing Al include antacids, astringents, buffered aspirin, food additives, antiperspirants, natural health products, cosmetics, beverage cans, pots, pans, and foil (ATSDR, 2008; GC, 2010). As a light-weight conductive metal, it is widely used in the construction, transportation, and electronic and electrical industries for products ranging from airplanes to power lines (ATSDR, 2008; NRCan 2018).

Bauxite, the primary Al ore, must be chemically refined into alumina, and then smelted to form pure Al metal. Bauxite is not mined in Canada; however, there is one alumina refinery (located in Quebec) and ten smelters (nine in Quebec and one in B. C.) (NRCan, 2018). Canada is the world's fourth largest primary Al producer after China, Russia, and India, producing an estimated 2.9 million tonnes in 2018 (NRCan, 2018). Some Al compounds are manufactured in Canada, notably aluminum chloride, and aluminum sulfate, primarily for use within Canada as opposed to exportation (GC, 2010). Anthropogenic sources of Al include effluent from water treatment plants where Al compounds are added as clarifying agents (industrial water, drinking water or wastewater), fossil fuel combustion, and emissions from the processing of Al ore and Al production (ATDSR, 2008; GC, 2010; USEPA, 2018).

4. FATE, BEHAVIOUR, AND PARTITIONING IN THE ENVIRONMENT

Aluminum chemistry in surface waters is complex. Aluminum may be present as dissolved complexes (with both organic and inorganic ligands), as a free ion (Al^{3+}), in polynuclear Al species, in association with particles, as colloids, or as solids precipitating to the sediment (GC, 2010). There are many factors that influence the fate, behaviour, and bioavailability of Al including temperature, the presence of complexing ions or ligands, and, most importantly, pH. Aluminum is amphoteric, which means it can act as either an acid or base. Aluminum is relatively insoluble at more neutral pH levels (6 - 8) (Gensemer and Playle, 1999; GC, 2010; USEPA, 2018). Aluminum solubility is also dependent on dissolved organic carbon (DOC) and temperature (Wilson, 2012; USEPA, 2018; Rodriguez et al., 2019). DOC is an important ligand with which Al forms complexes, reducing concentrations of monomeric Al in the water column. Aluminum is a strongly hydrolysing metal, and, unlike some metals (e.g., iron and manganese), Al speciation does not depend on redox conditions (Gensemer and Playle, 1999; GOC, 2010).

At low pH values (<6), dissolved Al is present mainly in the free ion form (Al^{3+}). As pH rises, hydrolosis occurs forming Al hydroxide complexes (e.g., $Al(OH)^{2+}$, $Al(OH)_2^{+}$. Solubility reaches a minimum at circumneutral pH (6-8) and starts to rise again at high pH value (>8) due to the formation of the anion $Al(OH_4)^-$ (Driscoll and Schecher, 1990; GC, 2010). Figure 4.1 depicts the solubility of Al species in relation to pH.

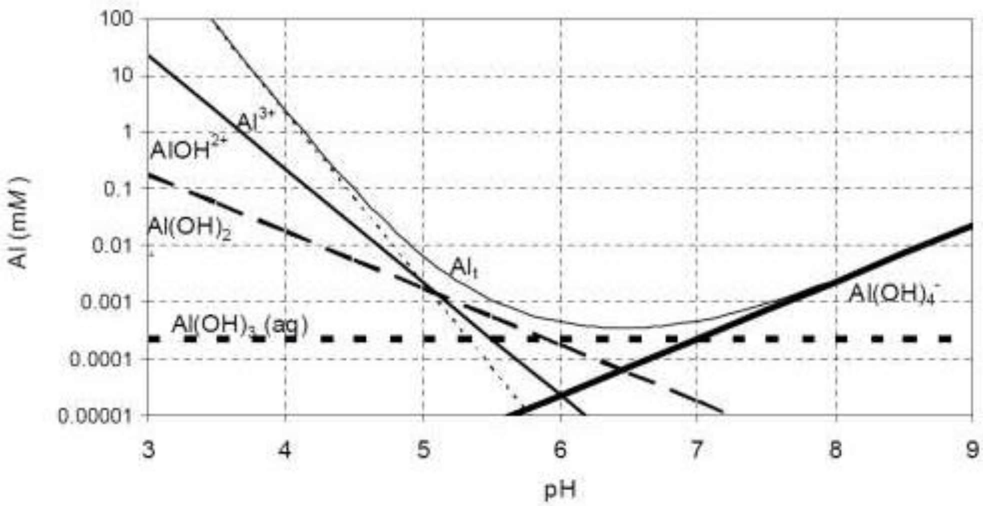

Figure 4.1. Solubility of aluminum species (and total aluminum, Alt) in relation to pH in a system in equilibrium with microcrystalline gibbsite (0.001 mM = 0.027 mg/L; GC 2010 redrawn from Driscoll and Schecher, 1990).

Under circumneutral pH conditions, Al changes from dissolved monomeric forms to insoluble polymers, which precipitate out of solution. Transient forms of polymeric Al (colloidal and amorphous) exist for a short time (minutes to hours) during this transformation. Larger polymers and minerals in crystalline forms take several days to weeks to fully form. Aluminum toxicity to aquatic species under these conditions may be of a lesser concern since the transient forms do not exist long enough to cause harm. However, an exception to this generalization occurs when there is a continual input of an acidic solution containing Al. For example, Al toxicity is a particular concern where episodic acidic pulses occur and in mixing zones where aluminum-rich acidic waters meet more neutral water (Rodriguez et al., 2019). Episodic acidic pulses, for example winter snowmelt or acid rain events, may mobilize Al from soil and sediment, increasing bioavailability and the potential for toxicity to aquatic organisms (Gensemer and Playle, 1999; Wilson, 2012; USEPA, 2018). Acid rain was the focus of much research during the late 1970s to early 1990s due to observed toxic effects in both terrestrial and aquatic environments. It was observed that not only were organisms affected by the decline in pH but also by the mobilization of metals. Aluminum like most metals increases in solubility at low pH and the combination was subsequently found to be a major factor in the decline of the affected ecosystems (Wilson, 2012).

Most Al from waterborne exposure rapidly adsorbs to external gill and body surfaces of fish and invertebrates. Internalization from cellular uptake also can occur but takes place more slowly, accumulating in internal organs like muscle, kidney, and liver over time (Wilson, 2012; USEPA, 2018). Uptake and bioaccumulation of Al via diet is considered unlikely and there is no evidence of biomagnification through the food chain (Wilson, 2012; USEPA, 2018).

Aluminum in air is transported as windblown particulate matter and can be deposited onto land and water (USEPA, 2018). Aluminum concentrations in the atmosphere are negligible compared to the majority of Al entering surface water from the weathering of rocks or soil (GC, 2010). Aluminum is ubiquitous in rocks and soil (silt and clay) in the form of aluminosilicate minerals. Gibbsite ($Al(OH)_3$) is generally considered to be the most important mineral in modelling the geochemistry and transport of Al in aqueous systems (Driscoll and Postek, 1996; Gensemer and Playle, 1999; Wilson, 2012). As these rocks and minerals weather and factors such as pH fluctuate, Al from soil can be transported into the aquatic environment. Aluminum in sediment is generally considered non-bioavailable when it is bound with DOC or in the form of silt or clay. Therefore, sediment can act as a sink for Al. However, as conditions change, such as a decrease in pH, Al in the sediment can be mobilized back into the water column.

