WATER QUALITY GUIDELINE SERIES

Iron Water Quality Guideline – Freshwater Aquatic Life

Ministry of Water, Land, and Resource Stewardship
Water Protection and Sustainability Branch

No. WQG-28

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 including 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 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 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 iron (Fe) WQGs for the protection of aquatic life.

Coal mining is a major industry in B.C. and the most common anthropogenic source of iron in surface water. When iron pyrites (FeS_2), which are common in coal seams, are exposed to weather and bacterial action during mining, it can lead to elevated concentrations of iron oxides and hydroxides in surface water which have low solubility and precipitate out of solution. These precipitates have been shown to cause physical effects to aquatic life from smothering, reduced habitat quality, reduced light penetration and constraining food access.

The toxic effects of iron have been observed across all life stages of fish. Iron precipitates can reduce oxygen diffusion to fish eggs, form coatings that limit food accessibility for aquatic invertebrates, and decrease light penetration, thereby inhibiting algal growth. Additionally, iron oxide precipitates can accumulate on fish gills, disrupting respiration.

Given these modes of action, total iron is considered the primary driver of ecological effects, superseding dissolved iron, which was previously used as the basis for the B.C. water quality guideline (WQG). In 2024, Environment and Climate Change Canada (ECCC) published a chronic Federal Water Quality Guideline (FWQG) for total iron to protect freshwater aquatic life. ECCC identified dissolved organic carbon (DOC) and pH as the two primary toxicity-modifying factors for iron and incorporated these parameters into the derivation of the FWQG.

B.C.'s 2008 WQGs for iron consist of fixed acute guidelines for both total and dissolved iron but do not include a chronic guideline. As a result, B.C. has adopted the FWQG as the chronic WQG, with the addition of an assessment factor to account for remaining sources of uncertainty. The existing B.C. acute WQG for total iron will be retained, while the dissolved iron WQG is rescinded.

The aquatic life chronic WQG is calculated using site-specific DOC and pH and therefore, it is presented below as variable (Table E.1). As an example, a waterbody with DOC of 0.5 mg/L and a pH of 7.5 will have a chronic freshwater aquatic life WQG for total iron of 55 µg/L.

Table E.1. Water quality guidelines for total iron (µg/L)

Designated use	**WQGs – Total Fe (µg/L)**	
	Long-term (Chronic)	**Short-term (Acute)**
Freshwater aquatic life	Variable*	1000

* The equation for the B.C. freshwater aquatic life iron WQG, which accounts for DOC and pH, is provided in Section 8.4.

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1. INTRODUCTION

B.C.'s 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 in B.C. WLRS defines a WQG as a scientifically derived numerical concentration or narrative statement considered to be protective of designated values under ambient conditions. WQGs provide a basis for water quality assessments and inform decision-making in the natural resource sector. They 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:

- Differences between laboratory and field 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 that 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 2024, Environment and Climate Change Canada (ECCC) published a chronic federal Water Quality Guideline (FWQG) for total iron (Fe) for the protection of freshwater aquatic life. In this technical document, B.C. adopts the chronic guideline with the addition of an assessment factor (AF) to account for remaining sources of uncertainty. Given that the primary mode of action is smothering by iron precipitates, the B.C. 2008 acute dissolved Fe WQG is rescinded, while the acute total Fe WQG is retained.

This document summarizes ECCC's derivation of the aquatic life guideline (replicated here verbatim, highlighted in grey and identified in the section titles) and provides a discussion of background iron concentrations in B.C. and the selection of the assessment factor.

2. SUBSTANCE IDENTITY

Section 2 is taken verbatim from ECCC, 2024.

Iron (Fe) is a naturally occurring element (CAS Number 7439-89-6) and is the fourth most abundant element by mass in the earth's crust. Iron ores are rocks and minerals from which metallic iron (Fe) can be extracted when heated in the presence of a reducing agent such as coke (NRCan, 2012). The ores are usually rich in iron oxides and carbonates. Iron is a transition metal with a density of 7.87 g/cm^3 and a molecular weight of 55.9 g/mol. Iron occurs in many minerals with the most important being magnetite, hematite, goethite, pyrrhotite, siderite, ilmenite, and pyrite. It is often a major constituent of soils (especially clays) and is found in waterways as a result of natural runoff, erosion of clay-based soils, and other geologic sources. Iron is essential for all forms of life and plays an important role in metabolic processes, but at higher concentrations it can be toxic (Vuori, 1995; Crichton *et al*., 2002). Iron has complex chemistry in surface waters and can exist as ferrous (Fe(II) and ferric (Fe(III) forms. Fe(II) is the dominant form of iron under reducing conditions, whereas Fe(III) is the dominant form under oxidizing conditions. Because Fe(II) is rapidly oxidized to Fe(III) under most conditions, including those under which Fe(II) toxicity tests are conducted and that the oxidized form predominates in most water bodies (UKTAG, 2012), this FWQG is developed for Fe(III). The FWQG applies to total iron, rather than the dissolved fraction, as iron precipitates can cause toxicity through physical effects (Sykora *et al*., 1972) and total iron correlates best with toxicity (CIMM, 2010a,b; 2011; OSU, 2013).

3. USES

Section 3 is taken verbatim from ECCC, 2024.

Canada was the seventh-largest producer of iron ore in the world in 2021 (NRCan, 2023). Iron ore production in Canada is primarily in Quebec, Newfoundland and Labrador, and Nunavut. Between 2012 and 2021, Canadian mine production of iron ore ranged from 32 to 58 million tonnes (Mt) annually (NRCan, 2023). Canada exported 53.8 Mt and imported 8 Mt of iron ore in 2021, compared to 55.1 Mt and 7.1 Mt in 2020, respectively. Approximately 98% of extracted iron ore is used in the production of steel, which is a key component in the majority of manufacturing, transport, and building industries (Bury *et al*., 2012). The remaining 2% is used in various other applications, such as powdered iron for certain types of steel, auto parts and catalysts; radioactive iron for medicine; and iron blue in paints, inks, cosmetics, and plastics (NRCan, 2023). Anthropogenic sources of iron into surface water are often related to mining activities (BCMOE, 2008). In addition, iron pyrites (FeS2), which are common in coal seams, are exposed to weathering and bacterial action during mining, the oxidation of which results in the production of sulphuric acid and release of soluble ferrous (Fe(II)) iron (Smith *et al*., 1973; BCMOE, 2008).

