WATER QUALITY OBJECTIVE SERIES

Water Quality Objectives for the kinosew sîpîy / whutone gah saghé / Murray River

Province of British Columbia, McLeod Lake Indian Band, Saulteau First Nations, and West Moberly First Nations

The **Water Quality Objective Series** is a collection of British Columbia (B.C.) water quality objectives. Water quality objectives are developed for a specific body of water to promote the protection and stewardship of provincially significant water resources. Once approved, water quality objectives constitute formal provincial policy and must be considered in any decision affecting water quality made within the Ministry of Environment and Climate Change Strategy. The policy may also be used by other agencies to inform resource management or land use decisions. For additional information visit: https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/water-quality/water-quality-objectives.

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EXECUTIVE SUMMARY

The kinosew sîpîy / whutone gah saghé / Murray River (KSWGSMR) watershed is located in northeast British Columbia (B.C.) within Treaty 8 Territory. The Ministry of Water, Land, and Resource Stewardship, Ministry of Environment and Climate Change Strategy, McLeod Lake Indian Band, Saulteau First Nations, and West Moberly First Nations (collectively the participating Treaty 8 First Nations) have worked collaboratively to develop water quality objectives (WQOs) for the KSWGSMR watershed. The co-development of these WQOs has strived to incorporate Indigenous knowledge, perspectives, and values in tandem with adherence to established WQO derivation protocols throughout the work. The WQOs and associated policy statements represent a significant contribution towards achieving respect for the spiritual value of water, and the protection and sustainable management of water in the KSWGSMR watershed for future generations.

Water quality objectives were established to protect the most sensitive water values and uses of the KSWGSMR watershed and are summarized in the below table. These objectives provide low-risk science-based benchmarks that support the protection of First Nations cultural values, aquatic life, wildlife, drinking water, agricultural uses, recreational uses, and the intrinsic values of water in the watershed. The WQOs consider background conditions, impacts from current land use, and potential future activities within the watershed. It is important to note that the absence of a specific water quality parameter in the WQOs does not imply its irrelevance to the KSWGSMR watershed; maintaining natural conditions, aquatic ecosystem health and improving trends in all contaminants in all media (water, sediment, and tissue) over time stands as an overarching objective.

Water Quality Objectives for the KSWGSMR Watershed.

Parameter	Upper Mainstem	Upper Mainstem Tributaries	Mining Region Sub-watersheds and Tributaries	Downstream Watershed
Water Quality - Numerical				
Total Aluminum (µg/L)	B.C. WQG Aquatic Life[1]			
Total Beryllium (µg/L)	0.13			
Total Chromium (µg/L)	1.0			
Dissolved Copper (µg/L)	1.0	1.0	B.C. WQG Aquatic Life[1]	1.0
True Colour (TCU)[2]	15	15	30-day average shall not exceed background levels by more than 5 TCU in clear flow conditions* or 20% in coloured systems	15
E. coli (CFU/100mL)[3]	No detectable *E. coli* from anthropogenic sources			
Total Iron (mg/L)	0.3			
Dissolved Iron (mg/L)	0.08	0.08	0.35	0.08

Parameter	Upper Mainstem	Upper Mainstem Tributaries	Mining Region Sub-watersheds and Tributaries	Downstream Watershed
Total Manganese (mg/L)	0.2			
Total Mercury (µg/L)	0.01			
Nitrate (mg/L)	0.2	0.5	3	0.5
Nitrite (mg/L)	0.01	0.01	0.02	0.01
Total Selenium (µg/L)	0.5	1.0	2.0	1.0
Total Silver (µg/L)	0.05	0.05	0.1	0.05
Sulphate (mg/L)	25	100	B.C. WQG Aquatic Life[1]	100
TSS (mg/L)	Increase over background: ≤5 mg/L for long durations (30-d) or 25 mg/L for short durations (24-h) during clear flow periods. ≤10 mg/L at any time when background TSS is 25 to 100 mg/L. Concentrations should not exceed 10% above background at any time when background TSS is >100 mg/L.			
Turbidity (NTU)[4]	Increase over background: ≤2 NTU for long durations (30-d) or ≤8 NTU for short durations (24-h) during clear flow periods. ≤5 NTU at any time when background turbidity is 8 to 50 NTU. Levels should not exceed 10% above background at any time when background turbidity is >50 NTU.			
Total Uranium (µg/L)	0.5	0.5	4.5 8.5 – Mast Creek and Wolverine River	0.5
Dissolved Zinc (µg/L)	5.0	5.0	B.C. WQG Aquatic Life[1]	5.0
Water Quality - Narrative				
Expected Local Visual Appearance	Meet expected conditions or quality based on Indigenous Knowledge.			
Expected Temperature				
Expected Local Taste				
Expected Local Odour				
Fish Tissue				
Mercury	0.14 µg/g dry weight / 0.035 µg/g wet weight[5]			
Selenium	4.2 µg/g dry weight / 1.0 µg/g wet weight[5]			

Notes: WQOs are based on a 30-day average* (5 weekly samples collected in 30 days); [1]toxicity modifying factors referenced in water quality guideline define the upper and lower limits for calculations; [2]TCU = total colour unit; [3]CFU = colony forming units; [4]NTU = nephelometric turbidity unit; [5]assumes 75% moisture content

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ACRONYMS

B.C.	British Columbia
CABIN	Canadian Aquatic Biomonitoring Network
ECCC	Environment and Climate Change Canada
EMA	*Environmental Management Act*
ENV	Ministry of Environment and Climate Change Strategy
KSWGSMR	kinosew sîpîy / whutone gah saghé / Murray River
MLIB	McLeod Lake Indian Band
MRWCEAF	Murray River Watershed Cumulative Effects Assessment Framework
POC	Parameter of Concern
SFN	Saulteau First Nation
SV	Screening value
TCU	True colour unit
TSS	Total suspended solids

UNESCO	United Nations Educational, Scientific and Cultural Organization
WLRS	Ministry of Water, Land, and Resource Stewardship
WMFN	West Moberly First Nation
WQG	Water Quality Guideline
WQO	Water Quality Objective
WSA	*Water Sustainability Act*
WSS	Water Science Series

GLOSSARY OF WATER QUALITY TERMS

Acute toxicity/effect: The adverse effects caused by a short-term exposure to a substance, usually 24 hours or less, resulting in severe health effects or death.

Ambient: The surrounding environment outside the zone where water quality may be directly affected by a waste discharge or other source of contamination.

Anthropogenic: Environmental change caused or influenced by people, either directly or indirectly.

Atmospheric deposition: The deposition of atmospheric pollutants or chemical constituents to land or water ecosystems through precipitation.

Background site: A location which represents natural or minimally impacted conditions within a watershed upstream of significant human activity or pollution.

Benthic: Associated with the sediments on the bottom of a waterbody.

Bioaccumulation: The uptake, retention, and concentration above background levels of environmental substances by an organism from its environment and food.

Biota: All living organisms including bacteria, plants, and animals.

Carcinogen: A substance capable of causing cancer.

Chronic toxicity/effect: Long-term consequences or impacts that result from repeated or prolonged exposure to a substance over an extended period, typically weeks, months, or years.

Colony forming units (CFU): A quantitative measure of the concentration of bacteria in a water sample, resulting from filtering and culturing bacteria from a water sample on laboratory media.

Composite sample: A series of samples taken over space and/or time to determine the average condition of an area or time.

Concentration: The quantitative amount of a solute, chemical or pollutant in a specified volume or weight of water or other medium.

Contaminant: A substance in water that causes harm by contact or association.

Discharge: The release of water which may or may not contain waste into the environment.

Disinfection: The process of destroying microorganisms in water by the application of a disinfectant, usually chlorine or exposure to ultraviolet radiation.

Dissolved metals: The fraction of metals in water which pass through a filter.

Erosion: The wearing of the land surface by wind, water, ice, or other geologic agents.

Euphotic zone: The surface layer of a waterbody which light can penetrate.

Eutrophication: The process of increasing the nutrient content of natural waters, primarily nitrate and phosphate, resulting in an increase of algal productivity and biomass.

Freshet: An annual increase in flow resulting from snow and ice melting.

Groundwater: Naturally occurring water below the surface of the ground.

Habitat: The place or environment where a plant or animal naturally or normally lives and grows.

Hardness (water): The amount of dissolved calcium and magnesium in water.

Headwaters: The source and upper reaches of a stream.

Mainstem: The main course of a river or stream where most of the water flows.

Method detection limit: The lowest concentration of a substance in water that can be reproducibly determined by a specific analytical procedure or test method.

Pathogen: An organism, generally a microorganism, causing, or capable of causing, disease or death.

Pollution: The presence in the environment of substances or contaminants that substantially alter or impair the usefulness of the environment.

Riparian zone: The transition zone between aquatic habitats and dry, upland habitats.

Reference site: A location representing conditions that are considered minimally impacted or undisturbed by human activities or pollution. These sites serve as benchmarks for assessing the health and quality of other water bodies, such as rivers, lakes, or streams, within the same region or watershed.

Sample: A small portion of water or other substance taken at a given place and time for analysis.

Sediment: Undissolved soil particles, sand and minerals in water and the substrate of a waterbody.

Tissue: A group of cells of similar structure and function which perform a specific task in an organism.

Toxicity: The negative impact of a substance on an individual, or a population of, animals, plants, or microbes in the environment.

Toxicological reference value: A measure used in assessing the potential health risks associated with human exposure to toxic substances, such as chemicals or pollutants. It represents an estimate of the level of exposure to a substance that is considered safe over a specific period, typically with respect to a certain population group (e.g., adults, children, sensitive individuals).

Tributary: A smaller stream which joins a larger stream.

Wastewater: Used water from any combination of domestic, industrial, commercial, or agricultural activities, surface water runoff, and stormwater that is not suitable for reuse unless treated.

Water quality: The chemical, physical and biological characteristics of water, usually in respect to its suitability for a particular purpose. Water quality includes the water column, substrate, and biota present.

Water quality guideline: A scientifically derived numerical concentration or narrative statement considered to be protective of water values and designated uses in ambient conditions.

Water quality objective: A scientifically derived numerical concentration or narrative statement considered to be protective of the water values and uses in ambient conditions for a specific waterbody.

Watershed: An area of land that channels rainfall, snowmelt, and runoff into a common body of water.

1. INTRODUCTION

1.1 Overview

This document presents water quality objectives (WQOs) for the kinosew sîpîy / whutone gah saghé / Murray River watershed (KSWGSMR watershed). The overarching goal of these WQOs is the improvement and sustainability of water quality in the KSWGSMR watershed for the benefit of all watershed users. The development of these WQOs was a collaborative effort between the McLeod Lake Indian Band, Saulteau First Nations, West Moberly First Nations, the British Columbia (B.C.) Ministry of Water, Land & Resource Stewardship (WLRS), and the B.C. Ministry of Environment & Climate Change Strategy (ENV). This policy formally establishes low-risk benchmarks that support the protection of water and its uses and values in the KSWGSMR Watershed in a manner which recognizes and incorporates Treaty 8 rights, Indigenous law, Indigenous knowledge and cultural values, and established WQO science protocols.

The KSWGSMR watershed is located along the slopes of the Canadian Rocky Mountains in Northeastern B.C. and is part of the preferred cultural use areas (including hunting, fishing, trapping, gathering, and other cultural practices) for McLeod Lake Indian Band, Saulteau First Nations, and West Moberly First Nations. The watershed encompasses the Tumbler Ridge UNESCO Global Geopark and two Class A Provincial Parks (Monkman and Gwillim); it is frequented by many recreational users and hosts a diverse community of aquatic life. The watershed is the drinking water source for First Nations members when exercising their way-of-life within the watershed, the District of Tumbler Ridge (the largest community in the watershed) and other smaller communities, individual homes, and industrial properties. The central portion of the KSWGSMR watershed is within the coal-bearing Rocky Mountain Foothills physiographic region and coal mining is the primary industry in the area. Other industries include conventional and unconventional oil and gas exploration (including shale gas), forestry, agriculture, wind power, and linear developments such as pipelines.

1.2 Water Quality Objectives

In B.C., WQOs are approved waterbody-specific policy statements that define low-risk benchmarks to inform environmental impact assessments, formalize goals for the protection or enhancement of water quality, and promote water sustainability and stewardship (ENV, 2021a). They inform the management of water quality (e.g., decisions under the *Environmental Management Act*) and guide other processes, such as land use decisions and the establishment of water objectives under the *Water Sustainability Act*.

Water quality objectives are derived from the best available information, sound scientific methods and processes, Indigenous Knowledge, and current technical protocols. They consider the characteristics of the waterbody, including:

- cultural values of Indigenous Nations;
- social and cultural values of local communities;
- ambient water quality;
- aquatic life, wildlife, and related habitat;
- hydrology;
- sediments; and
- risks to water quality from land use activities.

Water quality objectives are established for the most sensitive value or use identified and, in doing so, protect all other water values and uses associated with the waterbody. Water quality objectives define safe levels for the identified water quality parameters of concern (POC); the attainment of WQOs indicates the water values and uses are at a low risk of adverse effects to all values and uses with respect to a given contaminant. It is important to note that the absence of a specific water quality parameter in the WQOs does not imply its irrelevance to the KSWGSMR watershed; maintaining natural conditions, aquatic ecosystem health, and improving trends in all contaminants in all media (water, sediment, and tissue) over time stands as an overarching objective.

1.3 Collaborative Governance

The development of the KSWGSMR watershed WQOs aligns with B.C.'s *Declaration on the Rights of Indigenous People Act* (*Declaration Act*, 2019) which sets out a process to align B.C.'s laws and policies with the United Nations *Declaration on the Rights of the Indigenous Peoples* (UNDRIP, 2007). Broadly speaking, the collaborative process for development of the KSWGSMR watershed WQOs has supported the Articles of UNDRIP, including Article 18 (UNDRIP, 2021), by developing a process that respects the requirement for obtaining free, prior, and informed consent of affected First Nations communities.

The collaborative development of WQOs in B.C. is an emerging practice and involves significant effort by both western and Indigenous participants to share, understand, respect, incorporate, and reconcile worldviews and values. This collaboration requires each party to consider the knowledge, values, goals, and perspectives of other collaborating parties.

To support this collaboration, the participating Treaty 8 First Nations produced the document *kinosew sîpîy / Murray River Watershed Vision and Values (*Prince et al., 2020*)* which describes and explains the unique values Indigenous peoples hold for the waters within their territory, including the kinosew sîpîy / whutone gah saghé / Murray River. This document specifically identifies the need to "braid" (i.e., to respect distinctly and incorporate together) Indigenous ways of knowing alongside western science as a key aspect to successful, collaborative outcomes.

2. INDIGENOUS WATER VALUES AND CULTURE

In 2019, the participating Treaty 8 First Nations embarked on a process of describing Indigenous water values in the kinosew sîpîy / whutone gah saghé / Murray River watershed. These water values are closely linked to Treaty 8 and the rights protected therein. As detailed in the *kinosew sîpîy / Murray River Watershed Vision and Values (*Prince et al., 2020*),* access to safe, trusted water is central to maintaining Indigenous culture and way of life.

Impacts on the Indigenous way of life in general, and water specifically, by resource development, community development, recreation, and other aspects of western society are numerous. Establishing WQOs represents an opportunity for B.C. and the participating Treaty 8 First Nations to establish low-risk water quality benchmarks that help protect the water needed for Treaty 8 First Nations to meaningfully exercise their way of life, now and into the future.

The western concept of water quality was expanded to fulfill the commitment to include Indigenous values and rights in the development of WQOs. "Quality" is a multi-layered, relational, spiritual, and cultural attribute for Indigenous peoples. For instance, the participating Treaty 8 First Nations have asked "can we drink the water?", "can we eat the fish?", and "can we experience peaceful enjoyment of our way of life?".

While these questions may appear straightforward from a western perspective there are complex layers of spiritual values, relationships and kinship between water and Elders, and links to historical water quality that are not obvious to western practitioners. First Nations ask specific questions such as:

- Can we dip our cup in the waters that *kayas* / khutl'ench'e / (used to be safe[1]) and drink?
- Can we respectfully make tea for our Elders from these waters?

These questions are not answered simply by understanding the water chemistry and bio-physical properties of the water itself (properties that are often protected through numerical WQOs). Numerical WQOs represent a narrow but important aspect of the water quality and its environs that the participating Treaty 8 First Nations consider when answering fundamental questions about the ability to meaningfully exercise Treaty rights. Quality in relation to "healthy" water from an Indigenous perspective is more complex and encompasses personal, relational, spiritual, and cultural aspects including: the complex interplay of values and indicators, Indigenous laws, and cultural protocols related to the water, personal perspectives of clean water, and trusted water sources.

Two foundational aspects of WQO development required consideration of western science alongside and interconnected with Indigenous Knowledge:

- the identification of water uses and values to protect, and
- parameters to measure water quality, including Indigenous Knowledge based narrative indicators.

2.1 Sacred Nature of Water

Indigenous communities around the world have identified water as a sacred and central part of Indigenous life, their worldview, and their values. Indigenous peoples have called for water to be protected with personhood. To fully protect water, the sacred nature of water and the living relationships Indigenous peoples have with water must be included.

McLeod Lake Indian Band, Saulteau First Nations, and West Moberly First Nations have clearly expressed that water and water governance are central to cultural, spiritual, and socioeconomic wellness in First Nation individuals and communities. Water has been described as

> *a powerful medicine and sacred resource, as the lifeblood of the land, and as a relative that must be respected and cared for, echoed by Indigenous communities and organizations, and scholars. Not only is water itself critically important, so too is its governance*… (Harris and Simms, 2016).

In an Indigenous world, "Water is alive, Water has a spirit, Water holds memories" (Prince et al., 2020). And given that Indigenous peoples have a relationship with water, Indigenous peoples manage their relationships with water rather than managing the water itself. This relationship is guided by Indigenous laws (wâhkôhtowin, in Cree).

A full description of the worldview and water values which guided the participating First Nations' collaboration on these WQOs is provided in Prince et al. (2020).

2.2 First Nations Water Vision and Values

In Prince et al. (2020), the participating Treaty 8 First Nations created a vision statement for Water and the kinosew sîpîy / whutone gah saghé / Murray River watershed:

[1] kayas / khutl'ench'e emphasizes those waters that "used to be" safe prior to anthropogenic interference. Not all waters are considered safe to drink, even without anthropogenic influences (e.g., beaver ponds).

In our worldview, water is a sacred and life-giving being. Our peoples agreed to share use of these waters with others provided that in their use, they protect and respect the water, those beings that rely upon the water, and our sacred relationships with these things which we call all our relations. Our vision includes non-Indigenous people living and working in the watershed being aware of and respecting the sacred and central value of water in cultural practice and identity to Treaty 8 First Nations. Our vision is that the kinosew sîpîy / Murray River watershed is thriving and resilient because we share codes of conduct which reflect Indigenous laws. The watershed is tse' choo, which means at peace and healthy, and supports Mino Pimâtisiwin (a healthy Indigenous way of life). The kinosew sîpîy / Murray River Waterscape and Landscape supports the unobstructed, peaceful enjoyment and exercise of Treaty rights. Treaty rights are supported by water that is respected, trusted, drinkable, common water for social purposes, and water that provides a sustainable and consumable fish and hunting harvest for generations to come.

The vision statement above guided the identification of specific First Nation values and uses of water in the kinosew sîpîy / whutone gah saghé / Murray River watershed. The valued aspects of water, including the relationship with water, in kinosew sîpîy / whutone gah saghé / Murray River identified include:

1. **Water is respected:** respecting the sacred nature of water as a relation, water is home to living spirits, water has an energy, and that water holds stories, water holds memories, water is life giving.
2. **Thriving water and watershed** including positive growth and improvement or recovery in some cases.
3. **Resilient water and watershed** (clean, safe, healthy water that remains healthy through various changes, impacts and cumulative effects). As the Murray River has done in the past, the ability and room to overcome challenges.
4. **Shared codes of conduct** are developed and applied which reflect Indigenous laws; respecting spiritual areas and spiritual waters, how these areas are used or not used, avoiding creating unnatural conditions or additions, ("polluting" the earth is like polluting ourselves), recognizing our dependence on water and not being domineering / controlling, acting as caretakers.
5. **Water and the watershed is at peace and healthy**.
6. **Water and the watershed supports mino pimâtisiwin[2]** / ke'maah / and tse' choo (a healthy Indigenous way of life, the good life, and the water that supports this way of life); unobstructed, peaceful enjoyment and the meaningful exercise of Treaty rights.
7. **Trusted, healthy water for spiritual or ceremonial purposes**.
8. **Trusted, drinkable water** (based on community knowledge / community member use and trust).
9. **Trusted, safe common water** (immersing & physical contact, washing fish and berries, bathing, play).
10. **Trusted, healthy water that supports the Treaty right to fish, and consume fish that are safe to eat,** for subsistence, health and cultural needs.
11. **Trusted water that supports the Treaty right to hunt, and consume wildlife that is safe to eat,** for subsistence and cultural needs and provides a hunting harvest for generations to come.

[2] *Pimâtisiwin* in Cree, *Ke'maah* in the Dene language of the Dunne Za, and *Tse' choo specifically for water* in Tse'Khene

12. **Trusted source of "clean" plants and medicines** that supports the Treaty right to harvest (includes water bodies and riparian areas).
13. **Sustaining healthy ecosystems** including animals, plants, and fish (not necessarily for harvest).
14. **Reconciliation:** Non-Indigenous people living and working in the watershed being aware of and respecting the sacred and central value of water in cultural practices and identity of Treaty 8 First Nations.

While some of the values described in this policy document and in Prince et al. (2020) may not align directly with the typical approach to WQOs, they do comprise the key, core values these First Nations hold for water in the kinosew sîpîy / whutone gah saghé / Murray River.

3. WATERSHED DESCRIPTION

3.1 Physical Description

The Murray River is approximately 613 km long, originating at Upper Blue Lake, and flows north into the Pine River. The KSWGSMR watershed has 22 sub-watersheds in addition to the Murray River and drains an area of approximately 6,745 km^2 (Figure 1). The Murray and Pine rivers are a part of the greater Peace River Basin which drains into the Mackenzie River Basin, and ultimately into the Beaufort Sea in the Northwest Territories. Most of the KSWGSMR watershed is below an elevation of 1,900 m, however, a large elevational change is observed between the headwaters, at approximately 2,500 m, and the confluence with the Pine River at approximately 650 m.[3]

There are four biogeoclimatic zones in the KSWGSMR watershed including Boreal White and Black Spruce, Englemann Spruce-Subalpine Fir, Sub-Boreal Spruce, and Boreal Altai Fescue Alpine. The terrain has a rolling topography comprised of both upland forests and muskeg. Coniferous forests dominate the landscape with smaller areas (in descending order) of mixed forest and vegetation, deciduous forests, shrubs, and grasslands. The climate is characterized by long, extremely cold winters and short, moderately warm summers with extended days. The general precipitation pattern of the watershed is snow between October and March and rain between June and August.

The hydrology of the streams in the KSWGSMR watershed are influenced by seasonal precipitation and temperature patterns. Streamflow tends to peak between June and July because of warming temperatures and spring snowmelt while low streamflow occurs in the winter and early spring from January to March. The tributaries flows follow the same seasonal pattern although many are ephemeral and have almost no flow from November to March.

3.1 Watershed Uses and Risks to Water Quality

The KSWGSMR watershed is a preferred cultural use area (for hunting, fishing, trapping, gathering and other cultural uses) for McLeod Lake Indian Band, Saulteau First Nations, and West Moberly First Nations peoples. The First Nations identify the watershed, particularly the undisturbed headwaters and tributaries, as important places for the peaceful enjoyment of Treaty rights.

There is a large zone in the central portion of the KSWGSMR watershed which hosts several active, inactive (i.e., in care and maintenance or closed), and proposed future coal mining developments (Figure 2). Most

[3] For a more detailed, science-based, description on the characteristics of the KSWGSMR Watershed and influences on water quality refer to the Azimuth (2020) technical assessment report titled: Murray River Watershed - Science-Based Inputs and Recommendations Towards Water Quality Objectives.

Environmental Management Act (EMA) waste discharge authorizations in the KSWGSMR watershed are mine-related; specific concerns are related to elevated levels of selenium, sulfate, and nitrate in the mainstem Murray River, Wolverine and Flatbed sub-watersheds.

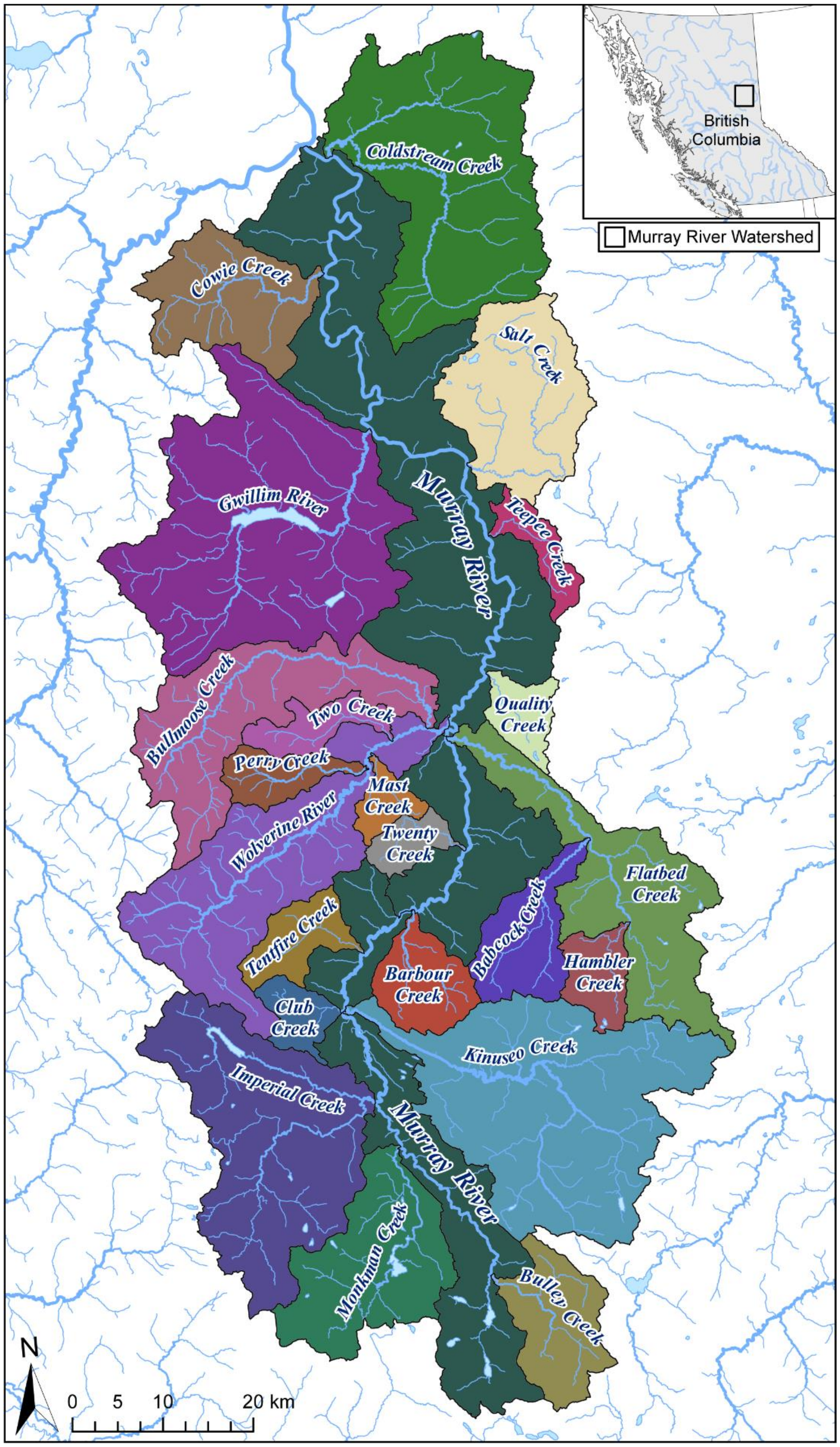

Figure 1: Overview map of the KSWGSMR watershed.

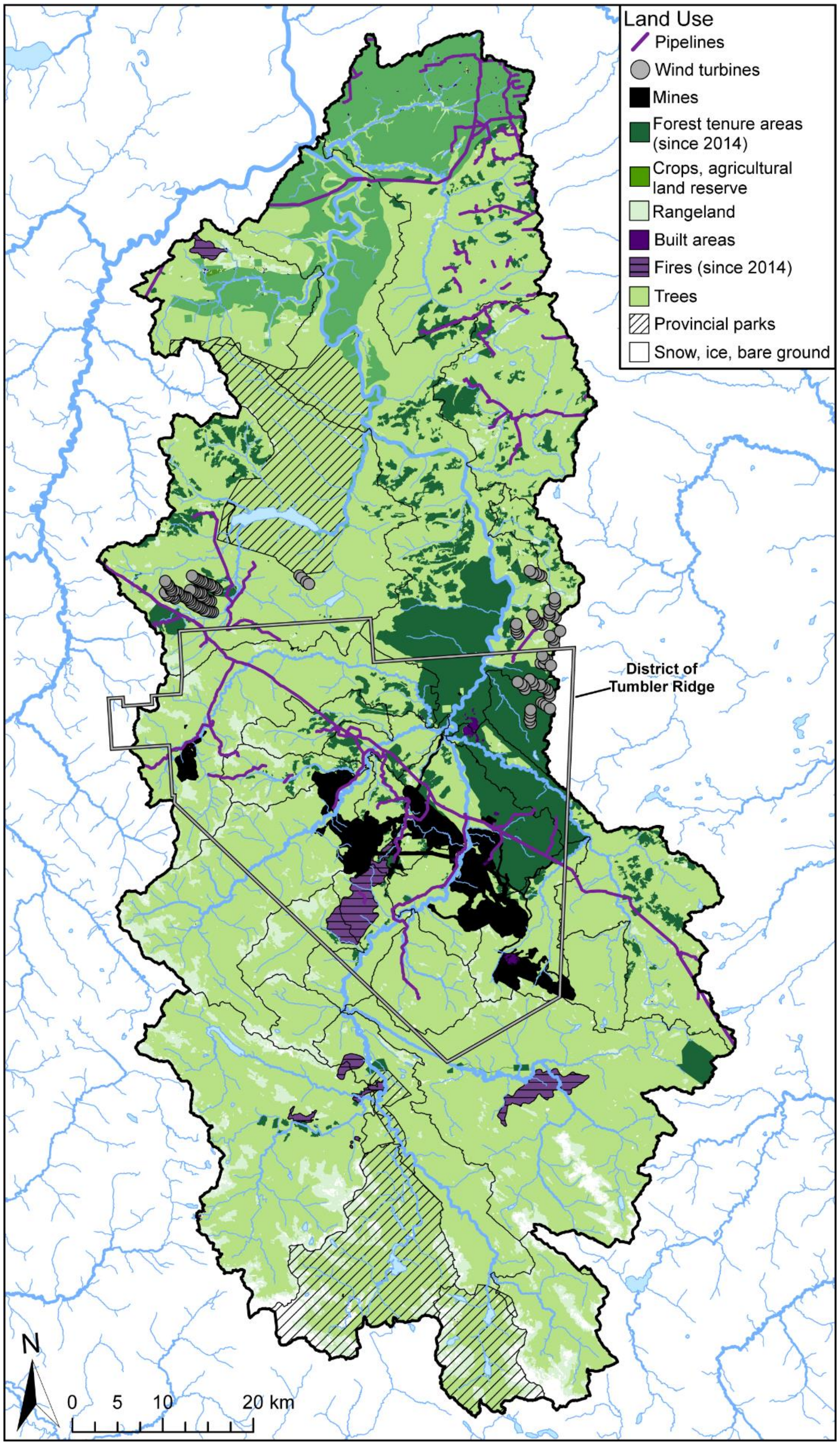

Figure 2: Land uses in the KSWGSMR watershed.

Sewage discharges, stormwater runoff, and septic systems have the potential to influence water quality from increases in total suspended solids (TSS), nutrients (e.g., nitrogen and phosphorus compounds), and microbiological indicators (e.g., *Escherichia coli*). The District of Tumbler Ridge operates a sewage treatment plant and storm sewer system that services about 2,000 people. Tumbler Ridge is authorized to discharge wastewater into the Murray River via a treatment lagoon below the confluence with the Flatbed River whereas stormwater is discharged directly into the mainstem. Other sources of nutrients may include industrial operations, forest harvesting, rangeland, agricultural operations, and rural properties and communities.

Oil and gas exploration and extraction, which can include seismic lines, well sites, processing facilities, and pipelines, also occurs in the KSWGSMR watershed (Figure 2). Most of the oil and gas activity is in the north/northeastern portion of the watershed with some gas fields in the southern region and oil fields in the northeastern portion of the Coldstream sub-watershed. Potential water quality concerns can arise from the allocation of water, increased surface flows and total suspended solids from land clearing and disturbance, and spills associated with flowback and produced water.

Other anthropogenic activities in the KSWGSMR watershed include forestry, agriculture, and windfarms (Figure 2). Forestry is concentrated to the east and south of Tumbler Ridge extending to the top of Monkman Provincial Park. There is approximately 154 km^2 of cropland with some Agricultural Land Reserve designated in the northern portion of the watershed. B.C.'s largest windfarm is in the Tumbler Ridge Area and there are wind power tenures and test towers located in the northeast and southwest of the KSWGSMR watershed, with potential for further development.

Climate change is a rising concern and has the potential to influence water quality in the KSWGSMR watershed. Climate models predict increased temperatures and mean annual precipitation. It is anticipated that more precipitation will fall as rain instead of snow, which has the potential to affect peak flows, sediment loads, channel stability, reduce summer low flows, and increase the duration of low flow periods.

4. WATER VALUES IN THE WATERSHED

4.1 Water Values and Uses

The selection of water values and uses was based on the First Nations view of the spiritual and cultural value of water as overarching and all-encompassing with the western view of water values and uses. The water values and uses are described in the following sections and include:

- Indigenous cultural values and uses;
- Aquatic life and its habitat;
- Wildlife and its habitat;
- Drinking water sources;
- Agriculture (livestock watering and irrigation);
- Recreational use and aesthetics; and
- Other social and cultural values and uses.

4.1.1 First Nations Water Values and Uses

The following First Nation water values from Section 2.0 were deemed appropriate to be included in the development of WQOs because: 1) there are water quality guidelines (WQGs) that align with the water value; or 2) a narrative or local component for the water value was developed. It must be recognized that WQOs may protect only part of the water value expressed by the First Nations. For instance, trusted, safe, common water also has an aspect of peaceful enjoyment of the water, which cannot be measured by testing the water column. The values that have been included in this policy are:

- trusted, safe, common water;
- trusted drinkable, water throughout the watershed;
- trusted water for ceremonial purposes;
- trusted water that provides a sustainable, consumable, fish harvest;
- trusted water that supports a sustainable, consumable, hunting harvest for generations to come;
- trusted source of "clean" plants and medicines (water bodies/riparian areas); and
- sustainable and healthy ecosystem including wetlands, animals, plants, and fish (not necessarily for harvest).