5. BACKGROUND CONCENTRATIONS OF ALUMINUM IN BRITISH COLUMBIA

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

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

Background (i.e., from non-impacted sites) total Al concentrations vary across B.C. as a function of local geology and hydrology, therefore, a regional approach was used to estimate background Al concentrations in aquatic environments following methods used in recent WQG derivation documents (e.g., ENV, 2021a). Data were obtained from two sources: the B.C. Environmental Management System (EMS) database and the Canadian Aquatic Biomonitoring Network (CABIN) database. 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 22 years for any water quality parameter (2000/01/01 to 2022/12/01) 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 Al 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) ≥5 µg/L were removed as these would influence the results of the analysis;
- samples were excluded where results were missing or reported as 0; and
- data were visually inspected, and samples were removed where results appeared to be obvious errors, assumed to be attributed to either data entry or analytical errors.

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 resultant data set was augmented with samples collected by ENV and ECCC at B.C. reference stations as part of the CABIN program. CABIN reference stations are located on stream reaches minimally impacted by anthropogenic activities and are generally sampled once during the late summer/early fall low flow period. The final data set consisted of 772 EMS and CABIN stations with a total of 6,625 results.

The results from each station were given equal weight within an ENV administrative region by calculating the mean Al 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 5.1). 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 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	0	0
2	0 < % non-detects < 100 AND # detects < 3	Substitute ½ MDL for non-detects and calculate arithmetic mean for all samples	1	2
3	0 < % non-detects < 100 AND # detects ≥ 3	Regression on order statistics	11	897
4	% non-detects = 0	Arithmetic mean	760	5,726

5.2 Background Concentration Results

The distribution of total Al concentrations by ENV administrative region is summarized in Table 5.2. Summary statistics for station mean total Al at minimally impacted stations in British Columbia.Table 5.2 and Figure 5.1. The median of station means ranged from 18.4 µg/L (Thompson) to 565 µg/L (Lower Mainland) (Figure 5.2). Of the 772 stations, 90 stations were on lakes and 682 were on rivers. The median of the distribution of station means in lakes (19 µg/L) was considerably lower than that of rivers (58 µg/L) (Figure 5.2).

Table 5.2. Summary statistics for station mean total Al 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	69	1,866	2000 – 2022	0.02 – 18,500	0.0002 – 0.5	0.2	45	3	500
Kootenay	76	443	2001 – 2022	0.3 – 22,000	0.002 –5	0.9	33	4	800
Lower Mainland	46	118	2000 – 2022	3 – 9,600	0.0002 – 0.3	0.8	565	68	1,950
Okanagan	97	898	2000 – 2022	0.2 – 28,200	0.0002 – 0.3	0.1	36	6	554
Omineca	54	674	2000 – 2022	0.9 – 8,710	0.0002 – 0.5	NA	20	6	231
Peace	113	214	2008 – 2022	0.95 – 8,500	0.0002 – 0.03	NA	100	4	460
Skeena	154	1,112	2000 – 2022	0.141 – 20,300	0.0002 – 0.5	0.1	59	13	500
Thompson	50	464	2000 – 2021	0.2 – 18,600	0.0002 – 0.03	2.8	18	3	142
Vancouver Island	113	836	2000 – 2022	0.5 – 18,900	0.0002 – 2	0.1	45	10	2,620

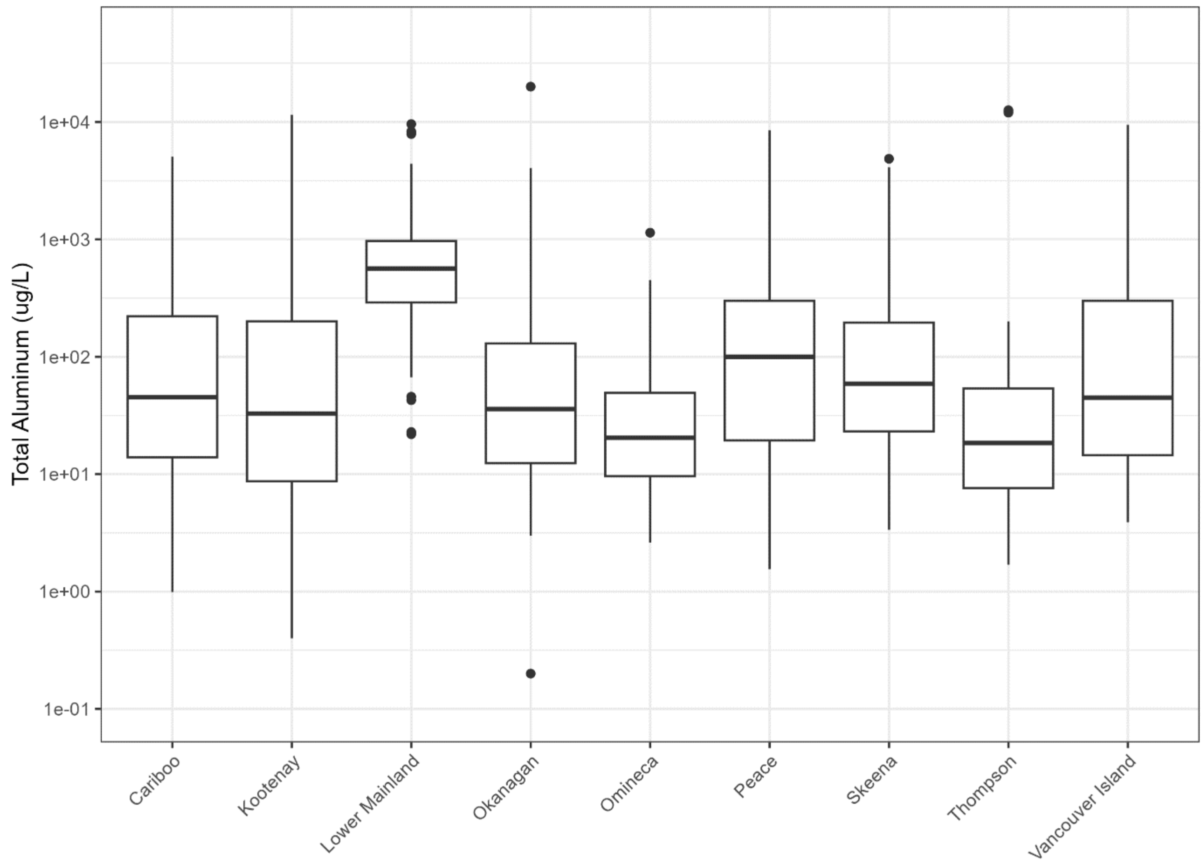

Figure 5.1. Distribution of station mean total Al at background stations in British Columbia by region. Solid horizontal bar and the lower and higher whiskers represent median, 10th and 90th percentile of station means.

