WATER QUALITY GUIDELINE SERIES

Cobalt Water Quality Guidelines – Freshwater Aquatic Life

Ministry of Water, Land, and Resource Stewardship
Watershed Stewardship and Security Branch

No. WQG-26

BRITISH COLUMBIA

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 B.C. 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 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 cobalt (Co) WQGs for the protection of aquatic life.

Elevated cobalt concentrations can adversely affect aquatic life. While background levels vary across B.C., activities such as mining, smelting, manufacturing, fossil fuel combustion, and waste disposal can raise cobalt concentrations to harmful levels.

Cobalt is an essential micronutrient; however, studies on cobalt chloride, cobalt sulfate, and other soluble cobalt compounds indicate that cobalt can be harmful to aquatic life at elevated concentrations, with toxicity varying depending on water hardness. When toxicity data are standardized for hardness, invertebrates, such as amphipods, tend to be more sensitive to cobalt than plants or fish, though sensitivity varies across species.

In 2017, Environment and Climate Change Canada (ECCC) published a Federal Water Quality Guidelines (FWQG) for cobalt 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 revised WQG is for dissolved cobalt and considers hardness, whereas the previous B.C. WQG was a fixed concentration for total cobalt across all hardness values. Exceedance of cobalt WQG at background sites were more frequent under the 2025 WQG than the 2004 WQG, as the updated hardness-based equation sets lower guideline values.

A summary of the cobalt WQGs is presented in Table E.1. The aquatic life guideline is calculated using site-specific hardness and, therefore, is listed below as variable. As an example, for a waterbody with hardness of 100 mg/L the freshwater aquatic life WQG for dissolved cobalt is 0.5 µg/L.

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

Designated use	Guideline µg/L	Guideline Type	Fraction
Freshwater aquatic life	Variable*	Long-term chronic	Dissolved
Livestock	1000**	Long-term chronic	Total
Irrigation	50**	Long-term chronic	Total

* The equation for the B.C. freshwater aquatic life cobalt WQG, which accounts for hardness, is provided in Section 7.3.
** The chronic livestock and irrigation guidelines are working guidelines adopted from the Canadian Council of Ministers of the Environment (CCME).

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1. INTRODUCTION

The British Columbia (B.C.) 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 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 May 2017, Environment and Climate Change Canada (ECCC) published a Federal Water Quality Guidelines (FWQG) for cobalt (Co) 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) and incorporates background concentrations in B.C., and the rationale for the addition of an assessment factor.

2. SUBSTANCE IDENTITY

Cobalt is a naturally occurring element. Cobalt is an essential micronutrient required for the formation of vitamin B_{12} and for its function in enzymatic processes (Gál et al. 2008). Anthropogenic sources to the environment include activities related to the production of cobalt (i.e., mining, smelting and refining); manufacture, import and use of cobalt-containing substances, products and manufactured items (e.g. use in metallurgical processes, alloys and carbides, batteries, catalysts, rubber, paints and coatings, plastic, automobile manufacturing, cosmetics, pigment and dyes, printing inks, pesticides, livestock feed, fertilizers); burning of fossil fuels and disposal and waste management of products and wastes containing cobalt (Hodge and Dominey 2001; IPCS 2006; Canada 2017). Canada completed a screening assessment of cobalt and cobalt-containing substances (Canada 2017). The assessment included the four previously assessed cobalt compounds for which a FWQG was previously developed (Environment Canada 2017). A list of the cobalt-containing substances identified as priorities for action and included in the assessment is provided in the screening risk assessment report (Canada 2017). This factsheet was developed in consideration of the above assessment which was based on data and information identified up to September 2014. Some of the data on uses, fate, ambient concentrations, and toxicity presented below relate to that assessment and the various compounds evaluated in the assessment. The FWQG derived (see Figure 1) is for the cobalt ion and can be considered pertinent for cobalt ion from all sources or forms.

3. FATE, BEHAVIOUR, AND PARTITIONING IN THE ENVIRONMENT

Cobalt can be found in various forms in ambient air, surface water, sediments, soils and groundwater. Cobalt is non-volatile, exerting zero partial pressure in air (Diamond et al. 1992). As such, it is emitted to air principally in the form of fine particulate matter. When released anthropogenically with fossil fuel and waste combustion, cobalt is mainly in the form of oxides. During ore extraction and refining, arsenide and sulphide forms are also released (IPCS 2006).