4.1.2 Aquatic Life

Native fish species present in the KSWGSMR watershed include the blue-listed Bull Trout (*Salvelinus confluentus*), Arctic Grayling (*Thymallus arcticus*), Mountain Whitefish (*Prosopium williamsoni*), Burbot (*Lota lota*), Northern Pike (*Esox lucius*), Slimy Sculpin (*Cottus cognatus*), Finescale Dace (*Chrosomus neogaeus*), Lake Chub *(Couesius plumbeus*), Longnose Dace (*Rhinichthys cataractae*), and Longnose Sucker (*Catostomus catostomus*). Non-native species include Brook Trout (*S. fontinalis*), Rainbow Trout (*Oncorhynchus mykiss*), and Westslope Cutthroat Trout (*O. clarkii lewisi*). Fish distribution throughout the KSWGSMR watershed is influenced by natural fish barriers such as waterfalls and beaver dams. The Murray River mainstem has the most diverse fish community with less species observed in the various sub-watersheds. The most widely distributed species are Bull Trout, Mountain Whitefish, and Slimy Sculpin.

4.1.3 Wildlife

The KSWGSMR watershed is home to a variety of wildlife including large mammals (e.g., moose, elk, deer, caribou, mountain goats, bears, wolves), small mammals (hares, martens, marmots), and birds (e.g., waterfowl, shorebirds, raptors). The waters of the KSWGSMR watershed provide wildlife with habitat, drinking water, and aquatic life for consumption. For example, wetland environments provide early season forage for bears, mid-summer forage for moose, and breeding habitat for waterfowl and amphibians such as the provincially blue-listed western toad (*Anaxyrus boreas*). Overall, a healthy and resilient aquatic ecosystem is an important value for the protection of wildlife.

4.1.4 Drinking Water

The KSWGSMR watershed is the drinking water source for Indigenous members when exercising their way-of-life within the watershed, the District of Tumbler Ridge, other smaller communities, and industrial properties. Clean and safe water for drinking, cultural, and ceremonial purposes is an important value to protect throughout the KSWGSMR watershed.

4.1.5 Agriculture

The KSWGSMR watershed is within the Peace River Regional District where 11% of the land is classified as Agricultural Land Reserve (Don Cameron Associates, 2014). Most of the agricultural land is in the rural areas outside of the main population centers and, specific to the KSWGSMR watershed, is concentrated in the northern portion. The growing season benefits from the warm microclimate and long daylight hours with the primary crops being forage for cattle and horses, grains (barley, oats, wheat), and vegetables. There are numerous cattle ranches and some game production, mainly bison.

4.1.6 Recreational Use and Aesthetic Value

The KSWGSMR watershed is an important Northern tourism and recreation asset because of its diverse landscape that provides many opportunities for outdoor recreation. It includes two Class A Provincial Parks (Gwillim and Monkman Provincial Parks) and the only UNESCO Global Geopark in western Canada. In addition to the unique geology of the Geopark, the impressive Kinuseo Falls on the mainstem of the Murray River plunges 60 m to the streambed below. Recreational activities in the KSWGSMR watershed include swimming, fishing, hunting, camping, boating, and wildlife viewing.

5. WATER QUALITY OBJECTIVES DEVELOPMENT

5.1 Overview

The WQOs developed for the KSWGSMR watershed were developed collaboratively with Indigenous and Western science and knowledge and include both narrative and numerical objectives. They were set to protect the most sensitive water value or use identified and, in doing so, protect all other water values and uses associated with the watershed. The overarching approach to WQO development in the KSWGSMR watershed is to protect the water from harm, thereby honouring the values of “Water is respected” and “Water is at peace and healthy”.

Narrative objectives are qualitative value judgements of the state of the watershed or waterbody made by Indigenous knowledge holders and were described by the participating First Nations (Prince et al., 2020). Numerical objectives are specific values or limits for a POC. The development of the KSWGSMR WQOs was based on the Indigenous Protection Levels, which are described in the following sections.

5.2 Indigenous Protection Levels

During the development of the *kinosew sîpîy / Murray River Watershed Vision and Values* document (Prince et al., 2020) and continuing into the WQO development process, the participating First Nations developed the concept of Indigenous Protection Levels as part of an emerging Water Classification system. The water classification framework is being developed to help guide water management strategies for the protection of First Nations water values. Full development of all components of the water classifications will require deep collaboration with Elders and Knowledge Holders. Water Classification components include: Attributes of Setting and Place, including existing water quality conditions; Indigenous Cultural Opportunity Spectrum (ICOS); and Indigenous Protection Level. The focus in the WQOs was on the Indigenous Protection Level component.

The attributes of setting and place of the watershed. This includes the existing conditions of the watershed like the extent and intensity of industrial/commercial/residential development, ecosystem attributes, spiritual and cultural attributes, and existing water conditions.

The *Indigenous Cultural Opportunity Spectrum (ICOS).* The ICOS is a state of the watershed evaluated by the Indigenous communities that identifies the existing and future potential of an area to be used for the uninhibited practice of Treaty Rights.

The *Indigenous Protection Level*. Protection level goals were developed that consider existing water conditions. For instance, water that is at peace and healthy should remain at peace and health (Do No Harm).

Based on the assessment of the above factors, a Water Classification would then be assigned to that watershed, sub-watershed or waterbody. For the purposes of Water Quality Objectives, the participating First Nations focused on the Protection Levels as they were most relevant to determining numerical water quality objectives.

Applying Indigenous laws and Indigenous knowledge, the Participating Treaty 8 First Nations goal is to protect water from harm thereby honoring the values of 'Water is respected' and 'Water is at peace and healthy'. 'Do No Harm' means maintaining the existing healthy water conditions or applying the most conservative B.C. WQG as the WQO.

Indigenous Protection Levels were identified for the KSWGSMR Watershed and are outlined in Table 1.

Table 1: Indigenous Protection Levels.

Indigenous Protection Level	Description
Do No Harm	Maintain background existing conditions where water quality and fish tissue are below the most conservative B.C. guidelines.
Do No More Harm 1	Maintain protective existing conditions where there may be anthropogenic disturbance, but water quality and fish tissue are below the most conservative B.C. guidelines (except where exceedances are seasonal and related to freshet) OR where natural conditions may be resulting in elevated water or fish tissue concentrations OR where limited data exists requiring more data collection
Do No More Harm 2	Restore water quality and/or fish tissue concentrations to most conservative B.C. guidelines or natural conditions

5.2.1 Indigenous Protection Levels and Numerical WQO Development

For the numerical objectives, since the KSWGSMR watershed has variable levels of development and existing conditions, the watershed was divided into four watershed zones for the purpose of assigning Indigenous Protection Levels. Figure 3 shows the watershed zones in the KSWGSMR Watershed. The four zones are:

- 'Upper Mainstem' of the Murray River to the confluence with Barbour Creek;
- 'Upper Mainstem Tributaries' of the Murray River;
- 'Mining Region Sub-Watersheds and Tributaries' which includes the Wolverine Sub-watershed, Flatbed River Sub-watershed, M19 and M20 Creeks; and
- 'Downstream Watershed' which includes the downstream mainstem of the Murray River and tributaries.

Each watershed zone was examined for the attributes of setting and place including:

- the concentrations of all parameters of concern (POC),
- the quality and quantity of POC data (i.e., some watershed zones had little available water chemistry data), and
- the extent and effects of development.

The participating Treaty 8 Nation representatives evaluated the watershed zones and discussed these zones within their communities.

A key characteristic of the Indigenous Protection Levels is existing conditions - the existing concentration of the POC in the water quality and fish tissue. Since there were 19 POCs identified in the KSWGSMR watershed, a given watershed zone may have more than one Indigenous protection level, depending on the POC (see Appendix 1).

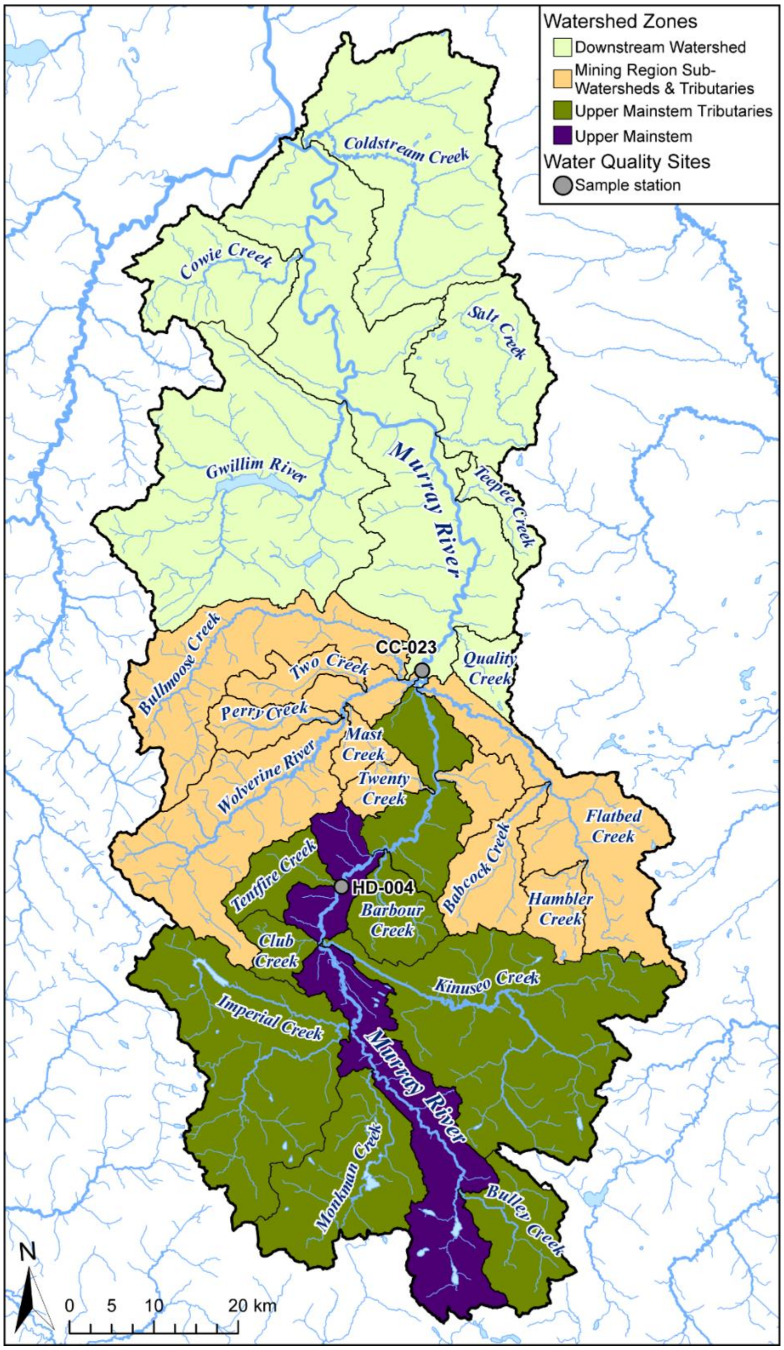

Figure 3: KSWGSMR watershed zones. HD-004 and CC-023 represent locations of key water quality sampling stations discussed in Section 7.2.

5.2.2 Indigenous Protection Level and Narrative WQOs

Narrative objectives incorporate the Indigenous Protection Levels in a different manner than the numerical water quality objectives. The attributes of setting and place including the normal or expected condition of a watershed/waterbody is inherently evaluated by the knowledge holder, as is the Indigenous cultural opportunity spectrum assessment. Therefore, the division of the watershed into watershed zones was not necessary for the narrative objectives. Each location within the watershed will have unique characteristics known to the knowledge holder based on generations of transferred knowledge. Therefore, the narrative objectives apply to the entire watershed and can only be evaluated by knowledge holders.

6. WATER QUALITY OBJECTIVES

This section presents the WQOs developed for the KSWGSMR watershed to protect the water values identified in Section 4.[4] For both the narrative and numerical WQOs, the WQO is presented followed by a description and the rationale of how the WQO was developed. The current state of water quality in the KSWGSMR watershed, which informed the WQO co-development discussions, is summarized in Appendix 2. It is important to note that the absence of a specific water quality parameter in the WQOs does not imply its irrelevance to the KSWGSMR; maintaining natural conditions, aquatic ecosystem health and improving trends in all contaminants in all media (water, sediment, and tissue) over time stands as an overarching objective.

6.1 Narrative Water Quality Objectives

The narrative WQOs for the KSWGSMR watershed, originally proposed in Prince et al. (2020), are provided in Table 2.

A number of the Indigenous water values will be evaluated using qualitative information, compared to the narrative objectives. The narrative objectives are evaluated by Knowledge Holders chosen by the First Nations. Knowledge Holders are equivalent to western science “Qualified Professionals”. This is a critical distinction as some may consider qualitative measurements less reliable than quantitative measurements and requiring broader agreement for validation.

Knowledge Holders possess the collective knowledge of generations of Indigenous land and water stewards and can evaluate whether a narrative WQO is met. It is not necessary for numerous different Knowledge Holders to evaluate the narrative objective in the same way for each evaluation to be valid.

[4] First Nations Water Values encompass more indicators of health and peaceful enjoyment than solely the water column that is protected by WQOs. The participating First Nations have expressed that the Water Values are partially protected by WQOs, but this is not meant to take away from the importance of WQOs and protecting the water itself.

Table 2: Narrative water quality objectives.

Indicator	Objective
Expected Local Visual Appearance	The need for a narrative, qualitative WQO for Expected Local Visual Appearance was identified. This is a description of the change from background and/or the level required for peaceful enjoyment. **WQO**: The visual appearance of water at a specific sampling location displays the overall appearance expected at that location and does not deviate from a background control location to a visually perceivable degree unless the specific location is known and expected to be visually different from background. At specific sampling locations, where visual appearance is expected to be different from background (e.g., highly turbid tributaries etc.), a baseline expected visual appearance must be established. In addition, qualitative measurement of the water visual appearance will be given specific descriptors by the Knowledge Holders.*
Expected Temperature	Expected Local Temperature may be able to be measured with field testing, alongside or after knowledge holder verification and establishment of expected norms, and eventually not require a qualitative local component of measurement. However, this objective must be verified by Knowledge Holders to be representative of Expected Local Temperature.
Expected Local Taste	This is a description of the change from background and/or the level required for peaceful enjoyment of Indigenous cultural practices. Qualitative description of change from background and/or level required for peaceful enjoyment. **WQO**: The taste of water in a specific sampling location, tastes as expected of that location and does not deviate from a background control location to a perceivable degree unless the specific location is known and expected to taste different from background. In specific sampling locations where taste is expected to be different from background (e.g., higher metal content tributaries etc.), a baseline expected taste must be established. In addition, qualitative measurement of the water taste will be given specific descriptors by the Knowledge Holders. Taste will include the overall taste and the "mouthfeel" or textural aspects of the water. The Nations understand the B.C. government does not recommend the drinking of raw untreated water; however the Nations defer to the judgement of the Knowledge Holders in implementing this WQO assessment.

Expected Local Odour	This is a description of the change from background and/or the level required for peaceful enjoyment of Indigenous cultural practices. **WQO:** The odour of water in a specific sampling location displays the overall odour expected of that location and does not deviate from a background control location to an olfactory perceivable degree unless the specific location is known and expected to be different in odour from background. In specific sampling locations where odour is expected to be different from background (e.g., higher sulphur tributaries etc.), a baseline expected odour must be established. In addition, qualitative measurement of the water odour will be given specific descriptors by the Knowledge Holders.

Note: *Knowledge Holders are individuals chosen by McLeod Lake Indian Band, Saulteau First Nations, West Moberly First Nations to evaluate the Narrative Water Quality Objective.

Additional detail on evaluating the narrative objectives is provided in Appendix 3.

6.2 Numerical Objectives for Water Quality

Numerical objectives for water quality have been developed for 18 parameters and are described in the following sections.

6.2.1 General Parameters

Turbidity and Total Suspended Solids (TSS)

Turbidity and TSS concentrations were compared to the B.C. WQGs for aquatic life (ENV, 2021b) in the KSWGSMR watershed. The WQGs are compare site-specific levels to background concentrations for clear and turbid flow periods. In general, turbidity and TSS concentrations increased from upstream to downstream throughout the watershed with the highest concentrations observed during spring freshet.

To protect Indigenous water values, aquatic life, and sustain healthy aquatic ecosystems, the WQOs for turbidity and TSS are set at the B.C. WQG level for the protection of aquatic life (Table 3). These WQOs apply to the entire watershed recognizing that turbidity and TSS levels are not static and fluctuate throughout the year. Concurrent upstream measurements are required to assess attainment of the turbidity and TSS WQOs.

Table 3: Turbidity and TSS WQOs for the KSWGSMR watershed.

Parameter	Upper Mainstem	Upper Mainstem Tributaries	Mining Region Sub-watersheds and Tributaries	Downstream Watershed
	Do No More Harm 1			
Turbidity	Increase over background: ≤2 NTU for long durations (30-d) or ≤8 NTU for short durations (24-h) during clear flow periods. ≤5 NTU at any time when background turbidity is 8 to 50 NTU. Levels should not exceed 10% above background at any time when background turbidity is >50 NTU.			
TSS	Increase over background: ≤5 mg/L for long durations (30-d) or 25 mg/L for short durations (24-h) during clear flow periods. ≤10 mg/L at any time when background TSS is 25 to 100 mg/L. Concentrations should not exceed 10% above background at any time when background TSS is >100 mg/L.			

True Color

The B.C. WQG for aquatic life is based on comparing site-specific levels to background concentrations (ENV, 1997). The source drinking water guideline (aesthetics) is a maximum of 15 true colour units (TCU) (ENV, 2020). For the waterbodies with available data, true colour increased slightly from upstream to downstream areas of the Murray River mainstem, and concentrations were highest during spring freshet in all areas of the watershed.

To protect Indigenous water values, aquatic life, drinking water quality, and sustain healthy aquatic ecosystems, the true colour WQO for the Murray River and its tributaries outside of the mining region is 15 TCUs (Table 4). This is a site-specific WQO that is based on background levels upstream in the Murray River. The WQO for the mining region is the B.C. WQG for the protection of aquatic life. The WQO recognizes that true colour levels are not static and fluctuate throughout the year. Concurrent upstream measurements are required to assess attainment of the true colour WQO for the mining region. The WQOs are an average concentration based on five weekly samples collected over a 30-day period.

Table 4: True colour WQOs for the KSWGSMR watershed.

Upper Mainstem	Upper Mainstem Tributaries	Mining Region Sub-watersheds and Tributaries	Downstream Watershed
Do No Harm	**Do No Harm**	**Do No More Harm 1**	**Do No Harm**
15 TCU	15 TCU	30-day average 5-samples shall not exceed background levels by more than 5 TCU in clear flow conditions* or 20% in coloured systems	15 TCU
Notes: The WQOs are based on a 30-day average (5 weekly samples collected in 30 days); * clear flow conditions are defined as background levels ≤20 TCU			

6.2.2 Nitrogen

Nitrate

Nitrate concentrations were compared to the B.C. WQG for aquatic life of 3 mg/L (ENV, 2009). Nitrate levels were low and well below the guideline in the Murray River. Nitrate concentrations in many mining tributaries were considerably higher than those in the Murray River mainstem, and frequently exceeded the B.C. WQG. Recent data show evidence that these have been decreasing in recent years.

To protect Indigenous cultural values, aquatic life, and sustained healthy aquatic ecosystems, three nitrate WQOs were derived based on the watershed zones (Table 5). For the upper mainstem of the Murray River, from the headwaters to the confluence with Barbour Creek, the WQO is 0.2 mg/L. This WQO is based on the current conditions observed at station HD-004. The goal is to maintain the good water quality in this unimpacted area of the watershed. For the upper mainstem tributaries the WQO is 0.5 mg/L, based on the precautionary principle until further monitoring can be conducted. For the mining region, the WQO is based on the B.C. WQG for the protection of aquatic life of 3 mg/L and provides the goal for the desired future state of water quality. For the downstream watershed, the WQO is 0.5 mg/L, based on the current conditions observed at the Murray River station CC-023. Station CC-023 integrates all the mining regions inputs and the District of Tumbler Ridges wastewater discharge. The WQOs are average concentrations based on five weekly samples collected over a 30-day period.

Table 5: Nitrate WQOs for the KSWGSMR watershed.

Upper Mainstem	Upper Mainstem Tributaries	Mining Region Sub-watersheds and Tributaries	Downstream Watershed
Do No Harm	**Do No Harm 1**	**Do No More Harm 2**	**Do No Harm 1**
0.2 mg/L	0.5 mg/L	3 mg/L	0.5 mg/L
Note: The WQOs are based on a 30-day average (5 weekly samples collected in 30 days).			

Nitrite

Nitrite concentrations in water were compared to the B.C. WQG for aquatic life (ENV, 2009). The nitrite guideline is based on chloride levels, which were generally low in the KSWGSMR watershed and result in a WQG value of 0.02 mg/L. Most nitrite concentrations were below the method detection limit of 0.001 mg/L and when detected were generally below the guideline.

To protect Indigenous water values, aquatic life, and sustained healthy aquatic ecosystems, the WQO for nitrite for the Murray River and its tributaries outside of the mining region is 0.01 mg/L (Table 6). This WQO is site-specific and based on the current conditions observed upstream in the Murray River. The WQO for the mining region is 0.02 mg/L. The WQOs are average concentrations based on five weekly samples collected over a 30-day period.

Table 6: Nitrite WQOs for the KSWGSMR watershed.

Upper Mainstem	Upper Mainstem Tributaries	Mining Region Sub-watersheds and Tributaries	Downstream Watershed
Do No Harm	**Do No Harm**	**Do No More Harm 1**	**Do No Harm**
0.01 mg/L	0.01 mg/L	0.02 mg/L	0.01 mg/L
Note: The WQOs are based on a 30-day average (5 weekly samples collected in 30 days).			

6.2.3 Major Ions

Sulphate

Sulphate concentrations were compared to the B.C. WQG for aquatic life (ENV, 2013a) which is based on water hardness as follows:

- Very Soft: 0-30 mg/L
- Soft to moderately soft: 31-75 mg/L
- Moderately soft/hard to hard: 76-180 mg/L
- Very hard: 181-250 mg/L

In general, waterbodies in the KSWGSMR watershed were characterized as moderately soft/hard to hard or very hard categories with a corresponding sulphate guideline of 309 and 429 mg/L, respectively. Sulphate and hardness concentrations increased from upstream to downstream, and the lowest concentrations were observed during spring freshet into the summer months. The sulphate guideline was met throughout the watershed except in Mast Creek. Sulphate concentrations in several mining region tributaries (e.g., Gordon Creek, Babcock Creek, Mast Creek, and Wolverine River) were generally higher than in the Murray River mainstem.

To protect Indigenous water values, aquatic life, and sustained healthy aquatic ecosystems, three sulphate WQOs were derived based on the watershed zones (Table 7). For the upper mainstem of the Murray River, from the headwaters to the confluence with Barbour Creek, the WQO is 25 mg/L. This WQO is based on the current conditions observed at station HD-004. The goal is to maintain the good water quality in this unimpacted area of the watershed. For the upper mainstem tributaries of the Murray River mainstem, the WQO is 100 mg/L. This WQO is based on the precautionary principle until further monitoring can be conducted. Station CC-023 integrates all the mining regions inputs and the District of Tumbler Ridges wastewater discharge. For the mining region, the WQO is based on the B.C. WQG for the protection of aquatic life. If hardness concentrations are greater than 250 mg/L, the WQO is the corresponding sulphate guideline concentration for very hard water (429 mg/L). Where sulphate concentrations are elevated, this WQO provides the goal for the desired future state of the waterbody. For the downstream watershed of the Murray River mainstem, the WQO is 100 mg/L, based on the current conditions observed at CC-023. The WQOs are an average concentration based on five weekly samples collected over a 30-day period.

Table 7: Sulphate WQOs for the KSWGSMR Watershed.

Upper Mainstem	Upper Mainstem Tributaries	Mining Region Sub-watersheds and Tributaries	Downstream Watershed
Do No Harm	**Do No Harm**	**Do No More Harm 1**	**Do No Harm**
25 mg/L	100 mg/L	B.C. WQG Aquatic Life*	100 mg/L
Notes: The WQOs are based on a 30-day average (5 weekly samples collected in 30 days); *The sulphate guideline of 429 mg/L for very hard water is the maximum concentration applied for the WQO.			

6.2.4 Metals

Aluminum

Total aluminum (Al) concentrations in water were compared to the B.C. WQG for aquatic life which accounts for the site-specific toxicity modifying effects of pH, hardness, and dissolved organic carbon (WLRS, 2023a). In general, there was a strong seasonal component to total Al concentrations with most guideline exceedances observed during spring freshet at downstream stations.

To protect Indigenous water values, aquatic life, and sustained healthy aquatic ecosystems, the WQO is set at the B.C. WQG for the protection of aquatic life. The WQO aligns with the Indigenous protection level of Do No More Harm 1, recognizing that natural seasonal variability can lead to elevated concentrations. The upper and lower bounds of the toxicity modifying factors should be used in the guideline calculation when concentrations are above or below those bounds. For example, if the water concentration for hardness is 500 mg/L, the upper bound of 430 mg/L should be applied when calculating the WQO. The WQO average concentration based on five weekly samples collected over a 30-day period and applies to the entire watershed because of the site specificity of the Al WQG.

Beryllium

Total beryllium (Be) concentrations were compared to the B.C. working WQG for aquatic life of 0.13 µg/L (ENV, 2021b). Most results were below the method detection limit of 0.1 µg/L, but when detected concentrations were associated with spring freshet.

To protect Indigenous water values, aquatic life, and sustained healthy aquatic ecosystems, the WQO for total Be is 0.13 µg/L. The WQO is based on the B.C. working WQG for aquatic life and the Indigenous protection level of Do No More Harm 1 recognizing that natural seasonal variability can lead to elevated concentrations. The WQO is an average concentration based on five weekly samples collected over a 30-day period and applies to the entire watershed.

Chromium

Total chromium (Cr) concentrations were compared to the B.C. working WQG for aquatic life of 1 µg/L (ENV, 2021b). This working WQG is based on hexavalent chromium (Cr(VI)) which is the most toxic form because of its high mobility and solubility in water, persistence in surface and groundwater, and adsorption into biological membranes (CCME 1997). Total Cr increased from upstream to downstream areas of the Murray River mainstem. Frequent guideline exceedances occurred downstream of mining operations within the mining tributaries. Most guideline exceedances were associated with high TSS levels during spring freshet or precipitation events.

To protect Indigenous water values, aquatic life, and sustained healthy aquatic ecosystems, the WQO for total Cr is 1 µg/L. The WQO is based on the B.C. working WQG for aquatic life which aligns with the Indigenous protection level of Do No More Harm 1 recognizing that natural seasonal variability can lead to elevated concentrations. The WQO is an average concentration based on five weekly samples collected over a 30-day period and applies to the entire watershed.

Copper

Dissolved copper (Cu) concentrations were compared to the B.C. WQG for aquatic life (ENV, 2019), which considers site-specific toxicity modifying factors including pH, water hardness, and dissolved organic carbon. Water quality guideline exceedances were infrequent throughout the watershed. Dissolved Cu was not affected by seasonality and a slight increase in concentration was observed from upstream to downstream areas of the Murray River mainstem and few of the mining tributaries. In many cases, there were insufficient data for the supporting parameters in the tributaries to assess water quality in relation to the WQG.

To protect Indigenous water values, aquatic life, and sustained healthy aquatic ecosystems, the WQO for dissolved Cu for the Murray River and its tributaries outside of the mining region is 1 µg/L (Table 8). This WQO is site-specific based on the current conditions observed upstream in the Murray River. The WQO for the mining region is the B.C. WQG for aquatic life. The upper and lower bounds of the toxicity modifying factors should be used in the guideline calculation when concentrations are above or below those bounds (see example provided for total aluminum). The WQOs are average concentrations based on five weekly samples collected over a 30-day period.

Table 8: Dissolved copper WQOs for the KSWGSMR Watershed.

Upper Mainstem	Upper Mainstem Tributaries	Mining Region Sub-watersheds and Tributaries	Downstream Watershed
Do No Harm	**Do No Harm**	**Do No More Harm 1**	**Do No Harm**
1 µg/L	1 µg/L	B.C. WQG Aquatic Life*	1 µg/L
Notes: * The WQOs are based on a 30-day average (5 weekly samples collected in 30 days).			

Iron

Total and dissolved iron (Fe) concentrations were compared to the B.C. WQGs of 0.3 mg/L (total Fe) for source drinking water aesthetics (ENV, 2020) and 0.35 mg/L (dissolved Fe) for aquatic life (ENV, 2008). Total Fe concentrations were highest during spring freshet corresponding with most guideline exceedances throughout the watershed occurring at this time. Slight increase in total Fe was observed from upstream to downstream area of the Murray River mainstem and several mining tributaries. Spring freshet had less influence on dissolved Fe and concentrations were more consistent between upstream and downstream stations. Dissolved Fe concentrations were below the B.C. WQG for aquatic life throughout the watershed except for a small number of exceedances observed in several creeks in the mining region. Total Fe B.C. WQG for source drinking water aesthetics was exceeded more frequently both in the mining tributaries as well as in the Murray River mainstem.

To protect Indigenous water values and the aesthetic value of drinking water, the WQO for total Fe is 0.3 mg/L from July to March (Table 9). This WQO recognizes the influence of spring freshet on total iron concentrations and that elevated concentrations may naturally occur. Any samples collected during freshet should include upstream and downstream stations to assess whether the results are natural or influenced by anthropogenic activities. The WQO is an average concentration based on five weekly samples collected over a 30-day period and applies to the entire watershed.

To protect Indigenous water values, aquatic life, and sustained healthy aquatic ecosystems, the WQO for dissolved Fe for the Murray River and its tributaries outside the mining region is 0.05 mg/L (Table 10). This WQO is site-specific and based on the background levels observed upstream in the Murray River. For the mining region, the dissolved Fe WQO is 0.35 mg/L. The WQOs are an average concentration based on five weekly samples collected over a 30-day period.

Table 9: Total iron WQOs for the KSWGSMR watershed.

Upper Mainstem	Upper Mainstem Tributaries	Mining Region Sub-watersheds and Tributaries	Downstream Watershed
Do No More Harm 1			
0.3 mg/L			
Notes: The WQO is a maximum concentration and applies July through March.			

Table 10: Dissolved iron WQOs for the KSWGSMR watershed.

Upper Mainstem	Upper Mainstem Tributaries	Mining Region Sub-watersheds and Tributaries	Downstream Watershed
Do No Harm	**Do No Harm**	**Do No More Harm 1**	**Do No Harm**
0.08 mg/L	0.08 mg/L	0.35 mg/L	0.08 mg/L
Notes: The WQOs are based on a 30-day average (5 weekly samples collected in 30 days).			

Manganese

Total manganese (Mn) concentrations were compared to the B.C. aesthetic WQG for source drinking water of 0.2 mg/L (ENV, 2020). Average concentrations were consistently below the guideline with the small number of guideline exceedances associated with spring freshet. Total Mn concentrations were higher in downstream stations compared to the upstream in the Murray River mainstem as well as in several mining tributaries.

To protect Indigenous water values and the aesthetic value of drinking water, the WQO for total Mn is 0.2 mg/L. The WQO aligns with the Indigenous protection level of Do No More Harm 1 recognizing that natural seasonal variability can lead to elevated concentrations. The WQO is an average concentration based on five weekly samples collected over a 30-day period and applies to the entire watershed.

Mercury

Total mercury (Hg) concentrations were compared to the B.C. WQG for aquatic life of 0.01 µg/L when methyl mercury (MeHg) is 1% of total Hg (ENV, 2001). Data collected prior to 2017 was difficult to assess because method detection limits were generally higher than the WQG and the available data were limited. For data collected in 2017 and 2018, there were no WQG exceedances for total mercury. In the three instances where MeHg data were available, total Hg met the guideline.

To protect Indigenous water values, aquatic life, and sustained healthy aquatic ecosystems, the WQO for total Hg is 0.01 µg/L. The WQO aligns with the Indigenous protection level of Do No More Harm 1 recognizing that data are limited. The WQO is an average concentration based on five weekly samples collected over a 30-day period and applies to the entire watershed. For a complete understanding of risk, both total and methyl Hg should be analyzed in future monitoring programs throughout the watershed.

Silver

Total silver (Ag) concentrations were compared to the BC WQG for aquatic life 0.1 µg/L (WLAP, 1996). No results were reported above the WQG in the headwater tributaries, upper mainstem and downstream watershed, although data were limited. In the mining region, there were a few exceedances of the WQG in Gordon Creek, Wolverine River, M20 Creek, and Flatbed Creek. Average concentrations of total Ag in these creeks were generally higher than other waterbodies in the mining region.

To protect Indigenous water values, aquatic life, and sustained healthy aquatic ecosystems, the WQO for total Ag for the Murray River and its tributaries outside the mining region is 0.05 µg/L (Table 11). This WQO is site specific based off the background levels observed upstream in the Murray River. For the mining region, the WQO is 0.1 µg/L. The WQOs are an average concentration based on five weekly samples collected over a 30-day period.

Table 11: Total silver WQOs for the KSWGSMR Watershed.

Upper Mainstem	Upper Mainstem Tributaries	Mining Region Sub-watersheds and Tributaries	Downstream Watershed
Do No Harm	**Do No Harm**	**Do No More Harm 1**	**Do No Harm**
0.05 µg/L	0.05 µg/L	0.1 µg/L	0.05 µg/L
Notes: The WQOs are based on a 30-day average (5 weekly samples collected in 30 days).			

Selenium

Total Selenium (Se) results were compared to the B.C. WQG for aquatic life of 2 µg/L (ENV, 2014). Exceedances of the guideline were observed throughout the mining region with highest exceedances occurring in Mast Creek, Perry Creek, and Gordon Creek. The B.C. WQG was generally met in the Murray River mainstem with slightly higher concentrations observed in the downstream area. Seasonally, lower Se levels were generally observed during spring freshet with the highest Se concentrations occurring during the summer months. Average concentrations in the mining region were generally higher than in the Murray River mainstem.

To protect Indigenous water values, aquatic life, and sustained healthy aquatic ecosystems, three Se WQOs were derived based on the watershed zones (Table 12). For the upper mainstem of the Murray River, from the headwaters to the confluence with Barbour Creek, the WQO is 0.5 µg/L. This WQO is based on the current conditions observed at station HD-004. The goal is to maintain the good water quality in this unimpacted area of the watershed. For the upper mainstem tributaries the WQO is 1 µg/L, based on the B.C. WQG for the protection of aquatic life alert concentration. For the mining region the WQO is 2 µg/L, based on the B.C. WQG for the protection of aquatic life. Where Se concentrations are elevated, this WQO provides the goal for the desired future state of a waterbody. For the downstream watershed, the WQO is 1 µg/L, based on the B.C. WQG for the protection of aquatic life alert concentration. The WQOs are an average concentration based on five weekly samples collected over a 30-day period.

Table 12: Total Selenium WQOs for the KSWGSMR watershed.

Upper Mainstem	Upper Mainstem Tributaries	Mining Region Sub-watersheds and Tributaries	Downstream Watershed
Do No Harm	**Do No Harm 1**	**Do No More Harm 2**	**Do No Harm 1**
0.5 µg/L	1 µg/L	2 µg/L	1 µg/L
Notes: The WQOs are based on a 30-day average (5 weekly samples collected in 30 days).			