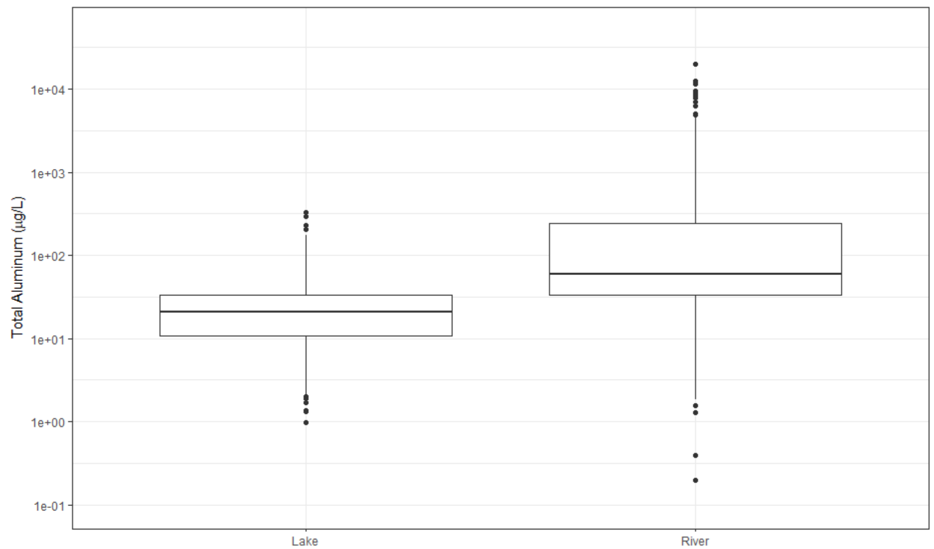

Figure 5.2. Distribution of station means for lakes and rivers for total Al. Solid horizontal bar and the lower and higher whiskers represent median, 10th and 90th percentile of station means.

6. MODE OF ACTION

Aluminum has no known biological function and is therefore considered a non-essential element. The toxic mode of action of Al for fish has been widely investigated, however information is less available for invertebrates and is especially limited for aquatic plants and algae. Aluminum elicits toxic effects on fish by two main modes of action; disturbance of ionoregulatory processes and respiratory disruption (Exley et al., 1991; Gensemer and Playle, 1999; GC, 2010; Gensemer et al., 2018; Cardwell et al., 2018). Gills are the primary biological ligand to which Al binds to fish (Exley et al., 1991; Teien et al., 2006; USEPA, 2018). Aluminum binding to the gill surface disturbs ionoregulation leading to reduced ion uptake, loss of plasma ions, and changes in blood parameters (GC, 2010; USEPA, 2018). Damage to ionoregulation, respiration, or a combination of the two may ultimately lead to death. The chemical impact on ionoregulatory processes, such as a decrease in plasma Na^+ and Cl^- ions, are more common under acidic conditions where dissolved monomeric Al species (Al^{3+}) are dominant (Gensemer and Playle, 1999; GC, 2010; Gensemer et al., 2018). Physical effects are more common at circumneutral pH values (6-8), where Al hydroxide precipitates at the gill surface causing the clogging of the interlamellar spaces with mucous which can eventually lead to hypoxia (Gensemer and Playle, 1999; GC, 2010; Gensemer et al., 2018).

Al accumulates on mostly respiratory or ionoregulatory surfaces of invertebrates but can accumulate over the whole body (Gensemer and Playle, 1999). Ionoregulatory effects are the most documented responses to Al exposure for invertebrates, while respiratory effects are reported much less frequently in invertebrates than in fish (Gensemer and Playle, 1999; GC, 2010; USEPA, 2018). Respiratory effects occur when Al binds to or precipitates onto the bodies of invertebrates, forming a physical barrier that obstructs respiration (GC, 2010).

The mode of toxic action of Al to aquatic plants and algae is not well understood. Aluminum can bind to polyphosphates, forming non-bioavailable complexes and thus making phosphorus less available for growth (Gensemer and Playle, 1999; GC, 2010; Pettersson et al., 1988; USEPA, 2018). This can occur intracellularly as well as in the surrounding water. Aluminum is also adsorbed into the cell wall when cyanobacteria are exposed to high concentrations of phosphate (Pettersson et al., 1985).

7. CRITERIA FROM OTHER JURISDICTIONS

Aluminum WQGs/criteria from seven provincial and national jurisdictions are summarized in Table 7.1. Three types of guidelines are used: a static number for different pH values, a pH-based equation, and Multiple Linear Regression (MLR) taking the influence of pH, hardness, and dissolved organic carbon (DOC) into account. In general, most of the older WQGs are pH-specific, while more recent WQGs are calculated using MLR. While older guidelines exist for both dissolved and total Al, more recent guidelines are based on total Al.

7.1 British Columbia

The B.C. Ministry of Environment and Parks established a pH-based Al WQG in 1988 (ENV, 1988) for freshwater aquatic life (Table 7.1). This guideline was for dissolved Al and is based on pH. At pH values below 6.5, chronic and acute WQGs are calculated using two equations (Table 7.1). For pH values equal to or greater than 6.5, the recommended chronic and acute guideline were 50 and 100 µg/L, respectively.

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 for long-term exposure to total Al is based on pH and is presented in (Table 7.1). When water pH is below 6.5, the WQG is 5 µg/L (CCREM, 1987). For water with a pH value of equal to or greater than 6.5, the long-term Al WQG is 100 µg/L. The CCME does not have an acute WQG for Al.

7.3 Environment and Climate Change Canada (ECCC)

Environment and Climate Change Canada has recently published a WQG for total Al which uses an MLR approach and pH, DOC, and hardness to derive a chronic Federal Water Quality Guideline (FWQG) (ECCC, 2022).

7.4 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 Al is based on three pH categories (i.e., 4.5-5.5, >5.5-6.5, and >6.5 - 9) (OMOEE, 1994). Alberta Environment and Parks (AEP) adopted the 1988 B.C. WQG for Al (AEP, 1996). Saskatchewan adopted the chronic CCME WQG as an interim surface water quality objective with some modifications (Water Security Agency, 2015). Manitoba has adopted the CCME 1987 WQG (MWS, 2011) and Quebec has adopted the USEPA updated Water Quality Criteria (WQC) published in 2018 (see below).

7.5 USEPA Water Quality Criteria

The USEPA developed acute (i.e., short-term) and chronic (i.e., long-term) national WQC for the protection of aquatic life based on total Al (USEPA, 2018). The USEPA Al WQC uses a bioavailability modeling approach based on MLR to calculate WQCs. The MLR used in USEPA criterion requires three water chemistry parameters (DOC, pH, and hardness) to calculate a Criterion Maximum Concentration (CMC), and a Criterion Continuous Concentration (CCC) (USEPA, 2018).

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 Al trigger value is dependant on the site-specific pH and is derived for pH values greater than and less than 6.5. For example, to protect 95% of aquatic life, ANZECC (2000a; 2000b) developed a trigger value for dissolved Al of 55 µg/L for waters with a pH greater than 6.5 (Table 7.1).

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

Jurisdiction	Chronic (µg/L)	Acute (µg/L)	Total or dissolved	Year published
British Columbia	pH <6.5 $e^{(1.209 - 2.426 (pH) + 0.286 K)}$ where $K = (pH)^2$	pH <6.5 $e^{(1.6 - 3.327 (median\ pH) + 0.402 K)}$ where $K = (median\ pH)^2$	Dissolved	1988
CCME	pH <6.5 5 pH ≥6.5 100	NA	Total	1987
ECCC	MLR (depending on pH, hardness, and DOC)	NA	Total	2022
Ontario	4.5 <pH ≤5.5 15	NA	Total	1994
Saskatchewan	pH <6.5, Ca <4 mg/L, and DOC <2 mg/L 5 pH ≥6.5, Ca ≥4 mg/L, and DOC ≥2 mg/L 100	NA	Total	2015
USEPA	MLR (depending on pH, hardness, and DOC)	Variable (depending on pH, hardness, and DOC)	Total	2018
Australia/ New Zealand	pH <6.5 0.8 pH ≥6.5 55	NA	Dissolved	2000

8. RECOMMENDED GUIDELINE

8.1 Toxicity data

Data compiled by the USEPA for the aquatic life ambient water quality criteria (AWQC) for Al (USEPA, 2018) formed the foundation of aquatic toxicity data considered for development of the Al FWQG. A detailed review of studies from this source was performed by ECCC following the CCME (2007) guidance for data quality. Determinants of test acceptability included, but were not limited to, exposure duration, analytical determination of Al 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. Aluminum nitrate, sulfate, and chloride salts were the Al compounds used in the toxicity tests considered for the derivation of the guideline. A total of 733 chronic toxicity endpoints for 24 species from 26 studies were identified as acceptable. Many acceptable studies reported results for multiple effects (e.g., reproduction, growth, mortality) with multiple endpoints (e.g., NOEC, LOEC, ECx). The full toxicity dataset is presented in [Appendix A of FWQG (ECCC, 2022)][1].