The water solubility of cobalt and cobalt-containing substances varies widely, from sparingly soluble to greater than 106 mg/L. Thus, if released to water bodies, some substances will release more cobalt ions than others upon dissolution or dissociation (Canada 2017). Elemental cobalt powders may also release cobalt ions if discharged to surface waters. Some undissolved elemental cobalt may be found in sediments and moist soils in cases where elemental cobalt has been directly released. For cobalt ions, the oxidation state (II) is more stable than the oxidation (III) state (Cotton and Wilkinson 1988), favouring chemical complexes with the divalent cobalt cation in aqueous solutions. For cobalt, soil-water partitioning is highly variable, depending on soil properties (Canada 2011). Cobalt binds strongly with sediments and suspended particulate matter; high sediment-water partition coefficients suggest that cobalt will remain for the most part in bottom sediments after entering this compartment. For aquatic organisms, bioaccumulation factors for cobalt range from 7.4 to 3110 L/kg, whereas values range from 0.091 to 0.645 for biota-sediment (Canada 2017). Field and laboratory investigations indicated a lack of biomagnification of cobalt in food webs. It is concluded that the bioaccumulation potential of cobalt in natural ecosystems is not high and therefore, despite meeting the criteria for persistence, elemental cobalt and cobalt-containing compounds do not meet the criteria for bioaccumulation as set out in the Persistence and Bioaccumulation Regulations of CEPA (Government of Canada (GC) 2000). Based on the information presented in the Screening Assessment Report (SAR), the Government of Canada (Canada 2017) concluded, at this time, that cobalt and soluble cobalt compounds meet the criteria under paragraph 64(a) of CEPA, that is, they are entering the environment in a quantity or concentration or under conditions that

have or may have an immediate or long-term harmful effect on the environment or its biological diversity and are considered to be toxic under CEPA such that risk management action may be required.

4. BACKGROUND CONCENTRATIONS OF COBALT IN BRITISH COLUMBIA

Cobalt is a naturally occurring element in aquatic and terrestrial ecosystems, therefore, background concentrations must be considered when deriving the WQG.

4.1 Methods for Estimating Background Concentrations

Background (i.e., from non-impacted sites) dissolved cobalt concentrations vary naturally in surface waters across B.C. as a function of local geology and hydrology. Therefore, a regional approach was used to estimate background cobalt concentrations, following methods used in recent WQG derivation documents; this approach divided the province into nine ENV administrative regions (e.g., ENV, 2021).

Data were obtained from two databases: the B.C. Environmental Management System (EMS) and the Canadian Aquatic Biomonitoring Network (CABIN).

EMS does not identify stations that represent natural background conditions, 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 for any water quality parameter between 2000 and 2023 were selected. 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 cobalt data from the EMS database. The CABIN reference sites, however, are in minimally impacted watersheds across the province; therefore, the CABIN sites were included in the analysis without additional screening.

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 results from each station were given equal weight within an ENV administrative region by calculating the mean cobalt concentrations for each station, although the means don't reflect seasonal variability and are a general measure of concentrations across B.C. 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	24	56
2	0 < % non-detects < 100 AND # detects < 3	Substitute ½ MDL for non-detects and calculate arithmetic mean for all samples	21	95
3	0 < % non-detects < 100 AND # detects ≥ 3	Regression on order statistics	25	511
4	% non-detects = 0	Arithmetic mean	34	73

4.2 Background Concentration Results

The final data set consisted of 104 stations with 735 samples. The distribution of dissolved cobalt concentrations by ENV administrative region and the summary statistics for station mean values are summarized in Figure 4.1 and Table 4.2. The median of station means ranged from 0.009 µg/L (Kootenay) to 0.05 µg/L (Cariboo, Kootenay-Boundary, Thompson-Okanagan). There were no data for dissolved cobalt concentrations at background sites in the Lower Mainland. Of the 104 stations, 30 were on lakes and 74 were on rivers. The median of the distribution of station means was 0.04 and 0.03 µg/L for lakes and rivers respectively (Table 4.2).

Table 4.2. Summary statistics for samples and station mean dissolved cobalt (µg/L) at minimally impacted stations in British Columbia.