Uranium

Total Uranium (U) results were compared to the B.C. working WQG for aquatic life of 8.5 µg/L (ENV, 2021b). Throughout the watershed, average U concentrations were below 1 µg/L except for Gordon Creek, Mast Creek, and the Wolverine River. Notably, concentrations were higher in the Wolverine River below the confluence with Mast Creek.

To protect Indigenous water values, aquatic life, and sustained healthy aquatic ecosystems, the WQO for total U for the Murray River and its tributaries outside the mining region is 0.5 µg/L (Table 13). This WQO is site-specific and based on the background levels observed upstream in the Murray River. For the mining region waterbodies, the WQO is 4.5 µg/L because of the low concentrations observed. The exceptions are Mast Creek and the Wolverine River where the WQO is 8.5 µg/L. For Mast Creek, this WQO provides the goal for the desired future state of the waterbody. The WQOs are an average concentration based on five weekly samples collected over a 30-day period.

Table 13: Total uranium WQOs for the KSWGSMR watershed.

Upper Mainstem	Upper Mainstem Tributaries	Mining Region Sub-watersheds and Tributaries	Downstream Watershed
Do No Harm	**Do No Harm**	**Do No More Harm 1 and 2**	**Do No Harm**
0.5 µg/L	0.5 µg/L	4.5 µg/L (Do No More Harm 1) Mast Creek, Wolverine River – 8.5 µg/L (Do No More Harm 2)	0.5 µg/L
Notes: The WQOs are based on a 30-day average (5 weekly samples collected in 30 days).			

Zinc

Dissolved zinc (Zn) concentrations in water were compared to the B.C. WQG for aquatic life which accounts for the site-specific toxicity modifying effects of hardness and dissolved organic carbon (WLRS, 2023b). No seasonal trend observed and the WQG, where it could be calculated, was generally met. Average concentrations in the mining region were generally higher than in the Murray River mainstem.

To protect Indigenous water values, aquatic life, and sustained healthy aquatic ecosystems, the WQO for dissolved Zn for the Murray River and its tributaries outside the mining region is 5 µg/L (Table 14). This WQO is site-specific based on the background levels observed upstream in the Murray River. In the mining region the WQO is set at the B.C. WQG for the protection of aquatic life. The upper and lower bounds of the toxicity modifying factors should be used in the guideline calculation when concentrations are above or below those bounds. For example, if the water concentration for hardness is 500 mg/L, the upper bound of 250 mg/L should be applied when calculating the WQO. The WQOs are an average concentration based on five weekly samples collected over a 30-day period.

Table 14: Dissolved zinc WQOs for the KSWGSMR watershed.

Upper Mainstem	Upper Mainstem Tributaries	Mining Region Sub-watersheds and Tributaries	Downstream Watershed
Do No Harm	**Do No Harm**	**Do No More Harm 1**	**Do No Harm**
5 µg/L	5 µg/L	B.C. WQG	5 µg/L
Notes: The WQOs are based on a 30-day average (5 weekly samples collected in 30 days).			

6.2.5 Microbial Indicators

Escherichia coli concentrations were screened against the B.C. source drinking WQG of 10 CFU/100 mL as the 90th percentile based on a minimum of five samples (ENV, 2020). This guideline assumes disinfection prior to human consumption. In the limited data available for *E. coli,* exceedances of the guideline were observed with the highest frequency occurring in the lower watershed.

First Nation Knowledge Holders that have the intergenerational knowledge of their ancestors will often drink water directly from rivers and lakes and are able to discern "safe" areas of drinking water based on their relationship with the land. WQOs are meant to protect this relationship, however in areas where industrial, municipal, and agricultural development have altered the landscape, fecal contamination of the water can occur from wastewater discharges and changes to the landscape.

Fecal contamination of water from human sources is generally regarded as a greater risk to human health than contamination from non-human sources, as they are more likely to contain human-specific enteric pathogens. The challenge of applying an *E. coli* WQO is understanding the sources of *E. coli* in the waters that Indigenous Peoples choose to drink from, recognizing there are also natural sources of *E. coli* such as wildlife.

To protect Indigenous water values and trusted safe drinking water, the WQO is no detectable *E. coli* from anthropogenic sources.

6.3 Numerical Objectives for Fish Tissue

Fish tissue WQO were developed for selenium and mercury, based on tissue contaminant concerns, to protect First Nations cultural values in the KSWGSMR watershed. The WQOs are based on the B.C.

recommended method to develop benchmarks to protect human health from harmful substances when eating fish (WLRS 2023c). These benchmarks, called screening values (SVs), are used to assess the potential risk to human health from contaminants in fish tissue. When an SV is exceeded, informed decisions can be made regarding next steps. The exceedance of an SV in areas where fish are consumed may indicate further investigation to assess human health risk at a particular site is warranted (ENV, 2021b). Aquatic sampling and monitoring considerations and protocols are provided in ENV (2013b) and Health Canada (2021).

Screening values are calculated from a specific fish consumer's body weight, fish ingestion rate, and toxicological reference values for a given chemical. Screening values are based on human toxicological information and are not related to water column concentrations or the selenium of mercury numerical WQOs. Fish tissue WQOs apply to country foods, that is, all foods sourced outside of retail food systems. These include any food that is trapped, fished, hunted, harvested, or grown for subsistence or medicinal purposes (Health Canada, 2018).

Fish tissue SVs were defined for selenium and mercury using the recommended B.C. approach (WLRS, 2023c). The SVs were used to assess tissue concentrations in the KSWGSMR watershed and derive an appropriate WQO based on the most sensitive fishing population, a subsistence toddler. See Appendix 4 for the SV calculations used to inform selenium and mercury fish tissue objectives. Further details on the methodology and equations used are provided in WLRS (2023c).

Selenium

Selenium levels in fish tissue in the KSWGSMR watershed were reviewed based on the limited available data. Most of the bull trout and slimy sculpin tissue samples exceeded the toddler SV. These exceedances were observed in both upstream reference sites and downstream sites on the same waterbody. There was no fish tissue information available for the Murray River and its tributaries. As selenium is naturally occurring, background concentrations in fish tissue are an important knowledge gap to be addressed. The Indigenous protection level for selenium in fish tissue is therefore Do No More Harm 2, recognizing that fish tissue concentrations of selenium are elevated to the point that some members of the community (i.e., toddlers) must limit how much fish they can eat.

Based on the selenium SV for a subsistence toddler, the fish tissue WQO is a single sample maximum concentration of 4.2 µg/g dry weight (1.0 µg/g wet weight) for the KSWGSMR watershed. The wet weight to dry weight conversion is based on 75% moisture content. The WQO applies to all tissue types and is based on at least one composite sample consisting of at least five fish.

Mercury

Mercury levels in fish tissue were reviewed based on the available, but limited, data. Concentrations were elevated above the SV in M19 Creek and Perry Creek, with occasional exceedances in the other waterbodies. No increasing pattern in concentrations from upstream to downstream was observed. Given mercury is a key parameter of concern for First Nations in the KSWGSMR watershed, concentrations in fish tissue throughout the watershed is an important data gap to be addressed. The Indigenous protection level for mercury in fish tissue is therefore Do No More Harm 1 recognizing that fish tissue concentrations of mercury are elevated, and the available data are limited.

Based on the mercury SV for a subsistence toddler, the fish tissue WQO is a single sample maximum of 0.14 µg/g dry weight (0.035 µg/g wet weight) for the KSWGSMR watershed. The wet weight to dry weight conversion is based on 75% moisture content. The WQO applies to all tissue types and is based on at least one composite sample consisting of at least five fish.

6.4 CABIN

Biomonitoring data, focussed on the benthic macroinvertebrate communities in the KSWGSMR watershed, was evaluated to support a more comprehensive assessment of the state of the aquatic ecosystem. Biomonitoring is an important component of aquatic monitoring programs as it provides a direct measure of the condition of aquatic biota. ENV collaborates with Environment and Climate Change Canada (ECCC) to promote the use of the nationally standardized Canadian Aquatic Biomonitoring Network (CABIN) program in B.C. CABIN provides a consistent, scientifically defensible approach using benthic macroinvertebrate communities to assess freshwater ecosystems across Canada and throughout B.C.

Details of the CABIN data available are provided in Appendix 5. CABIN results generally suggest that waterbodies in the KSWGSMR watershed support healthy benthic communities. Exceptions include:

- M19 Creek – the most recent data collected (2015) indicates sites were “divergent” from reference condition; these results may have been influenced by the shallow, intermittent habitat sampled.
- Perry Creek – 2012 results found sites to be “mildly divergent” from reference condition with declining diversity at the downstream site. 2019 results indicate that the downstream site is divergent from reference condition.
- Wolverine River - Sampling in 2009 and 2019 indicate that sites were “mildly divergent” from reference condition with the sites adjacent and closest to the Wolverine Mine shifting to “divergent” in the most recent monitoring period.
- Murray River – variable results were observed at the 8 downstream sites sampled between 2011 and 2019 ranging from “similar to reference” to “divergent”; no clear temporal or spatial pattern was noted.

No WQO is proposed for benthic communities at this time.

7. MONITORING RECOMMENDATIONS

The WQOs presented in this document establish benchmarks to assess water quality and determine if the identified water values are being protected. They apply throughout the KSWGSMR watershed (see Figure 1) and should be used in all ambient water quality monitoring programs conducted in the watershed including baseline monitoring, WQO data gap filling, WQO attainment monitoring, and water quality and aquatic effects monitoring conducted under an *Environmental Management Act* waste discharge permit.

To attain trusted water for cultural purposes, community-led monitoring of water and fish, and communication with land users and other community members about water conditions, is recommended. However, it is important to understand that, from a First Nation perspective, such a monitoring program will only be successful if the broader objective of protection of all First Nation Water Values identified in Section 2 is also being advanced.

7.1 Engagement with First Nation Representatives

The first step in planning and implementing an attainment monitoring program in KSWGSMR watershed is to engage with the participating First Nations. These Nations are: McLeod Lake Indian Band, Saulteau First Nations and West Moberly First Nations.

Engagement means contacting directly, and speaking directly with, representatives of each of the participating Nations to describe the proposed monitoring program, the reason monitoring is being conducted, and capacity considerations and support. This first engagement must be completed at least 3 months before the monitoring program is to begin. This provides these First Nations advance notice to review the monitoring program and to prepare internally for the monitoring program.

7.2 Narrative WQOs and Engagement with Elders and Knowledge Holders

In order to evaluate the narrative WQOs, full involvement of the participating Nation Elders and Knowledge Holders is required. Frequency of monitoring for the narrative objectives is at the discretion of the knowledge holders. Elder and Knowledge Holder input is also necessary for planning the monitoring program. Monitoring locations, culturally appropriate sampling techniques and timing of the monitoring program must be discussed and agreed upon with the Elders and Knowledge Holders.

7.3 Western Science Data Monitoring

Data collection and analysis methods should follow the guidance from the BC Field Sampling Manual (ENV 2013b) and be clearly documented and to ensure data comparability between monitoring programs.

The following tables (Tables 15 – 17) provide guidance of when and how often to sample and the parameters to be included, for each media. Routine sampling of non-WQO parameters is also recommended to understand the general water quality conditions in the KSWGSMR watershed and to support data interpretation. These monitoring recommendations provide an outline and do not limit the addition of other parameters.

Water Quality

Table 15: Water quality monitoring considerations.

Frequency and Timing	Parameters to be Measured
Monthly samples Spring Freshet: five weekly samples in a 30-day period Summer/Fall low flows: five weekly samples in a 30-day period	Field: Temperature, dissolved oxygen, pH, specific conductivity, turbidity) Lab: total and dissolved metals (selenium include speciation (selenate, selenite, organoselenides), dissolved hardness, orthophosphate, nitrogen species, total mercury (methyl mercury?), TSS, turbidity, SO4, DOC, E. coli., color

Sediment Quality

Table 16: Sediment quality monitoring considerations.

Frequency and Timing	Parameters to be Measured
Once/year during late summer low flow period	Lab: particle size distribution (grain size in mm), moisture content, total organic carbon, total metals

Biological Tissues

Table 17: Fish and benthic invertebrate tissue monitoring considerations.

Frequency and Timing	Parameters to be Measured
Once/year during late summer low flow period	Lab: trace metals, mercury, % moisture

7.4 Monitoring Frequency

In terms of frequency, whenever a western science measurement is being made, the knowledge holders and Elders of the participating Nations should be consulted on whether the narrative objectives require evaluation. While the narrative objectives may be evaluated less frequently, (depending on recommendations and guidance from Knowledge Holders and Elders) including the narrative objective results alongside the western science data will create a comprehensive data set with both ways of knowing represented equally by the data.

8. FUTURE MANAGEMENT

McLeod Lake Indian Band, Saulteau First Nations, and West Moberly First Nations and the Province have collaborated on the development of specific WQOs for the KSWGSMR watershed. Moving forward, one important goal is to establish a coordinated approach to attainment monitoring the water quality of the KSWGSMR watershed, and to ensure data accessibility and regular attainment monitoring reporting.

In addition, these First Nations have shared a complex framework of Indigenous values that guide their relationship with water (Sections 2 and 3). One of the aims of the First Nations' work was to raise the understanding of First Nation Water Values and demonstrate that B.C. Water Quality Guidelines and water quality are one piece of the puzzle that sustain, restore, and protect a watershed where First Nations can meaningfully exercise their Treaty rights and have peaceful enjoyment of their way of life within their territory. The intention for sharing this spectrum of Indigenous water values was to demonstrate how a collaborative, G2G, approach to policy development of Water Quality Objectives, and comprehensive water and fishery monitoring regimes, can help to protect **some** of these values.

One of the next steps in this journey will be advancing collaborative, G2G Landscape and Watershed Management Planning processes, monitoring protocols and regimes that protect First Nations Water Values. Planning and management options and needs include:

- Indigenous-led collaborative watershed monitoring and management. Some potential avenues for conduct of this work have also been identified such as, regional land and resource management planning, land use-based management plans, and community watershed initiatives.
- Increase education, awareness and trust among First Nation land users and other community members regarding watershed health.
- Increase education and awareness for local communities regarding watershed health and management.
- Carry out directed research or monitoring to improve waste management techniques or address identified knowledge gaps.

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Appendix 1: Narrative objective assessments compared to numerical objective assessments.

There are many aspects of collecting western science data and comparing to a WQO that are well known and not explicitly discussed in a WQO Policy document. The narrative objectives, however, are new and require an additional level of detail in the Policy document. The intention of this section is to illustrate how the project manager of a monitoring program would contact the First Nations and initiate the process of assessing the narrative objective. To illustrate this, the process of measuring a narrative objective is broken down in Table 1 and compared with the western science process. The examples used are Typical Local Visual Appearance (Narrative Objective) and Water Chemistry (Western Science Objective).

Table 1 - Assessing Narrative Objectives.

	Narrative Objectives	**Water Chemistry Objectives**
Indicator	Typical Local Visual Appearance	Concentration of contaminants in water
Assessment	Indigenous Knowledge Holders observe and measure based on their experience and knowledge passed down for generations.	Water sample and lab analysis
How to get a qualified person to measure the indicator	Identify and engage appropriate Indigenous groups (at a minimum SFN, WMFN, MLIB). Request a group of Knowledge Holders be formed to conduct the WQO assessment for Typical Local Visual Appearance. Traditional protocols may exist that must be followed to make this request and they may differ between Nations. It is the responsibility of the person conducting the monitoring program to know and follow these protocols.	Hire a consultant or qualified person with field staff trained in collecting water samples
How to prepare to collect the measurement	Hold joint coordination meeting with Knowledge Holders, Lands Department representatives and technicians. Explain purpose of measurements and how the Knowledge Holders' traditional knowledge will be used to determine if a WQO has been met. Listen to Knowledge Holders initial thoughts about the measurement and Murray River watershed in general. Plan how to access measurement location.	Order bottles from laboratory, organize field gear, create health and safety plan. Plan how to access water sampling location.

How to collect the measurement	Knowledge holders visit the measurement location, as well as other locations deemed by the Knowledge Holders to be important for them to provide the Indigenous knowledge required to understand if the WQO is being met. Indigenous knowledge assessment is collected through observation and recorded either by written notes or voice recording by a person identified by the Indigenous communities (may be a Guardian, youth, other Knowledge Holder, Lands Department staff, technician etc.)	Field technician visits location* with laboratory supplied bottles and collects water sample in accordance with their sampling protocols and training. Water sample preserved, packed in cooler and shipped to certified laboratory with custody seals to track chain of custody.
How to process the measurement (meaning how to get the actual information you need to compare to the WQO)	Indigenous knowledge on Typical Local Visual Appearance is reviewed by Lands Departments and/or technicians. Voice recordings are transcribed. Indigenous knowledge is compiled and interpreted (often Knowledge Holders will answer questions and communicate by telling stories and these communications will need to be interpreted to determine whether the WQO of Typical Local Visual Appearance has been met).	Laboratory analyses the water sample using certified techniques and under a rigorous quality assurance and quality control program. Produces a certificate of analysis that reports the concentrations of contaminants in the water sample.
How to determine if the WQO has been met.	Hold joint coordination committee verification meeting with Knowledge Holders, Lands Department representatives and technicians. Present interpretation of whether the WQO of Typical Local Visual Appearance has been met. Obtain community feedback of this interpretation. Modify interpretation if necessary.	Compare the concentration of each contaminant reported by the laboratory with the WQO. If the water sample concentration is lower, the WQO is met. If the concentration is higher, the WQO is not met.
How to evaluate and validate WQO data over time	Document the extent to which a number of Knowledge Holders use the same, or comparable physical cues as the basis for their assessment and language to characterize the WQO attributes.	Document trends in water chemistry and exceedances of WQO over time.

*Notes: *Location in general, means any place in the Murray River watershed subject to the WQOs.*

Appendix 2: Water quality current conditions of the kinosew sîpîy / whutone gah saghé / Murray River watershed

Introduction

This appendix provides a technical overview of current surface water quality conditions in the kinosew sîpîy / whutone gah saghé / Murray River watershed (KSWGSMR). The goal of this appendix is to clarify the linkages between the initial technical assessment and proposed water quality objectives prepared by Azimuth (2021), and the Water Quality Objectives (WQOs) Policy co-developed by the Province and the participating Treaty 8 First Nation governments (BC, MLIB, SFN, and WMFN 2024).

Available water quality data for the 16 parameters of concern identified in Azimuth (2021) are summarized below by parameter and organized by location, namely the Murray River mainstem and the mining region water bodies. Additional general parameters were included to support the understanding of the current state of water quality, including temperature, dissolved organic carbon (DOC), pH, dissolved hardness, and true color. Further information on hydrology, influences on water quality, and water basin characteristics is provided in Azimuth (2021).

Data Analysis Approach

To support the WQO co-development discussions in the KSWGSMR, the raw data from the Murray River Aquatic Cumulative Effects Steering Committee database were compiled, plotted, and assessed with the WQO technical working group to reach consensus. All data manipulations and visualizations were conducted using R software. The following steps were taken to prepare the data for analysis (see Azimuth (2021) for additional information):

All raw water quality data were cleaned by:

- Standardizing parameter names;
- Standardizing units to align with how they are reported in the water quality guidelines (WQGs);
- Removing outliers that deviated significantly from the other data points, even after accounting for seasonal variability.

Censored data (data below MDL) were processed using the method described in ENV (2019). Monitoring site arithmetic averages were calculated using four different approaches depending on the number of results above (detects) and below (non-detects) the MDL:

- A value of half the minimum MDL was used to represent station averages when all results were below the MDL, chosen to accommodate decreasing MDLs over time.
- For stations with less than three detects, half of the MDL was substituted for non-detect values, and the arithmetic average of all station results was calculated.
- Regression on order statistics (ROS) was used to estimate the average for stations with a mixture of non-detects and detects, with at least three detected values (Huston and Juarez-Colunga, 2009). However, a minimum of three detects is required to calculate a valid regression using the Non-detects and Data Analysis for Environmental Data (NADA) package (Lee, 2017) in R (R Core Team, 2020).
- The arithmetic average was calculated for stations where all samples were above the MDL.

This assessment utilized the dataset compiled by Azimuth (2021), which included water quality data collected in the Murray River basin between 2008 and 2018. Data sources included provincial and municipal governments, mining companies, and participating Treaty 8 First Nation governments. The dataset included information from reference (relatively unimpacted), mid-stream, and downstream sites on the Murray River mainstem and its tributaries in the mining region, focusing on sites with the highest number of data points (Table 1) (Figure 1). Sites on the Murray River mainstem were assessed if there were more than 30 datapoints between 2008 and 2018. Two additional sites were selected based on their location's importance: (1) CC-023 to capture mining region effects, and (2) CC-010, the most downstream monitoring site before the confluence with the Pine River, to assess cumulative effects throughout the watershed. Where available, data collected from at least one upstream (reference) location on each waterbody were reviewed and compared in this assessment to downstream data. This approach was chosen due to the significance of the tributary watersheds to the participating First Nations. Azimuth (2021) took a slightly different approach in two ways: firstly, the assessment focused on six waterbodies with the most data and pooled data from other waterbodies for the water quality assessment. Secondly, reference and downstream sites were grouped according to the data contributor label in the database, as opposed to the furthest upstream monitoring site. This resulted in some waterbodies lacking both reference and/or downstream locations to compare upstream and downstream conditions within a waterbody.

Table 1. Sites selected for the current condition analysis of the KSWGSMR. These sites were used to calculate summary statistics and summary plots. The reference sites for each waterbody are shaded. Sites for each waterbody are listed from upstream to downstream direction. Indented waterbody names are tributaries of waterbody listed above. See Figures 1 and 2.

Waterbody	Sites included in analysis
Murray River mainstem	MOE-077, MOE-070, HD-004, TK-012, TK-014, HD-014, HD-023, HD-028, HD-027, TK-031, TK-029, HD-033, TK-028, HD-021, PRC-004, PRC-003, CC-023, HD-040, TK-038, MOE-076, MOE-067, CC-010
M20 Creek	MOE-59, HD-012, HD-026
M19 Creek	HD-041, HD-038, HD-036
Flatbed Creek	PRC-077, PRC-023, MOE-069
Babcock Creek	PRC-015, PRC-031, PRC-052
Gordon Creek	PRC-035, PRC-044
Wolverine River	CC-007, CC-028, CC-019, MOE-068, CC-022
Perry Creek	CC-005, CC-006, CC-027
Mast Creek	TK-013, TK-007
Bullmoose Creek	MOE-018, MOE-021, MOE-023

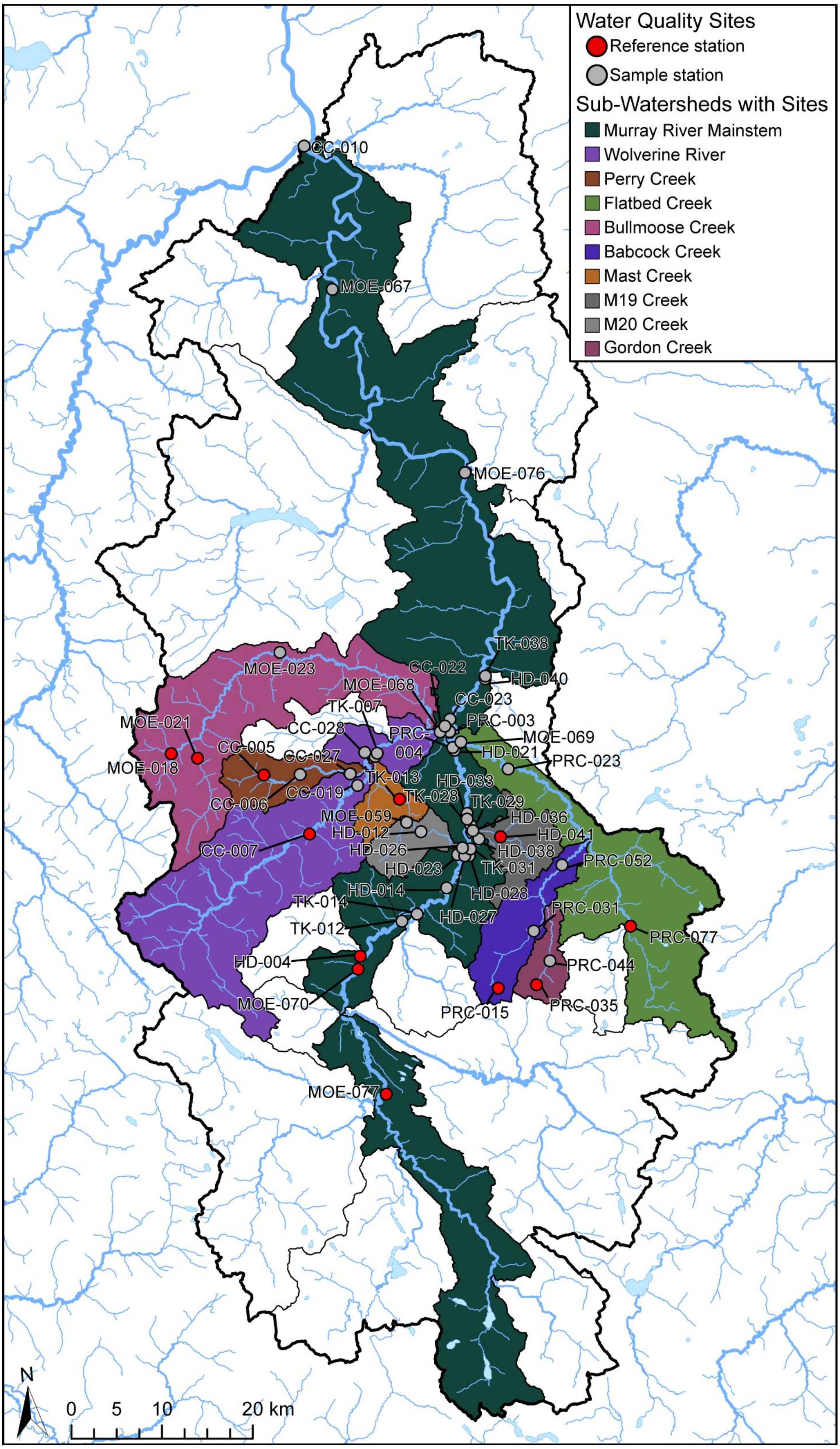

Figure 1. Water quality monitoring locations used in the KSWQMRW current conditions assessment.

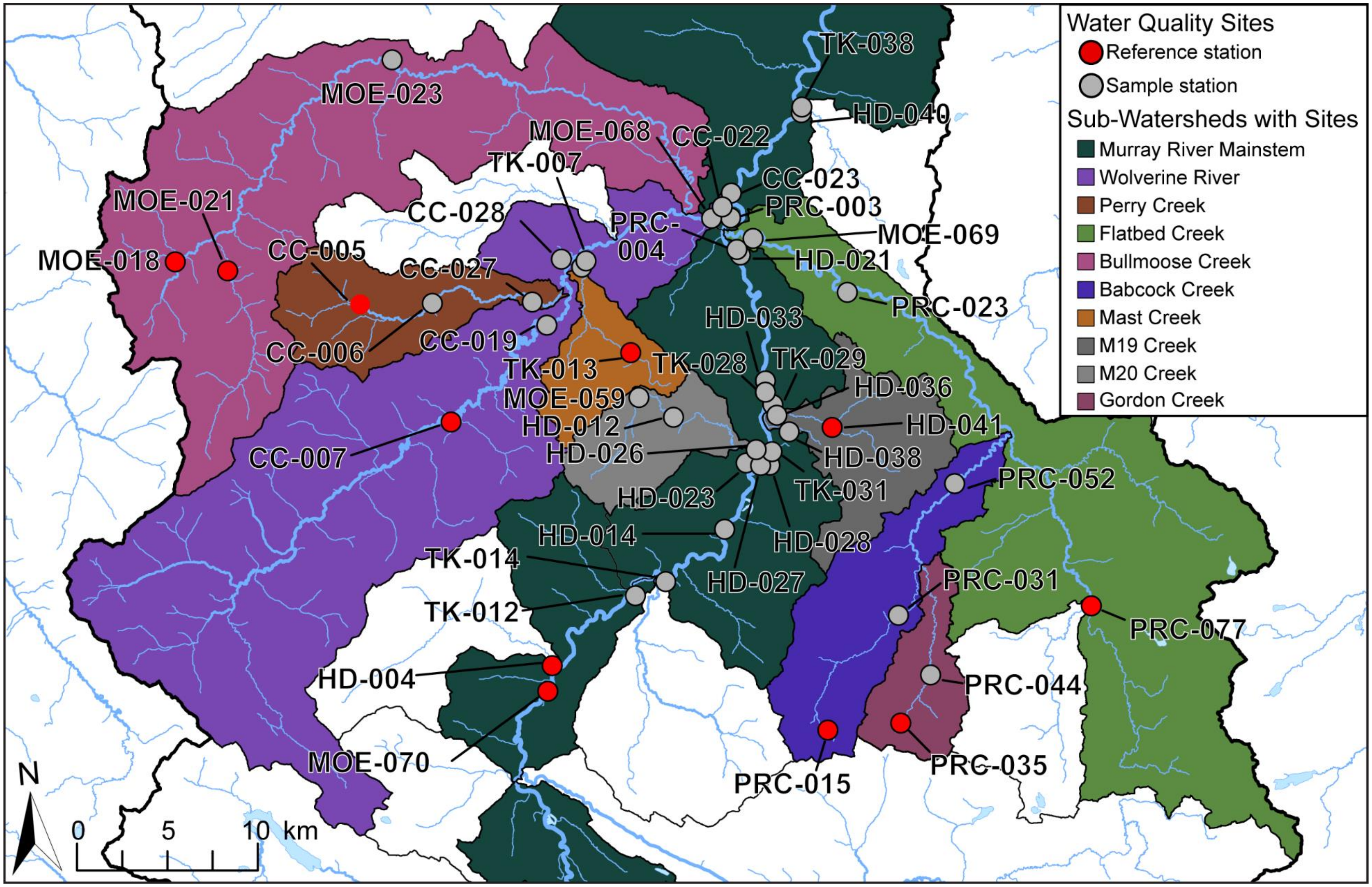

Figure 2. Close up of water quality monitoring locations in the Mining Region.

For each parameter, the data were plotted across space and time, with monthly means considered if affected by seasonal patterns. These plots were then compared to the most conservative British Columbia (B.C.) Water Quality Guidelines (WQGs), based on the values identified by the participating Treaty 8 First Nations. Concentrations downstream were compared to those at upstream reference stations.

When calculating WQGs with toxicity-modifying factors (such as hardness, dissolved organic carbon (DOC), pH, or chloride) and concurrent data were not available, average values were computed for the waterbody to inform the WQG.

Summary statistics, including averages, minimums, maximums, and 95th percentiles, were calculated for key stations with sufficient data and are presented in tables. Plots for each parameter, organized by waterbody, are depicted in figures.

Water quality information was generally limited for the tributaries outside of the mining region; six of these 12 tributaries had a maximum of four sampling dates from 2008 to 2018, and five tributaries had no available data. The exception was Club Creek, which had a dataset comprising about 86 sampling dates. The scarcity of data outside of the mining region highlights a significant information gap in the current conditions assessment.

Results

General Parameters

Water Hardness, DOC, pH

Water hardness is predominantly influenced by the presence of dissolved calcium and magnesium in the water. It serves as a crucial constituent that affects the toxic effects of certain metals, with metal toxicity decreasing as hardness increases. In this document, dissolved hardness was calculated by summing the concentrations of dissolved magnesium and calcium. Anthropogenic factors, such as mining and industrial discharge, can also impact water hardness. The water hardness categories outlined in ENV (2013) were utilized to describe conditions in this document.

Dissolved organic carbon (DOC) in water comprises humic substances and partially degraded animal and plant materials. Carbon is a necessary nutrient for biological processes, and DOC plays a vital role in mitigating metal toxicity by binding with the inorganic forms of metals (e.g., copper), thus reducing exposure to fish and other aquatic organisms.

pH, a measure of the hydrogen-ion concentration in water, is significant due to its influence on aquatic ecosystems. It can lead to the destruction of gill tissue and alter chemical species, thereby increasing the toxicity of certain water quality characteristics, such as metals.

Murray River

In the Murray River, the average water hardness ranged between 100 and 200 mg/L, indicative of moderately soft to very hard water (Table 2). There was a slight increase in average water hardness downstream compared to background levels, with no clear increasing or decreasing trends over time (Table 2, Figure 3). The lowest hardness concentrations were observed during freshet in the spring and early summer, while the highest values occurred during the winter months (Figure 4). Site CC-023 recorded the highest hardness values, likely influenced by mining activities (Table 2).

Available dissolved organic carbon (DOC) data for the Murray River were very limited (Figure 3), and summary statistics were not calculated. Concentrations generally remained below 2 mg/L (indicating low organic matter levels) except during freshet in May and June (Figure 4). The maximum DOC value reported was 14 mg/L, recorded during freshet at CC-010, the most downstream station (Figure 3).

The Murray River exhibited a slightly alkaline pH, consistently averaging 8.2 throughout the mainstem (Table 2, Figure 3).

Table 2. Summary statistics for water hardness (mg/L) and pH at select sites on the Murray River mainstem. Sites are presented in an upstream to downstream order. Reference stations are shaded grey.

	Dissolved Hardness (mg/L)					pH				
Site	**Average**	**Min**	**Max**	**95th %ile**	**N**	**Average**	**Min**	**Max**	**95th %ile**	**N**
MOE-070	108	79	216	168	40	8.1	7.6	8.5	8.3	52
HD-004	127	81	207	189	94	8.2	7.6	8.4	8.3	91
TK-014	120	93	216	207	15	8.2	8.0	8.4	8.3	31
HD-014	143	55	200	191	100	8.2	7.3	8.4	8.3	99
HD-023	123	66	216	199	63	8.2	6.2	8.4	8.4	104
HD-028	149	88	191	186	49	8.2	8.0	8.4	8.3	78
HD-027	140	79	218	199	115	8.2	7.3	8.4	8.3	184
TK-029	132	93	205	202	13	8.2	8.0	8.4	8.3	31
HD-033	135	60	221	201	98	8.2	7.0	8.4	8.3	101
HD-021	155	81	225	212	90	8.2	7.7	8.3	8.3	89
CC-023	203	121	306	302	23	8.2	7.4	8.4	8.4	23
HD-040	161	96	234	222	30	8.2	8.1	8.5	8.4	30
MOE-067	133	98	191	170	40	8.1	7.9	8.4	8.3	44

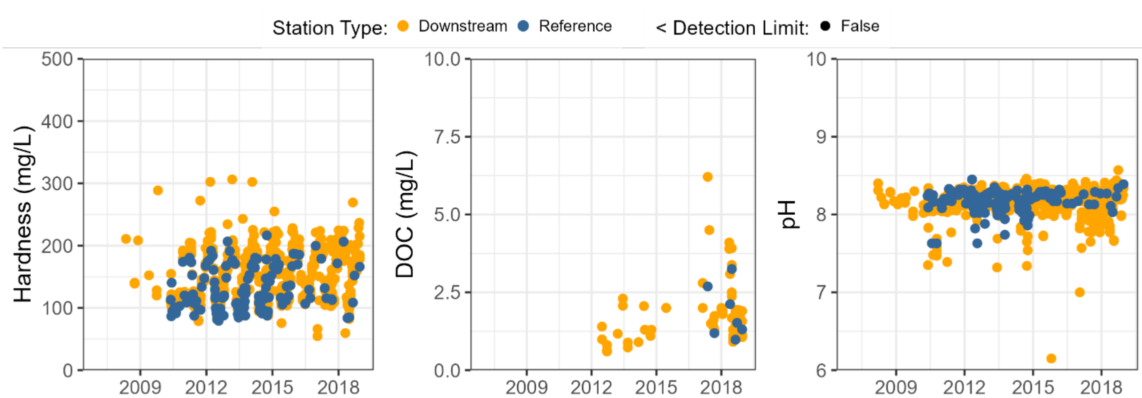

Figure 3. Hardness, DOC, and pH values in Murray River from 2008 to 2018. Each graph includes a pooled station dataset.