It is often not possible to measure the absolute total Al concentration in water because of the limitations in routine sampling and analytical methods. The total recoverable Al is often used to represent the total Al concentration. Within the total recoverable fraction, herein referred to as total, both particulate (bound to or incorporated into suspended matter and minerals) and dissolved Al fractions are included. The FWQG for Al is based on measurements of total Al. Aluminum toxicity studies were only considered if total concentrations were reported in the toxicity test.

Often metal toxicity is best characterized by the dissolved fraction of a metal (operationally defined as the concentration recovered after being passed through a 0.45 µm filter), as it is often shown to correlate with toxicity better than total concentrations (e.g., zinc, copper). However, Al behaves differently because of chemical speciation and solubility characteristics at different pH values. Multiple studies available in the scientific literature demonstrate the dissolved fraction alone does not correspond with Al toxicity. Gensemer et al. (2018) conducted both acute and chronic tests using fathead minnow (*Pimephales promelas*), water flea (*Ceriodaphnia dubia*), and the alga *Pseudokirchneriella subcapitata* at circumneutral pHs (6–8), finding that toxicity was either reduced or removed by filtration and that dissolved concentrations did not correlate with toxicity. This finding is consistent with results of Cardwell et al. (2018) where similar tests were conducted on several other freshwater species. These two studies also showed that concentrations of dissolved Al remained relatively constant regardless of the initial added Al, suggesting that concentrations of dissolved Al are limited by the solubility of the Al test compounds (Cardwell et al., 2018; Gensemer et al., 2018). Colloidal and precipitated forms of Al, which are removed by a filter in dissolved measurements, were found to cause toxicity to aquatic organisms under circumneutral pH conditions (Cardwell et al., 2018; Gensemer et al., 2018).

Since a FWQG based on dissolved Al would underestimate toxicity, dissolved measurements were not used. The FWQG is instead based on total Al measured in laboratory water to reflect all forms of Al that result in toxicity. This decision is consistent with the AWQC for Al from the USEPA (2018). All Al concentrations are expressed as total Al herein unless otherwise specified.

[1] This text has been modified and appears as "Appendix A" in ECCC, 2022.

8.2 Toxicity Modifying Factors

Toxicity modifying factors (TMFs), such as pH, DOC, and water hardness as $CaCO_3$ (herein referred to as hardness) can alter the bioavailability of Al and hence the toxicity to aquatic organisms. Therefore, it is important in guideline derivation to incorporate TMFs when the data are available. TMFs are often incorporated into FWQGs by either a multiple (or single) linear regression approach or a biotic ligand model (BLM). MLRs (DeForest et al., 2018) and a BLM (Santore et al., 2018) for total Al were published in 2018. Both approaches were investigated for potential use for the development of the FWQG for Al.

8.2.1 *Biotic Ligand Model*

The Al BLM (Santore et al., 2018) was investigated as a method to incorporate bioavailability into the FWQG. The BLM models the toxicity of both dissolved and precipitated forms of Al, attributing the toxic effect to the dissolved portion of Al until the solubility limit is reached, then attributing the rest of the toxic effect to precipitated Al. The effects caused by each form of Al are modeled as a concentration-response relationship. The slopes of the response curves were calibrated for three species: *P. promelas*, *C. dubia*, and *P. subcapitata*. These three species are used as representatives for fish, invertebrate, and plant/algae species, respectively, for which specific parameter files have not yet been calibrated. Please refer to Santore et al., (2018) for more information on the approach. Several inconsistencies and uncertainties were identified after assessing the available versions of the Al BLM. For example, there were unexplained differences between versions, specifically large differences in the effect of temperature and the subsequently generated guideline values. Due to these uncertainties the BLM method was not used for the development of the Al FWQG.

8.2.2 *Multiple Linear Regression*

A MLR approach was used to incorporate TMFs into the FWQG for Al. Chronic MLRs were developed by DeForest et al., (2018) for the three main trophic levels within a freshwater environment, represented by the fathead minnow (*P. promelas*), the water flea (*C. dubia*), and an alga (*P. subcapitata*). Most data used to create the MLR relationships were published by Gensemer et al., (2018). Nine additional *C. dubia* and *P. promelas* toxicity tests were conducted by Oregon State University (OSU) in order to expand the ranges of water chemistry conditions for model development (DeForest et al., 2020; OSU, 2018 a,b,c). The MLRs were updated by the authors and made available to ECCC. Three-day EC_{10}s (growth) for *P. subcapitata* (n= 27), 7-d EC_{10}s (reproduction) for *C. dubia* (n=32), and 7-d EC_{10}s (biomass) for *P. promelas* (n=31) were used to create the MLR relationships (DeForest et al., 2020). One 33-d EC_{10} (survival) for *P. promelas* was also included. The inclusion of this endpoint was justified by the authors because the 7-d survival and growth test had a similar sensitivity as the 33-d survival and growth test. A pooled MLR model was also derived, combining *C. dubia* and *P. promelas* Al toxicity datasets (DeForest et al., 2020).

MLR models were developed for a variety of terms including the independent variables of DOC, pH, and hardness. A pH^2 term and the following interaction terms were also considered based on the knowledge of Al speciation and bioavailability: DOC × pH; DOC × hardness; and hardness × pH. The pH^2 term accounts for the decrease in Al bioavailability from pH 6 to 7 and then increases from pH 7 to 8 (DeForest et al., 2018). A negative DOC × pH term characterizes the tendency for a decrease in the mitigating effect of DOC as pH increases; a negative DOC × hardness term would reflect the tendency of a decrease in the mitigating effect of DOC as hardness increases; and a negative hardness × pH term would reflect the tendency of a decrease in the mitigating effect of hardness as pH increases (DeForest et al., 2018). A summary of the results for the best fit MLR models is presented in Table 8.1. All three MLRs for the different taxa retained DOC, hardness, and pH but different interactive terms. For more detailed information on the MLR analyses see DeForest et al. (2018; 2020). The DeForest et al. (2018; 2020) MLRs do not include temperature as a TMF and there are currently not enough data to do so.

Ninety-one percent of predicted *C. dubia* EC_{10} values (29 of 32), 94% of predicted *P. promelas* EC_{10} values (29 of 31), and 100% of predicted *P. subcapitata* EC_{10} values (27/27) were within a factor of two of observed EC10 values from the dataset used to create the individual species MLR relationships (DeForest et al., 2018; 2020). Using the pooled MLR model, the predictability of *P. promelas* endpoints decreased slightly from 94% to 90% and the predictability of *C. dubia* endpoints remained the same at 91%.

Table 8.1. Summary results of MLR analysis (DeForest et al., 2018; 2020).