Region	Number of Stations	Number of Samples	Date Range	% Samples < MDL	MDL Range Across all Samples	Concentration Range Across all Samples	Distribution of Station Means		
							Median	10th Percentile	90th Percentile
Cariboo	39	227	2000 – 2023	43%	0.005 – 1	0.005 – 1380	0.05	0.0168	0.25
Kootenay-Boundary	8	24	2009 – 2023	100%	0.1 – 0.5	0.1 – 0.5	0.05	0.05	0.25
Lower Mainland	0	0	NA	NA	NA	NA	NA	NA	NA
Northeast	1	5	2012 – 2014	NA	NA	0.007– 0.014	0.01	0.01	0.01
Omineca	2	15	2010 – 2023	6.7 %	0.5 – 0.5	0.002 – 0.5	0.02	0.02	0.02
Skeena	18	77	2001 – 2023	62 %	0.005 – 0.1	0.005 – 1	0.03	0.00	0.08
South Coast	3	10	2003 - 2023	NA	NA	0.009 – 0.063	0.02	0.01	0.03
Thompson-Okanagan	7	293	2000 – 2023	64%	0.1 – 2	0.01 – 65.05	0.05	0.02	2.86
West Coast	26	84	2001 – 2023	33%	0.005- 0.1	0.005 – 0.1	0.01	0.00	0.03

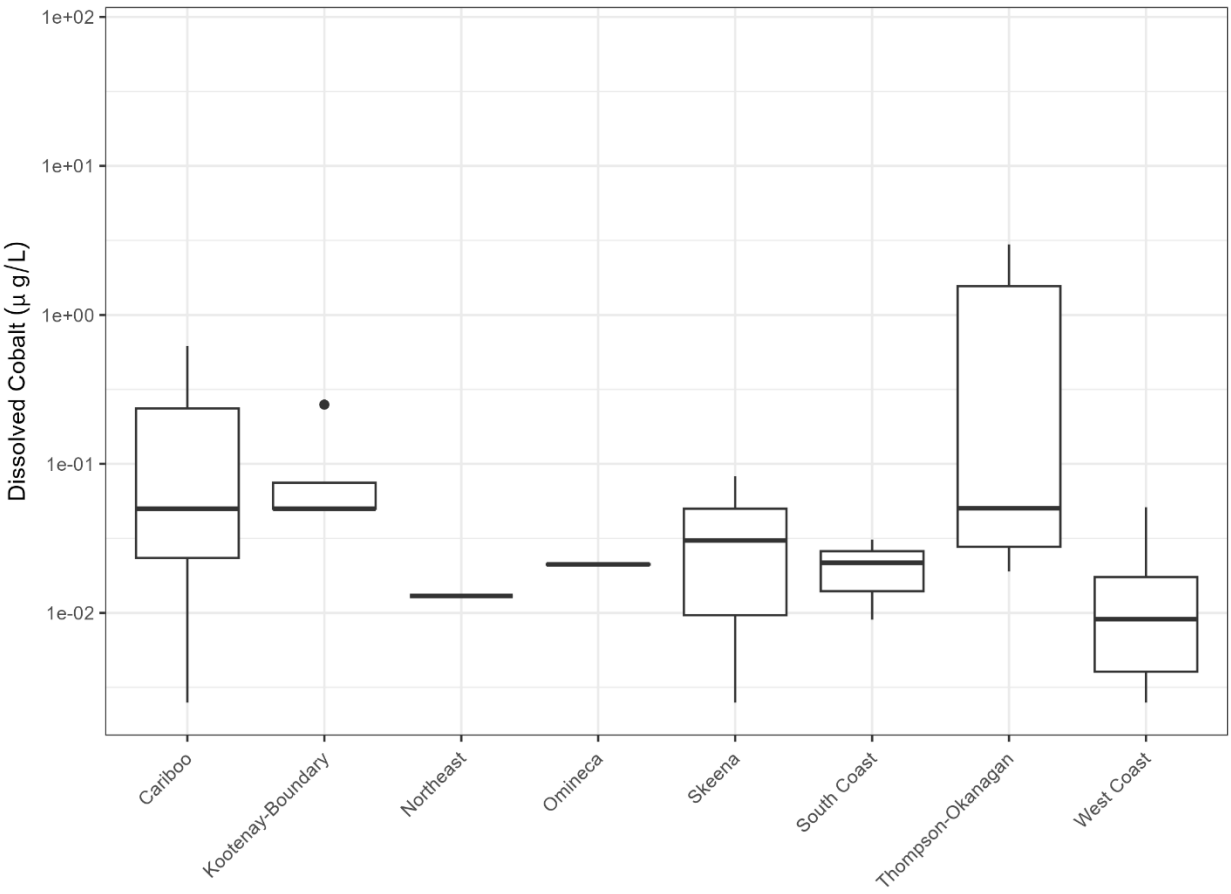

Figure 4.1. Distribution of station mean dissolved cobalt (µg/L) values for regions in British Columbia. Note: There were no data available for dissolved cobalt concentrations at background sites in the Lower Mainland.