4. FATE, BEHAVIOUR, AND PARTITIONING IN THE ENVIRONMENT

Section 4 is taken verbatim from ECCC, 2024.

Iron can occur in the environment as Fe(II) and Fe(III) oxidation states. The reduced form (i.e., Fe(II)) occurs under low redox conditions (e.g., groundwater, sediment porewater, and acidic streams) and exhibits a relatively high solubility. Under oxic aqueous conditions Fe(II) is rapidly oxidized to Fe(III), which forms oxides and hydroxides that have low solubility (Stumm and Morgan, 1996; Bury *et al.,* 2012). The relative presence of almost insoluble Fe(III) and the bioavailable and bioactive Fe(II) in surface waters are dependent on a wide range of factors including pH, dissolved oxygen, dissolved organic carbon (DOC), humic and other organic acids, exposure to sunlight, and chloride concentrations (BCMOE, 2008). It has been found that Fe(II) has a relatively minor impact on biota compared to iron precipitates of Fe(III) in laboratory studies and that it is difficult to separate the effects of these two forms of iron in field studies (Rousch *et al.,* 1997).

The oxidation rate of Fe(II) in water is faster in well-oxygenated waters at neutral pH (Bury *et al.,* 2012). Under saturated oxygen and alkaline conditions (e.g., pH ≥ 8), the oxidation of iron is rapid and does not change with increasing pH. Under these conditions, the half-life of Fe(II) is on the order of seconds (Bury *et al.*, 2012). In mildly acidic (e.g., pH 6) and oxygen-saturated water, the oxidation rate of Fe(II) at 100 mg/L is approximately two hours at 25°C (Morgan and Lahav, 2007). Thus, over the pH ranges associated with natural waters (i.e., pH 6 to 9), Fe(II) is expected to have a short half-life (seconds to a few hours) when present in oxic conditions.

When iron is released into natural bodies of water in the form of sulphate (FeSO4) or pyrite (FeS2), it oxidizes and forms Fe(OH)3. This iron hydroxide may precipitate out and form a yellow brown slime on bottom sediments (Smith and Sykora, 1976), which decreases light penetration and thus inhibits algal growth, causing an overall decrease in the production of the ecosystem (Maltby *et al*., 1987). Smith and Sykora (1976) reported mortality of trout and salmon eggs coated with Fe particulates. The hydroxide precipitate can also plug the gills of fish and benthic invertebrates, causing death by suffocation (Loeffelman, 1985) and even interfere with the respiration in fish eggs (OME, 1979).

Organic matter may control both the oxidation state and size of Fe species present in waters. Reduction in the ratio of Fe : organic carbon causes reduction in oxidation of Fe (II) and this has a potential for the iron load in natural waters to remain in a reduced form, even in well-oxygenated waters (Gaffney *et al*., 2008). Fe(II) and Fe(III)) differ in their binding affinities to humic and fulvic acids (UKTAG, 2012). Fe(III) binds to fulvic and humic acids in fresh waters and these Fe(III)-dissolved organic matter (DOM) complexes are important for maintaining iron solubility (Tipping *et al*., 2002). The proportion of Fe found in this form is pH- and temperature-dependent, with the Fe(III)-DOM ratio decreasing as pH increases (Lofts *et al*., 2008). When complexed with organic compounds, Fe(III) can be photo-reduced by UV light to the soluble Fe(II) state, which can cause large diurnal fluctuations in the speciation and concentration of iron (BCMOE, 2008).

5. BACKGROUND CONCENTRATIONS OF IRON IN BRITISH COLUMBIA

Section 5 is original text.

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

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

Background (i.e., from non-impacted sites) total iron concentrations vary across B.C. as a function of local geology and hydrology. Therefore, a regional approach was used to estimate background iron concentrations in aquatic environments following methods used in recent WQG derivation documents (e.g., WLRS, 2025). 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 subset 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 2023/01/01) 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 iron 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;
- Samples were excluded where results were missing or reported as 0; and
- Samples with pH less than 5 or greater than 9 were excluded.

Arithmetic means were calculated for laboratory replicates (analytical replicates taken from one field sample) with ½ the MDL substituted for values below detection. All field replicates were included as independent samples. The final data set consisted of 255 stations with 1107 samples.

The results from each station were given equal weight within an ENV administrative region by calculating the mean iron 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 (**Error! Reference source not found.**). 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	113	120
2	0 < % non-detects < 100 AND # detects < 3	Substitute ½ MDL for non-detects and calculate arithmetic mean for all samples	2	6
3	0 < % non-detects < 100 AND # detects ≥ 3	Regression on order statistics	23	382
4	% non-detects = 0	Arithmetic mean	117	599

5.2 Background Concentration Results

The distribution of total iron concentrations by ENV administrative region and the summary statistics for station mean values are summarized in

Figure 5.1 and Table 5.2. Iron concentrations illustrate significant variability across the province with concentrations ranging from 0.5 to 376,000 µg/L observed in the Northeast region. The median of station means ranged from 9.51 µg/L (Kootenay-Boundary) to 160 µg/L (Skeena). Of the 255 stations, 60 were on lakes and 195 were on rivers. The median of the distribution of station means was 30.5 and 71 µg/L for lakes and rivers respectively (Table 5.2). It should be noted that both Northeast and Southcoast regions did not have method detection limits entered in the data from the EMS and CABIN databases.