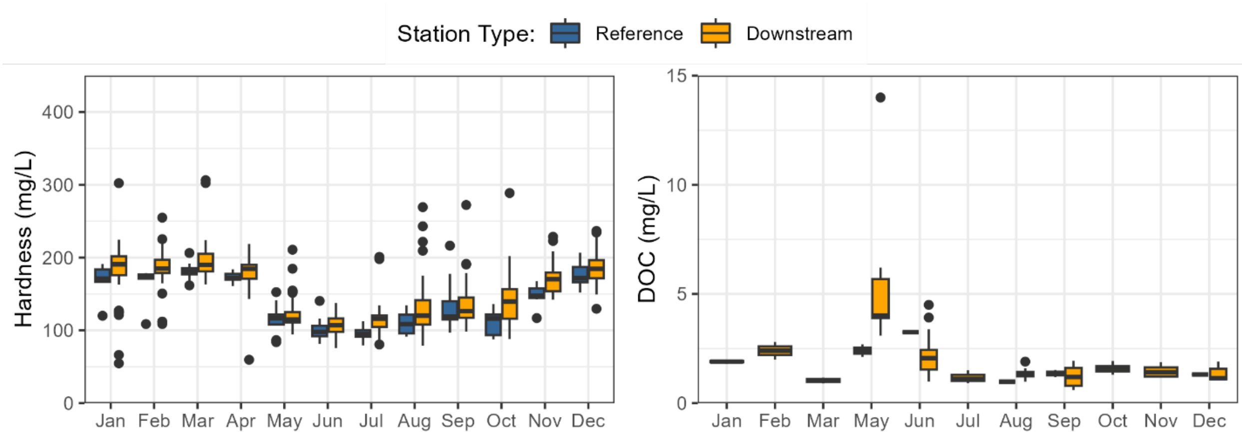

Figure 4. 2008 to 2018 hardness and DOC concentrations in the Murray River grouped by month (black dots represent outliers). Each graph includes a pooled station dataset for the waterbody.

Mining Region

M19 Creek

M19 Creek exhibited water hardness levels ranging from moderately soft to very hard, with concentrations ranging from 100 mg/L to 266 mg/L (Table 3, Figure 5). Similar to the Murray River mainstem, the lowest hardness values were observed during the freshet period (Figure 6). Higher hardness levels were noted downstream of mining areas compared to upstream locations. Additionally, this creek displayed slightly alkaline characteristics, with an average pH of 8.2. The average dissolved organic carbon (DOC) concentration was 11 mg/L.

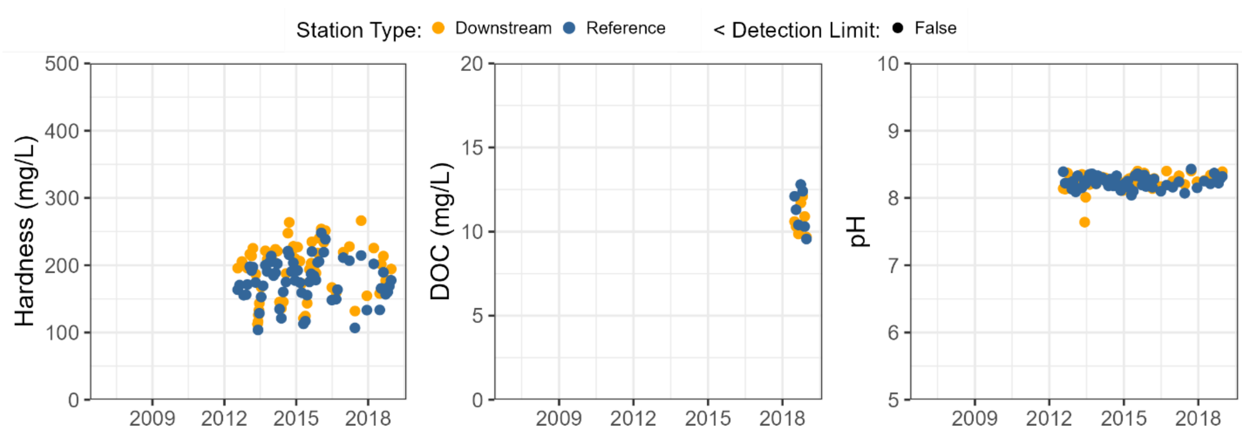

Figure 5. Hardnes, DOC, and pH values in M19 Creek from 2008 to 2018. Each graph includes a pooled station dataset.

Table 3. Water hardness, pH, and DOC data summary statistics for the waterbodies in the mining region of the KSWGSMR.

Parameter	Watershed	Waterbody	Average	Min	Max	95th %ile	N
Dissolved Hardness (mg/L)	**M19 Creek**	M19 Creek	184	104	266	240	121
	M20 Creek	M20 Creek	193	85	251	241	211
	Flatbed Creek	Gordon Creek	230	37	634	464	300
		Babcock Creek	169	36	328	290	243
		Flatbed Creek	197	78	343	263	133
	Wolverine River	Bullmoose Creek	NA	NA	NA	NA	NA
		Mast Creek	468	115	951	932	29
		Perry Creek	100	27	225	139	124
		Wolverine River	250	1	465	360	308
DOC (mg/L)	**M19 Creek**	M19 Creek	11	10	13	13	14
	M20 Creek	M20 Creek	4	2	5	5	14
	Flatbed Creek	Gordon Creek	3	1	14	5	301
		Babcock Creek	4	1	14	9	222
		Flatbed Creek	6	1	20	14	94
	Wolverine River	Bullmoose Creek	NA	NA	NA	NA	NA
		Mast Creek	4	1	11	10	13
		Perry Creek	NA	NA	NA	NA	NA
		Wolverine River	NA	NA	NA	NA	NA
pH	**M19 Creek**	M19 Creek	8.2	7.6	8.4	8.4	118
	M20 Creek	M20 Creek	8.3	7.7	8.6	8.5	288
	Flatbed Creek	Gordon Creek	7.9	6.5	8.4	8.2	355
		Babcock Creek	7.9	6.8	8.5	8.3	260
		Flatbed Creek	8.1	7.1	8.5	8.4	162
	Wolverine River	Bullmoose Creek	8.2	7.9	8.4	8.3	29
		Mast Creek	8.3	7.6	8.5	8.4	86
		Perry Creek	7.9	6.2	8.4	8.2	135
		Wolverine River	8.2	6.6	8.5	8.4	310

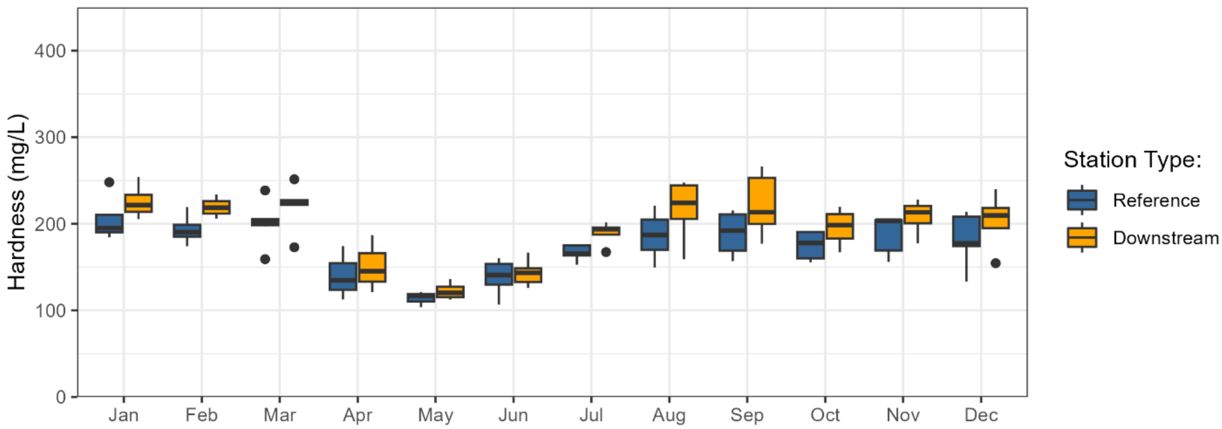

Figure 6. 2008 to 2018 hardness concentrations in the M19 Creek grouped by month (black dots represent outliers).

M20 Creek

M20 Creek displayed water hardness levels ranging from moderately soft to very hard, with concentrations varying between 85 and 251 mg/L (Figure 7, Table 3). Additionally, it exhibited a slightly alkaline pH of 8.3 and an average dissolved organic carbon (DOC) concentration of 4 mg/L. Reference site information was not available for this watershed.

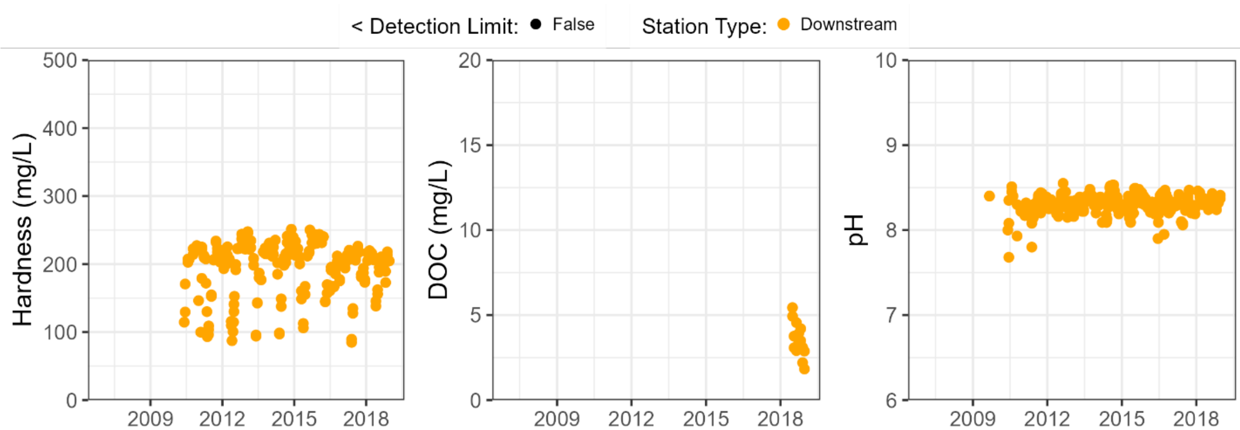

Figure 7. Hardness, DOC, and pH values in M20 Creek from 2008 to 2018. Each graph includes a pooled station dataset.

Flatbed Creek Watershed (Gordon Creek, Babcock Creek, Flatbed Creek)

Gordon Creek had moderately soft/hard to very hard water, with hardness increasing in stations downstream of mining areas over time (Table 3, Figure 8). Seasonal differences were observed with lowest hardness values occurring during freshet in May and June (Figure 9). Hardness was considerably higher and more variable in stations downstream of mining operations compared to the upstream reference station. Gordon Creek was neutral with an average pH of 7.9 and no apparent differences between upstream and downstream areas. DOC was relatively low throughout the waterbody (average of 3 mg/L), with some high values occurring during the freshet in 2015. DOC was slightly higher in downstream stations compared to the upstream reference area.

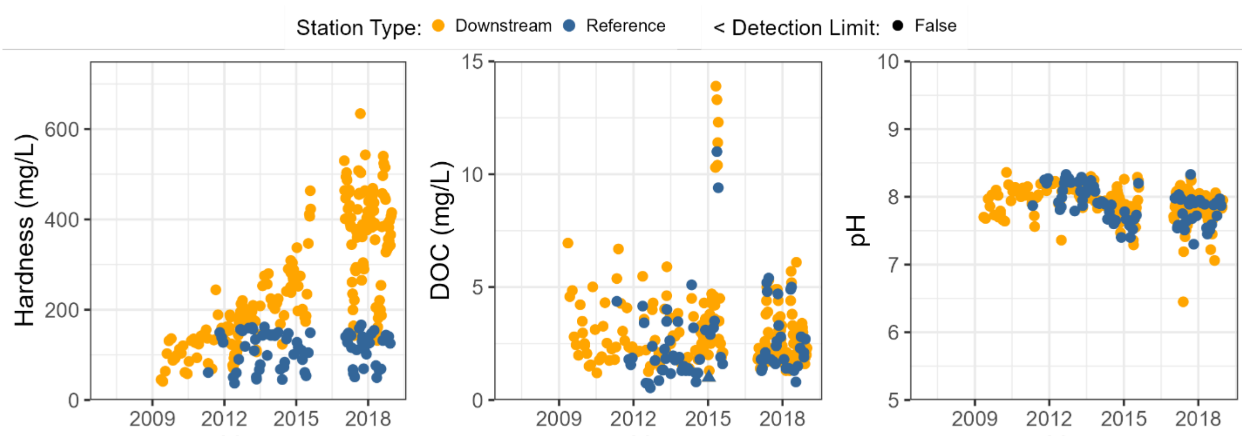

Figure 8. Hardness, DOC and pH values in Gordon Creek from 2008 to 2018. Each graph includes a pooled station dataset.

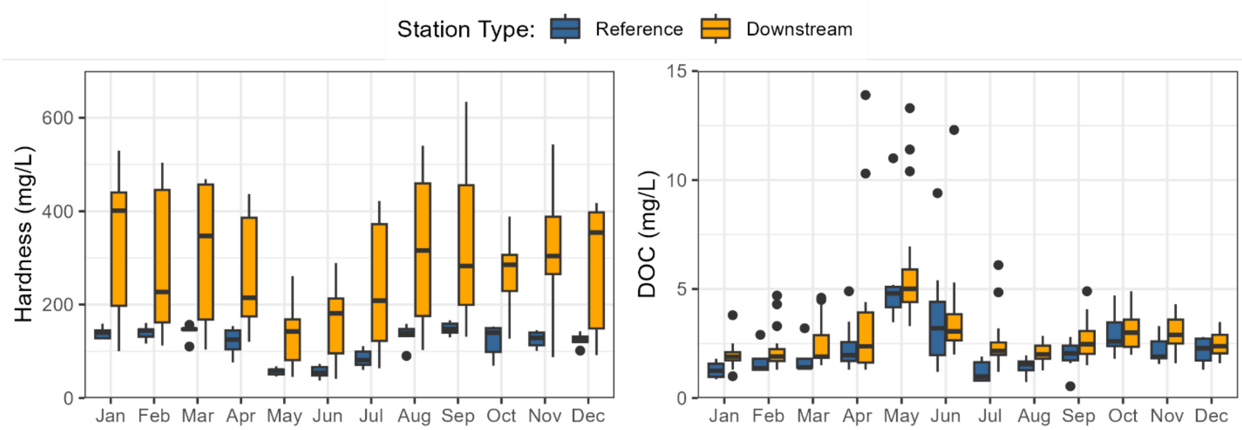

Figure 9. Gordon Creek 2008 to 2018 hardness and DOC results grouped by month (black dots represent outliers).

Hardness in Babcock Creek increased from upstream to downstream, changing from soft to moderately soft to very hard (Table 3). Similar to Gordon Creek, hardness in downstream stations of Babcock Creek appears to be increasing over time (Figure 10, Azimuth 2021), and lowest hardness values occurred during the freshet in May and June (Figure 11). Hardness in Babcock Creek was higher and more variable downstream of mining operations compared to upstream. The average pH in Babcock Creek varied between 6.8 and 8.5. DOC ranged from 1 to 14 mg/L, was slightly higher in downstream stations compared to the upstream reference area with highest concentrations observed during freshet.

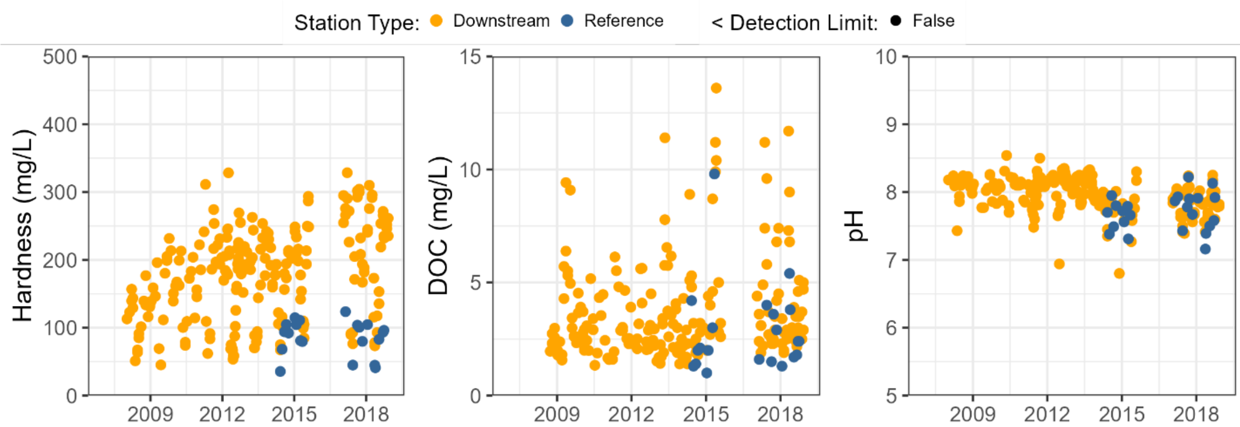

Figure 10. Hardness, DOC, and pH values in Babcock Creek from 2008 to 2018. Each graph includes a pooled station dataset.

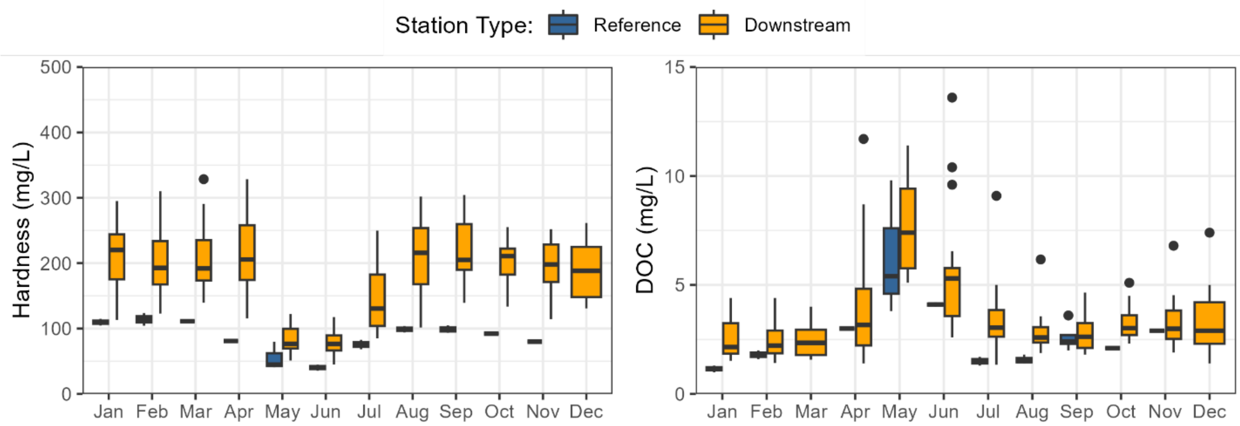

Figure 11. 2008 to 2018 hardness and DOC results in Babcock Creek grouped by month (black dots represent outliers).

Flatbed Creek had limited reference data. The waterbody was characterized by moderately soft/hard to very hard water ranging from 78 to 343 mg/L, with no obvious differences between downstream and upstream areas (Table 3, Figure 12 - 13). Flatbed Creek was slightly alkaline, with an average pH of 8.1. DOC ranged from 1 to 20 mg/L, with the highest values occurring during freshet in May and June.

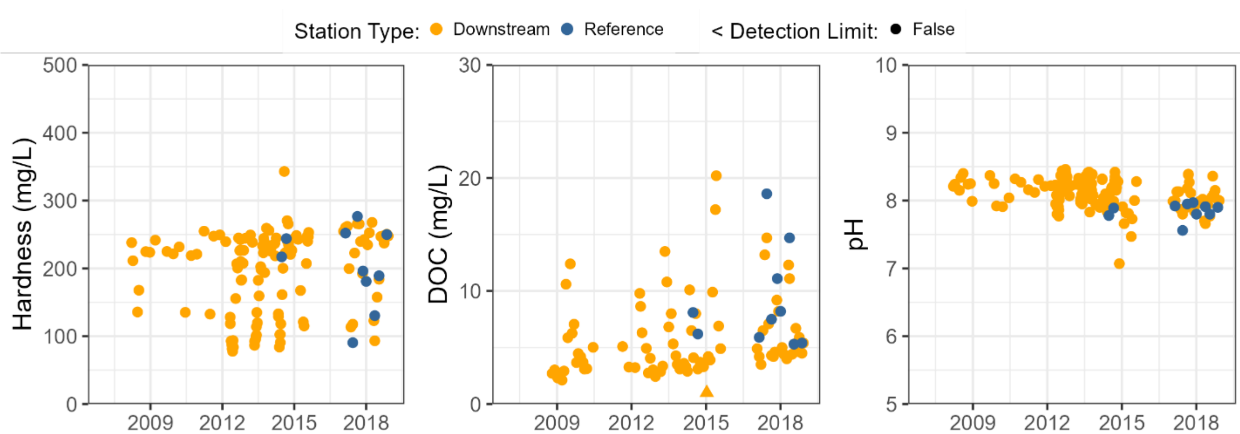

Figure 12. Hardness, DOC, and pH values in Flatbed Creek from 2008 to 2018.

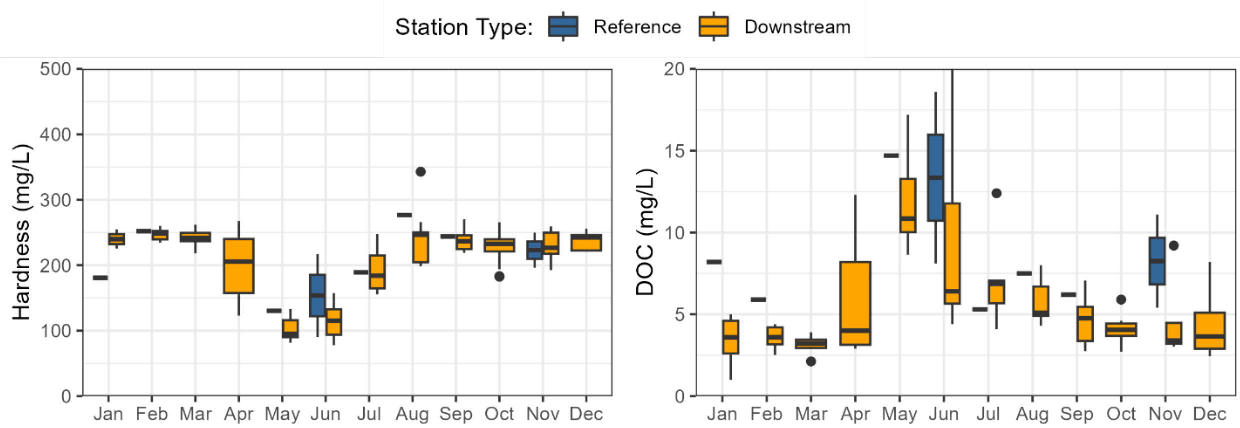

Figure 13. 2008 to 2018 Flatbed Creek hardness and DOC grouped by month (black dots represent outliers).

Wolverine River Watershed (Bullmoose Creek, Mast Creek, Perry Creek, Wolverine River)

For Bullmoose Creek, only pH data were available, and these were limited to two sampling events at multiple sites. These data indicate that this waterbody is slightly alkaline, with an average pH of 8.2 (Table 3).

Mast Creek exhibited the highest hardness values recorded in the Wolverine River watershed, with an average of 468 mg/L and ranging from moderately hard to very hard (Figure 14, Table 3). Hardness levels were notably higher in sites downstream of mining activities compared to the upstream reference area. Additionally, this waterbody displayed slightly alkaline characteristics, with an average pH of 8.3. The concentration of dissolved organic carbon (DOC) was low, with an average of 4 mg/L, ranging from 1 to 11 mg/L.

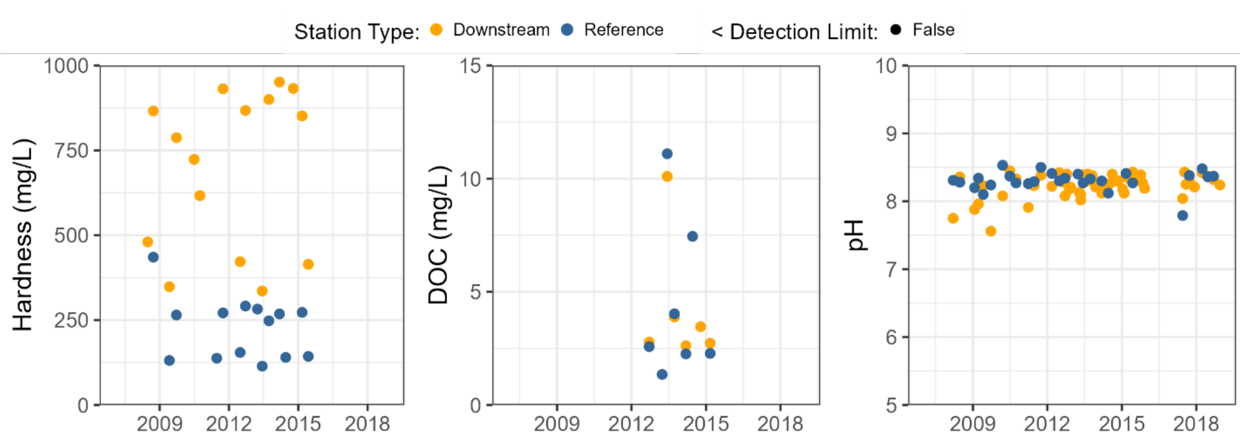

Figure 14. Hardness, DOC and pH values in Mast Creek from 2008 to 2018. Each graph includes pooled station dataset for the waterbody.

In Perry Creek, water hardness ranged from very soft to hard, with concentrations ranging from 27 to 225 mg/L (Figure 15, Table 3). The lowest values were observed during the freshet period (Figure 16). Unlike other mining creeks in the Wolverine River watershed, there didn't appear to be a notable difference in hardness between upstream and downstream mining areas.

The water in Perry Creek was neutral, with an average pH of 7.9 throughout the waterbody. However, dissolved organic carbon (DOC) data were not available for Perry Creek.

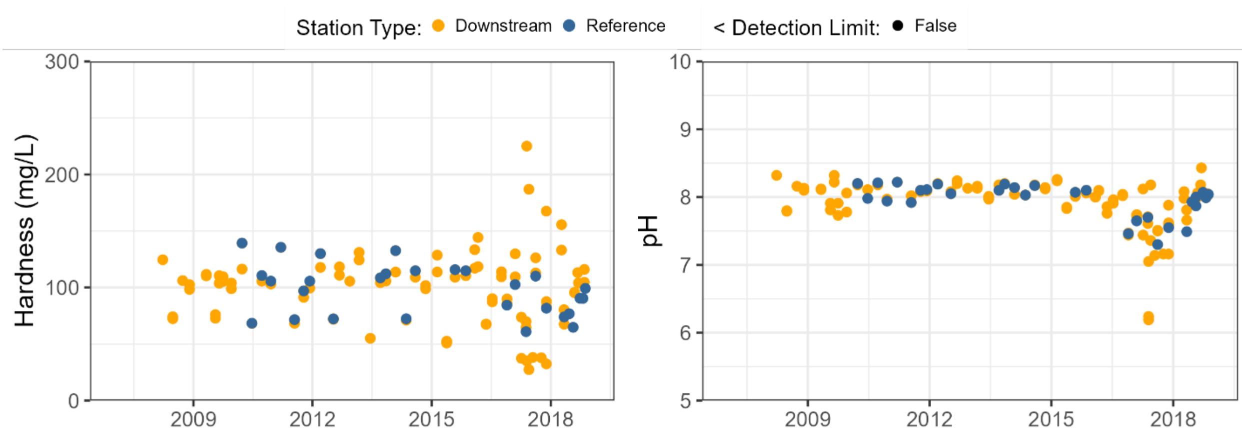

Figure 15. Hardness and pH values in Perry Creek from 2008 to 2018. Each graph includes a pooled station dataset for the waterbody.

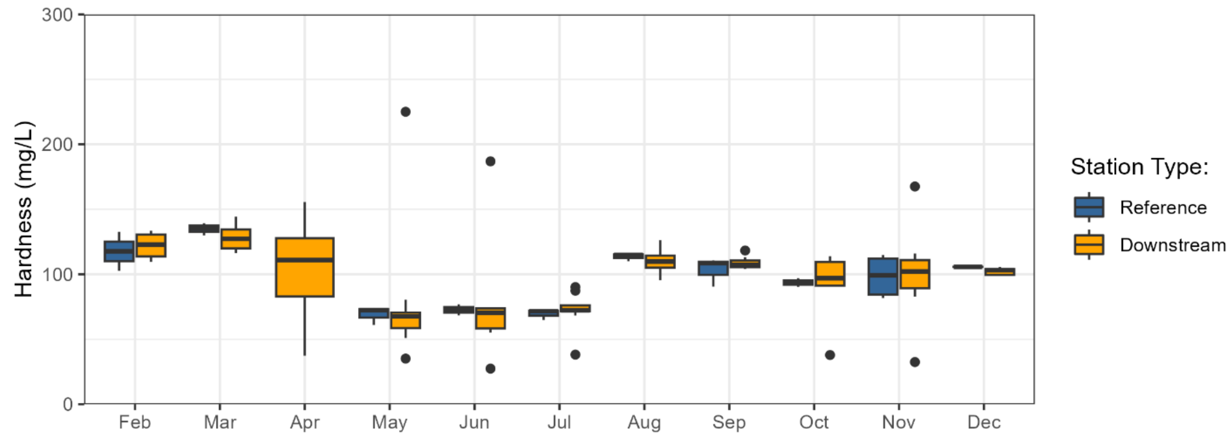

Figure 16. 2008 to 2018 Perry Creek hardness grouped by month (black dots represent outliers). Each graph includes a pooled station dataset for the waterbody.

In the Wolverine River, the average hardness ranged from moderately soft to very hard, with an average hardness of 250 mg/L (Table 3, Figure 17). Hardness values observed at stations downstream of mining areas were higher than those at upstream reference stations, except during freshet (Figure 18). Throughout the waterbody, hardness generally followed a similar seasonal pattern observed in other waterbodies, with the lowest values occurring during freshet (Figure 18). The Wolverine River was slightly alkaline, with an average pH of 8.2. However, dissolved organic carbon (DOC) data were not available for this waterbody.

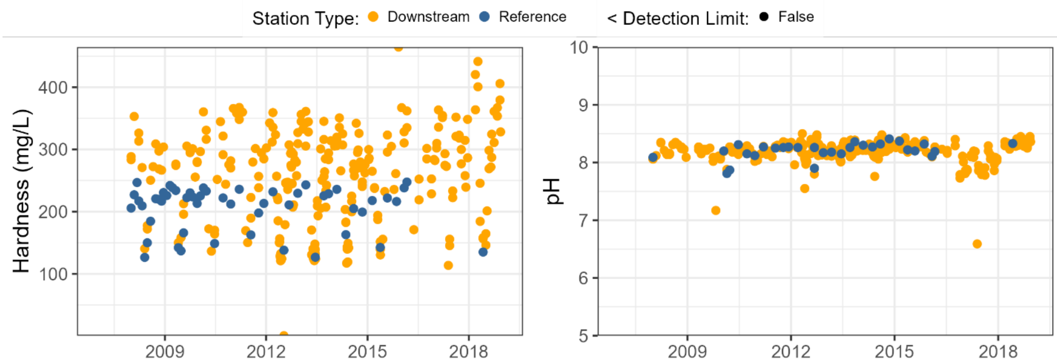

Figure 17. Hardness and pH values in Wolverine River from 2008 to 2018. Each graph includes a pooled station dataset.

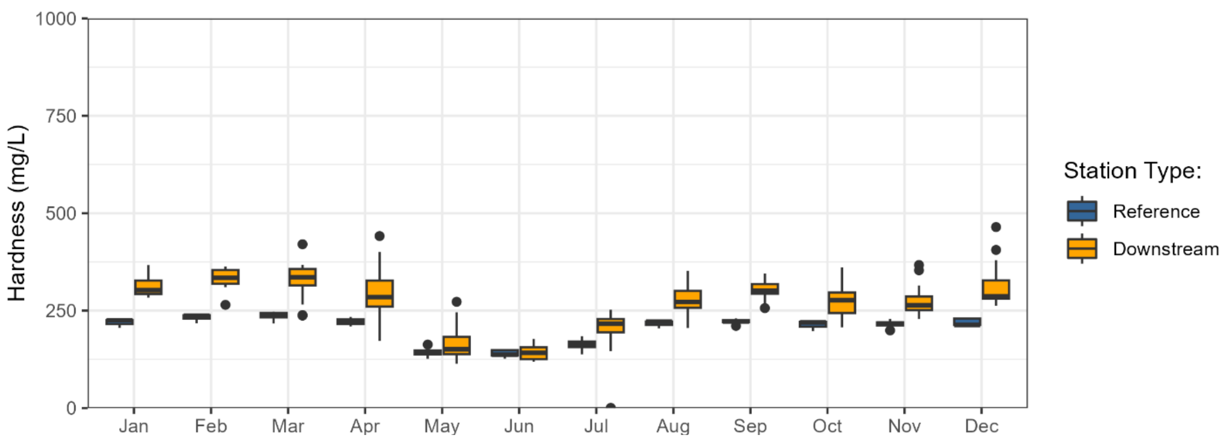

Figure 18. Hardness and pH values in Wolverine River from 2008 to 2018 grouped by month (black dots represent outliers). Each graph includes pooled station dataset for the waterbody.

Turbidity and Total Suspended Solids

Turbidity is a measure of suspended particulate matter in a waterbody, including silt, clay, organic material, and microorganisms. Elevated turbidity increases the total available surface area of suspended solids, which can promote bacterial growth. Additionally, high turbidity reduces light penetration and may interfere with the disinfection of drinking water. Since turbidity levels can naturally vary, Water Quality Guidelines (WQGs) for turbidity are based on increases over background or upstream conditions. In this assessment, the most conservative WQG, the B.C. WQG for the protection of aquatic life, was utilized.

According to the guidelines, the increase in turbidity over background or reference conditions should not exceed:

- 2 NTU for long durations (30 days) or 8 NTU for short durations (24 hours) during clear flow periods.
- 5 NTU at any time when background turbidity ranges from 8 to 50 NTU.
- 10% over background at any time when background turbidity exceeds 50 NTU.