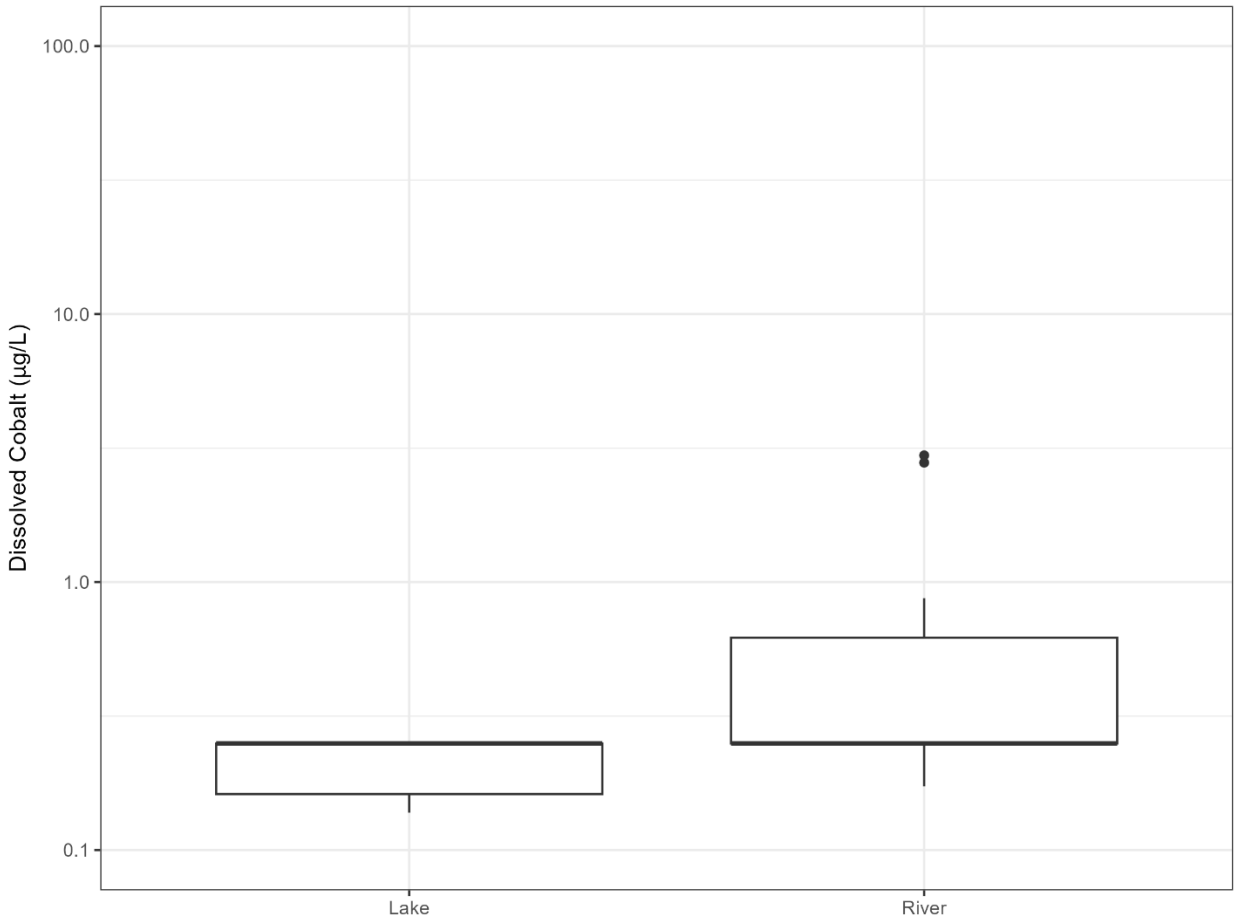

Figure 4.2. Distribution of station dissolved cobalt (µg/L) means for lakes and rivers. Solid horizontal bar and the lower and higher whiskers represent median, 10th and 90th percentile of station means.