Model coefficients										
Species	n	Adj. R^2	Intercept	DOC	Hardness	pH	pH^2	DOC x pH	DOC x hardness	Hardness x pH
C. dubia	32	0.87	-32.273	0.673	2.613	8.325	-0.431	-	-	-0.31
P. promelas	31	0.90	- 6.7	1.828	1.914	1.932	-	-0.193	-	-0.248
P. subcapitata	27	0.94	-77.283	2.342	4.560	20.923	-1.274	-0.288	-	-0.628
Pooled (C. dubia + P. promelas)	63	0.88	-8.618 (*C.dubia*) -7.606 (P. promelas)	0.645	2.255	1.995	-	-	-	-0.284

An approach was investigated which used the *C. dubia* MLR to normalize all invertebrate endpoints, the *P. promelas* MLR to normalize all fish endpoints, and the *P. subcapitata* MLR to normalize all aquatic plant endpoints before plotting SSDs. Since this approach involves several MLRs with different slopes, a final guideline equation could not be calculated. The CCME (2007) protocol requires the use of SSD software to create fitted SSD curves. Therefore, one y-intercept for use in the guideline equation cannot be derived when using multiple MLRs. Instead, look up tables of hazard concentration values for the fifth percentile (herein referred to as HC_5 values) derived from different SSDs normalized to various water chemistry combinations were used, requiring rounding when user inputs fall between the pre-calculated SSDs. In addition, because all three individual MLRs differ in slope, including interaction term slopes, combining them into SSDs caused trends in HC_5 values that may not be supported by the science, and some of which were believed to be statistical artifacts of the SSD. Following this approach, *P. subcapitata* was often an outlier in SSDs normalized to high pH values (pH>8). This caused a particularly poor fit of the SSD at this pH range. Therefore, the individual MLR approach was not used to develop the FWQG.

A pooled MLR (*C. dubia* and *P. promelas*) was also investigated. The pooled MLR incorporates 68 toxicity data points from 2 different species and taxonomic groups, has a high R^2 value of 0.88, and has a similar level of accuracy in predicted EC_{10}s compared to the individual species models. Algae data were not incorporated into the pooled MLR since the data showed significantly different slopes compared to fish and invertebrate data. The lack of algae data in the pooled MLR is recognized as an uncertainty, however the protectiveness assessment concluded plants/algae are protected by the FWQG (see protectiveness assessment). The pooled MLR approach allows for a guideline equation to be derived, results in a SSD with good fit, is considered protective and predictive, and is transparent and easy to use. The pooled (invertebrate and fish) EC_{10} MLR model was therefore chosen to be used in the guideline derivation for Al.

This approach is generally aligned with the USEPA AWQC (USEPA, 2018). The USEPA also applied the DeForest et al. (2018 a,b) MLR approach, but used the separate fish and invertebrate MLRs instead of the pooled MLR. In addition, the two jurisdictions differ in general guideline derivation methods which includes the USEPA preference for EC_{20} values compared to EC_{10}s preferred following CCME (2007) protocol.

8.3 Federal Water Quality Guideline Derivation

FWQGs are preferably developed using the CCME (2007) protocol. In the case of Al, 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 SSDs comprised of primarily "no effect" data to calculate HC_5 values, which in turn become the final guideline value (CCME 2007).

Only data that fell within the acceptable ranges of the MLR (Table 8.2) were used in guideline derivation to avoid extrapolations beyond the MLR relationship. EC_{10} values were calculated using the USEPA toxicity relationship analysis program (TRAP v. 1.3) (USEPA, 2015) where needed and the necessary underlying data were available. Reported DOC values less than the MDL were substituted with half the MDL for use in equations based on USEPA recommendations (USEPA, 2007; 2018). Reported DOC values of 0 mg/L were substituted with 0.3 mg/L representing near zero values for use in equations. Seven endpoints used in the SSD dataset did not have reported DOC concentrations and therefore were estimated following USEPA recommendations (USEPA, 2007; 2018). All SSD endpoints had reported hardness and pH values. Refer to Appendix A of the FWQG for Al (ECCC, 2022) for the full list of toxicity endpoints, experimental conditions, water chemistry, and other study details.

Table 8.2. MLR water chemistry range.

Variable	pH	DOC (mg/L)	Hardness (mg/L)
Range	6-8.7	0.08-12.3	10-430

The pooled MLR model and slopes (Table 8.1) were used to normalize all acceptable toxicity data points to a common water chemistry (DOC of 0.5 mg/L, pH of 7.5, and hardness of 50 mg/L) using the equation:

EC_x (at DOC of 0.5 mg/L, pH of 7.5, and hardness of 50 mg/L) = EXP[(ln (original EC_x)) – 0.645*(ln(original DOC) – ln(0.5)) – 2.225*(ln(original hardness) – ln(50)) – 1.995*(original pH 7.5) + 0.284*((ln(original hardness)*original pH) – (ln(50)*7.5))]

A geometric mean was calculated where multiple comparable endpoints were available for the same species, effect, life stage, and exposure duration. The most sensitive and preferred endpoint (or geometric mean) was then selected for each species following CCME (2007). A total of 54 endpoints for 14 species (three fish, eight invertebrates, two aquatic plants/algae, and one amphibian) were included in the SSD dataset and are summarized in Table 8.38.3. *Salvelinus fontinalis* (fish) was the most sensitive species in the dataset with a normalized effect concentration of 171 µg/L. *Lemna minor* (plant) was the least sensitive species in the dataset with a normalized effect concentration of 14,607 µg/L.

The R package (R version 4.03) 'ssdtools' (ssdtools version 0.3.2) as well as the corresponding user friendly "Shiny App" were used to create SSDs from the dataset (Dalgarno, 2018; Thorley and Schwarz, 2018). The package fit several cumulative distribution functions (CDFs) (log-normal, log-logistic, and log-gumbel) 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, 2004). Using AICc, which is AIC corrected for small sample size, a model averaged HC_5 can be established. The smaller the AICc, the better the distribution fits the data set. Each model was then weighted; models with higher weight values better fit the data. See Schwarz and Tillmanns (2019) for more information on the approach.

Table 8.3. Chronic freshwater toxicity data used in the SSD for deriving the FWQG for Al. The normalized effect concentrations are for the water chemistry of an example site (pH=7.5, DOC=0.5 mg/L, hardness=50 mg/L).

Species scientific name	**Species common name**	**Group**	**Endpoint**	**Effect concentration (µg/L)**	**Normalized effect concentration[a] (µg/L)**	**Reference**
Salvelinus fontinalis	Brook trout	Fish	60-d EC_{10} (Weight)	103.24	170.65	Cleveland et al. 1989
Pimephales promelas	Fathead minnow	Fish	7-d EC_{10} (Mean dry weight)	Geomean [b] (n=2)	271.52	ENSR 1992a
Hyalella azteca	Amphipod	Invertebrate	28-d EC_{10} (Biomass)	142.6	307.46	Cardwell et al. 2018
Lampsilis siliquoidea	Fatmucket	Invertebrate	28-d EC_{10} (Dry weight)	109	312.73	Wang et al. 2018
Pseudokirchneriella subcapitata	Green algae	Plant/algae	72-h EC_{10} (Biomass)	Geomean [b] (n=30)	358.77	Gensemer et al. 2018
Danio rerio	Zebrafish	Fish	33-d EC_{10} (Biomass)	98.2	358.77	Cardwell et al. 2018
Ceriodaphnia dubia	Water flea	Invertebrate	6-d EC_{10} (Reproduction)	Geomean [b] (n=3)	435.88	ENSR 1992b
Bufo bufo	Common toad	Amphibian	7-d >NOEC	Geomean [b] (n=2)	421.44	Gardner et al. 2002
Daphnia magna	Water flea	Invertebrate	21-d EC_{10} (Reproduction)	709.4	535.04	Gensemer et al. 2018
Lymnaea stagnalis	Great pond snail	Invertebrate	30-d EC_{10} (Dry weight)	Geomean [b] (n=3)	870.38	OSU 2018d
Brachionus calyciflorus	Rotifer	Invertebrate	48-h EC_{10} (Reproduction)	Geomean [b] (n=6)	1,506.69	OSU 2018e, Cardwell et al. 2018
Chironomus riparius	Midge	Invertebrate	10-d EC_{10} (Growth)	971.6	1,722.97	Cardwell et al. 2018
Aeolosoma sp.	Oligochaete	Invertebrate	17-d EC_{10} (Reproduction)	987.9	5,942.63	Cardwell et al. 2018
Lemna minor	Duckweed	Plant/algae	7-d EC_{10} (Weight)	2175	14,607.41	Cardwell et al. 2018