Table 5.2. Summary statistics for station mean total iron 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	41	345	2000 – 2023	7.8%	5 – 30	1.1 – 130,000	148	5.7	999
Kootenay-Boundary	17	61	2000 – 2023	18%	5 – 10	0.5 – 139	9.51	0.96	30
Northeast	65	76	2008 - 2023	NA	NA	1.3 – 376,000	15.1	1.3	104,000
Omineca	21	129	2000 – 2023	0.8%	0.4	0.4 – 11,300	19.7	1.2	552
Skeena	32	191	2000 – 2023	1.0%	0.5 - 10	0.5 – 54,000	160	33	17,600
South Coast	6	18	2000 - 2023	0%	NA	6.1 – 419	53.1	24	251
Thompson-Okanagan	29	204	2000 – 2023	11%	5 – 50	1.6 – 4,740	65.5	5.9	523
West Coast	44	83	2000 – 2023	1.2%	10	0.5 – 100,000	37.4	6.3	34,000

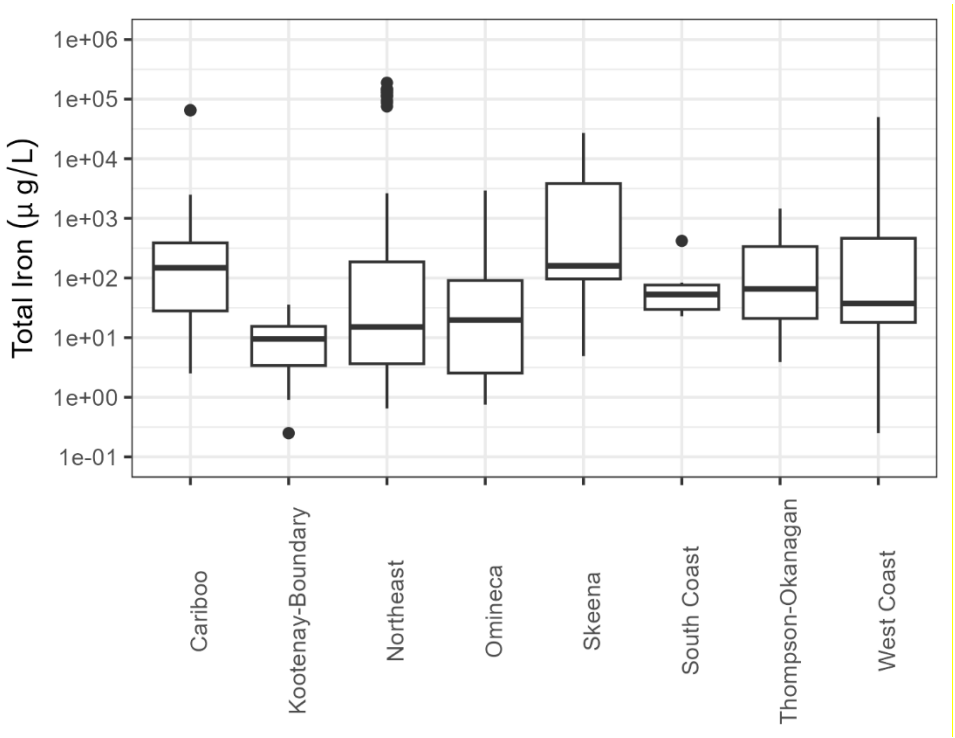

Figure 5.1. Distribution of total iron station mean values for regions in British Columbia.

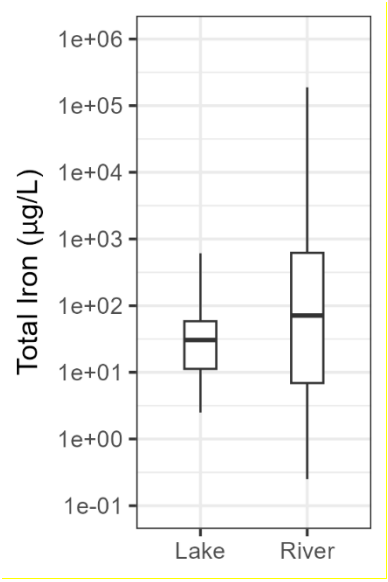

Figure 5.2. Distribution of station means for lakes and rivers for total iron.

Solid horizontal bar and the lower and higher whiskers represent median, 10th and 90th percentile of station means.

6. MODE OF ACTION

Section 6 is taken verbatim from ECCC, 2024.

Dissolved concentrations of metals are typically considered to be most relevant to any evidence of ecological effects. However, this may not be the only cause of toxicity for iron. If the mode of action of iron is not only exerted through chemical toxicity, then other expressions of iron concentrations may be required. Total or particulate iron concentrations usually cause ecological effects via physical effects, such as smothering. Iron can adversely affect macroinvertebrates by reducing habitat quality and structure and by constraining food access (Linton *et al*., 2007). The precipitation of ferric hydroxide onto stream or lake bottoms can reduce light penetration and decrease plant productivity, thus decreasing food sources for the fish (Sykora *et al*., 1972).

Iron toxicity to algal species may be attributed to removal of essential nutrients, for example phosphate (Arbildua *et al.,* 2017). Iron oxide precipitates in well-oxygenated and circum-neutral pH waters that receive acid mine drainage and naturally high iron input can result in smothering of fish gills (Bury *et al*., 2012). In non-acid mine exposure scenarios, toxicity in Atlantic salmon (*Salmo salar*) was associated with increased iron accumulation on the gills, respiratory disruption, interference with gas exchange, fusion of gill lamellae, separation of the outer epithelial layer and/or necrosis of the lamellar epithelium (Peuranen *et al*., 1994; Dalzell and MacFarlane, 1999; Teien *et al*., 2008). Iron was detected only at the gill epithelium, not inside, which indicated that the toxicity was mediated through action on the gill surface (Peuranen *et al*., 1994). High iron concentrations during fertilization have been shown to cause hardening of fish eggs, which may be of particular importance for salmonid spawning in headwaters that may receive high iron concentrations (Bury *et al*., 2012). Finally, iron can contribute to free radical production and oxidative damage (Bury *et al*., 2012).

The precipitation of ferric hydroxide can also affect fish according to their life stage. At low iron concentrations (~1.5 mg/L) the hatchability of fathead minnows (*Pimephales promelas*) was lower than at higher concentrations (Smith *et al*., 1973). Smaller particles have a greater potential to clog the pores of egg chorion and thus cause reduced dissolved oxygen diffusion and increased mortality. However, high concentrations of iron (up to 52.9 mg/L) can reduce visibility in the water and cause impaired food perception to fry and juvenile stages, causing prolonged stress and reduced growth (Smith *et al*., 1973).