5. MODE OF ACTION

As mentioned above, cobalt is an essential micronutrient. Nevertheless, the toxic mode of action of cobalt is not entirely understood. It is known to inhibit various enzymes, causing a reduction in tissue respiration and metabolism (Smith and Carson 1981). For example, cobalt impedes the citric acid cycle and can also inhibit or stimulate different enzymes in the liver, including drug-metabolizing enzymes. In its 2^+ state, the cobalt ion can substitute for other divalent cations, reacting with the thiol group of amino acids, proteins, and other coenzymes and cofactors, resulting in altered enzyme activity (Smith and Carson 1981).

6. CRITERIA FROM JURISDICTIONS

Following a review of available guidelines, cobalt WQGs from the jurisdictions summarized in Table 6.1were identified. Two types of guidelines are used: a static number or hardness-based equations.

6.1 British Columbia

In B.C., the WQG for cobalt was established in 2004 (ENV, 2004) to protect freshwater aquatic life (Table 6.1). The guideline includes a chronic, long-term value of 4 µg/L for total cobalt in water, averaged over a 30-day period. Additionally, an acute WQG of 110 µg/L was set for short-term exposure scenarios.

6.2 Environment and Climate Change Canada

Environment and Climate Change Canada (ECCC) published a chronic WQG for dissolved cobalt in 2017 which uses hardness to derive a chronic FWQG (ECCC, 2017). The equation to derive the FWQG is as follows: $\exp^{\{0.414[\ln(\text{hardness})] - 1.887\}}$.

6.3 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 cobalt is 0.9 µg/L cobalt (OMOEE, 1994). Government of Alberta adopted the 2017 ECCC guideline for cobalt (Government of Alberta, 2018).

6.4 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, b). 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, moderately disturbed ecosystems, and high conservation/ecological value ecosystems, respectively (ANZECC, 2000). For example, to protect 95% of aquatic life, ANZECC (2000) developed a trigger value for total cobalt of 1 µg/L (Table 6.1).

Table 6.1. Summary of WQGs for cobalt (µg/L).

Jurisdiction (Year Published)	Guideline (µg/L)	Fraction
	Chronic long-term	
British Columbia (1987)	4	**Total**
ECCC (2017)	$\exp^{\{0.414[\ln(\text{hardness})] - 1.887\}}$	**Dissolved**
Ontario (1994)	0.9	**Total**
Australia/New Zealand (2000)	1	**Total**
	Acute short-term	
British Columbia (1987)	110	**Total**

7. RECOMMENDED GUIDELINE

7.1 Aquatic Toxicity Data

Cobalt toxicity has been demonstrated in aquatic organisms, sometimes occurring at concentrations observed in contaminated environments. Many empirical data are available in the literature for the short- and long-term aquatic toxicity of cobalt chloride, cobalt sulphate and other soluble cobalt compounds, which after entering water transform to a greater or lesser extent into bioavailable dissolved cobalt species, in particular, the free ion, Co^{2+}. Because the toxicity of metals is often influenced by hardness, pH, ionic strength and dissolved organic carbon (CDI 2009; Canada 2017), toxicity data are standardized for the effects of these factors where possible depending on the assessment needs. In Canada (2017), hardness was identified as the key toxicity modifying factor for cobalt among the various water quality parameters that can influence metal uptake and toxicity. Within the acceptable dataset, one study (Parametrix 2010) evaluated the influence of water hardness on cobalt toxicity to *Ceriodaphnia dubia* and fathead minnow (*Pimephales promelas*). From this study, an equation relating cobalt toxicity to water hardness (ranging from 52 to 396 mg/L) was developed. All acceptable cobalt toxicity data were subsequently corrected to a hardness value of 100 mg/L using this equation as part of the FWQG development process.

Of the studies considered in the SAR, seven studies provided acceptable long-term toxicity data for 13 different species, with hardness-corrected values ranging from 2.2 to 2055 µg/L for various endpoints (Table 7.1). Invertebrates are more sensitive to cobalt than fish, however, the sensitivities do overlap across taxa. *Hyalella azteca* was the most sensitive species, while rainbow trout (*Oncorhynchus mykiss*) was the least sensitive. The most sensitive fish and plant species were zebrafish (Brachydanio=*Danio rerio*) and duckweed (*Lemna minor*), respectively. The least sensitive invertebrate and plant species were the oligochaete *Aeolosoma* and green algae (*Chlamydomonas reinhardtii*), respectively.