Total Suspended Solids (TSS) are a measure of particulate matter suspended in the water column and are closely related to turbidity. Suspended materials can harm fish gills and disrupt fish habitat by smothering spawning beds. Similar to turbidity, water quality guidelines for TSS are based on increases over upstream or background conditions. In this assessment, the most conservative WQG for the protection of aquatic life, the B.C. WQG, was applied.

According to the guidelines, the increase in TSS over background or reference conditions should not exceed:

- 5 mg/L for long durations (30 days) or 25 mg/L for short durations (24 hours) during clear flow periods.
- 10 mg/L at any time when background TSS ranges from 25 to 100 mg/L.
- 10% above background at any time when background TSS exceeds 100 mg/L.

Murray River

The average turbidity in the Murray River mainstem ranged between 6 and 44 NTU, with the highest levels recorded at the three most downstream stations (Table 4, Figures 19 - 20). A maximum turbidity of 218 NTU was observed at the most downstream station (CC-010) in April 2017. Turbidity levels also exhibited seasonal variation, with the highest and most variable values occurring during freshet between April and June (Figure 20).

Table 4. Summary statistics for turbidity (NTU) at select sites on the Murray River mainstem. Sites are presented in an upstream to downstream order. Reference stations are shaded grey.

Site	Average	Min	Max	95th %ile	N
HD-004	6	0.4	56	26	91
HD-014	6	0.6	77	27	100
HD-023	9	0.3	74	34	126
HD-028	4	0.7	35	16	80
HD-027	11	0.7	172	47	208
HD-033	8	0.8	109	33	99
HD-021	9	0.1	90	49	91
CC-023	19	0.4	69	67	23
HD-040	12	0.7	107	48	30
CC-010	44	1.4	218	218	16

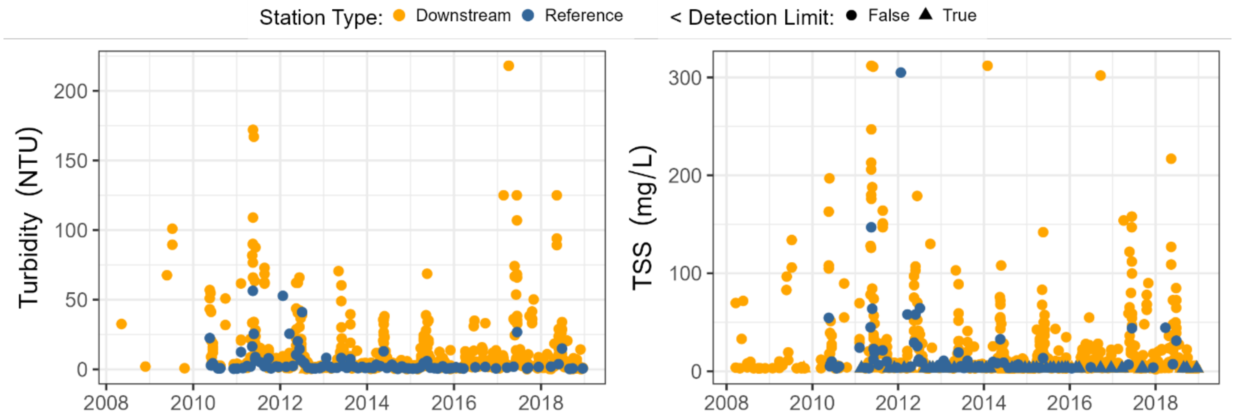

Figure 19. Turbidity concentrations in the Murray River from 2008 to 2018. The WQG is not presented because it is calculated on a site-specific basis, and the figure includes multiple monitoring sites.

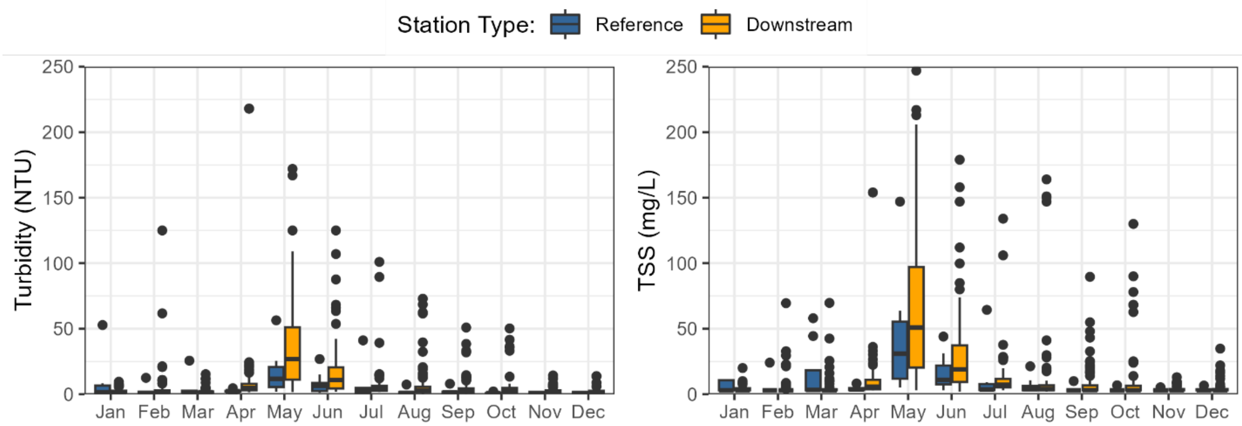

Figure 20. 2008 to 2018 turbidity and TSS concentrations in the Murray River by month (black dots represent outliers). Each graph includes a pooled station dataset for the waterbody. The WQG is not presented because it is calculated on a site-specific basis, and the figure includes multiple monitoring sites.

Total Suspended Solids (TSS) exhibited a similar pattern to turbidity, with higher average concentrations observed at stations located further downstream in the mainstem (Table 5). Similarly, the highest average concentrations were recorded at CC-023 and CC-010. The maximum TSS values (312 mg/L) were observed at CC-023 and HD-027. As with turbidity, TSS concentrations were elevated and more variable during freshet between April and June (Figure 19 - 20).

Table 5. Summary statistics for TSS (mg/L) at select sites on the Murray River mainstem. Sites are presented in an upstream to downstream order. Reference stations are shaded grey.

Site	Average	Min	Max	95th %ile	N
HD-004	16	3	305	58	89
TK-014	12	3	106	43	32
HD-014	12	3	180	41	100
HD-023	19	3	176	85	126
HD-028	7	3	53	27	79
HD-027	17	3	312	69	206
TK-029	21	3	134	100	52
HD-033	15	3	247	44	97
HD-021	20	3	213	98	88
CC-023	68	3	312	300	23
HD-040	29	3	302	127	30
CC-010	39	3	154	154	16

Mining Region

Turbidity in the central mining region varied from 0.1 to 1,160 NTU, with average concentrations ranging between 2 and 52 NTU (Table 6, Figure 21). Total Suspended Solids (TSS) in the mining region ranged from 1 to 1,140 mg/L, with average concentrations ranging between 5 and 47 mg/L. During freshet, turbidity and TSS peaked in M20 Creek, Gordon Creek, and Flatbed Creek, with M20 Creek recording the highest maximum values (Table 6, Figures 21 - 23). In areas where data for upstream reference stations were available, turbidity and TSS generally exhibited lower levels upstream of mining operations, particularly during freshet.

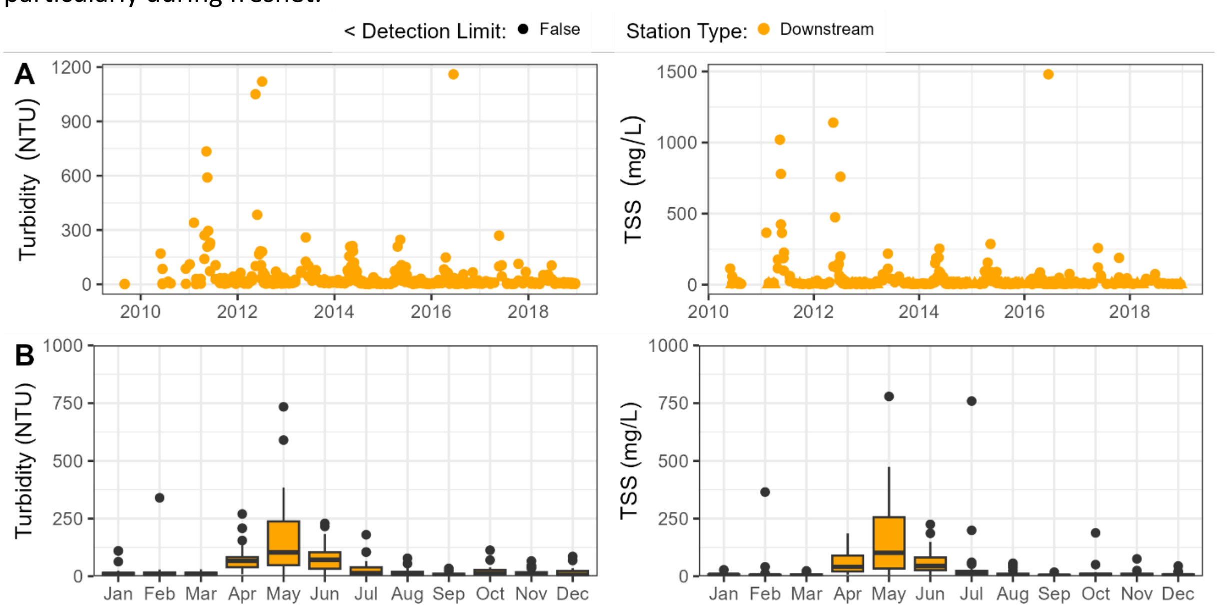

*Figure 21. Turbidity and TSS measured in M20 Creek between 2008 and 2018. **A:** All values plotted individually. **B**: Values pooled by month. Each graph includes a pooled station dataset for the waterbody. The WQG is not presented because it is calculated on a site-specific basis, and the figure includes multiple monitoring sites.*

Table 6. Turbidity and total suspended solids summary statistics for the waterbodies in the mining region of the KSWGSMR.

Parameter	Watershed	Waterbody	Average	Min	Max	95th %ile	N
Turbidity (NTU)	**M19 Creek**	M19 Creek	2	0.3	29	6	120
	M20 Creek	M20 Creek	52	0.6	1,160	207	332
	Flatbed Creek	Gordon Creek	19	0.2	320	94	620
		Babcock Creek	11	0.1	323	49	680
		Flatbed Creek	18	0.3	361	75	179
	Wolverine River	Bullmoose Creek	6	0.2	42	17	29
		Mast Creek	8	0.1	110	25	63
		Perry Creek	4	0.1	112	17	284
		Wolverine River	4	0.1	114	16	311
TSS (mg/L)	**M19 Creek**	M19 Creek	5	3	47	16	119
	M20 Creek	M20 Creek	47	3	1,480	188	326
	Flatbed Creek	Gordon Creek	19	2	382	82	622
		Babcock Creek	11	2	947	40	682
		Flatbed Creek	28	2	708	109	181
	Wolverine River	Mast Creek	11	3	162	33	121
		Perry Creek	7	1	260	14	278
		Wolverine River	13	2	320	57	306

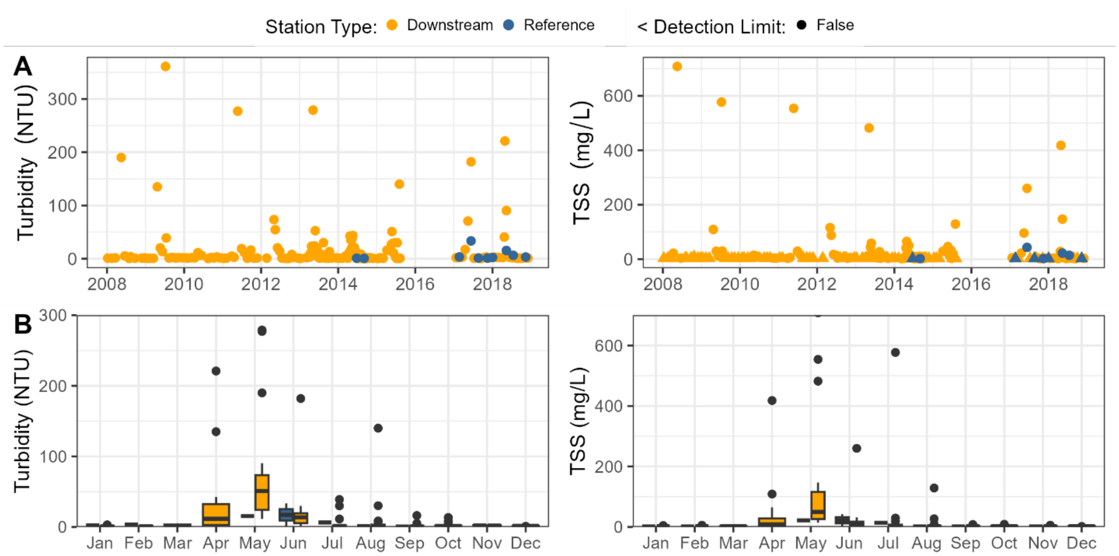

*Figure 22. Turbidity and TSS in the Flatbed Creek between 2008 and 2018. **A:** All values plotted individually. **B**: Values pooled by month (black dots represent outliers). Each graph includes a pooled station dataset for the waterbody. The WQG is not presented because it is calculated on a site-specific basis, and the figure includes multiple monitoring sites.*

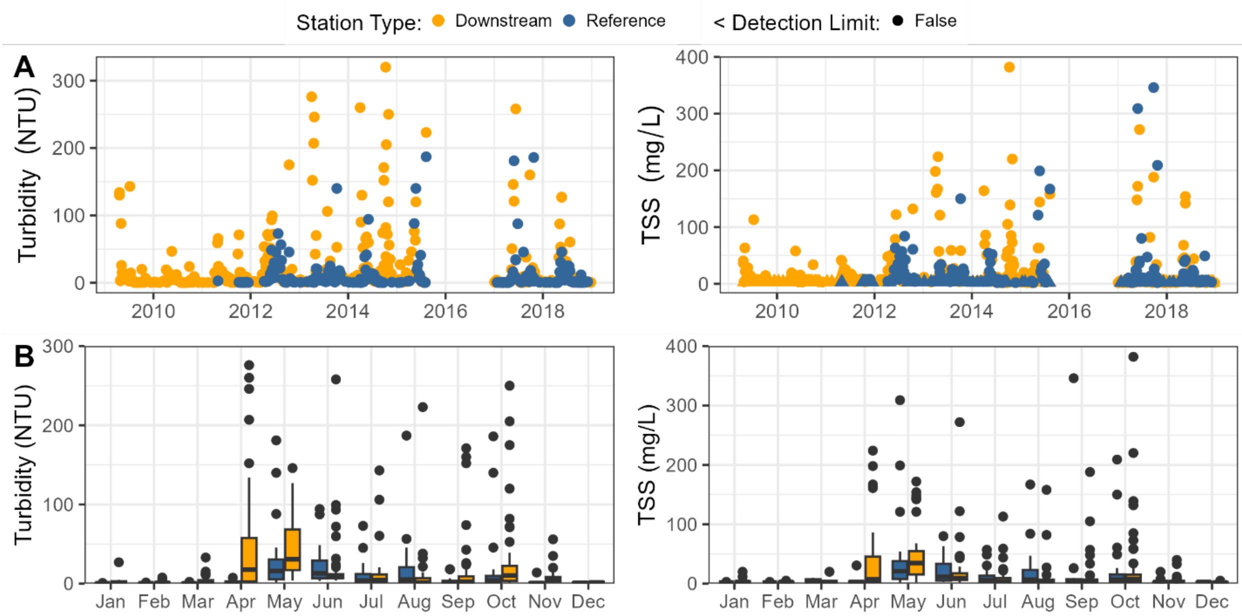

Figure 23. Turbidity and TSS concentrations measured in Gordon Creek between 2008 and 2018. ***A:*** *All values plotted individually.* ***B****: Values pooled by month (black dots represent outliers). Each graph includes a pooled station dataset for the waterbody. The WQG is not presented because it is calculated on a site-specific basis, and the figure includes multiple monitoring sites.*

True Colour

True color is a measure of dissolved organic and inorganic compounds in water and their capacity to absorb different light frequencies. It is quantified in true color units (TCU), and higher values are often associated with swamps and bogs. Color is considered a pollutant in terms of aesthetics, and elevated levels can have an impact on aquatic life (ENV 1999a). The true color Water Quality Guideline (WQG) stipulates a maximum increase of 5 TCU above background levels to safeguard aquatic life. Increases exceeding 5 TCU above ambient levels can affect the depth of the euphotic zone and the photosynthetic rates of algae and macrophytes (ENV 1999a).

Murray River

Overall, true color in the Murray River was low, with most of the results falling below the method detection limit (MDL) of 5 TCU (Table 7; Figure 24). Average color increased from upstream to downstream; however, elevated levels were also observed at upstream sites, primarily during freshet in May and June. When comparing upstream results (at MOE-070) to downstream results (at MOE-067), the Water Quality Guideline (WQG) was exceeded 63% of the time.

Table 7. Summary statistics for true colour (TCU) at select sites on the Murray River mainstem. Sites are presented in an upstream to downstream order. Shaded rows are reference stations.

Site	Average	Min	Max	95th %ile	% < MDL	N
MOE-070	8.7	1.55	80	15	22	50
HD-004	5.3	0.74	19	14	57	86
HD-014	5.3	0.56	24	14	59	94
HD-023	8.4	0.58	123	16	51	57
HD-028	5.3	1.37	13	12	60	48
HD-027	6.2	0.77	25	14	57	105
HD-033	7.5	0.38	175	16	53	97
HD-021	5.7	0.46	41	17	56	80
CC-023	19.9	0.42	231	29	43	23
MOE-067	18.9	0.69	100	80	19	43
CC-010	22.2	4.32	82	64	13	16

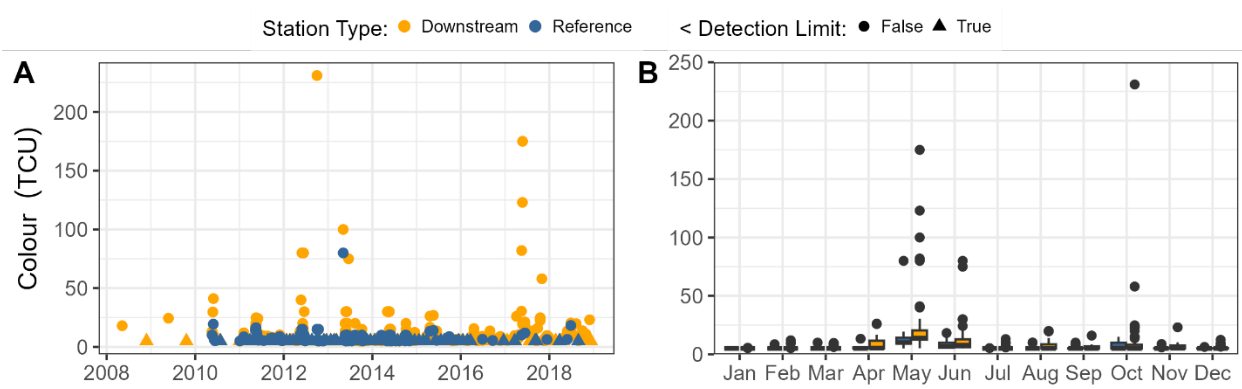

*Figure 24. True colour measured in Murray River between 2008 and 2018. **A:** All values plotted individually. **B**: Values pooled by month (black dots represent outliers). Each graph includes a pooled station dataset for the waterbody. The WQG is not presented because it is calculated on a site-specific basis, and the figure includes multiple monitoring sites.*

Mining Region

Color data in the mining region creeks were limited. True color ranged from 5 TCU up to a maximum of 474 TCU (Table 8, Figures 25 – 29). The data indicated elevated levels in the Wolverine River, M20 Creek, M19 Creek, Flatbed Creek, and Perry Creek during freshet. Slightly higher color levels were observed upstream of mining areas in M19 Creek, although this phenomenon was not observed in the other mining region waterbodies. No color data were available for Bullmoose Creek, Mast Creek, Babcock Creek, or Gordon Creek. Assessing true color WQGs in the mining region was challenging due to limited concurrent background site measurements required for comparison to the downstream sites.

Table 8. Summary statistics for true colour (TCU) for the waterbodies in the mining region of the KSWGSMR.

Watershed	Waterbody	Average	Min	Max	95th %ile	N
M19 Creek	M19 Creek	36	8	92	78	108
M20 Creek	M20 Creek	14	5	260	35	199
Flatbed Creek	Flatbed Creek	33	5	150	86	55
Wolverine River	Perry Creek	17	5	90	51	114
	Wolverine River	10	5	474	20	305

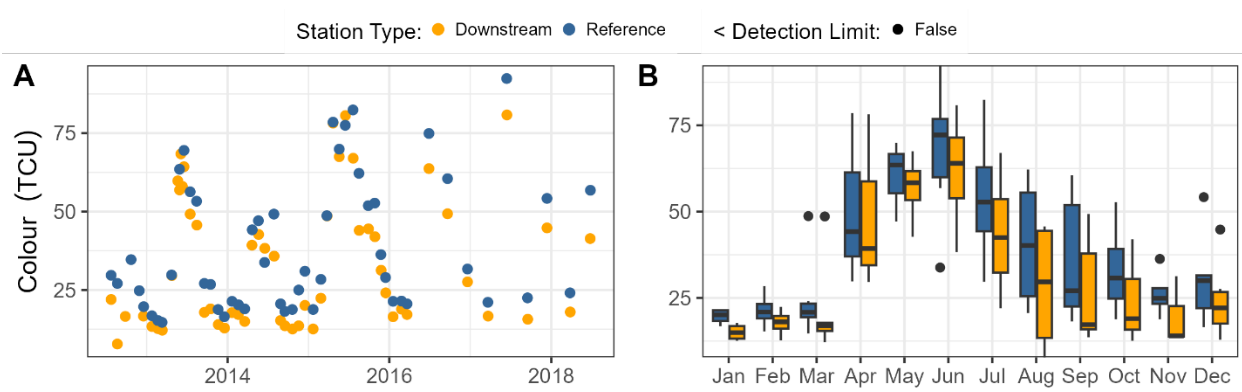

*Figure 25. Colour measured in M19 Creek between 2008 and 2018. **A:** All values plotted individually. **B**: Values pooled by month (black dots represent outliers). Each graph includes a pooled station dataset for the waterbody.*

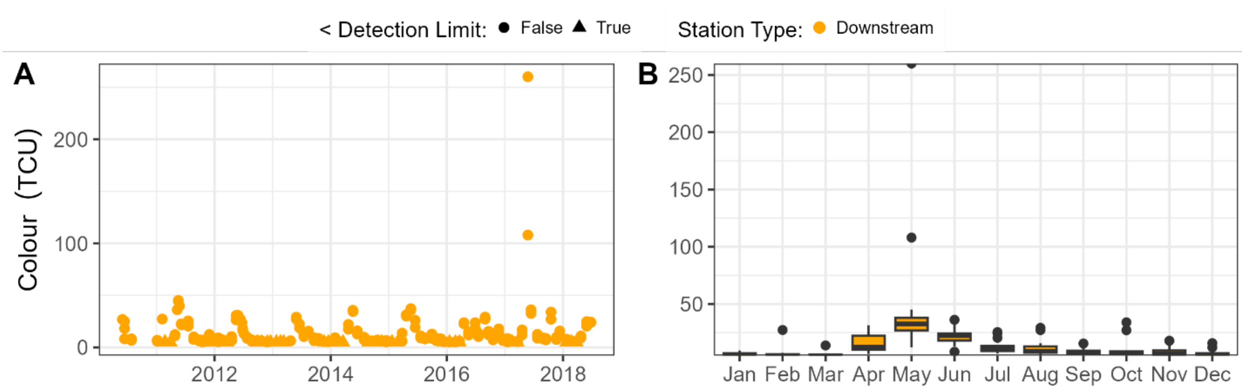

*Figure 26. Colour measured in the M20 Creek between 2008 and 2018. **A:** All values plotted individually. **B**: Values pooled by month (black dots represent outliers). Each graph includes a pooled station dataset for the waterbody.*

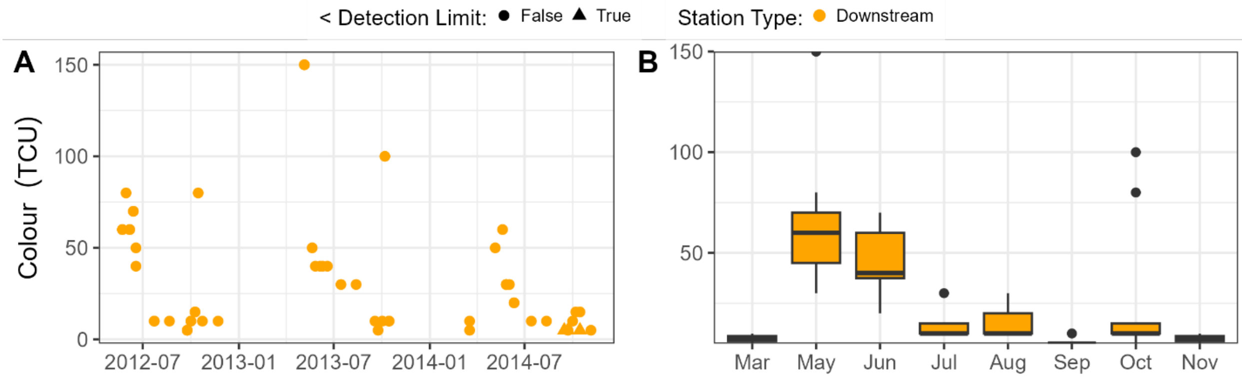

Figure 27. Colour measured in Flatbed Creek between 2008 and 2018. ***A:*** *All values plotted individually.* ***B****: Values pooled by month (black dots represent outliers). Each graph includes a pooled station dataset for the waterbody.*

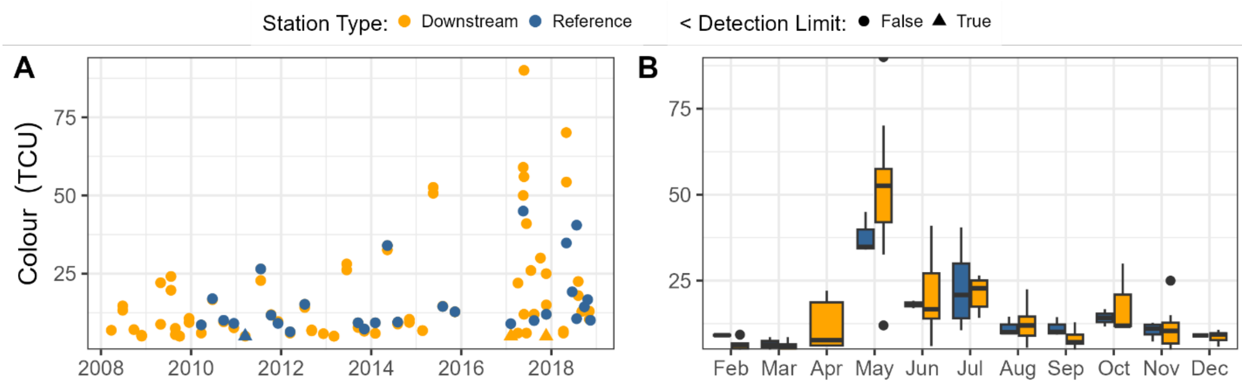

Figure 28. Colour measured in Perry Creek watershed between 2008 and 2018. ***A:*** *All values plotted individually.* ***B****: Values pooled by month (black dots represent outliers). Each graph includes a pooled station dataset for the waterbody.*

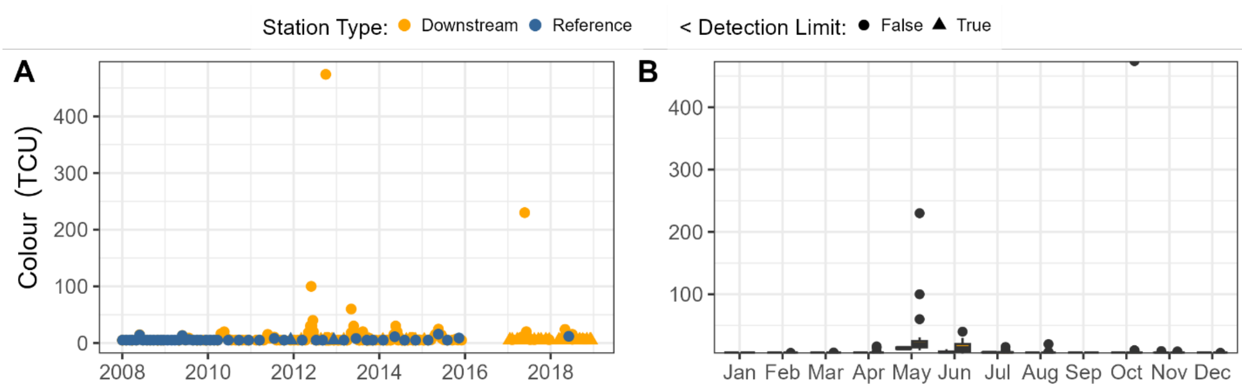

Figure 29. True colour measured in Wolverine River between 2008 and 2018. ***A:*** *All values plotted individually.* ***B****: Values pooled by month (black dots represent outliers). Each graph includes a pooled station dataset for the waterbody.*

Temperature

Water temperature affects the solubility of many chemical compounds and can influence the impact of pollutants on aquatic life. Elevated temperatures increase metabolic oxygen demand, which, coupled with reduced oxygen solubility, affects many aquatic species. The British Columbia aquatic life WQG for temperature are shown in Table 9. Due to limited data availability, the most conservative WQG used in this assessment was the maximum daily temperature of 15°C for streams inhabited by Bull Trout and/or Dolly Varden.

Table 9. B.C. temperature water quality guidelines (°C) for aquatic life protection (ENV, 2001b).

Water Use: Aquatic Life	Water quality guideline
Streams with Bull Trout and/or Dolly Varden	• Maximum Daily Temperature is 15 °C • Maximum Incubation Temperature is 10 °C • Minimum Incubation Temperature is 2 °C • Maximum Spawning Temperature is 10 °C
Streams with known fish distribution	• + or - 1 °C change beyond optimum temperature range (Table 2 in ENV 2001b) for each life history phase of the most sensitive salmonid species present. • Hourly rate of change not to exceed 1 °C
Streams with unknown fish distribution	• Average weekly maximum temperature = 18 °C • Maximum Daily Temperature = 19 °C • Hourly rate of change not to exceed 1 °C • Maximum Incubation Temperature = 12 °C (spring and fall)

<u>Murray River</u>

Average temperatures throughout the mining region ranged between 2.4 and 8.4°C (Table 10, Figures 31 – 36). Gordon Creek and Babcock Creek had limited temperature data available, collected between 2017 and 2018, with the least amount of data available for Bullmoose Creek. The highest temperatures were observed in Flatbed Creek, exceeding the maximum daily temperature WQG of 15°C for streams with Bull Trout and/or Dolly Varden. Temperatures were generally higher in the summer months, reaching a peak of 20°C in Flatbed Creek, while lower temperatures occurred in the winter months, dropping to just above 0°C. Higher temperatures were observed downstream of mining areas in Gordon and Babcock Creek compared to upstream reference areas. No temperature data were available for Perry Creek, M19 Creek, or M20 Creek.

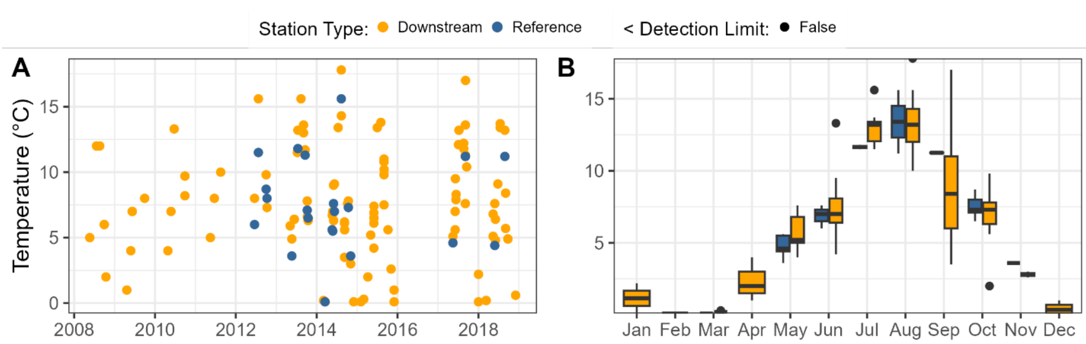

*Figure 30. Temperature measured in Murray River between 2008 and 2018. **A:** All values plotted individually. **B:** Values pooled by month (black dots represent outliers). Each graph includes a pooled station dataset for the waterbody.*

Mining Region

Average temperatures throughout the mining region ranged between 2.4 and 8.4°C (Table 10, 31 – 36). Gordon Creek and Babcock Creek temperature data were limited to data collected between 2017 and 2018, with least amount of data available for Bullmoose Creek. The highest temperatures were observed in Flatbed Creek, above the maximum daily temperature WQG of 15°C for stream with Bull Trout and/or Dolly Varden. Temperatures were higher in the summer months, reaching a high of 20°C in Flatbed Creek while lower temperatures occurred in the winter months, reaching a low of just above 0°C. Higher temperatures were observed downstream of mining areas in Gordon and Babcock Creek compared to upstream reference areas. No temperature data were available for Perry Creek, M19 Creek, or M20 Creek.

Table 10. Temperature (°C) data summary statistics for the waterbodies in the mining region of the KSWGSMR.