[a] Effect concentrations normalized using the Pooled MLR model to a common water chemistry.

[b] Geometric mean

The SSD and accompanying summary statistics at water hardness of 50 mg/L, pH of 7.5, and DOC of 0.5 mg/L are presented in Figure 8.1 and Table 8.4, respectively. The full R script is available in [Appendix A of FWQG (ECCC, 2022)].[2]

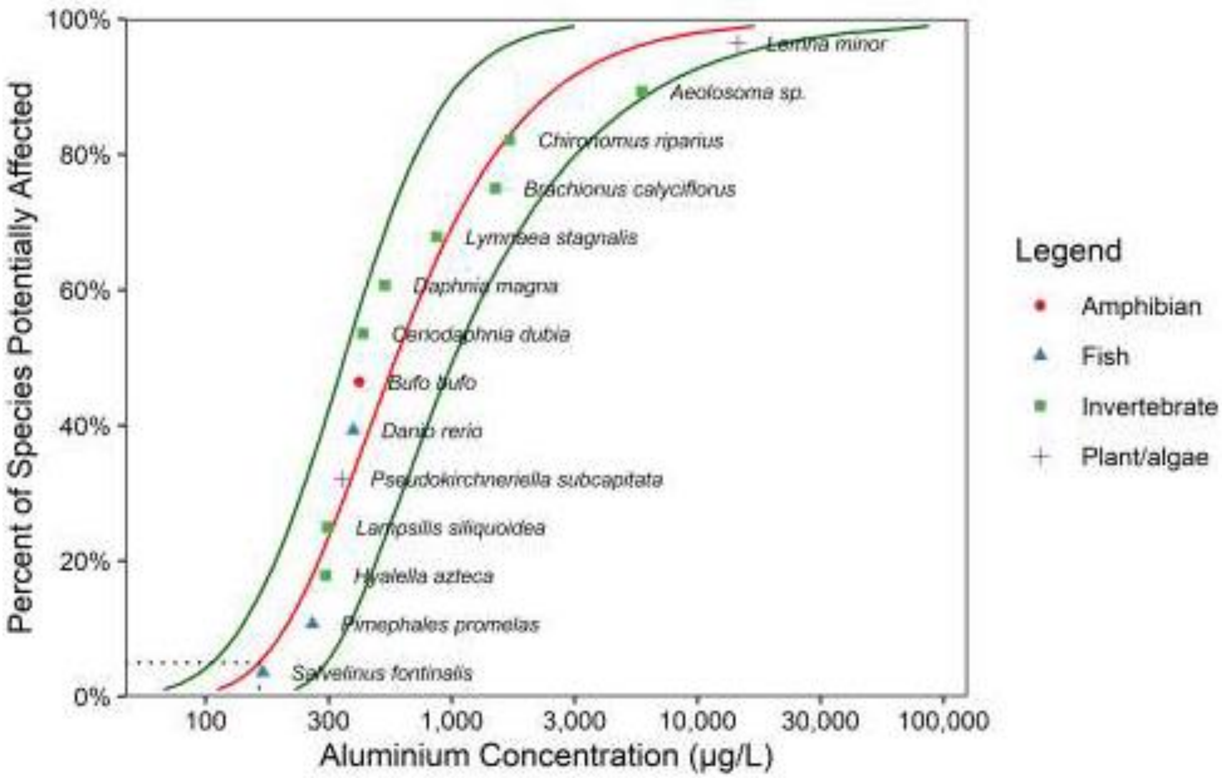

Figure 8.1. FWQG model averaged species sensitivity distribution for Al for an example site (pH = 7.5, DOC = 0.5 mg/L, hardness = 50 mg/L). The 5th percentile is 170 µg Al/L.

Table 8.4. FWQG summary statistics for water with a hardness of 50 mg/L, pH of 7.5, and DOC of 0.5 mg/L.

Distribution	AICc	Predicted HC_5 (µg/L)	95% LCL (µg/L)	95% UCL (µg/L)	Weight	Weighted HC_5 (µg/L)	Weighted 95% LCL (µg/L)	Weighted 95% UCL (µg/L)
Log-normal	235	98.6	40.3	283	0.066	7	3	19
Log-logistic	234	87.5	31.1	244	0.09	8	3	22
Log-Gumbel	230	178	119	316	0.844	150	100	267
FWQG value						165	106	308

Because pH, DOC, and hardness were identified as significant toxicity modifying factors as well as the interaction between hardness and pH, the FWQG is expressed as an equation to calculate a site-specific FWQG. The equation is based on the pooled MLR model slopes of 1.995 (pH), 0.645 (DOC), 2.255 (hardness), and -0.284 (hardness x pH), and the HC_5 value of 165 µg/L derived from the SSD at a pH of 7.5, DOC of 0.5 mg/L, and hardness of 50 mg/L.

[2] This text has been modified and appears as "Appendix A" in ECCC, 2022.

Based on the pooled MLR model and the HC5 from the SSD, the y-intercept can be derived using the following equation:

y-intercept = $\ln(HC_5) - [\text{DOC slope} \times \ln(\text{DOC})] - [\text{hardness slope} \times \ln(\text{hardness})] - [\text{pH slope} \times \text{pH}] - [\text{hardness*pH slope} \times (\ln(\text{hardness}) \times \text{pH})]$

$= \ln(165) - [0.645 \times \ln(0.5)] - [2.255 \times \ln(50)] - [1.995 \times 7.5] - [-0.284 \times (\ln(50) \text{ x } 7.5)]$

$= -9.898$

The FWQG equation for total Al is therefore:

FWQG (µg/L) = $\exp([0.645 \times \ln(\text{DOC})] + [2.255 \times \ln(\text{hardness})] + [1.995 \times \text{pH}] + [-0.284 \times (\ln(\text{hardness}) \times \text{pH})]\ -9.898)$

where the FWQG is in µg/L total Al, hardness is measured as $CaCO_3$ equivalents in mg/L, pH is in standard units, and DOC is in mg/L.