7.2 Federal Water Quality Guideline Derivation

The Federal Water Quality Guideline (FWQG) developed here identifies hardness-dependent benchmarks for aquatic ecosystems that are intended to protect all forms of aquatic life for indefinite exposure periods. A species sensitivity distribution (SSD) curve was developed using the long-term toxicity data (normalized to a hardness of 100 mg/L) (Table 7.1), for a total of thirteen species: three fish, six invertebrates and four plant/algae species (Figure 7.1). Each species for which appropriate toxicity data were available was ranked according to sensitivity, and its position on the SSD was determined. Concentrations are expressed in micrograms of cobalt per litre (µg Co/L). Therefore, the FWQG derived from this data applies to total cobalt rather than the compounds tested (e.g., CoCl2).

Following the CCME protocol (CCME 2007), several cumulative distribution functions were fit to the data using regression methods and the best model was selected based on consideration of goodness-of-fit. The Normal model provided the best fit of the models tested upon visual inspection, lowest levels of statistical variability (residuals), even distribution of the residuals, lowest normalized confidence interval spread and best significance of the Anderson-Darling Statistic test (A2) = 0.384 ($p < 0.05$). The 5^{th} percentile (HC_5), i.e., hazardous concentration to 5% of species, of the SSD plot is 1.0 µg/L with lower and upper confidence limits of 0.5 and 2.0 µg/L, respectively.

Because hardness was a significant toxicity modifying factor, the FWQG is expressed as an equation where the site-specific hardness must be entered in order to calculate a site-specific FWQG.

Table 7.1 Long-term toxicity data (normalized to a hardness of 100 mg/L) used for developing the Federal Water Quality Guideline for cobalt.

Species	Group	Endpoint	Concentration (µg/L)	Reference
Amphipod (Hyalella azteca)	●	28-d IC10 (growth)	2.2*	Norwood et al. (2007); Heijerick et al. (2007)
Water flea (Daphnia magna)	●	21-d EC10 (reproduction)	22.6	Heijerick et al. (2007)
Duckweed (Lemna minor)	▲	7-d EC10 (growth)	6.3	Heijerick et al. (2007)
Water flea (Ceriodaphnia dubia)	●	21d EC10 (reproduction)	7.7	Parametrix 2010
Snail (Lymnea stagnalis)	●	28-d EC10 (growth)	8.36	Heijerick et al. (2007)
Green algae (Pseudokirchneriella subcapitata)	▲	4-d EC10 (growth)	31	Heijerick et al. (2007)
Midge (Chironomus tentans)	●	20-d EC10 (survival)	202	Pacific Ecorisk (2005)
Giant duckweed (Spirodela polyrhiza)	▲	4-d EC50 (growth)	257	Gaur et al. (1994)
Oligochaete (Aeolosoma)	●	14-d EC10 (growth)	200	Parametrix 2010
Zebrafish (Brachydanio rerio)	■	16-d EC10 (survival)	348	Dave and Xiu (1991)
Fathead minnow (Pimephales promelas)	■	35-d EC10 (survival)	339	Parametrix 2010
Green algae (Chlamydomonas reinhardtii)	▲	5-d EC30 (growth)	2055	Macfie et al. (1994)
Rainbow trout (Oncorhynchus mykiss)	■	81-d EC10 (biomass)	2049	Parametrix 2010

Legend: ■ = Fish; ● = Invertebrate; ▲ = Plant

*Geomean

Notes: ICx/ ECx = Concentration at which there is inhibition/ effect on X percent of the population

The equation is based on the toxicity-hardness slope value of 0.414 and the 5th percentile value of 1.0 µg/L is derived from the SSD when hardness is 100 mg/L.

Based on the toxicity-hardness slope value and the SSD, the equation to derive FWQG for cobalt is:

$$\text{y-intercept} = \ln(5^{th}\text{ percentile}) - [\text{hardness slope} \times \ln(\text{hardness})]$$

$$= \ln(1.02) - [0.414 \times \ln(100)]$$

$$= -1.887$$

$$\text{FWQG (µg/L)} = e^{\{0.414[\ln(\text{hardness})] - 1.887\}}$$

Since the slope relating hardness to toxicity was based on a study conducted over hardness levels from 52-396 mg/L, the FWQG should not be extrapolated beyond this hardness range. Accordingly, the minimum and maximum FWQG for cobalt at water hardness levels of 52 and 396 mg/L are 0.78 and 1.80 µg/L, respectively.