Watershed	Waterbody	Average	Min	Max	95th %ile	N
Flatbed Creek	Gordon Creek	4.2	0.1	14.9	11.5	161
	Babcock Creek	5.6	0.1	18.5	15.2	171
	Flatbed Creek	8.4	0.0	20.2	17.5	86
Wolverine River	Bullmoose Creek	2.4	0.8	4.6	4.5	7
	Mast Creek	5.4	0.1	13.9	12.1	85
	Wolverine River	7.3	0.7	13.6	13.2	16

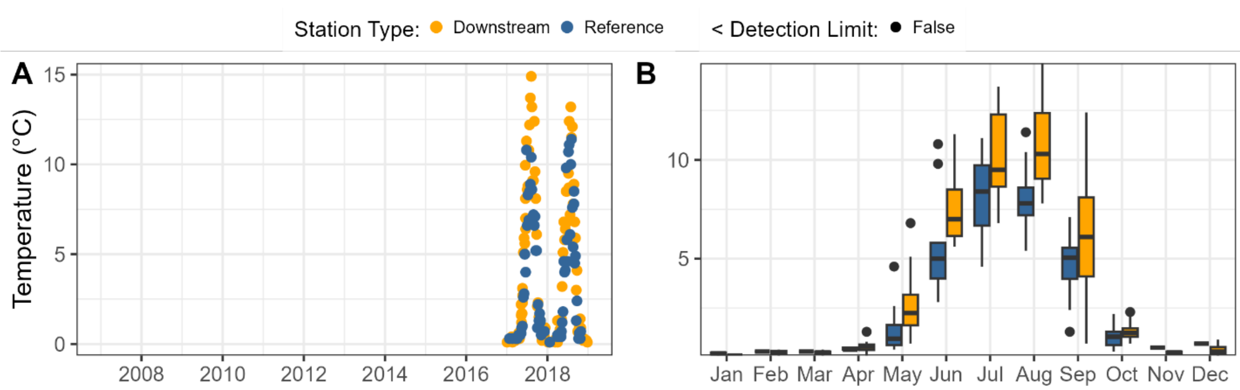

Figure 31. Temperature measured in Gordon Creek between 2008 and 2018. ***A:*** *All values plotted individually.* ***B****: Values pooled by month (black dots represent outliers). Each graph includes a pooled station dataset for the waterbody.*

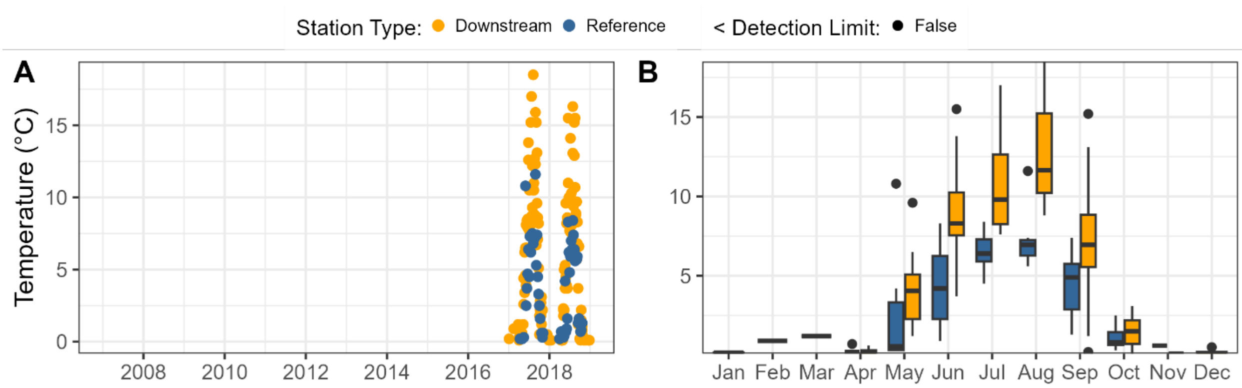

*Figure 32. Temperature measured in Babcock Creek between 2008 and 2018. **A:** All values plotted individually. **B**: Values pooled by month (black dots represent outliers). Each graph includes a pooled station dataset for the waterbody.*

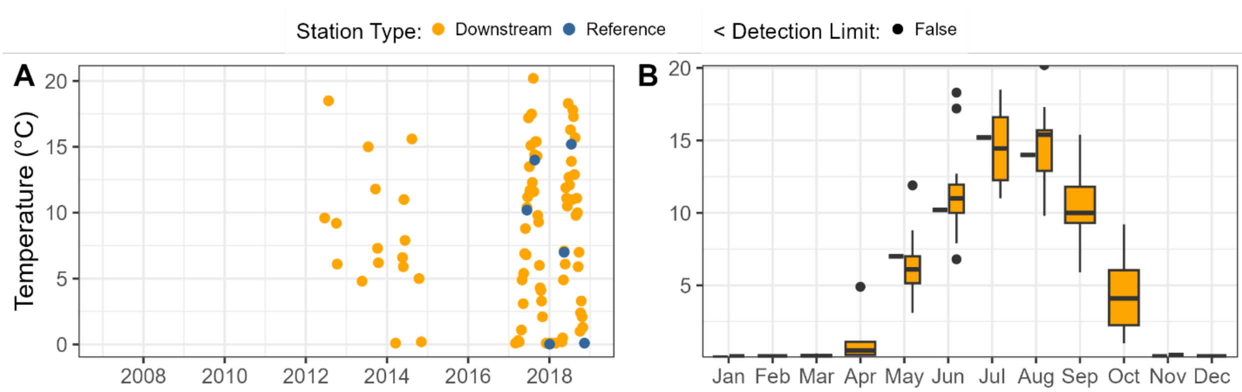

*Figure 33. Temperature measured in Flatbed Creek between 2008 and 2018. **A:** All values plotted individually. **B**: Values pooled by month (black dots represent outliers). Each graph includes a pooled station dataset for the waterbody.*

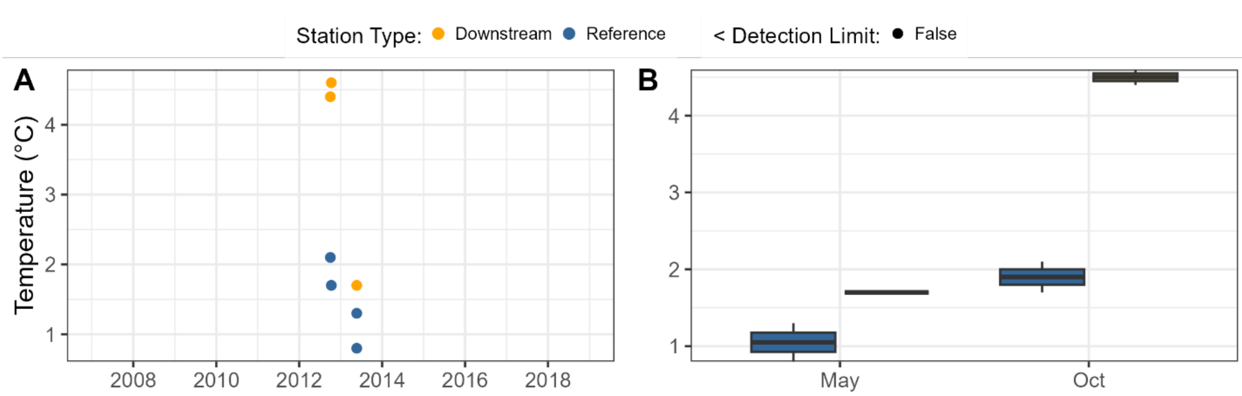

*Figure 34. Temperature measured in Bullmoose Creek between 2008 and 2018. **A:** All values plotted individually. **B**: Values pooled by month (black dots represent outliers). Each graph includes a pooled station dataset for the waterbody.*

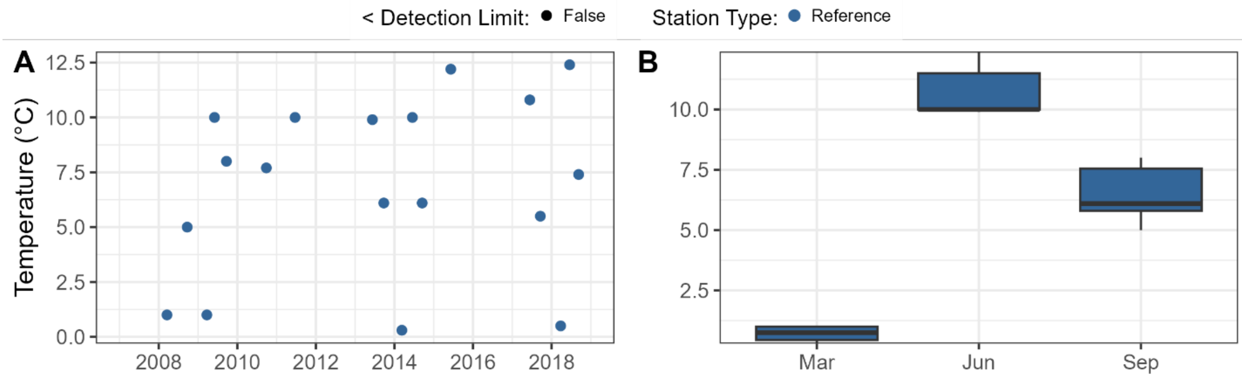

Figure 35. Temperature measured in Mast Creek between 2008 and 2018. ***A:*** *All values plotted individually.* ***B****: Values pooled by month (black dots represent outliers). Each graph includes a pooled station dataset for the waterbody.*

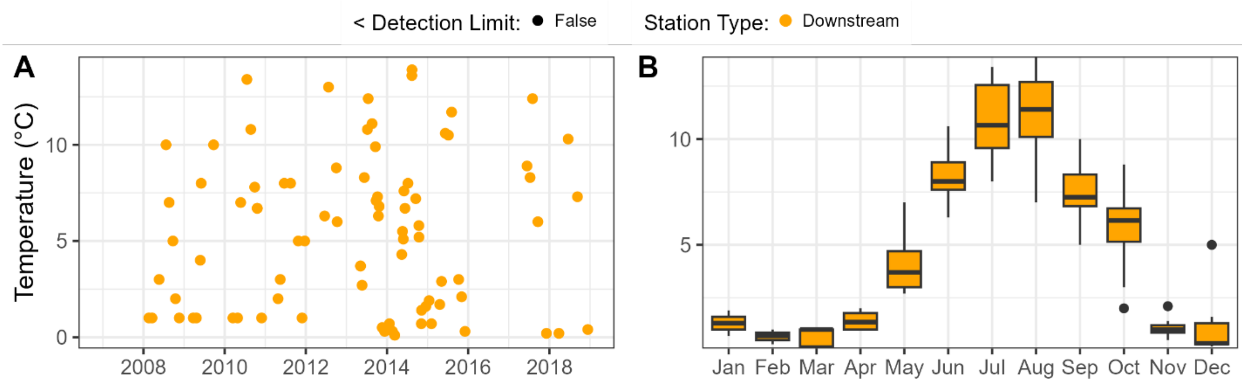

Figure 36. Temperature measured in Wolverine River between 2008 and 2018. ***A:*** *All values plotted individually.* ***B****: Values pooled by month (black dots represent outliers). Each graph includes a pooled station dataset for the waterbody.*

Nitrate

Nitrate (NO3) is a form of nitrogen that occurs as part of the nitrogen cycle. Nitrogen undergoes conversion from one form to another depending on environmental conditions, such as the presence or absence of oxygen. Naturally, nitrogen enters water bodies from local geology, vegetation, and animals (e.g., post-spawning salmon carcasses), along with significant anthropogenic inputs. One unique anthropogenic source of nitrogen in the KSWGSSMR is from the detonation of nitrogen-based explosives during coal mining. Other sources in the KSWGSMR include wastewater discharge from the District of Tumbler Ridge (i.e., sewage) into the mainstem Murray River and agricultural activities (i.e., livestock manure and fertilizers) in the downstream portion of the watershed.

Nitrogen compounds are essential nutrients for photosynthetic and bacterial production, playing a necessary and integral role in aquatic ecosystems. However, elevated concentrations of nitrate can lead to nitrate toxicity. Moreover, excessive nitrogen contributes to the eutrophication (nutrient enrichment) of downstream water bodies, which can result in toxic algal blooms. The most conservative WQG for NO3 in British Columbia is the chronic WQG for the protection of aquatic life, set at 3 mg/L (ENV 2009), and served as the benchmark in this assessment.

Murray River

Nitrate concentrations were slightly elevated at downstream stations compared to upstream reference stations (Table 11, Figure 37). CC-023 exhibited the highest average and 95th percentile NO3 concentrations (0.258 and 0.613 mg/L, respectively), likely due to inputs from the mining region, as this station is situated just downstream of the Murray River's confluence with the Wolverine River and Flatbed Creek. Overall, the NO3 levels were well below the WQG of 3 mg/L throughout the Murray River mainstem. The highest NO3 concentrations were recorded between December and May and declined considerably during the summer months (Figure 37).

Table 11. Summary statistics for nitrate (mg/L) at select sites on the Murray River mainstem. Sites are presented in an upstream to downstream order. Shaded rows summarize upstream reference data.

Site	Average	Min	Max	95^{th} %ile	N
HD-004	0.062	0.00829	0.154	0.118	91
HD-014	0.066	0.00970	0.174	0.122	100
HD-023	0.053	0.00830	0.194	0.107	63
HD-028	0.072	0.00870	0.151	0.108	48
HD-027	0.063	0.00790	0.379	0.116	113
HD-033	0.066	0.00930	0.471	0.122	99
HD-021	0.060	0.00590	0.578	0.110	89
CC-023	0.258	0.0213	0.825	0.613	23
HD-040	0.143	0.0215	0.306	0.245	30
CC-010	0.067	0.0150	0.282	0.262	15

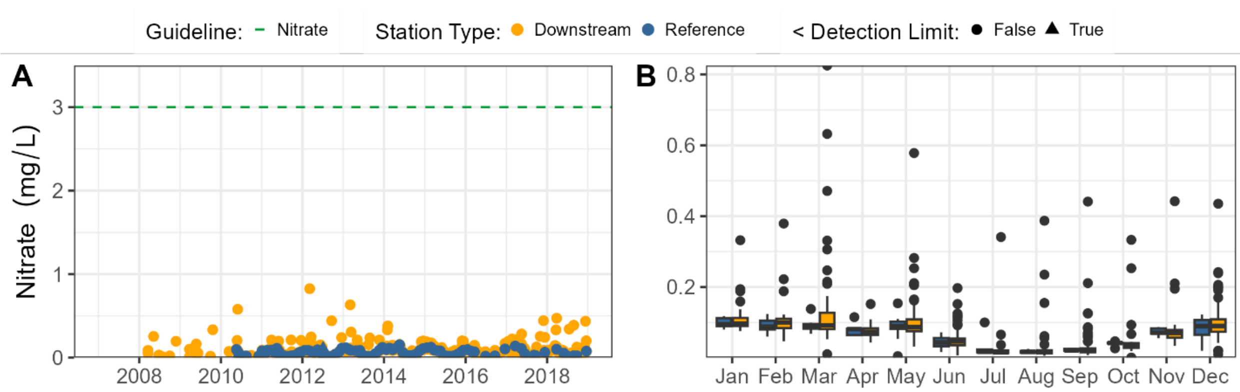

Figure 37. Nitrate measured in Murray River between 2008 and 2018. ***A****: All values plotted individually.* ***B****: Values pooled by month (black dots represent outliers). Each graph includes a pooled station dataset for the waterbody. The green dashed line in A represents the WQG for the protection of aquatic life of 3 mg/L.*

Mining Region

The available nitrate data for streams in the mining region are summarized in Table 12 and Figures 38 – 41. Total nitrate concentrations were well below the WQG at all upstream reference monitoring locations in the mining region where data were available. Overall, average NO3 levels were below the WQG except in Gordon and Babcock Creeks, where the highest maximum NO3 concentration of 27.9 mg/L was measured (Table 12). Nitrate levels in individual observations frequently exceeded the WQG downstream of mining activities, particularly in Gordon and Babcock Creeks, and occasionally in Flatbed Creek, Mast Creek, and the Wolverine River.

NO3 concentrations in most mining region streams tended to be lowest in May and June, coinciding with the timing of the freshet. The exception was M20 Creek, where seasonal NO3 concentrations followed the pattern observed in the Murray River mainstem, with the lowest concentrations occurring between July and October. NO3 levels appear to be increasing over time in Gordon Creek and decreasing in Babcock and Mast Creeks.

Table 12. Total nitrate (mg/L) summary statistics for the waterbodies in the mining region of the KSWGSMR.

Watershed	Waterbody	Average	Min	Max	95th %ile	N
M19 Creek	M19 Creek	0.08	0.005	0.50	0.22	120
M20 Creek	M20 Creek	0.06	0.005	0.39	0.14	216
Flatbed Creek	Gordon Creek	5.59	0.005	27.90	13.11	380
	Babcock Creek	3.46	0.005	14.10	8.51	282
	Flatbed Creek	0.97	0.005	3.70	2.19	159
Wolverine River	Bullmoose Creek	0.16	0.002	0.48	0.44	29
	Mast Creek	2.86	0.005	8.49	6.58	128
	Perry Creek	0.07	0.005	0.54	0.28	133
	Wolverine River	0.45	0.001	4.86	1.45	332

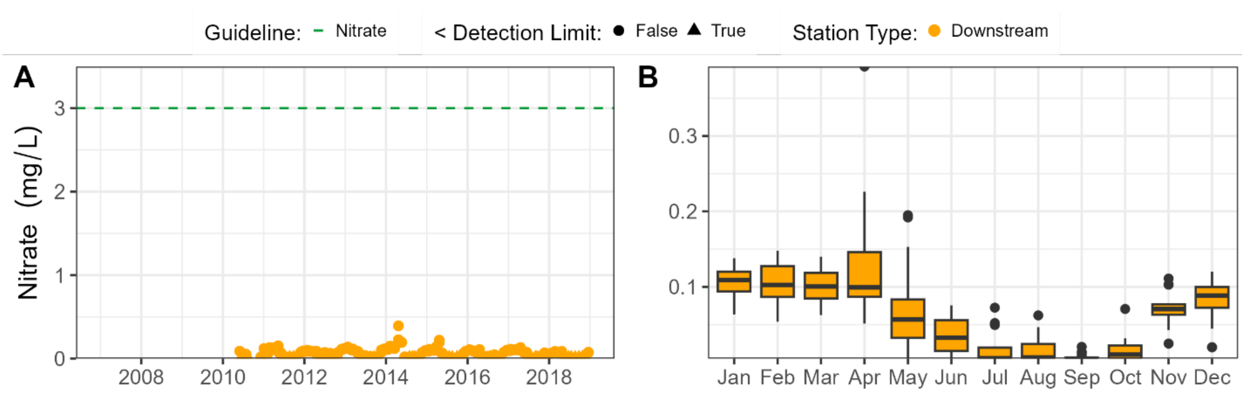

Figure 38. Nitrate measured in M20 Creek between 2008 and 2018: ***A:*** *All values plotted individually.* ***B****: Values pooled by month (black dots represent outliers). Each graph includes a pooled station dataset for the waterbody. The green dashed line represents the WQG for the protection of aquatic life of 3 mg/L.*

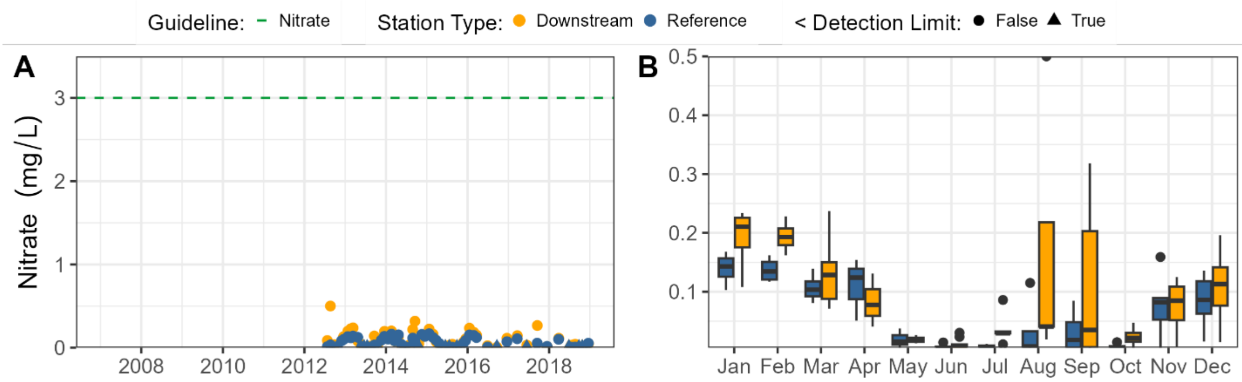

*Figure 39. Nitrate measured in M19 Creek between 2008 and 2018: **A:** All values plotted individually. **B**: Values pooled by month (black dots represent outliers). Each graph includes a pooled station dataset for the waterbody. The green dashed line represents the WQG for the protection of aquatic life of 3 mg/L.*

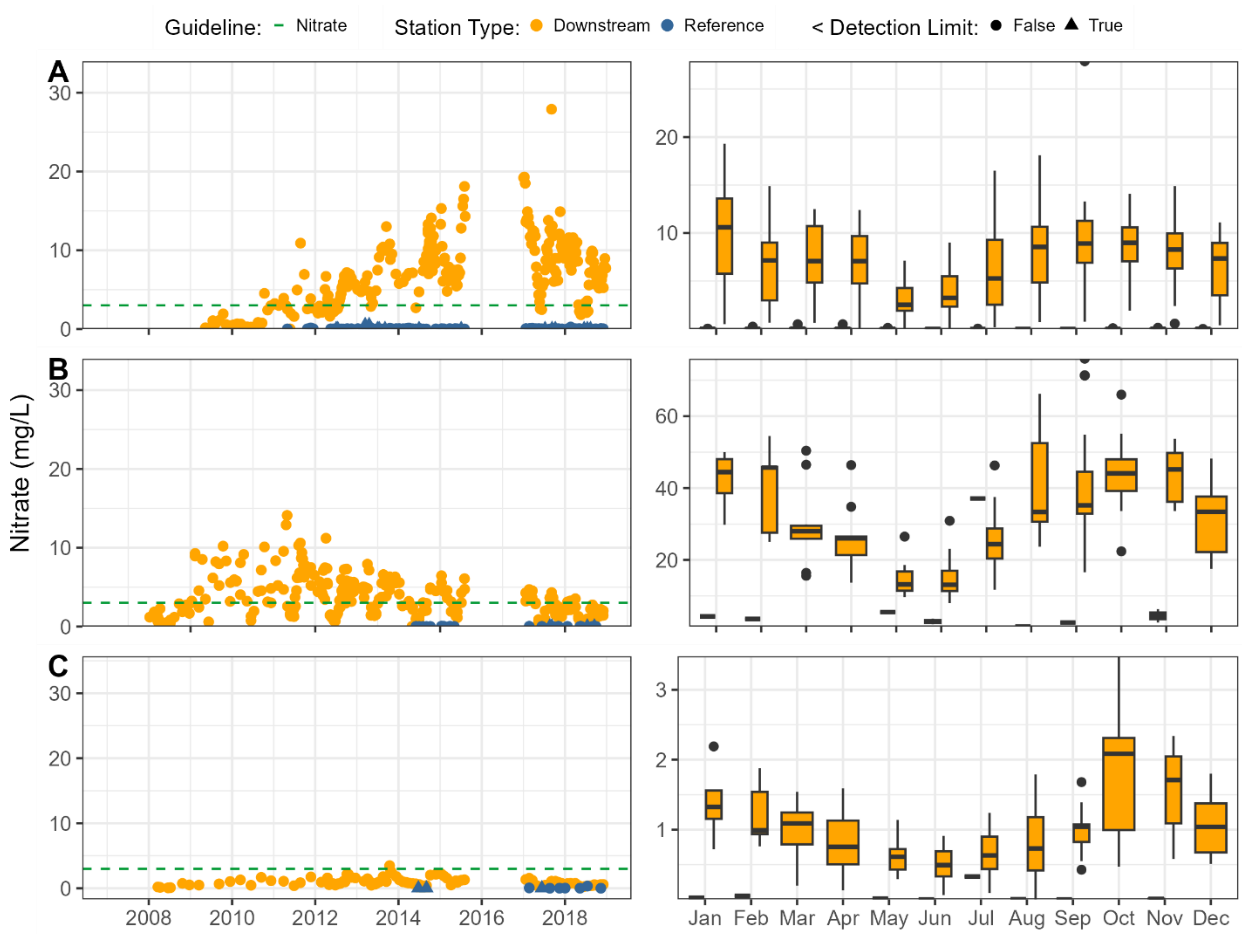

*Figure 40. Nitrate concentrations measured in Flatbed Creek watershed between 2008 and 2018 in: Gordon Creek **(A)**, Babcock Creek **(B)**, and Flatbed Creek **(C)**. Graphs on the left include individual values. Graphs on the right group values by month (black dots represent outliers). Each graph includes a pooled station dataset for the waterbody. The green dashed line represents the WQG for the protection of aquatic life of 3 mg/L.*

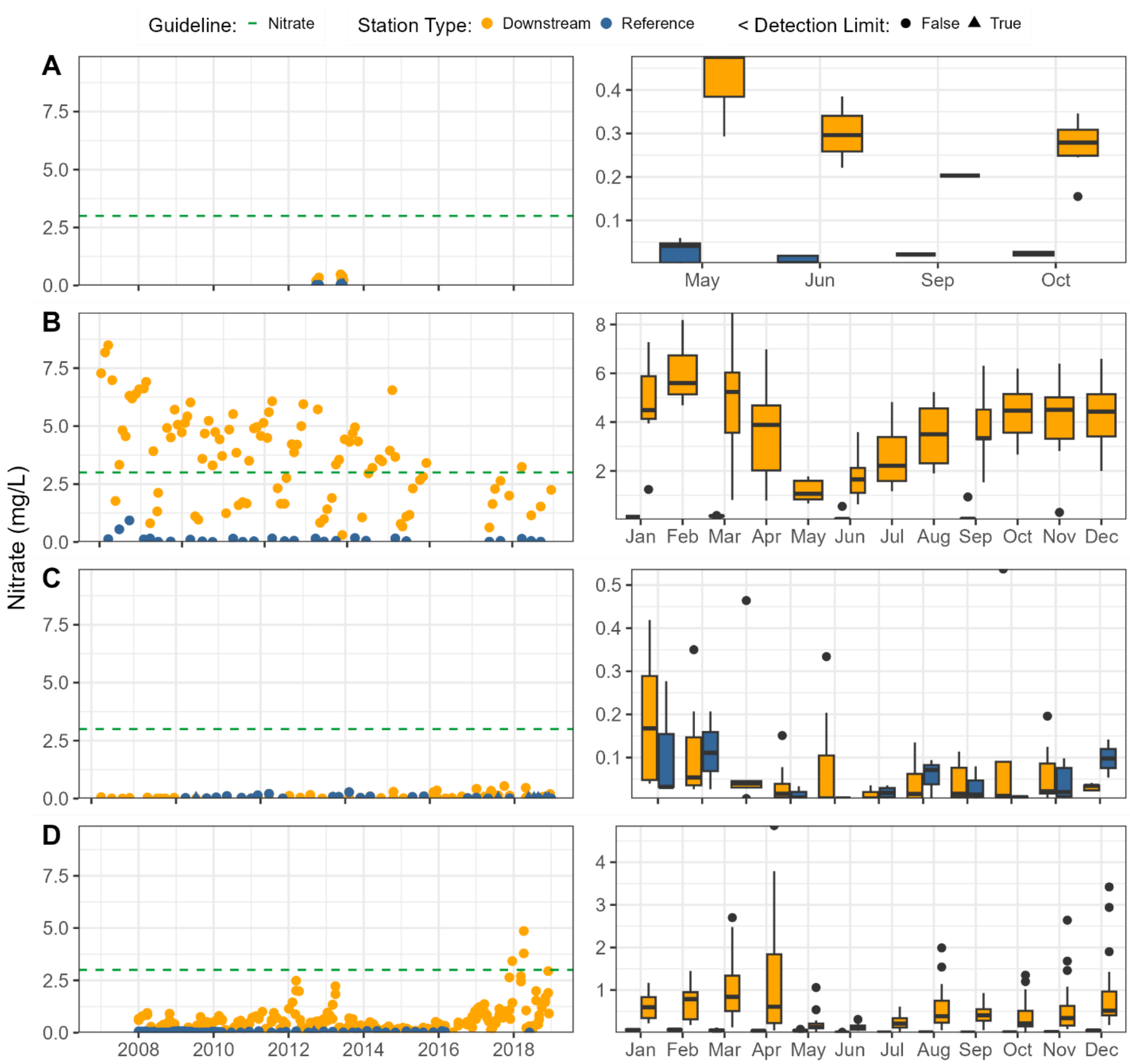

*Figure 41. Nitrate concentrations measured in Wolverine River watershed between 2008 and 2018 in: Bullmoose Creek **(A)** Mast Creek **(B)**, Perry Creek **(C)**, and the Wolverine River **(D)**. Graphs on the left include individual values. Graphs on the right group values by month (black dots represent outliers). Each graph includes a pooled station dataset for the waterbody. The green dashed line represents the WQG for the protection of aquatic life of 3 mg/L.*

Nitrite

Nitrite (NO2) is an intermediary form between nitrate and ammonium in the nitrogen cycle and is typically found in low concentrations due to its instability compared to the other forms. Nitrite can be toxic to certain groups of fish, particularly salmonids (ENV 2009). For this assessment, the most conservative NO2 guideline, the chronic WQG for the protection of aquatic life, was selected. This WQG is based on chloride levels, with guideline values increasing as chloride concentrations increase. When chloride concentrations are below 2 mg/L, the NO2 WQG is set at 0.02 mg/L (ENV 2009).

Murray River

Chloride concentrations throughout the Murray River were typically below 2 mg/L, resulting in a WQG value of 0.02 mg/L (Azimuth 2021). Nitrite concentrations were generally below the method detection limit (MDL) (Figure 42), and WQG exceedances occurred in less than 5% of the samples (Azimuth 2021).

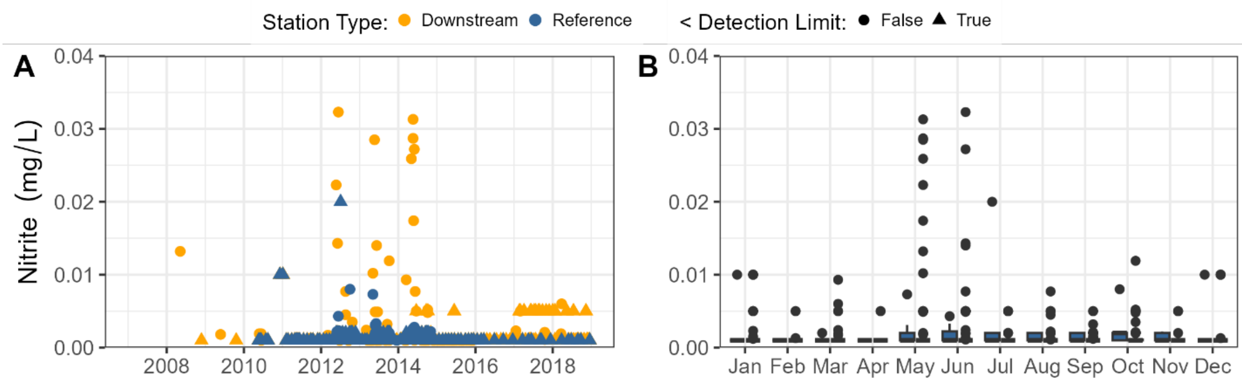

Figure 42. Nitrite concentrations measured in Murray River watershed between 2008 and 2018. ***A:*** *All values plotted individually.* ***B****: Values pooled by month (black dots represent outliers). Each graph includes a pooled station dataset for the waterbody. The WQG is not presented because it is calculated on a site-specific basis, and the figure includes multiple monitoring sites.*

Mining Region

Most of the nitrite (NO2) levels in the mining region were either below the method detection limit (MDL) or, if detected, were below the WQG of 0.02 mg/L (Figures 43 - 46). There were no discernible seasonal patterns in NO2 concentrations. Gordon Creek had the highest NO2 levels (up to 0.3 mg/L), with some exceedances above the site-adjusted WQG of 0.04 mg/L. Additionally, some exceedances were observed in Babcock Creek, Flatbed Creek, and the Wolverine River, although these have become less prevalent in recent samples (Azimuth 2021).