7. CRITERIA FROM OTHER JURISDICTIONS

Section 7 is original text.

Iron WQGs from provincial, national and international jurisdictions are summarized in Table 7.1. Two types of guidelines are used: a static number or a pH and DOC based guideline.

7.1 British Columbia

In B.C., the WQG for Fe was established in 2008 (ENV, 2008) to protect freshwater aquatic life (Table 7.1). The guideline includes a short-term maximum guideline for total iron of 1000 µg/L and a short-term maximum guideline for dissolved iron of 350 µg/L.

7.2 Canadian Environmental Quality Guidelines

The Canadian Council of Ministers of the Environment (CCME) develops Canadian Environmental Quality Guidelines (CEQG) for the protection of aquatic life and other values. The CCME aquatic life WQG for long-term exposure to total Fe is 300 µg/L (CCME, 1987).

7.3 Environment and Climate Change Canada

Environment and Climate Change Canada (ECCC) published a chronic WQG for total iron in 2024 which uses DOC and pH to derive a chronic Federal Water Quality Guideline (FWQG) (ECCC, 2024). The FWQG for a range of DOC and pH values can be found using the FWQG look-up table and/or calculator which are valid between DOC 0.3 and 10.9 mg/L and a pH between 6 and 8.5 (ECCC, 2024).

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 chronic PWQO for total iron is 300 µg/L iron (OMOE, 1979). Government of Alberta adopted the 1987 CCME guideline for dissolved iron of 300 µg/L (Government of Alberta, 2018). The chronic surface water quality criteria for the protection of aquatic life in the Province of Quebec is 1.3 mg/L at a hardness of 20 mg $CaCO_3$/L (Government of Quebec, 2026).

7.5 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). However, there was insufficient data to derive a trigger value for iron and in the meantime, the CCME guideline of 300 µg/L is being used as an interim indicative working level (ANZECC, 2000a, b).

7.6 United States Water Quality Criteria

The United States Environmental Protection Agency (US EPA) developed a freshwater chronic (i.e., long-term) national water quality criteria (WQC) for the protection of aquatic life based on total iron (US EPA, 1986). The US EPA WQC for freshwater aquatic life is 1000 µg/L (US EPA, 1986).

Table 7.1. Summary of Iron Freshwater Aquatic Guidelines in Different Jurisdictions

Jurisdiction (Year Published)	Guideline (µg/L)	Fraction
Chronic Guideline		
ECCC (2024)*	Variable	Total
CCME (1987)	300	Total
Ontario (1979)	300	Total
Alberta (1987)	300	Total
Quebec	1300	Total
Australia/New Zealand (2000)	300	Total
US EPA (1986)	1000	Total
Acute Guideline		
British Columbia (2008)	1000	Total
	350	Dissolved

* The ECCC chronic WQG is based on pH and DOC and is available in a published lookup table.

8. RECOMMENDED GUIDELINE

Section 8.1 to 8.3 is taken verbatim from ECCC, 2024.

8.1 Aquatic Toxicity Data

The chronic freshwater toxicity studies for iron were identified and evaluated for data quality following CCME (2007) protocol. Because iron solubility is low and it readily sorbs to surfaces, iron toxicity studies were only considered if total iron concentrations were measured in the toxicity test. Unlike other divalent metals, the total iron fraction correlates best with toxicity (CIMM, 2010a,b; CIMM, 2011; OSU, 2013). This suggests that there are non-dissolved iron species that are bioavailable to the test organisms or that toxicity is exerted by mechanisms beyond just chemical toxicity, for example physical effects. An underlying assumption for the selection of toxicity data was that the iron guidelines developed here would be also protective of physical effects, such as smothering. Acceptable chronic toxicity data for iron were available for 27 species (ECCC, 2024). The acceptable dataset is comprised of endpoints from both laboratory toxicity tests as well as mesocosm tests. The endpoints selected for guideline derivation are further discussed in the section "Federal Water Quality Guideline Derivation" and are presented in Table 8.3.

8.2 Toxicity Modifying Factors

Within the acceptable toxicity dataset, several chronic studies have focused on how varying DOC, pH and hardness concentrations influence the bioavailability, and hence toxicity, of iron. These species include an alga (*Raphidocelis subcapitata,* formerly known as *Pseudokirchneriella subcapitata*), an invertebrate (*Ceriodaphnia dubia*), and a fish (*Pimephales promelas*) (Cardwell *et al.,* 2023). The chronic toxicity data for iron (added as Fe (III)) for these species were used by Brix *et al.,* (2023) to evaluate toxicity modifying factors (TMFs) and develop multiple linear regression (MLR) models for iron. These MLR models were incorporated in the development of the FWQGs for iron to adjust for site-specific water chemistry.

The details on the development of the MLR models for predicting iron toxicity can be found in Brix *et al.,* (2023). Briefly, DOC, water hardness, and pH were examined as TMFs in three aquatic organisms (*R. subcapitata, C. dubia,* and *P. promelas*) representing three taxa. Stepwise MLR analyses were conducted to evaluate whether chronic iron toxicity to these three species could be modelled as a linear function of DOC, hardness, and pH (Brix *et al.,* 2023). The results of the MLR analyses using effect concentrations at the 10% level (i.e., EC10 endpoints) are presented in Table 8.1. In summary, DOC was a significant parameter in MLR models for *R. subcapitata*, *C. dubia,* and *P. promelas*, while pH was significant in *R. subcapitata* and *P. promelas* models, but not in the *C. dubia* model. Hardness was not found to be a statistically significant parameter in the models evaluated for any of the three species. Model evaluation (e.g., adjusted R2, predicted R2, observed versus predicted plots, residual analysis) and model validation (cross-validation to evaluate model performance) for the MLR models are described in Brix *et al.,* (2023). A pooled model was not possible due to differences between species in the MLR models (Brix et al. 2023). Therefore, for the purposes of FWQG derivation, species-specific models were assumed to be representative of the three individual taxa and were applied accordingly for normalization of the iron toxicity dataset (i.e., *R. subcapitata* model applied to algal data*, C. dubia* model applied to invertebrate data and *P. promelas* model applied to fish and amphibian data).