8.3.1 *Protectiveness Assessment*

A protectiveness assessment was conducted to determine if the protection clause of the CCME (2007) protocol should be invoked. Note that only laboratory derived data were used in this assessment. Assessing protectiveness using data from natural ecosystems, such as species diversity, is beyond the scope of this document. To determine whether the guideline is sufficiently protective, FWQGs were calculated for each of the acceptable endpoints in the toxicity dataset within the valid water chemistry ranges of the MLR. The FWQGs were then compared to measured toxicity values at their tested water chemistry. Ratios (measured toxicity value:FWQG) >1 indicate that the FWQG is protective of the toxicity value in that particular test, while ratios <1 indicate that the FWQG is higher than the observed toxicity, and hence may require further evaluation (Figure 8.2). This protectiveness assessment found 98% (668/680) of acceptable toxicity values were greater than the FWQG for the corresponding water chemistry. To ensure protectiveness, each of the 12 endpoints with ratios <1 were further examined to ensure none of them triggered the protection clause (CCME, 2007). Endpoints plotting below the site specific FWQGs are for *C. dubia* (n=2; NOEC and LOEC (reproduction)), *H. azteca* (n=1; NOEC (biomass)), *S. fontinalis* (n=1; NOEC (growth), and *P. subcapitata* (n=8, seven EC_{10}s (biomass) and one EC_{50} (biomass)). The geometric mean of all species ratios were above 1. For example, the species geometric mean ratio for *P. subcapitata* was 5, meaning on average the reported measured toxicity values were approximately five times higher than the FWQG for the corresponding water chemistry. 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 that the MLR-based aluminium FWQG is protective.

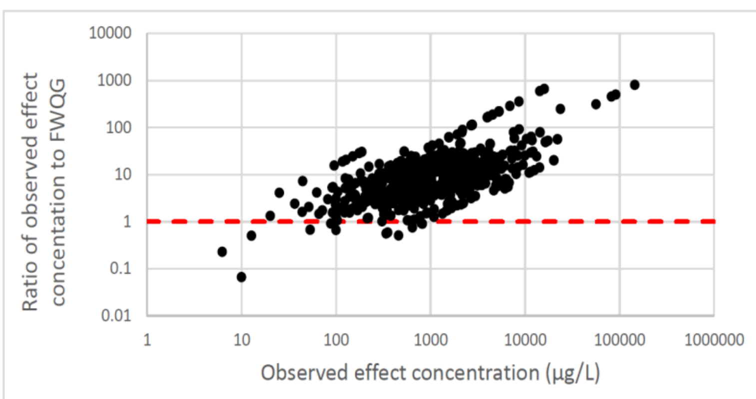

Figure 8.2. Ratio of observed effect concentrations to FWQG for all acceptable toxicity endpoints plotted against observed effect concentrations.

8.4 B.C. Aluminum Water Quality Guidelines

The FWQG is based on a SSD and uses a MLR approach to incorporate the toxicity modifying factors of pH, hardness, and DOC in the calculation of the WQG (ECCC, 2022). The toxicity dataset used to derive the Al FWQG consists of data for two plants, eight invertebrates, three fishes, and one amphibian. The chronic dataset used for the Al FWQG fulfills the minimum number of species required for a B.C. Type A2 guideline (ENV, 2019) with some considerations. Of the three fish species, two are Canadian species (i.e., brook trout; *Salvelinus fontinalis* and fathead minnow; *P. promelas*) and one is a non-Canadian species (i.e., zebrafish, *Danio rerio*). The amphibian is also a non-Canadian species (i.e., common toad, *Bufo bufo*). All other species included in the SSD are Canadian species. The B.C. WQG derivation protocol allows for the use of tropical species as surrogates for Canadian species on a case-by-case basis depending on the nature of the substance. The Canadian fish species are the most sensitive species in the Al dataset with the zebrafish being relatively tolerant to Al.

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 use of surrogate species (e.g., zebrafish), the lack of data for relevant Canadian species such as EPT (Ephemeroptera, Plecoptera, Tricoptera) and Canadian amphibians, and the lack of data for reproduction in fish. Given these sources of uncertainty, an AF of 3 was applied to the calculated HC_5.

The B.C. Al WQG is calculated using the following equation:

$$\text{Al WQG } (\mu g/L) = \frac{e^{\{[0.645*\ln(DOC)]+[2.255*\ln(hardness)]+[1.995*pH]+[-0.284*(\ln(hardness)*pH)]-9.898\}}}{3}$$

Table 8.5 provides examples of B.C. Al WQGs in various water chemistry scenarios. For other water chemistry scenarios, an Al WQG calculator is available on the BC WQGs web page[3].

The [B.C. WQG][4] is for total Al and is found using the [Al WQG][4] equation above, which has also been incorporated into the [B.C. Al WQG Calculator][5] in Excel. The [B.C. WQG][4] equation is valid for hardness concentrations from 10 mg/L to 430 mg/L, pH from 6.0 and 8.7, and DOC 0.08 and 12.3 mg/L, which are the ranges of data used to derive the MLR slopes (DeForest et al., 2018; 2020) (Table 8.2). Only values within these ranges should be entered into the guideline equation to ensure the equation is accurate and the [B.C. WQG][4] is protective. Any user inputs into the [BC Al WQG Calculator][5] that are outside of these ranges are automatically rounded to the upper or lower bounds. If site-specific water hardness, pH or dissolved organic carbon (DOC) is not known, use the corresponding lower limits from Table 8.2 (the [B.C. Al WQG Calculator][5] will do this automatically).

The protectiveness of the WQGs calculated by BC Al WQG has been shown only within the ranges of the water chemistry parameters of the MLR model (Table 8.2). Therefore, the B.C. Al WQG Calculator only works within the water chemistry ranges of the MLR model and automatically replaces the values outside of the ranges with the lower or higher bounds. If water chemistry parameters are outside of these bounds for a specific water body, a first step is to use the above equation (B.C. Al WQG equation) to estimate the Al concentration. If this concentration is lower than the WQG generated by the B.C. Al WQG calculator

[3] Available at https://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/waterquality/water-quality-guidelines/approved-wqgs/aluminum/bc_al_wqg_calculator.xlsx

[4] This text has been modified and appears as "FWQG" in ECCC, 2022.

[5] This text has been modified and appears as "FWQG Calculator" in ECCC, 2022.

(i.e., using the bounds of the model) then the risk should be minimal. However, if the total Al concentration is higher than the concentration produced by the B.C. Al WQG calculator, then a site-specific assessment may be required to assess potential risks to aquatic life.

Table 8.5. BC total Al WQGs (µg/L) at various levels of dissolved organic carbon, pH, and hardness levels (adapted from ECCC, 2022).

a) DOC = 1 mg/L

				pH			
Hardness	**6**	**6.5**	**7**	**7.5**	**8**	**8.5**	**8.7**
10	9	18	36	70	140	270	350
50	23	36	55	86	130	210	250
100	33	47	67	94	130	190	210
200	49	63	80	100	130	170	180
300	61	74	89	110	130	160	170
≥430	75	86	98	110	130	150	160

b) DOC = 4 mg/L

				pH			
Hardness	**6**	**6.5**	**7**	**7.5**	**8**	**8.5**	**8.7**
10	23	45	88	170	340	660	860
50	56	87	140	210	330	510	610
100	82	120	160	230	320	460	520
200	120	150	200	250	320	410	450
300	150	180	220	260	320	380	410
≥430	180	210	240	280	320	360	380

c) DOC = 8 mg/L

				pH			
Hardness	**6**	**6.5**	**7**	**7.5**	**8**	**8.5**	**8.7**
10	33	70	140	270	530	1000	1300
50	87	140	210	330	510	800	950
100	130	180	250	360	510	710	820
200	190	240	310	390	500	640	700
300	230	280	340	410	500	600	650
≥430	290	330	380	430	490	570	600

d) DOC ≥ 12.3

				pH			
Hardness	**6**	**6.5**	**7**	**7.5**	**8**	**8.5**	**8.7**
10	48	93	180	360	690	1400	1800
50	120	180	280	430	680	1100	1300
100	170	240	340	470	670	940	1100
200	250	320	400	520	660	840	930
300	310	370	450	540	660	790	850
≥430	380	430	500	570	650	750	790

9. COMPARISON OF AMBIENT ALUMINUM 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 Al WQG. To answer this question, water quality data (dissolved Al, total Al, pH, DOC, and hardness) from freshwater sites were extracted from the EMS database. Non-detect data for either form of Al 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. An additional data cleaning step was conducted to focus on data from minimally disturbed sites. A total of 2,027 records were retrieved to calculate the 1988 WQG (i.e., pH and dissolved Al) and a total of 772 records were retrieved to calculate 2022 WQG (i.e., pH hardness, DOC, and total Al).