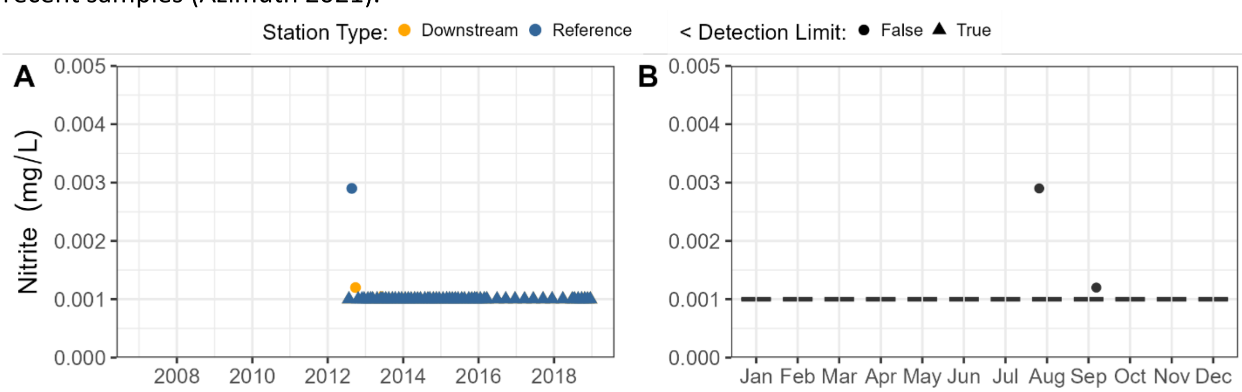

Figure 43. Nitrite concentrations measured in M19 Creek watershed between 2008 and 2018. ***A:*** *All values plotted individually.* ***B****: Values pooled by month (black dots represent outliers). Each graph includes a pooled station dataset for the waterbody. The WQG is not presented because it is calculated on a site-specific basis, and the figure includes multiple monitoring sites.*

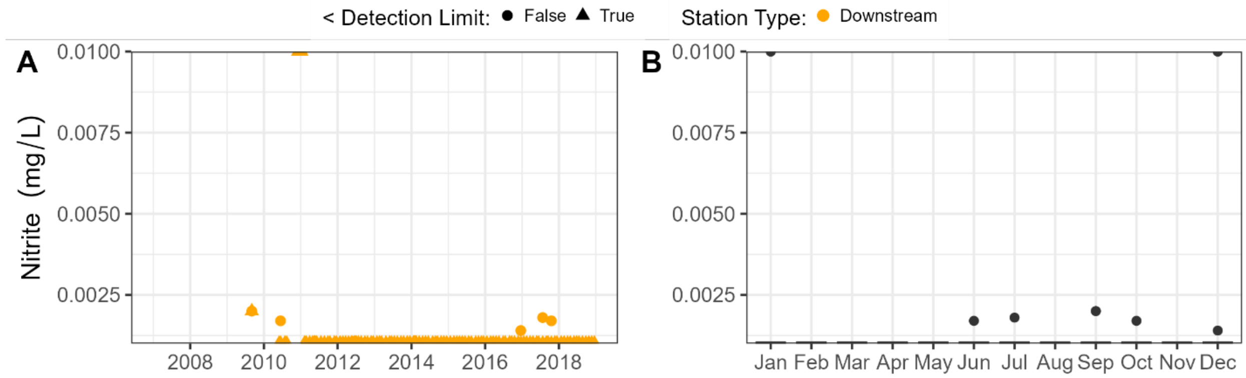

*Figure 44. Nitrite concentrations measured in M20 Creek watershed between 2008 and 2018. **A:** All values plotted individually. **B**: Values pooled by month (black dots represent outliers). Each graph includes a pooled station dataset for the waterbody. The WQG is not presented because it is calculated on a site-specific basis, and the figure includes multiple monitoring sites.*

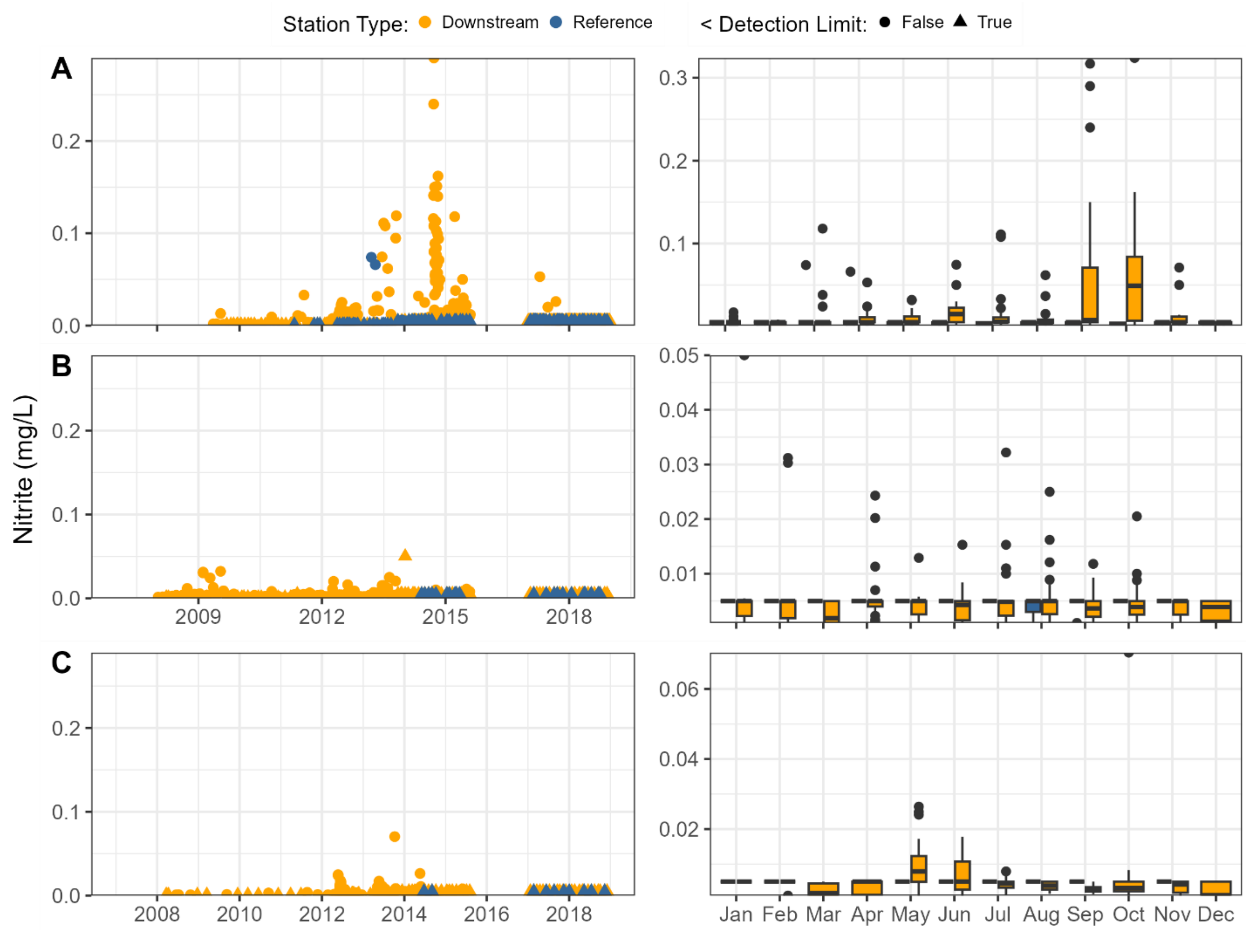

*Figure 45. Nitrite concentrations measured in Flatbed Creek watershed between 2008 and 2018 in: Gordon Creek **(A)**, Babcock Creek **(B)**, and Flatbed Creek **(C)**. Graphs on the left include individual values. Graphs on the right group values by month (black dots represent outliers). Each graph includes a pooled station dataset for the waterbody. The WQG is not presented because it is calculated on a site-specific basis, and the figure includes multiple monitoring sites.*

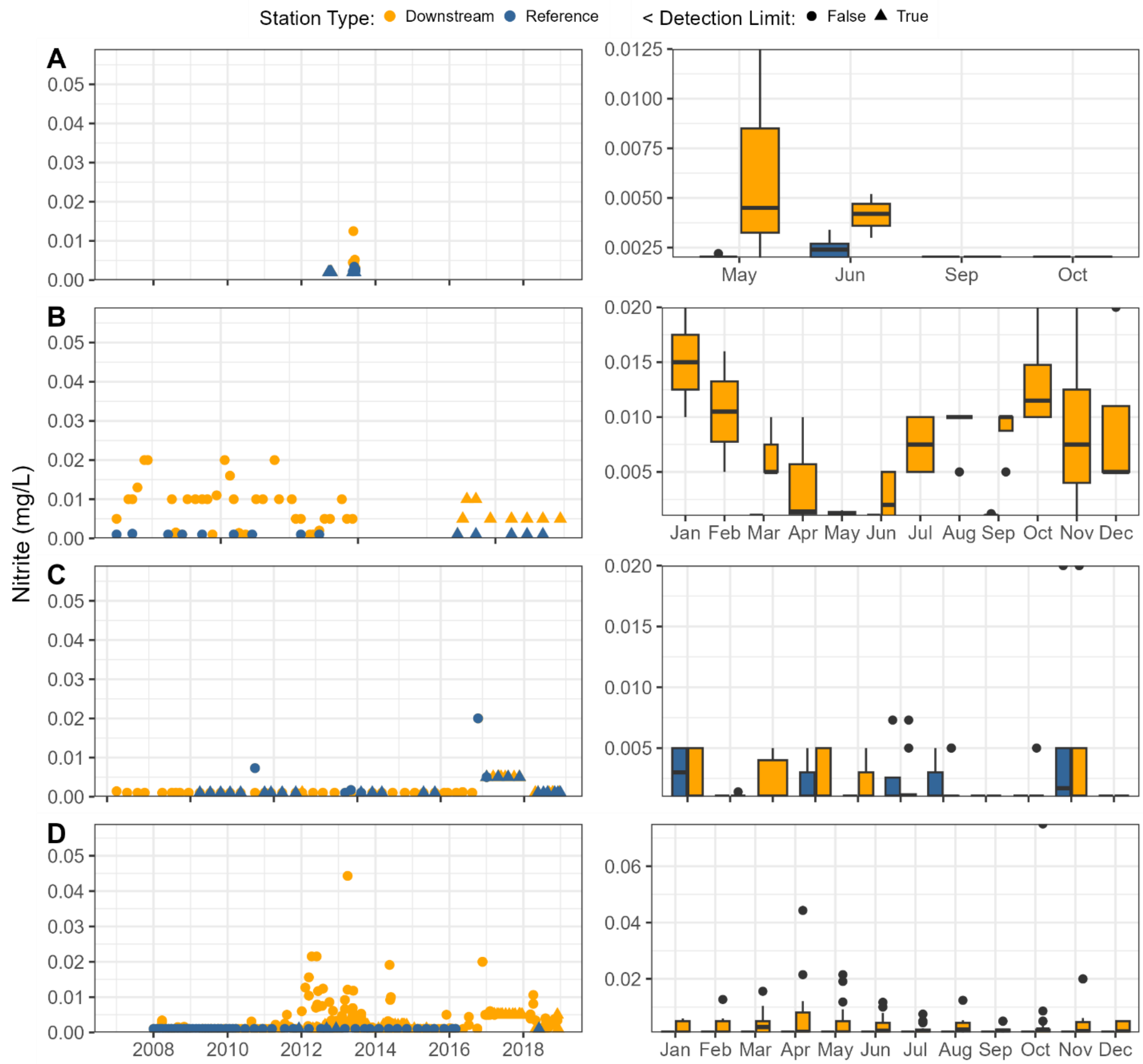

*Figure 46. Nitrite concentrations measured in Wolverine River watershed between 2008 and 2018 in: Bullmoose Creek **(A)**, Mast Creek **(B)**, Perry Creek **(C)**, and the Wolverine River **(D)**. Graphs on the left include individual values. Graphs on the right group values by month (black dots represent outliers). Each graph includes a pooled station dataset for the waterbody. The WQG is not presented because it is calculated on a site-specific basis, and the figure includes multiple monitoring sites.*

Sulphate

Sulphate (SO_4) concentrations in water result from natural weathering of minerals, atmospheric deposition, and anthropogenic discharges, with particular concern in mining regions, especially coal mining. Elevated SO_4 concentrations pose a risk to aquatic life; however, sulphate toxicity is mitigated with increasing water hardness, as reflected in the current British Columbia (B.C.) sulphate WQG for the protection of aquatic life (ENV 2013). The B.C. SO_4 WQG is the most conservative guideline and is therefore used in this assessment.

Murray River

SO_4 concentrations were lower at reference sites (sites MOE-070 and HD-004) compared to sites downstream of the mining region (Table 13, Figure 47). The highest levels were observed at station CC-023, located just downstream of the confluences with Flatbed Creek and the Wolverine River, with average and 95th percentile concentrations of 41 and 89 mg/L, respectively. SO_4 and water hardness follow the same seasonal pattern in the Murray River mainstem, with the lowest concentrations occurring during freshet (i.e., in May and June). All SO_4 measurements in the Murray River mainstem were well below the upper bounds of the Water Quality Guideline (WQG) (309 mg/L) calculated for the waterbody.

Table 13. Summary statistics for sulphate (mg/L) at select sites on the Murray River mainstem. Sites are presented in an upstream to downstream order. Shaded rows summarize information for reference stations.

Site	Average	Min	Max	95th %ile	N
MOE-070	6.73	2.04	16.2	13.2	52
HD-004	9.66	2.72	18.8	17.1	91
HD-014	10.4	1.42	17.8	16.4	100
HD-023	10.1	3.87	26.8	22.5	63
HD-028	12.9	4.54	21.6	20.3	48
HD-027	12.7	5.16	52.1	24.6	113
HD-033	12.7	2.13	33.4	25.4	99
HD-021	15.5	4.36	32.5	25.5	89
CC-023	40.6	0.02	90.5	89.0	23
HD-040	22.9	7.19	36.6	36.2	30
MOE-067	15.0	7.22	33.9	24.8	44
CC-010	33.8	16.8	56.4	47.4	17

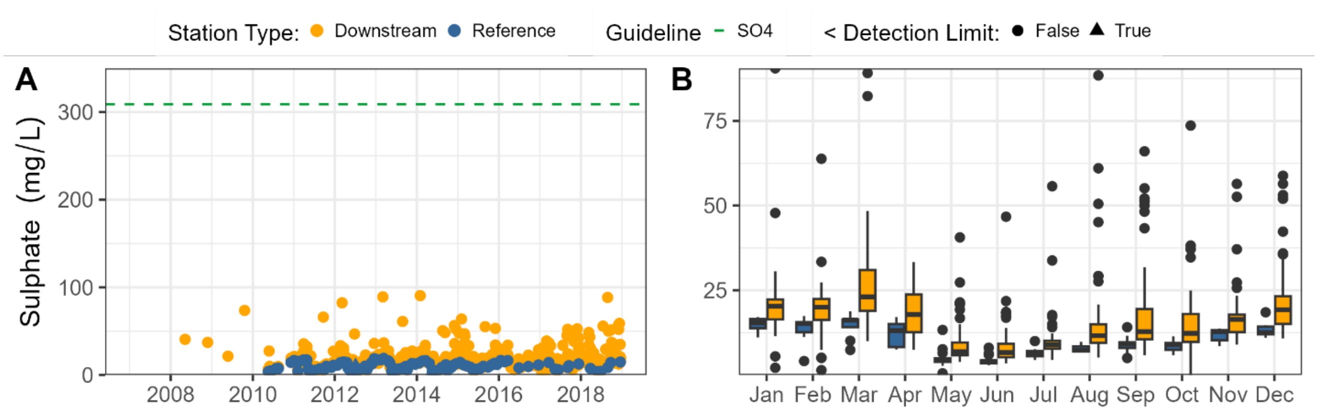

*Figure 47. Sulphate concentrations measured in the Murray River watershed between 2008 and 2018. **A:** All values plotted individually. **B**: Values pooled by month (black dots represent outliers). Each graph includes a pooled station dataset for the waterbody. The green dashed line represents the upper bounds of the WQG based on toxicity modifying factor hardness.*

Mining Region

SO_4 increased from upstream to downstream in most waterbodies in the mining region (Table 14). Concentrations were lowest during freshet in May and June (Figures 48– 51). SO_4 concentrations in most mining waterbodies were below the upper bounds of the Water Quality Guideline (WQG) based on the lowest hardness values measured in each waterbody between 2008 and 2018. The one exception was Mast Creek, which frequently exceeded the hardness-dependent WQG of 409 mg/L at site TK-007, with average and 95th percentile concentrations of 366 and 747 mg/L, respectively. SO_4 values in Babcock and Gordon Creek appear to be increasing over time, and in Gordon Creek approached the WQG of 429 mg/L with a maximum recorded value of 398 mg/L in 2018 (Figure 53). SO_4 levels were lowest in M19 Creek.

Table 14. Sulphate summary statistics for the waterbodies in the mining region of the KSWGSMR. Data were not available for Bullmoose Creek.

Watershed	Waterbody	Average	Min	Max	95th %ile	N
M19 Creek	M19 Creek	9	2	31	18	119
M20 Creek	M20 Creek	46	1	80	67	214
Flatbed Creek	Gordon Creek	94	2	398	255	380
	Babcock Creek	62	1	179	149	281
	Flatbed Creek	29	2	76	55	160
Wolverine River	Mast Creek	366	6	847	747	101
	Perry Creek	24	2	55	36	133
	Wolverine River	69	0	215	143	333

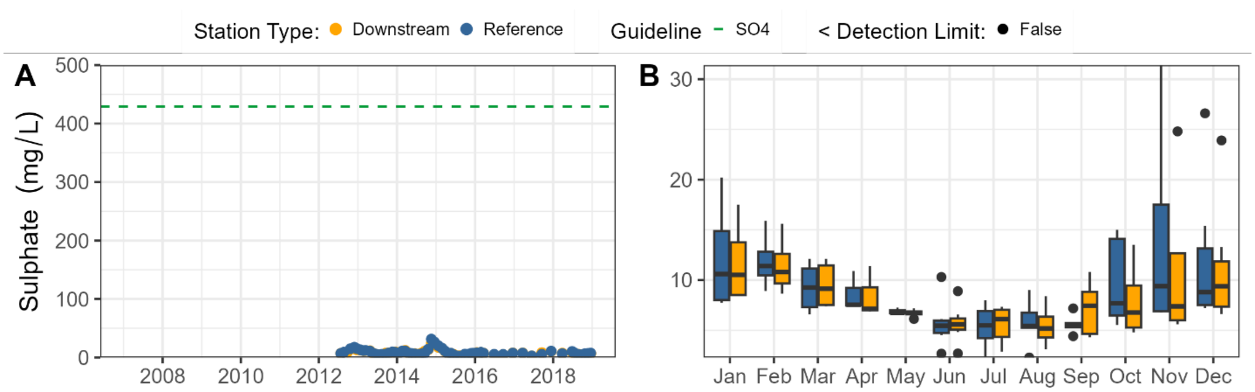

*Figure 48. Sulphate concentrations measured in M19 Creek watershed between 2008 and 2018. **A:** All values plotted individually. **B**: Values pooled by month (black dots represent outliers). Each graph includes a pooled station dataset for the waterbody. The green dashed line represents the upper bounds of the WQG based on hardness.*

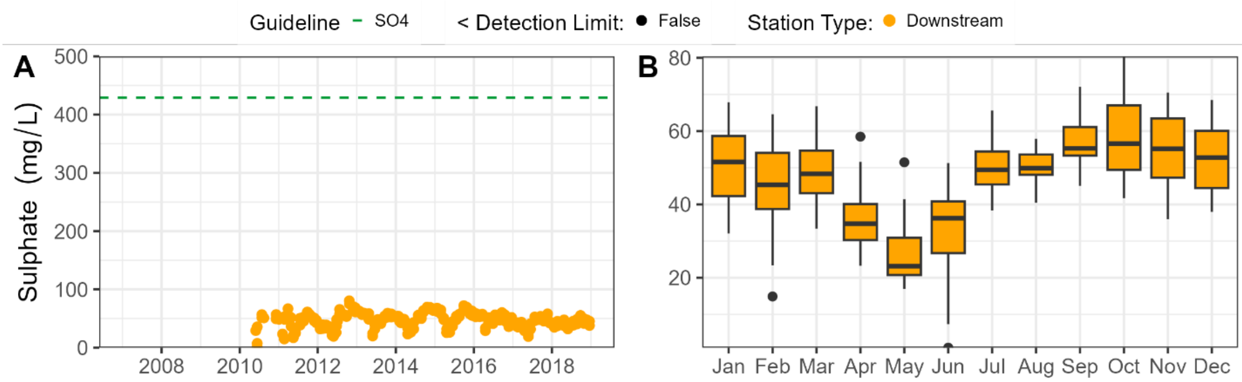

Figure 49. Sulphate concentrations measured i M20 Creek watershed between 2008 and 2018. ***A:*** *All values plotted individually.* ***B****: Values pooled by month (black dots represent outliers). Each graph includes a pooled station dataset for the waterbody. The green dashed line represents the upper bounds of the WQG based on hardness.*

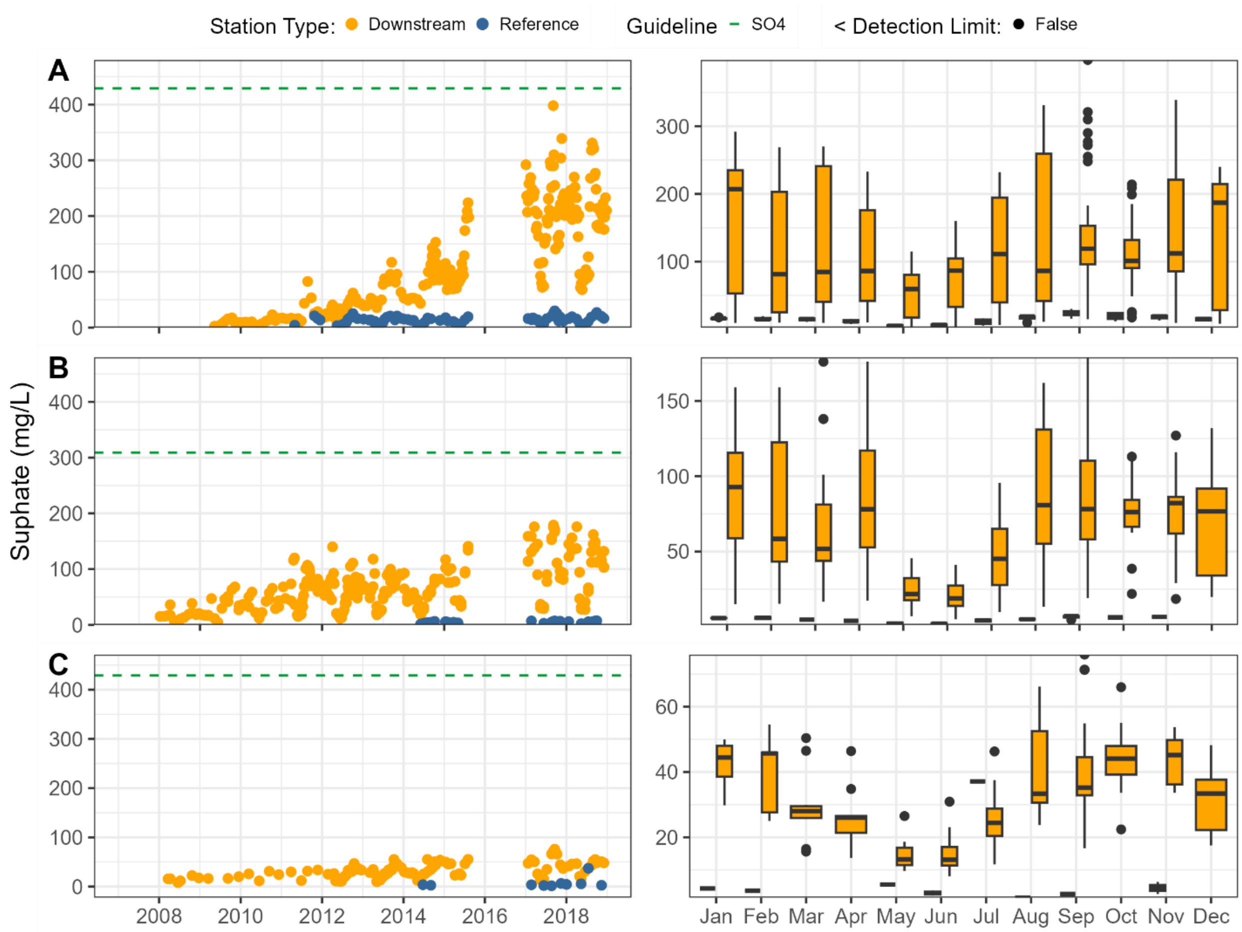

Figure 50. Sulphate concentrations in Flatbed Creek watershed between 2008 and 2018 in: Gordon Creek ***(A)****, Babcock Creek* ***(B)****, and Flatbed Creek* ***(C)****. Graphs on the left include individual values. Graphs on the right group values by month (black dots represent outliers). Each graph includes a pooled station dataset for the waterbody. The green dashed line represents the upper bounds of the WQG based on hardness.*

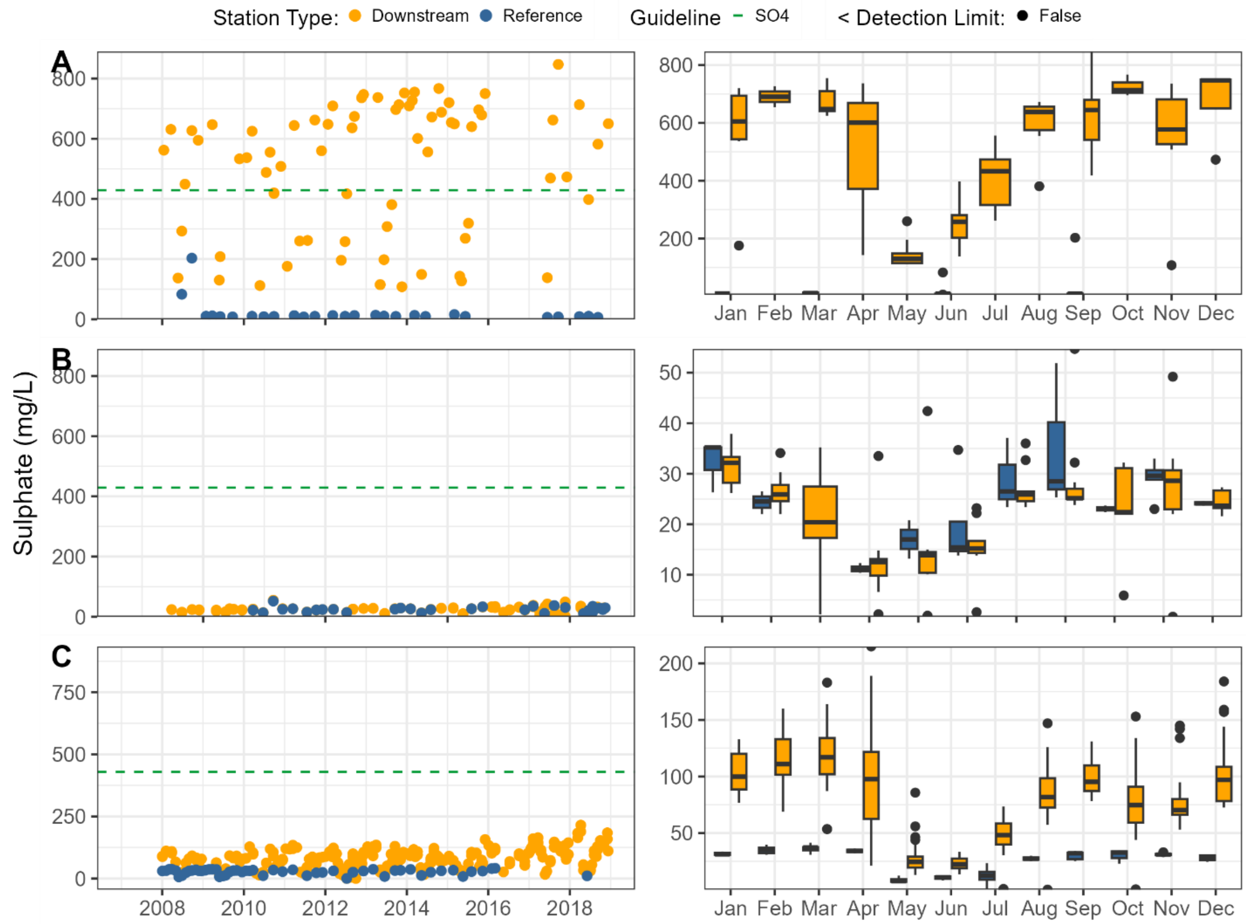

*Figure 51. Sulphate concentrations measured in Wolverine River watershed between 2008 and 2018: in Mast Creek **(A)**, Perry Creek **(B)**, and the Wolverine River **(C)**. Graphs on the left include individual values. Graphs on the right group values by month (black dots represent outliers). Each graph includes a pooled station dataset for the waterbody. The green dashed line represents the upper bounds of the WQG based on hardness. Sulphate data were not available for Bullmoose Creek.*

Aluminum

Aluminum (Al) is considered a non-essential metal because fish and other aquatic organisms do not require it to function. It is naturally present in most soils and rocks and enters water through processes such as rock weathering. Additionally, it is released by mining and other industrial activities, as well as wastewater discharges. Elevated levels of Al can adversely impact aquatic life, affecting the ability of some species to regulate ions and respiratory function. The British Columbia (B.C.) Al WQG for the protection of aquatic life is based on total Al and calculated from concurrent measurements of dissolved organic carbon (DOC), pH, and hardness (WLRS 2023a). This WQG is the most conservative of the B.C. WQGs for total Al and was used in this assessment. However, it was difficult to assess the current conditions for total Al given the lack of information to properly calculate the WQGs. Guideline values have been calculated where data were available.

Murray River

In the Murray River, total aluminum (Al) concentrations were slightly higher downstream compared to upstream areas of the mainstem, with average concentrations ranging from 45 to 606 µg/L (Table 15, Figure 52). Total suspended solids (TSS) and total Al were positively correlated in both the Murray River mainstem and streams in the mining region (Azimuth 2021). Total Al followed similar seasonal patterns to TSS, with increasing concentrations during freshet. Elevated concentrations were also periodically observed throughout the year, likely related to short-term storm events.

Water quality guidelines were calculated where monthly averages for total Al, dissolved organic carbon (DOC), pH, and hardness were available. The frequency of guideline exceedances increased from upstream to downstream areas of the Murray River mainstem (e.g., 0% and 22% at MOE-070 and HD-004 compared to 44% and 39% at MOE-067 and CC-010, respectively), and the magnitude of exceedance was higher during freshet when total metal concentrations were naturally elevated.

The highest values were observed just downstream of the confluence with M20 Creek at HD-027 (average and 95th percentile of 392 and 1,810 µg/L, respectively) and downstream of the confluences with the Wolverine River and Flatbed Creek at CC-023 (average and 95th percentile of 660 and 1,900 µg/L, respectively). Relatively high total Al concentrations were also observed in stations upstream of the mining area. For example, average and 95th percentile total Al concentrations at HD-023 (50 m upstream of M20 Creek confluence) were 363 and 1,400 µg/L, respectively, while the reference site HD-004 had average and 95th percentile concentrations of 190 and 856 µg/L, respectively.

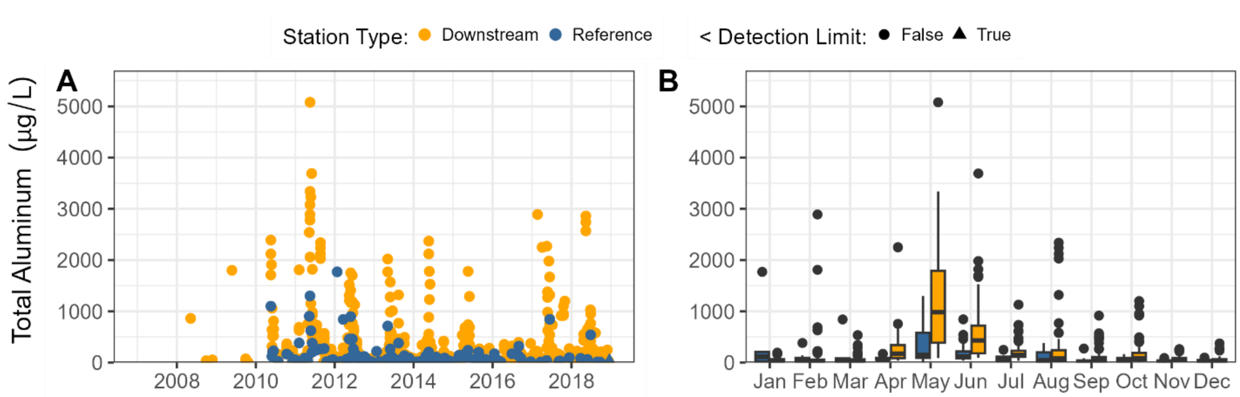

Figure 52. Total aluminum concentrations measured in the Murray River watershed between 2008 and 2018. ***A:*** *All values plotted individually.* ***B****: Values pooled by month (black dots represent outliers). Each graph includes a pooled station dataset for the waterbody. The WQG is not presented because it is calculated on a site-specific basis, and the figure includes multiple monitoring sites.*

Table 15. Summary statistics for total aluminum (µg/L) at select sites on the Murray River mainstem. Sites are presented in an upstream to downstream order. Monthly water quality guideline exceedance rates (%) for total Al compared to the Al WQG for aquatic life are included. Shaded rows represent reference stations.

Site	Average	Min	Max	95th %ile	n	% WQG exceedance
MOE-070	44.6	1.44	713	125	52	0
HD-004	190	4.10	1,770	856	96	22
HD-014	187	2.55	2,780	735	104	21
HD-023	363	4.10	2,060	1,400	65	40
HD-028	78.9	12.5	664	561	50	13
HD-027	392	5.34	5,080	1,810	115	33
HD-033	98.2	8.80	3,340	925	99	30
HD-021	290	8.90	3,080	1,020	92	27
CC-023	606	8.40	3,690	1,900	23	35
HD-040	267	7.72	1,670	1,310	30	30
MOE-067	127	18.5	2,370	1,780	44	44
CC-010	579	36.6	2,270	2,250	17	39

Mining Region

Total aluminum (Al) concentrations over time and seasonally are presented in Figures 53 – 56. The highest total Al concentrations were recorded in M20 Creek, although they appear to be decreasing over time (Table 16 and Figure 54). Average total Al levels across the mining region ranged from 57 µg/L in M19 Creek to 1,210 µg/L in M20 Creek. Water quality guidelines could not be calculated at all sites because dissolved organic carbon (DOC), pH, and/or hardness data were unavailable. Where available, monthly averages were used to calculate the water quality guideline (WQG). The WQG was generally met in the mining region, with some exceedances observed at downstream stations during freshet and into the fall (Azimuth 2021).

Table 16. Total aluminum data (µg/L) summary statistics for the waterbodies in the mining region of the KSWGSMR.