Table 8.1 Summary results of multiple linear regression analysis
(adapted from Brix et al., 2023)

Species	n	Adj. R^2	Pred. R^2	DOC	pH	Hardness	Intercept
R. subcapitata	25	0.87	0.84	0.744	0.332	-	5.435
C. dubia	27	0.74	0.71	0.600	-	-	7.577
P. promelas	18	0.84	0.81	1.102	0.787	-	2.176

Notes: Adj – adjusted; DOC = dissolved organic carbon; Pred. = predicted

8.3 Federal Water Quality Guideline Derivation

The FWQG for iron is for chronic exposure and identifies the waterborne concentration of total iron intended to protect all forms of aquatic life for an indefinite exposure period. Chronic effect concentrations in the acceptable iron toxicity dataset were normalized to consistent DOC and pH values. Species-specific equations using the MLR-derived slopes for *R. subcapitata*, *C. dubia*, and *P. promelas* (Table 8.1) were used to normalize effect concentrations for algae, invertebrates, and fish and amphibians, respectively, and are included below:

***R. subcapitata* equation:**

Normalized EC = EXP(ln(ECmeas)-0.744*(ln(DOCmeas)-ln(DOCtarget))-0.332*(pHmeas -pHtarget))

***C. dubia* equation:**

Normalized EC = EXP(ln(ECmeas)-0.6*(ln(DOCmeas)-ln(DOCtarget)))

***P. promelas* equation:**

Normalized EC = EXP(ln(ECmeas)-1.102*(ln(DOCmeas)-ln(DOCtarget))-0.787*(pHmeas-pHtarget))

Where DOC = dissolved organic carbon; EC= effect concentration; meas = measured variable from original study; target = level to which variable is being normalized.

The selection of datapoints for guideline derivation followed CCME (2007) protocol and involved selecting the most sensitive and preferred endpoint (or geometric mean) for each species. Where there were multiple comparable endpoints available for the same species, effect, life stage and exposure duration, a geometric mean was calculated (ECCC, 2024). A total of 27 species (five fish, 20 invertebrates, one amphibian, and one alga) were available and were used in derivation of the iron FWQG (Table 8.2). The dataset met CCME (2007) minimum data requirements for developing a guideline using a Species Sensitivity Distribution (SSD) (i.e.,Type A guideline)[1]. A Type A guideline is a statistical approach that uses SSDs comprised of primarily "no effect" data to calculate HC_5 values (or hazard concentration of the fifth percentile), which in turn become the final guideline value (CCME, 2007).

[1] CCME (2007) provides two approaches for developing water quality guidelines, depending on the availability and quality of the available data. The preferred approach is to use the statistical distribution of all acceptable data to develop Type A guidelines. The second approach is based on extrapolation from the lowest acceptable toxicity endpoint to develop Type B guidelines. For further detail on the minimum data requirements for CCME guidelines see CCME (2007).

Table 8.2 Chronic freshwater toxicity data used in the Species Sensitivity Distribution (SSD) for deriving the Federal Water Quality Guideline (FWQG) for iron.

The normalized effect concentrations are for water chemistry of pH 7.5 and dissolved organic carbon (DOC) 0.5 mg/L using species-specific multiple linear regression (MLR) models.

Species Scientific Name	Species Common Name	Group	Endpoint	Effect Concentration (µg/L)	Normalized effect concentration (µg/L)	Reference
Tanytarsini	Midge	Invertebrate	10-d EC20 (Abundance)	234	89.1	Cadmus et al. 2018a
Epeorus sp.	Mayfly	Invertebrate	10-d EC20 (Abundance)	335	127.5	Cadmus et al. 2018a
Micrasema sp.	Caddisfly	Invertebrate	10-d EC20 (Abundance)	356	135.5	Cadmus et al. 2018a
Prosopium williamsoni	Mountain whitefish	Fish	78-d EC10 (Biomass)	868	199.3	Cadmus et al. 2018a
Lumbriculus variegatus	Worm	Invertebrate	35-d EC10 (Number of organisms)	470	211.0	Cadmus et al. 2018a
Heterlimnius sp.	Beetle	Invertebrate	10-d EC20 (Abundance)	747	284.4	Cadmus et al. 2018b
Orthocladiinae	Midge	Invertebrate	10-d EC20 (Abundance)	776	295.4	Cadmus et al. 2018a
Cinygmula sp.	Mayfly	Invertebrate	10-d EC20 (Abundance)	930	354.1	Cadmus et al. 2018b
Prostoia sp.	Stonefly	Invertebrate	10-d EC20 (Abundance)	1176	447.7	Cadmus et al. 2018a
Oncorhynchus kisutch	Coho salmon	Fish	60-d EC10 (Survival)	3035	595.8	Smith and Sykora 1976
Taenionema sp.	Stonefly	Invertebrate	10-d EC20 (Abundance)	1626	619.1	Cadmus et al. 2018a
Bufo boreas	Boreal toad tadpole	Amphibian	35-d EC10 (Biomass)	2607	820.2	Cadmus et al. 2018a
Capnia sp.	Stonefly	Invertebrate	10-d EC10 (Abundance)	2200	837.6	Cadmus et al. 2018b
Daphnia pulex	Cladoceran	Invertebrate	21-d EC10 (Reproduction)	852	852.0	Birge et al. 1985
Salmo trutta	Brown trout	Fish	79-d NOEC (Hatch, survival, weight)	≥5146	1181.8	Cadmus et al. 2018a
Ceriodaphnia dubia	Cladoceran	Invertebrate	7-d EC10 (Mean reproduction)	Geometric mean (n=27)	1288.5	Cardwell et al. 2023
Baetis sp.	Mayfly	Invertebrate	10-d EC10 (Abundance)	3905	1486.8	Cadmus et al. 2018b