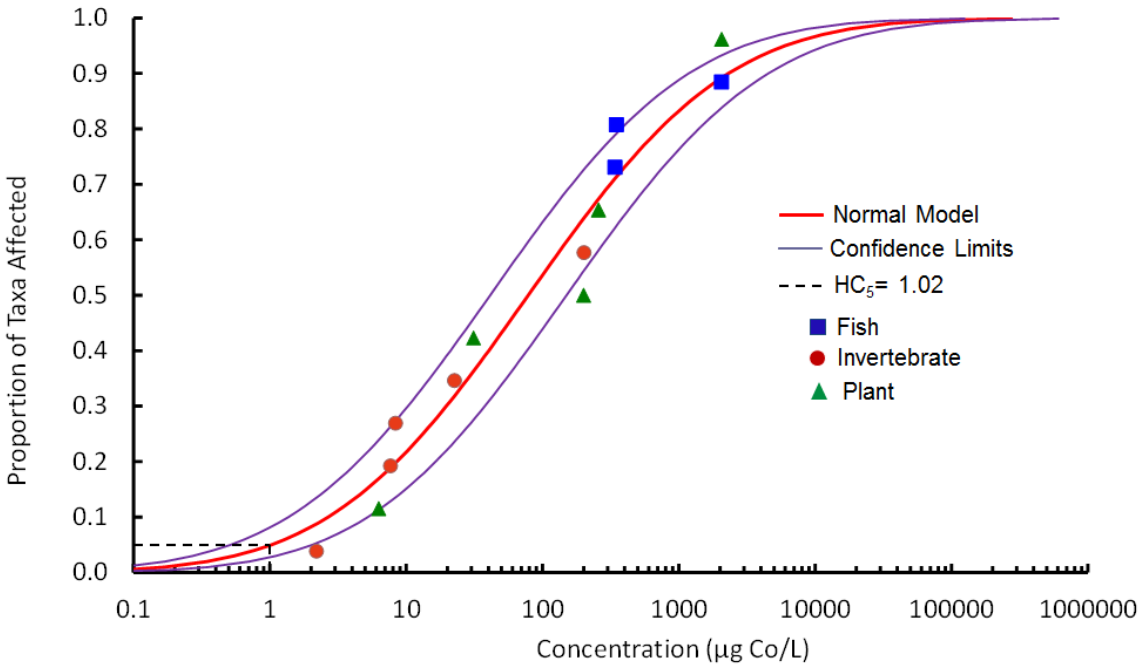

Figure 7.1. Species sensitivity distribution (SSD) for chronic toxicity of cobalt.

7.3 B.C. Chronic Cobalt Water Quality Guideline

The FWQG is based on an SSD and uses hardness as a toxicity modifying factor (ECCC 2017). The chronic toxicity dataset consists of data for 13 species: 3 fish, 5 invertebrates, and 5 plants/algae (ECCC 2017) and fulfills the minimum number of species required for a Type A2 guideline (ENV, 2019). Of the 3 fish species, two are Canadian species (i.e., fathead minnow and rainbow trout [*Oncorhynchus mykiss*]) and one is not Canadian (zebrafish). All plant and invertebrate species are Canadian. The invertebrates are the most sensitive species to cobalt, with *Hyalella azteca*, the most sensitive species on the SSD, followed by *Daphnia magna* (ECCC, 2017).

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, lack of data for sensitive insects (i.e., Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies)) 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 cobalt WQG for dissolved cobalt is calculated using the following equation:

$$\text{Dissolved cobalt WQG (µg/L)} = \frac{e^{\{(0.414[\ln(\text{hardness})] - 1.887\}}}{2}$$

Table 7.2 provides examples of B.C. chronic dissolved cobalt WQGs in various water hardness. The B.C. cobalt WQG equation is valid for hardness concentrations ranging from 52 mg/L to 396 mg/L, as specified by ECCC (2017). Outside this range, the equation may not accurately reflect the relationship between hardness and cobalt toxicity. In such cases, while the lower and upper limits of the equation can be applied, site-specific assessments should be conducted to account for local conditions and ensure a more accurate evaluation of cobalt toxicity.

Table 7.2. British Columbia chronic dissolved cobalt WQGs at various hardness levels (adapted from ECCC, 2017).

Hardness(mg/L)	WQG (µg/L)
52	0.39
100	0.50
150	0.60
200	0.70
250	0.75
300	0.80
350	0.85
396	0.90

8. COMPARISON OF BACKGROUND COBALT 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 background conditions. In general, if background 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 cobalt WQG. To answer this question, total and dissolved cobalt and hardness values were extracted from the EMS and CABIN database and background levels were compared to both the 2004 and 2025 WQGs.