Dissolved Al exceeded the 1988 WQGs concentrations 18.3% of the time (371/2,027) (Figure 9.1) and total Al exceeded the updated WQG 8.9% of the time (69/772) (Figure 9.2). The lower rate of exceedance of the updated WQG compared to the 1988 WQG is mainly because the updated WQG is capped at 900 µg/L whereas the 1988 WQG is capped at 50 µg/L.

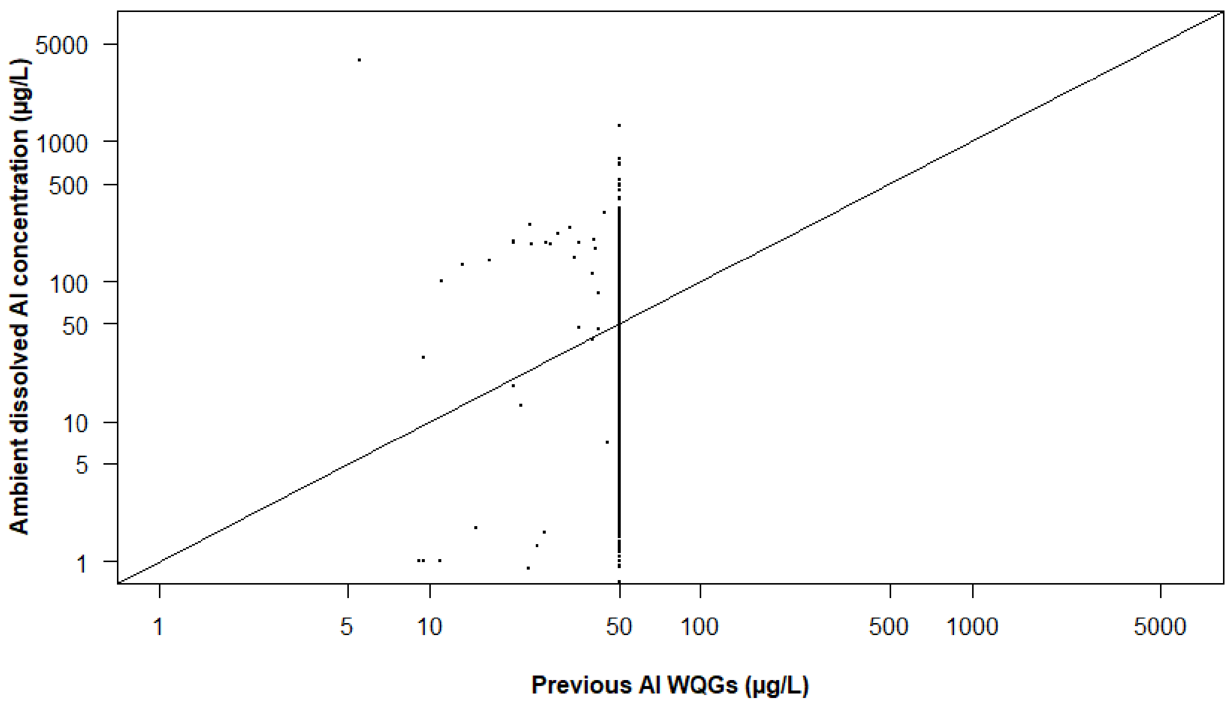

Figure 9.1. Ambient Al concentrations compared to the 1988 chronic dissolved Al WQGs. Points above the solid 1:1 line represent exceedances. The maximum value for the 1988 chronic WQG is 50 µg/L.

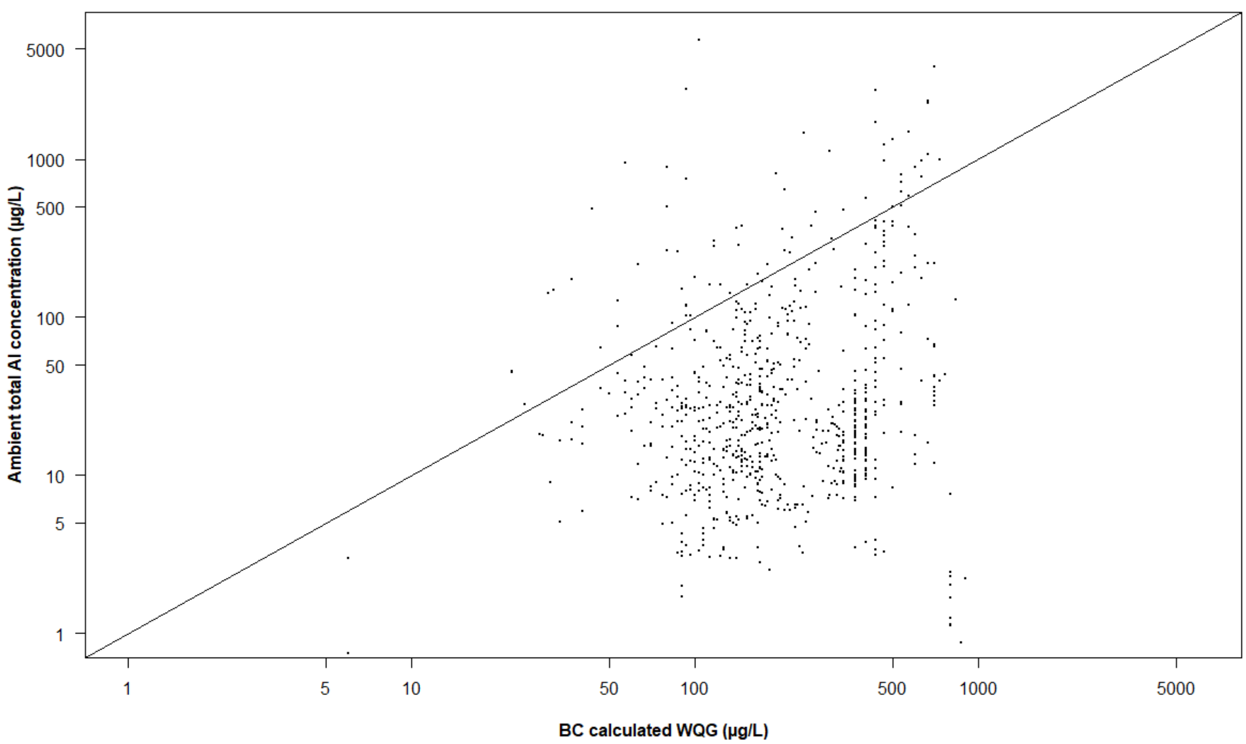

Figure 9.2. Ambient Al concentrations compared to the 2022 chronic total Al WQGs. Points above the solid 1:1 line represent exceedances.

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