Species Scientific Name	Species Common Name	Group	Endpoint	Effect Concentration (µg/L)	Normalized effect concentration (µg/L)	Reference
Pimephales promelas	Fathead minnow	Fish	7-d EC10 (Mean biomass)	Geometric mean (n= 18)	1502.4	Cardwell et al. 2023
Raphidocelis subcapitata	Green algae	Plant/Algae	72-h EC10 (Mean growth rate)	Geometric mean (n= 25)	1649.9	Cardwell et al. 2023
Brachycentrus sp.	Caddisfly	Invertebrate	10-d EC10 (Abundance)	5698	2169.4	Cadmus et al. 2018b
Salvelinus fontinalis	Brook trout	Fish	>90-d NOEC (Hatch, survival, growth)	≥12000	2355.7	Smith and Sykora 1976
Daphnia magna	Cladoceran	Invertebrate	21-d EC16 (Reproduction)	4380	2729.1	Biesinger and Christensen 1972
Hexagenia limbata	Mayfly	Invertebrate	30-d NOEC (Survival, weight)	≥7863	3529.5	Cadmus et al. 2018a
Ephemerella sp.	Mayfly	Invertebrate	10-d NOEC (Abundance)	≥14073	5358.0	Cadmus et al. 2018a
Rhithrogena sp.	Mayfly	Invertebrate	10-d NOEC (Abundance)	≥14073	5358.0	Cadmus et al. 2018a
Sweltsa sp.	Stonefly	Invertebrate	10-d NOEC (Abundance)	≥14100	5368.3	Cadmus et al. 2018b
Dugesia dorotocephala	Planarian	Invertebrate	30-d NOEC (Population response)	≥40134	18015.3	Cadmus et al. 2018a

Notes: ECx = Effect Concentration affecting x% of test organisms; NOEC = no observed effect concentration

SSDs were created using R package (R version 4.3.1) 'ssdtools' (ssdtools version 1.0.2 as well as the corresponding "Shiny App" (shinyssdtools version 0.1.1) (Dalgarno, 2018; Thorley and Schwarz, 2018). The package can fit several cumulative distribution functions (CDFs) to the data using maximum likelihood estimation (MLE) as the regression method. The model averaging approach was examined for the iron dataset, however the resulting distribution of HC_5 values across the range of water chemistry combinations did not reflect the general understanding of iron speciation and toxicity. In particular, the trend in HC_5 values with increasing pH was widely inconsistent with individual species models. Consequently, the highest-weighted model across most water chemistry conditions (the log-normal distribution) was used to fit the SSDs.

The SSD and accompanying summary statistics for water of DOC 0.5 mg/L and pH 7.5 are presented in Figure 8.1 and Table 8.3, respectively.

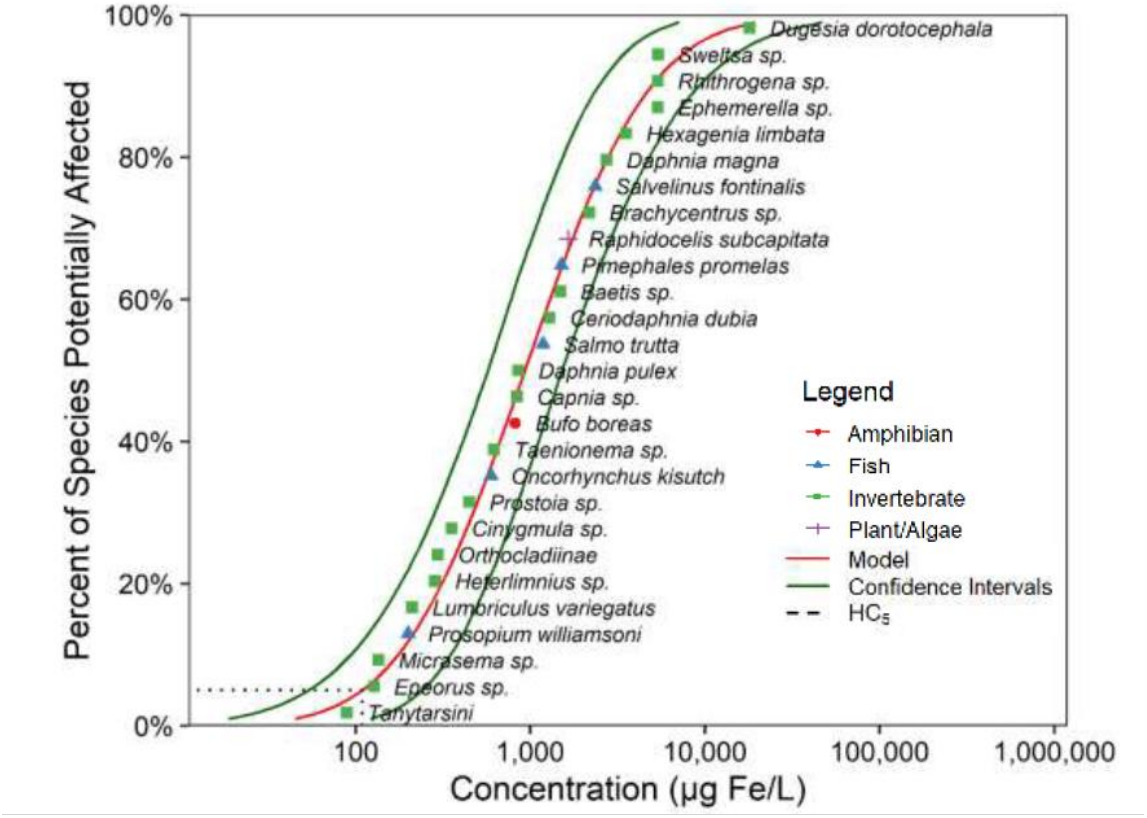

Figure 8.1 Species sensitivity distribution (SSD) for the chronic toxicity of iron at a dissolved organic carbon (DOC) of 0.5 mg/L and pH of 7.5.

The 5th percentile hazard concentration (HC5) is 110 µg Fe/L.

Table 8.3. Federal Water Quality Guideline (FWQG) summary statistics for water with a dissolved organic carbon (DOC) of 0.5 mg/L and pH of 7.5.