Data from minimally disturbed sites included a total of 1455 records of total cobalt data to compare against the 2004 WQG, and a total of 205 records of both hardness and dissolved cobalt data to calculate the 2025 WQG[1].

[1] Non-detect data were replaced by the method detection limit (MDL), but MDL that were greater than 5 µg/L for cobalt were excluded.

Total cobalt exceeded the 2004 WQGs concentrations 1.7% of the time (25/1455) and exceeded the 2025 WQG 6.3 % of the time (13/205) (Figure 8.1). The higher rate of exceedance of the 2025 WQG compared to the 2004 WQG is mainly because the updated WQG uses a hardness-based equation, which generally provides a lower value compared to the 2004 WQG.

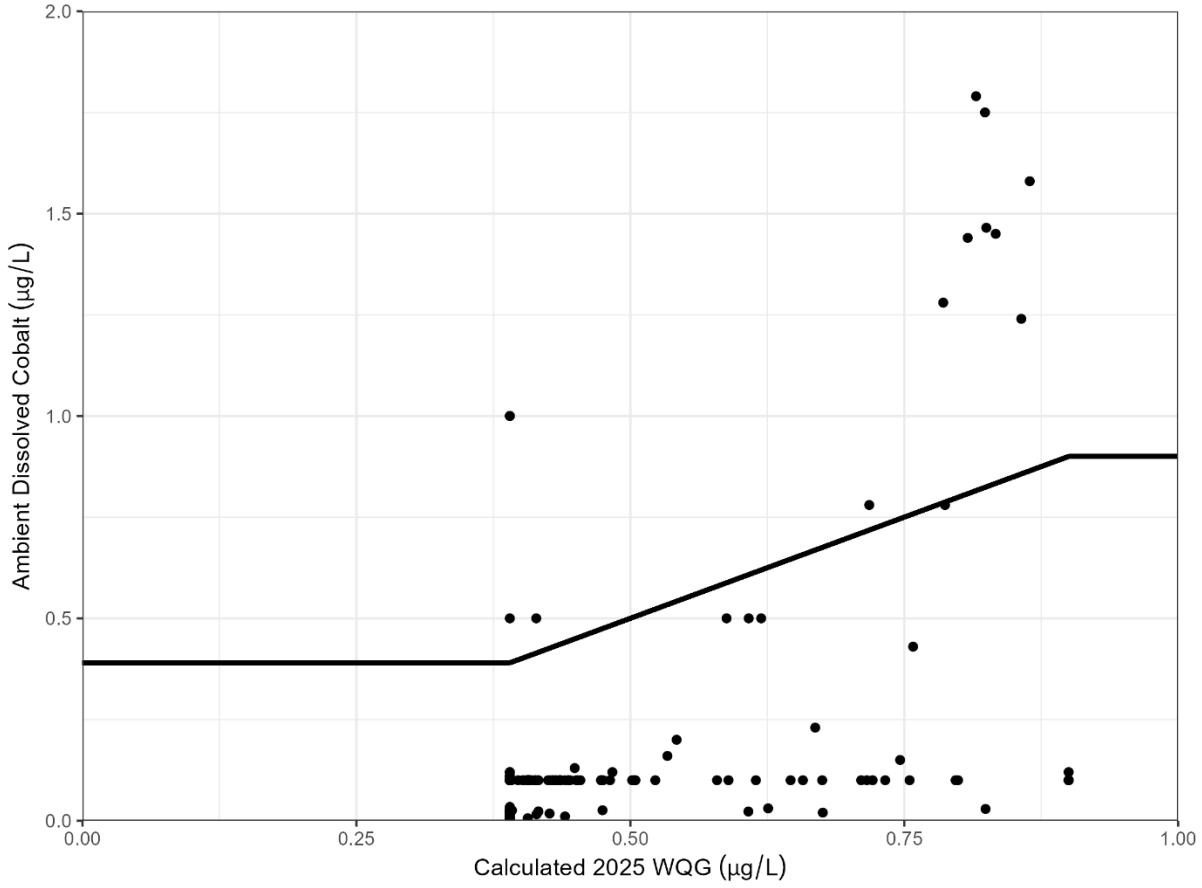

Figure 8.1: Background dissolved cobalt concentrations compared to the 2025 chronic WQGs. Points above the solid black line represent exceedances.

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