Distribution	AICc	Predicted HC_5 (µg/L)	95% LCL (µg/L)	95% UCL (µg/L)
Log-normal	-64.6	110	54.8	247

Notes: AICc= Akaike information criterion corrected for small sample size; HC_5= hazard concentration for 5th percentile; LCL= lower confidence limit; UCL= upper confidence limit

The HC_5 value of the SSD represents the FWQG at that combination of DOC and pH. Over 300 SSDs were run across a range of water chemistry combinations within the model boundaries of the MLR equation, and HC_5 values at these various DOC and pH levels were incorporated into a final guideline lookup table

8.4 B.C. Chronic Iron Water Quality Guideline

Section 8.4 is original text.

The FWQG is based on an SSD and uses pH and DOC as toxicity modifying factors (ECCC 2024). As stated in section 8.3, the chronic toxicity dataset consists of 27 species (five fish, 20 invertebrates, one amphibian, and one alga; ECCC 2024) and fulfills the minimum number of species required for a Type A guideline (ENV, 2019). All 27 species are Canadian. The dataset meets the requirements for a Type A1 guideline, with all endpoints being either NOEC, EC_{10}, or EC_{20} (ENV, 2019).

To account for the sources of uncertainty associated with WQG derivation, an AF must be applied to the calculated HC_5 (ENV, 2019). The minimum AF for a Type A WQG is 2 which accounts for the extrapolation of lab results to field conditions and the cumulative effects of other environmental stressors. Given that this dataset satisfies the requirements for a Type A1 guideline and the sources of uncertainty are minimal, an AF of 2 was applied to the calculated HC_5.

Illustrative examples of the B.C. chronic total iron WQG are presented in the lookup table (Table 8.5). The toxicity data were normalized using three different equations (one for fish, one for invertebrates, and one for algae) and therefore, the relative positions of species on the SSD are dynamic. As a result, the HC_5 varies with each unique water chemistry combination, and a single fixed equation cannot be provided for the chronic WQG. Instead, the lookup table and calculator are required to generate values under specific conditions. For additional parameter combinations not included in the table, users should consult the B.C. chronic long-term WQG calculator in Appendix A.

The B.C. iron WQG is valid for DOC concentrations ranging from 0.3 mg/L to 10.9 mg/L, and pH values of 6.0 and 8.5, which are the range of data used to derive the DOC and pH slopes respectively (ECCC, 2024). Values of pH between 5.5 to <6 or DOC concentrations of 0.1 to < 0.3 were calculated outside the of the model bounds and should be used with caution (Figure 8.5; ECCC, 2024). Consultation with the appropriate regulatory authority is recommended prior to application.

Table 8.5 BC chronic total iron WQGs (µg Fe/L) at various DOC and pH levels (adapted from ECCC, 2024).

DOC (mg/L)	pH 5.5	pH 5.7	pH 5.9	pH 6	pH 6.1	pH 6.3	pH 6.5	pH 6.7	pH 6.9	pH 7.1	pH 7.3	pH 7.5	pH 7.7	pH 7.9	pH 8.1	pH 8.3	pH 8.5
0.1	6.5	7.5	8	8.5	9	10	11	12	13	14	15	16	17	18	19	20	20.5
0.3	18.5	20	22	23	24	25.5	27.5	29.5	32	33.5	35.5	37.5	39	41	42.5	43.5	44.5
0.5	28.5	31.5	34	35.5	36.5	39.5	42	45	47.5	50	55	55	55	60	60	60	60
1	50	55	60	65	65	70	75	75	80	85	85	90	90	95	95	95	95
1.5	75	80	85	85	90	95	100	105	110	110	115	115	120	120	120	120	120
2	95	100	105	110	110	115	125	130	130	135	140	140	145	145	145	145	145
2.5	110	120	125	130	130	140	145	150	155	160	160	165	165	165	165	165	165
3	130	135	145	150	150	160	165	170	175	180	180	185	185	185	185	185	180
3.5	145	155	160	165	170	175	185	190	195	200	200	200	205	205	200	200	200
4	160	170	180	185	185	195	200	205	210	215	220	220	220	220	220	215	215
4.5	175	185	195	200	205	210	220	225	230	230	235	235	235	235	235	230	230
5	190	200	210	215	220	230	235	240	245	250	250	250	250	250	250	245	240
5.5	205	215	225	230	235	245	250	255	260	265	265	265	265	265	260	260	255
6	220	230	240	245	250	260	265	270	275	280	280	280	280	280	275	270	265
6.5	235	245	255	260	265	275	280	285	290	295	295	295	295	290	285	285	280
7	250	260	270	275	280	290	295	300	305	305	310	310	305	305	300	295	290
7.5	260	275	285	290	295	300	310	315	320	320	320	320	320	315	310	305	300
8	275	285	295	300	305	315	320	325	330	335	335	335	330	325	320	315	310
8.5	285	300	310	315	320	330	335	340	345	345	345	345	340	340	335	325	320
9	300	310	325	330	335	340	350	355	355	360	360	355	355	350	345	335	330
9.5	310	325	335	340	345	355	360	365	370	370	370	370	365	360	355	345	340
10	325	335	350	355	360	365	370	375	380	380	380	380	375	370	365	355	350
10.5	335	350	360	365	370	380	385	390	390	395	390	390	385	380	375	365	355
10.9	345	355	370	375	380	385	395	400	400	400	400	400	395	390	380	375	365

Notes (adapted from ECCC, 2024): Guideline values are derived as hazardous concentrations for 5% of species (HC5) from chronic Species Sensitivity Distributions (SSDs) fit with the log-normal model with the addition of an AF of 2. Values highlighted in orange (for pH 5.5 to < 6, or dissolved organic carbon (DOC) 0.1 to <0.3) were calculated outside of the model bounds and should be used with caution. Guidelines highlighted in yellow represent the lowest guideline within the corresponding DOC level. Guidelines highlighted in dark green represent the highest guideline within the corresponding DOC level.

8.5 B.C. Acute Total Iron Water Quality Guideline

Section 8.5 is original text.

The B.C. acute total iron WQG was approved in 2008 (ENV, 2008) and has been retained in addition to the newly adapted chronic iron WQG (Section 8.4). The acute WQG for total iron is 1000 µg/L and was originally published by EIFAC (1964); the same criterion was, with some additional rationale, used again by the National Academy of Sciences (1974) and then again in the EPA Redbook in 1976, and finally the US EPA in 1986 and has not been revised since then. In 2008 a review of the total iron benchmark was made by the B.C. Ministry of Environment. However, a critical assessment of the guideline proved to be

difficult as studies evaluating the influence of toxicity modifying factors were limited and contradictory (ENV 2008). Considering this, it was decided to base the B.C. WQG on the field-based research of Linton *et al.* (2007) which is also discussed above in section 6. Linton *et al.* 2007 derived a benchmark of 1740 µg/L total iron that allowed for slight to moderate changes in aquatic community structure and function (ENV 2008). Their approach used quantile regression to model the decline in maximum abundance of benthic taxa along a gradient of increasing iron concentrations (Linton *et al.* 2007). The B.C. WQG derivation protocol requires the use of LC_{50} endpoints for each species when establishing an acute guideline. Because the Linton et al. (2007) study assessed changes in sensitive species community structure, its endpoint was deemed unacceptable. As a result, the current total acute iron WQG of 1000 µg/L (1 mg/L) was adopted as the most appropriate value and is predicted to protect aquatic organisms against severe effects such as lethality due to short-term and/or transient exposures to total iron.

9. COMPARISON OF AMBIENT IRON CONCENTRATIONS TO WATER QUALITY GUIDELINES

Section 9 is original text.

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 chronic total iron WQG. To answer this question, water quality data (total iron, pH, and DOC) from freshwater sites were extracted from the EMS and CABIN databases and ambient levels were compared to the 2026 WQGs. Total iron exceeded the 2026 chronic WQG 24% of the time (71/295; Figure 9.1). The updated chronic guideline incorporates water quality parameters (DOC and pH) and this generally results in lower values than when guidelines are derived without the consideration of toxicity modifying factors. Both this, and the high variability in ambient concentrations of iron (see Table 4.2) may contribute to some of these exceedances. However, the incorporation of toxicity modifying factors specific to site conditions allows for more accurate protection of aquatic life.

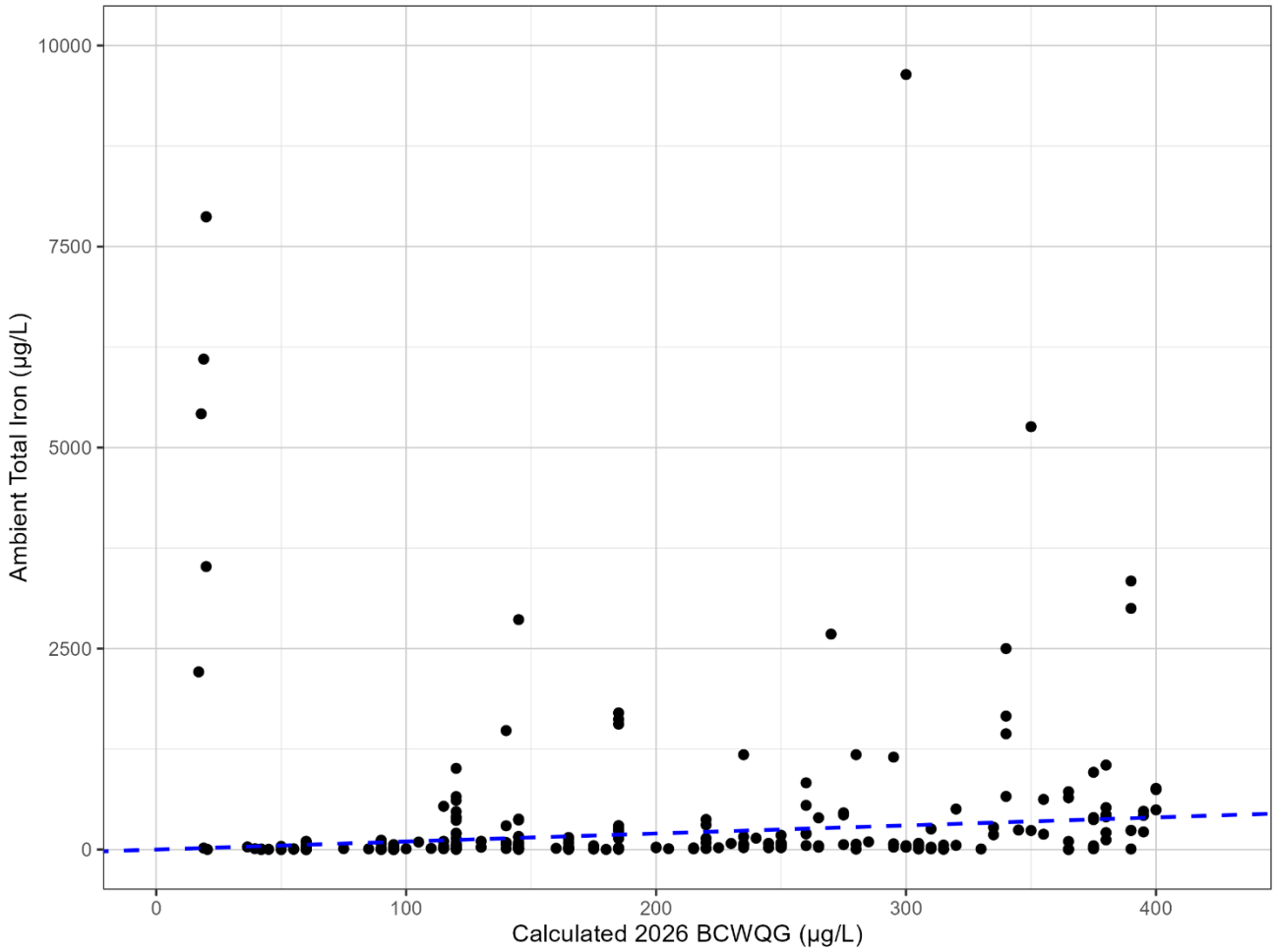

Figure 9.1: Ambient total iron concentrations compared to the 2026 chronic total iron WQGs (blue dashed line).

Points above the blue dashed 1:1 line represent exceedances. Note: Two data points with a concentration of 130,000 µg/L, and one data point with a concentration of 14,700 µg/L were removed from the plot for improved visualization of the data.

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