Watershed	Waterbody	Average	Min	Max	95th %ile	N
M19 Creek	M19 Creek	57	3	799	222	125
M20 Creek	M20 Creek	1,210	6	14,800	4,983	220
Flatbed Creek	Gordon Creek	382	6	5,510	1,926	317
	Babcock Creek	229	5	3,730	994	357
	Flatbed Creek	335	2	8,020	1,453	239
Wolverine River	Bullmoose Creek	76	5	754	233	29
	Mast Creek	181	3	2,810	582	58
	Perry Creek	83	5	2,120	293	135
	Wolverine River	137	1	3,510	692	331

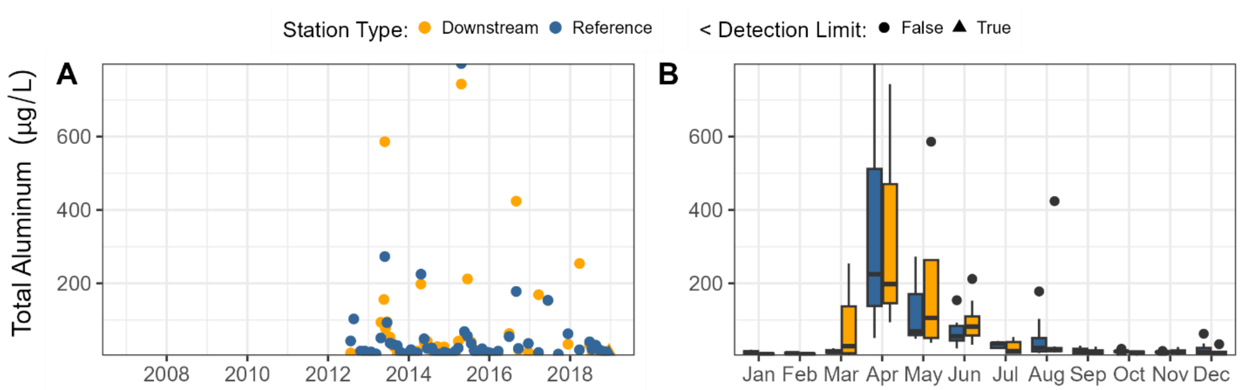

Figure 53. Total aluminum concentrations measured in M19 Creek watershed between 2008 and 2018. ***A:*** *All values plotted individually.* ***B****: Values pooled by month (black dots represent outliers). The WQG is not presented because it is calculated on a site-specific basis, and the figure includes multiple monitoring sites.*

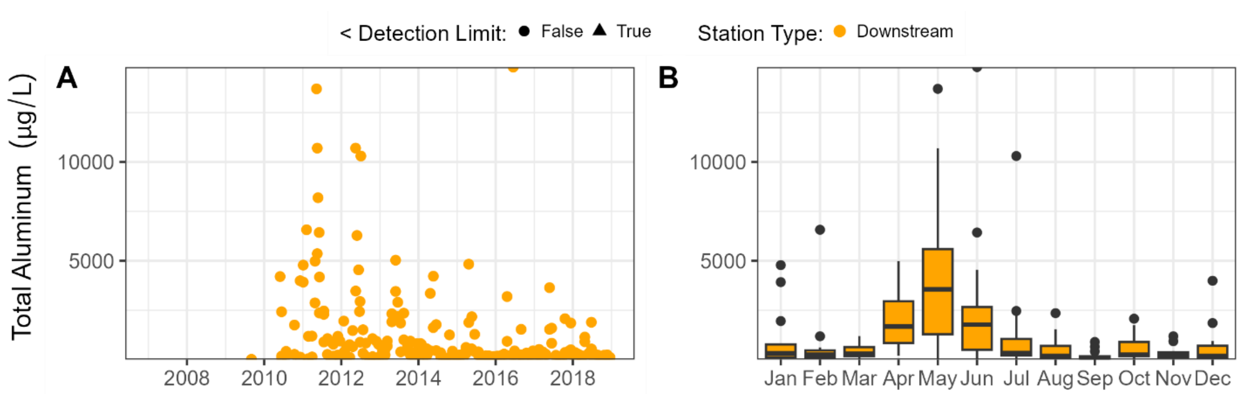

Figure 54. Total aluminum concentrations measured in M20 Creek watershed between 2008 and 2018. ***A:*** *All values plotted individually.* ***B****: Values pooled by month (black dots represent outliers). Each graph includes a pooled station dataset for the waterbody. The WQG is not presented because it is calculated on a site-specific basis, and the figure includes multiple monitoring sites.*

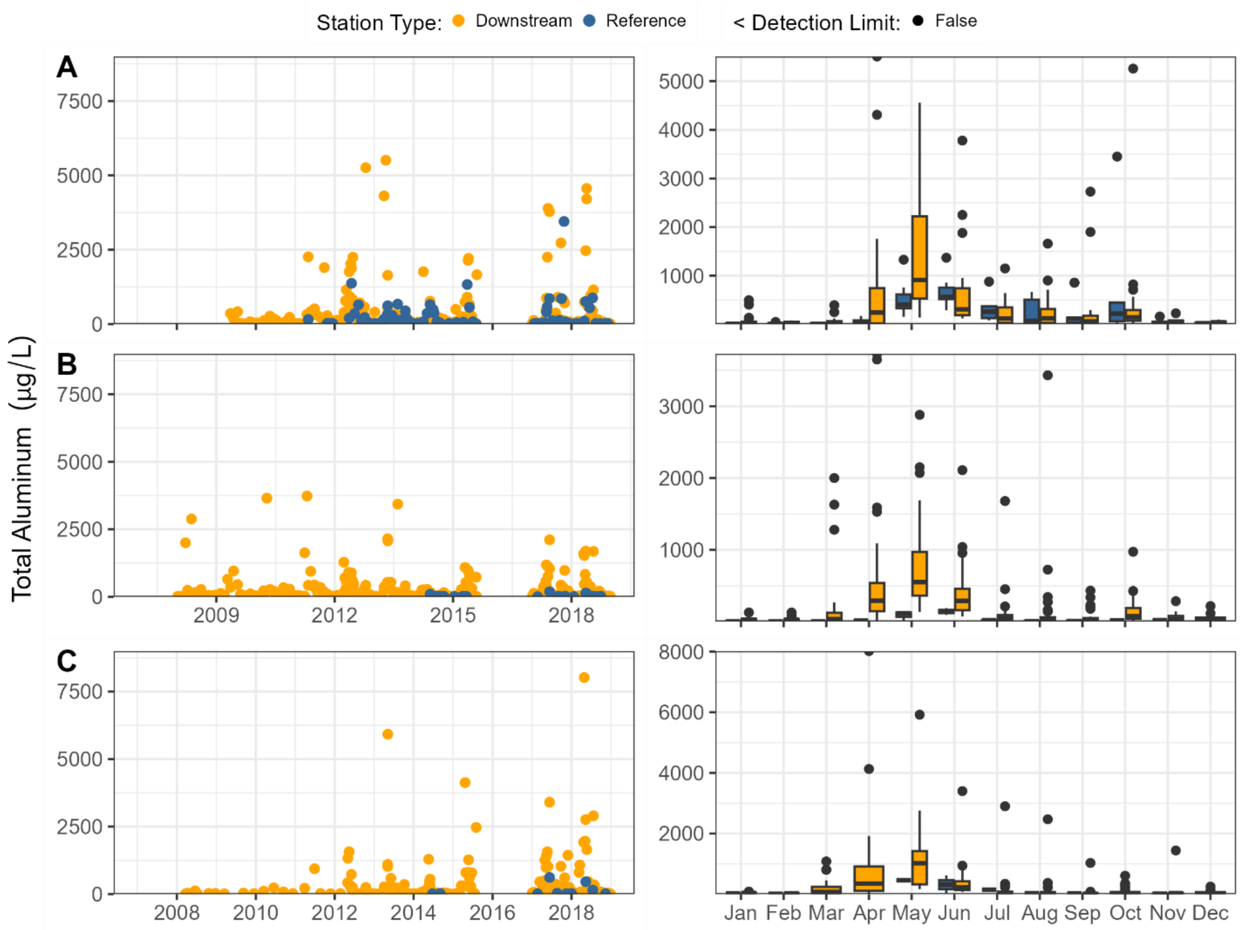

*Figure 55. Total aluminum concentrations measured in Flatbed Creek watershed between 2008 and 2018: in Gordon Creek **(A)**, Babcock Creek **(B)**, and Flatbed Creek **(C)**. Graphs on the left include individual values. Graphs on the right group values by month (black dots represent outliers). Each graph includes a pooled station dataset for the waterbody. The WQG is not presented because it is calculated on a site-specific basis, and the figure includes multiple monitoring sites.*

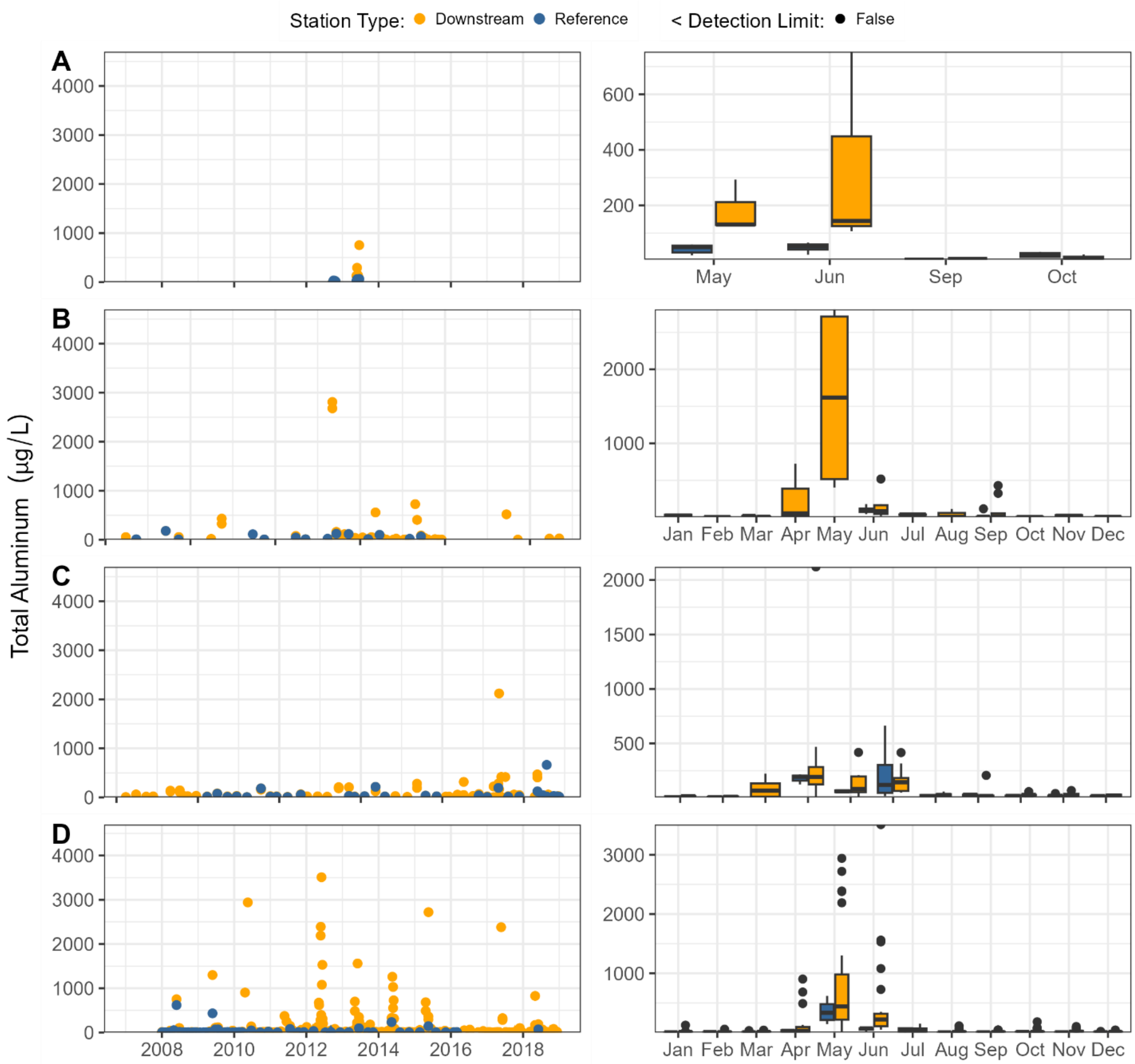

*Figure 56. Total Aluminum in Wolverine River watershed (2008 – 2018) in Bullmoose Creek **(A)**, Mast Creek **(B)**, Perry Creek **(C)**, and the Wolverine River **(D)**. Graphs on the left include individual values. Graphs on the right group values by month (black dots represent outliers).*

Beryllium

Beryllium (Be) is naturally found in rocks, coal, oil, and soil, and it enters water through natural erosion and the burning of fossil fuels. Toxicological information on Be is very limited; therefore, British Columbia (B.C.) has adopted a working WQG of 0.13 µg/L for the protection of freshwater aquatic life (ENV 2021), providing a conservative benchmark for assessing risks associated with Be.

Murray River

In the Murray River, average Be concentrations appeared to be lower at stations within the upstream area of the mainstem (e.g., 0.0079 µg/L at MOE-070) compared to those downstream (e.g., 0.073 µg/L at CC-010; Table 17). This dataset was challenging to assess due to multiple method detection limits (MDLs) that changed over time. For example, data collected at stations HD-004 and HD-014 were mostly below the higher MDL of 0.10 µg/L (95% and 98% of the datasets, respectively). Data collected at MOE-070 and MOE-067 were analyzed with a lower MDL of 0.01 µg/L, allowing for a more reliable comparison to the WQG of 0.13 µg/L. Concentrations were typically below the WQG except during freshet, when total metal concentrations tend to be naturally elevated (Figure 57). Similar to total aluminum, total beryllium was found to be strongly associated with total suspended solids (TSS) (Azimuth 2021).

Table 17. Summary statistics for total beryllium (µg/L) at select sites on the Murray River mainstem. Sites are presented in an upstream to downstream order. Shaded rows represent reference stations.

Site	Average	Min	Max	95^{th} %ile	n	% < MDL
MOE-070	0.00786	0.000105	0.160	0.0184	52	75
HD-004	0.0500	0.0100	0.500	0.243	42	95
HD-014	0.0500	0.0320	0.0500	0.0500	40	98
CC-023	0.0500	0.0250	0.130	0.130	7	71
MOE-067	0.0500	0.00100	0.400	0.170	44	43
CC-010	0.0730	0.00940	0.306	0.197	17	65

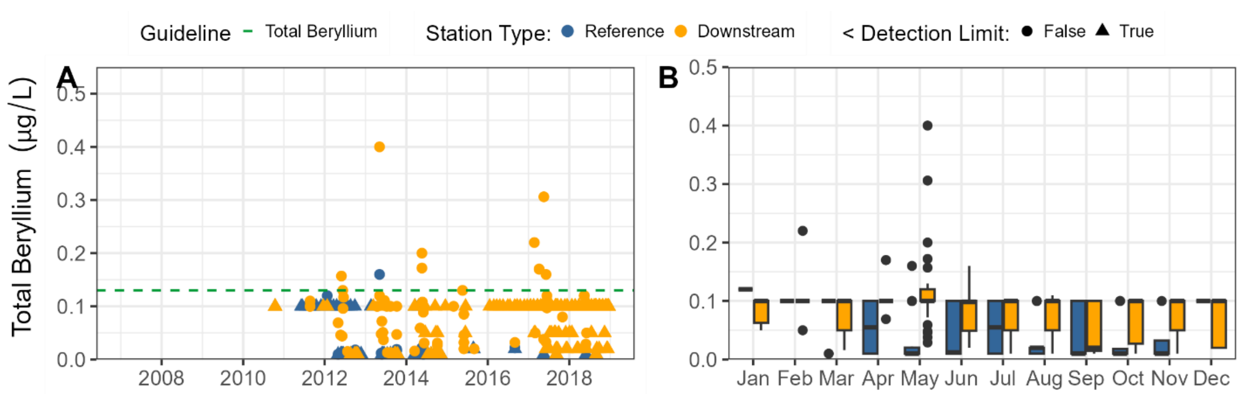

*Figure 57. Total beryllium concentrations in the Murray River watershed from 2008 to 2018. **A:** All values plotted individually. **B**: Values pooled by month (black dots represent outliers). The green dashed line represents the working water quality guideline for the protection of aquatic life of 0.13 µg/L. Each graph includes a pooled station dataset for each waterbody.*

Mining Region

At reference stations, total beryllium (Be) concentrations were mostly below the MDL in waterbodies in the mining region (Table 18; Figures 58 – 61). The highest concentrations were observed in M20 Creek, with exceedances of the WQG occurring most frequently from April to August when total suspended solids (TSS) were also elevated. Beryllium data were not available for Mast Creek.

Table 18. Total beryllium (µg/L) data summary statistics for the waterbodies in the mining region of the KSWGSMR.

Watershed	Waterbody	Average	Min	Max	95th %ile	N
M19 Creek	M19 Creek	0.10	0.03	0.10	0.10	25
M20 Creek	M20 Creek	0.19	0.01	1.11	0.79	97
Flatbed Creek	Gordon Creek	0.11	0.05	0.50	0.50	268
	Babcock Creek	0.06	0.05	0.25	0.10	261
	Flatbed Creek	0.06	0.01	0.50	0.13	207
Wolverine River	Bullmoose Creek	0.02	0.01	0.12	0.04	29
	Perry Creek	0.08	0.02	0.20	0.17	28
	Wolverine River	0.08	0.05	0.18	0.10	64

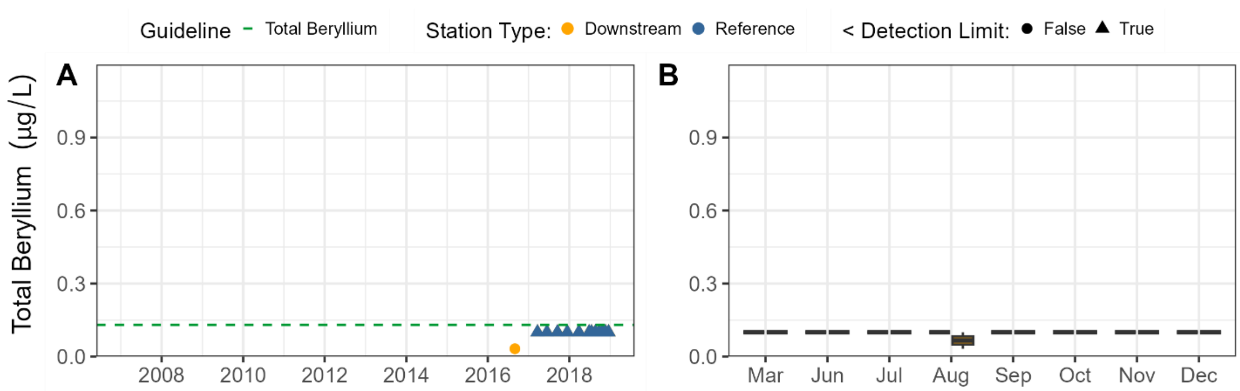

*Figure 58 Total beryllium concentrations measured in M19 Creek watershed between 2008 and 2018. **A:** All values plotted individually. **B**: Values pooled by month (black dots represent outliers). Each graph includes a pooled station dataset for the waterbody. The green dashed line represents the working water quality guideline for the protection of aquatic life of 0.13 µg/L.*

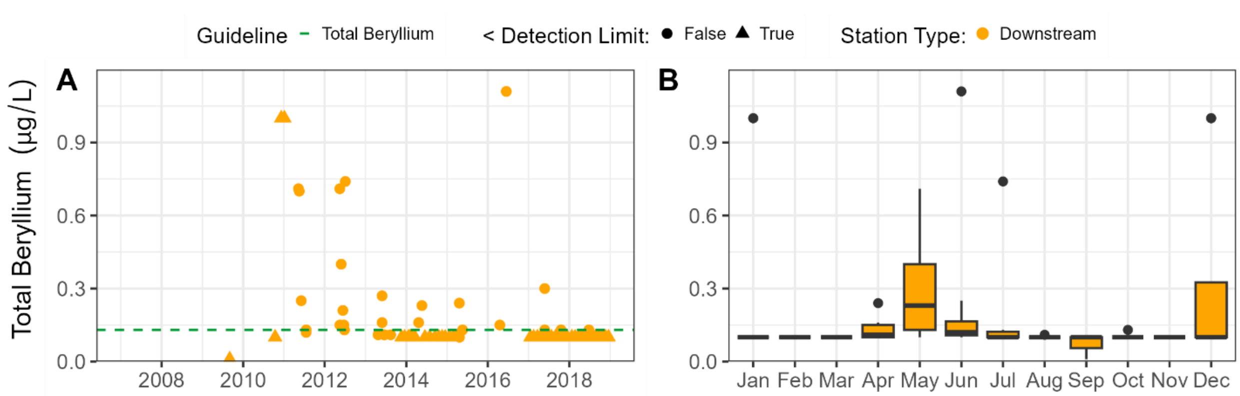

*Figure 59. Total beryllium concentrations measured in M20 Creek watershed between 2008 and 2018. **A:** All values plotted individually. **B**: Values pooled by month (black dots represent outliers). Each graph includes a pooled station dataset for the waterbody. The green dashed line represents the working water quality guideline for the protection of aquatic life of 0.13 µg/L.*

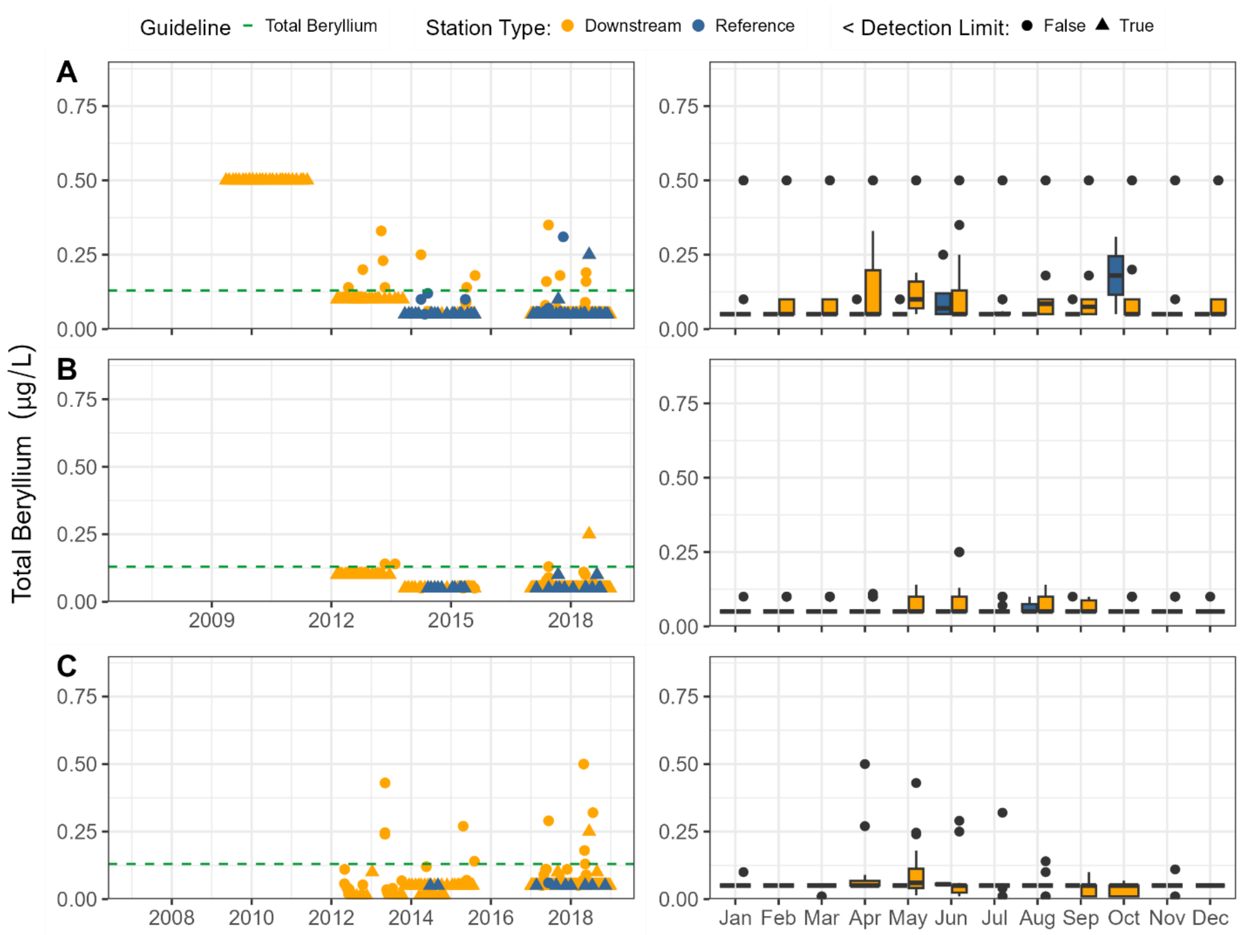

Figure 60. Total beryllium concentrations measured in Flatbed Creek watershed between 2008 and 2018 in Gordon Creek ***(A)****, Babcock Creek* ***(B)****, and Flatbed Creek* ***(C)****. Graphs on the left include individual values. Graphs on the right group values by month (black dots represent outliers). Each graph includes a pooled station dataset for the waterbody. The green dashed line represents the working water quality guideline for the protection of aquatic life of 0.13 µg/L.*

*Figure 61. Total beryllium concentrations measured in Wolverine River watershed between 2008 and 2018 in Bullmoose Creek **(A)**, Perry Creek **(B)**, and the Wolverine River **(C)**. Graphs on the left include individual values. Graphs on the right group values by month (black dots represent outliers). Each graph includes a pooled station dataset for the waterbody. The green dashed line represents the working water quality guideline for the protection of aquatic life of 0.13 µg/L. No data were available for Mast Creek.*

Chromium

Chromium (Cr) enters the aquatic environment from various industries, including metal production, glass manufacturing, asbestos processing, wood treatment, and chemical plants (CCME 1997). Chromium typically exists in two oxidation states: Cr(III) and Cr(VI), with the latter being more toxic to aquatic life. While British Columbia (B.C.) has working WQGs for both Cr(III) and Cr(VI), only total Cr data were available for this assessment. Since there is no specific WQG for total Cr, a conservative approach was adopted. The total Cr values were compared to the Cr(VI) working WQG of 1 µg/L. This comparison served as a total Cr benchmark for the assessment, acknowledging the uncertainty surrounding the actual level of risk. The method detection limit (MDL) for total Cr is 0.1 µg/L.

Murray River

Total Cr data for stations along the Murray River mainstem are summarized in Table 19 and Figure 62. Elevated concentrations of Total Cr were frequently observed in May and June, although individual results exceeding the benchmark of 1 µg/L occurred throughout the year. These elevations were likely associated with individual precipitation events and correlated with high TSS levels. Alongside other metals, Total Cr showed a positive correlation with TSS (Azimuth 2021). Total Cr concentrations increased from upstream to downstream, with the highest average concentrations recorded at the three most downstream sites. The benchmark was exceeded at all sites, with 10% of samples surpassing this threshold upstream at site HD-004 and 50% at the most downstream site, CC-010. Maximum concentrations at HD-014, HD-023, HD-027, HD-033, and HD-021 all occurred during the same week in May 2011.

Table 19. Summary statistics for total chromium (µg/L) at select sites on the Murray River mainstem. Sites are presented in an upstream to downstream order. Shaded rows represent reference stations.

Site	Average	Min	Max	95th %ile	n	% WQG exceedance
MOE-070	0.175	0.0348	1.23	0.380	52	2
HD-004	0.438	0.0362	3.24	1.63	92	10
HD-014	0.411	0.0386	4.71	1.22	98	9
HD-023	0.705	0.0301	3.32	2.16	64	27
HD-028	0.314	0.110	1.51	1.00	48	6
HD-027	0.725	0.0238	7.69	2.81	114	22
HD-033	0.549	0.0317	5.13	1.52	97	15
HD-021	0.634	0.0252	4.98	2.08	82	22
CC-023	1.27	0.0131	5.31	3.50	20	40
MOE-067	0.824	0.0124	4.29	3.06	44	21
CC-010	1.60	0.140	4.35	4.09	16	50

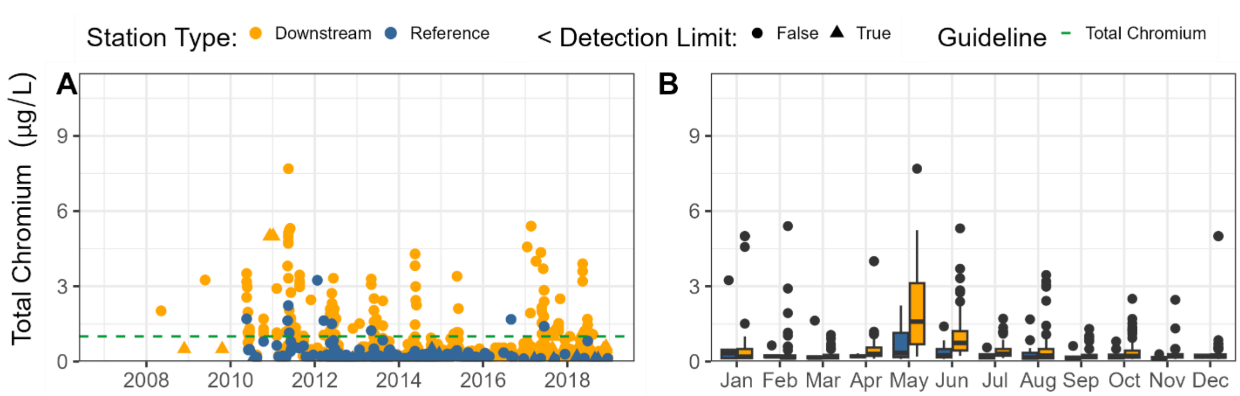

Figure 62. Total chromium concentrations in the Murray River from 2008 to 2018. ***A:*** *All values plotted individually.* ***B****: Values pooled by month (black dots represent outliers). Each graph includes a pooled station dataset for the waterbody. The green dashed line represents the working water quality guideline of 1 µg/L for Cr(VI) for the protection of aquatic life.*

Mining Region

Total Cr concentrations in the reference stations, when available, were often below MDL and seldom exceeded the benchmark (Figures 63 – 66). When the benchmark was surpassed in the reference stations, it typically occurred during the freshet period between April and June. Downstream of mining operations, frequent exceedances of the WQG were observed in M20 Creek, Babcock Creek, Flatbed Creek, Gordon Creek, and Wolverine River, usually in May and June (Table 20, Figures 63 – 66).

Table 20. Total chromium data (µg/L) summary statistics for the waterbodies in the mining region of the KSWGSMR.

Watershed	Waterbody	Average	Min	Max	95th %ile	N
M19 Creek	M19 Creek	0.24	0.10	1.48	0.62	92
M20 Creek	M20 Creek	1.99	0.10	23.50	7.91	220
Flatbed Creek	Gordon Creek	0.95	0.11	10.40	3.21	277
	Babcock Creek	0.80	0.10	20.40	2.17	292
	Flatbed Creek	0.89	0.10	12.20	2.86	209
Wolverine River	Bullmoose Creek	0.22	0.10	1.37	0.50	29
	Mast Creek	0.49	0.10	4.95	1.22	45
	Perry Creek	0.68	0.07	10.70	3.78	107
	Wolverine River	0.54	0.10	7.32	2.20	251

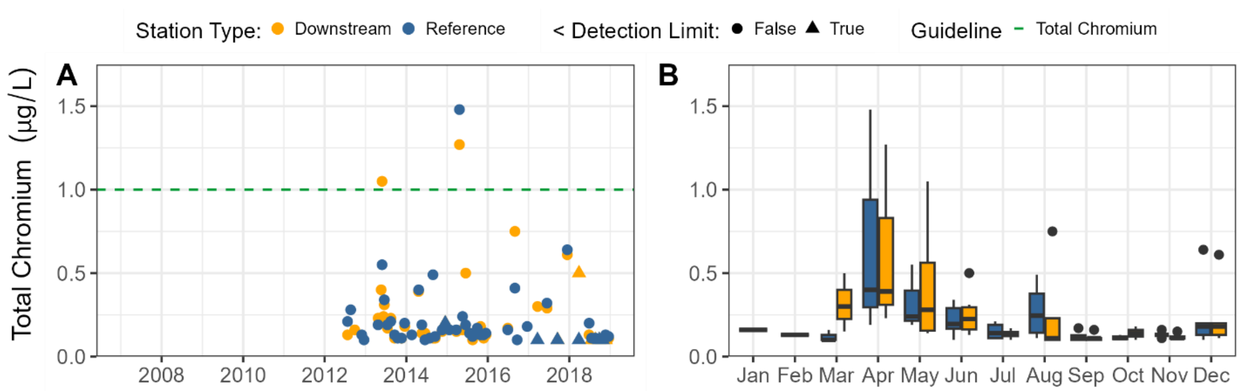

Figure 63. Total chromium concentrations in M19 Creek Watershed from 2008 to 2018. ***A:*** *All values plotted individually.* ***B****: Values pooled by month (black dots represent outliers). The green dashed line represents the working water quality guideline of 1 µg/L for Cr(VI) for the protection of aquatic life. Each graph includes a pooled station dataset for each waterbody.*

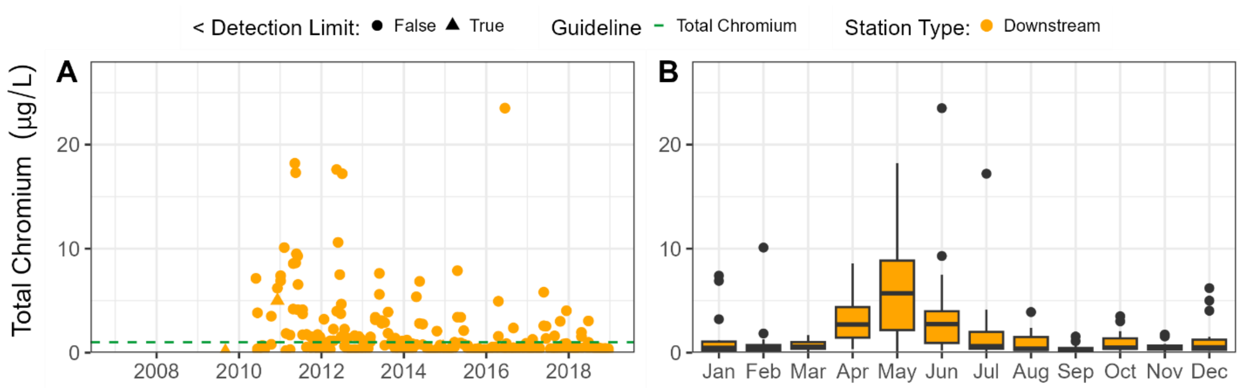

*Figure 64. Total chromium concentrations in M20 Creek watershed from 2008 to 2018. **A:** All values plotted individually. **B**: Values pooled by month (black dots represent outliers). Each graph includes a pooled station dataset for the waterbody. The green dashed line represents the working water quality guideline of 1 µg/L for Cr (VI) for the protection of aquatic life.*

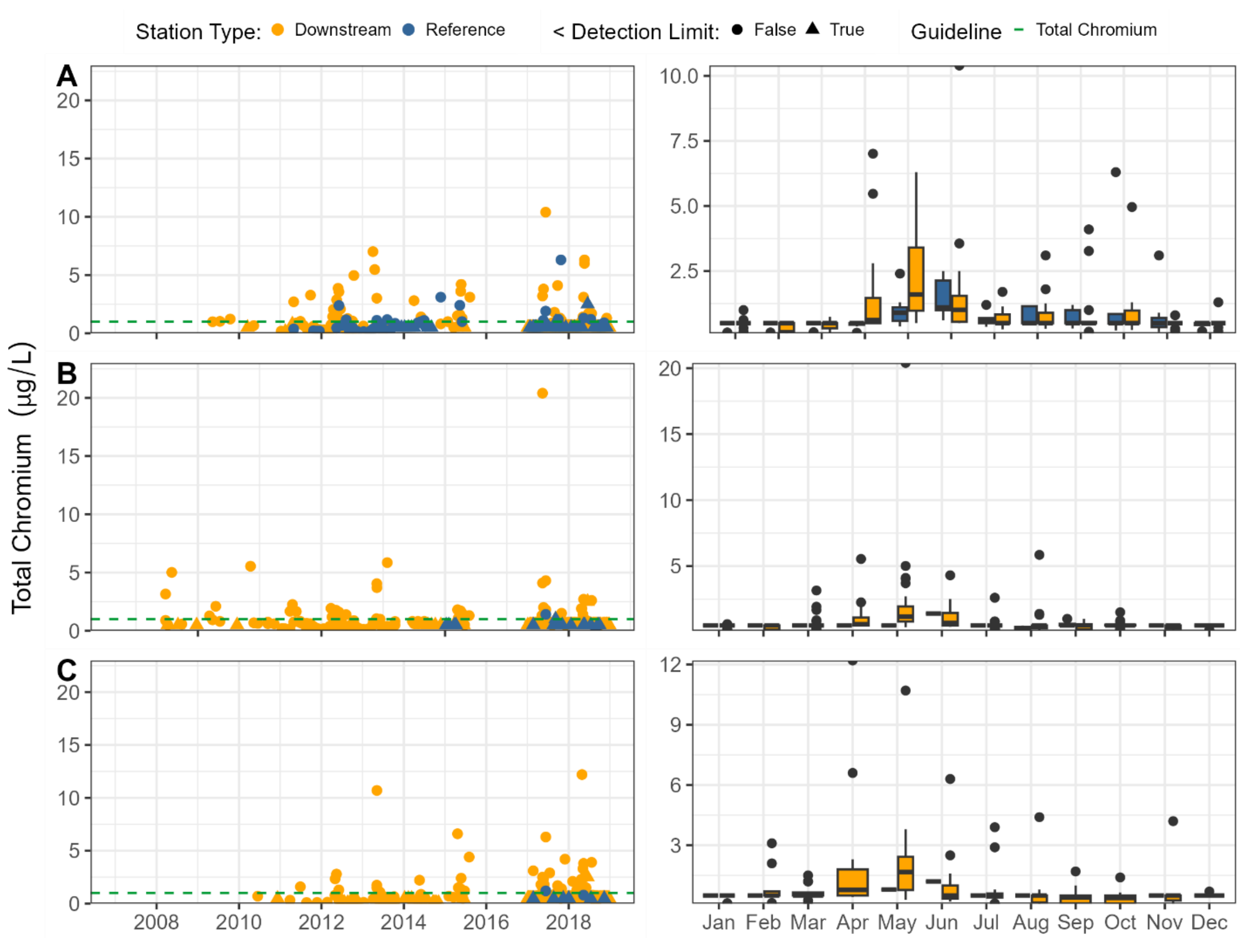

*Figure 65. Total chromium concentrations measured in Flatbed Creek watershed between 2008 and 2018 in Gordon Creek **(A)**, Babcock Creek **(B)**, and Flatbed Creek **(C)**. Graphs on the left include individual values. Graphs on the right group values by month (black dots represent outliers). Each graph includes a pooled station dataset for the waterbody. The green dashed line represents the working water quality guideline of 1 µg/L for Cr(VI) for the protection of aquatic life.*

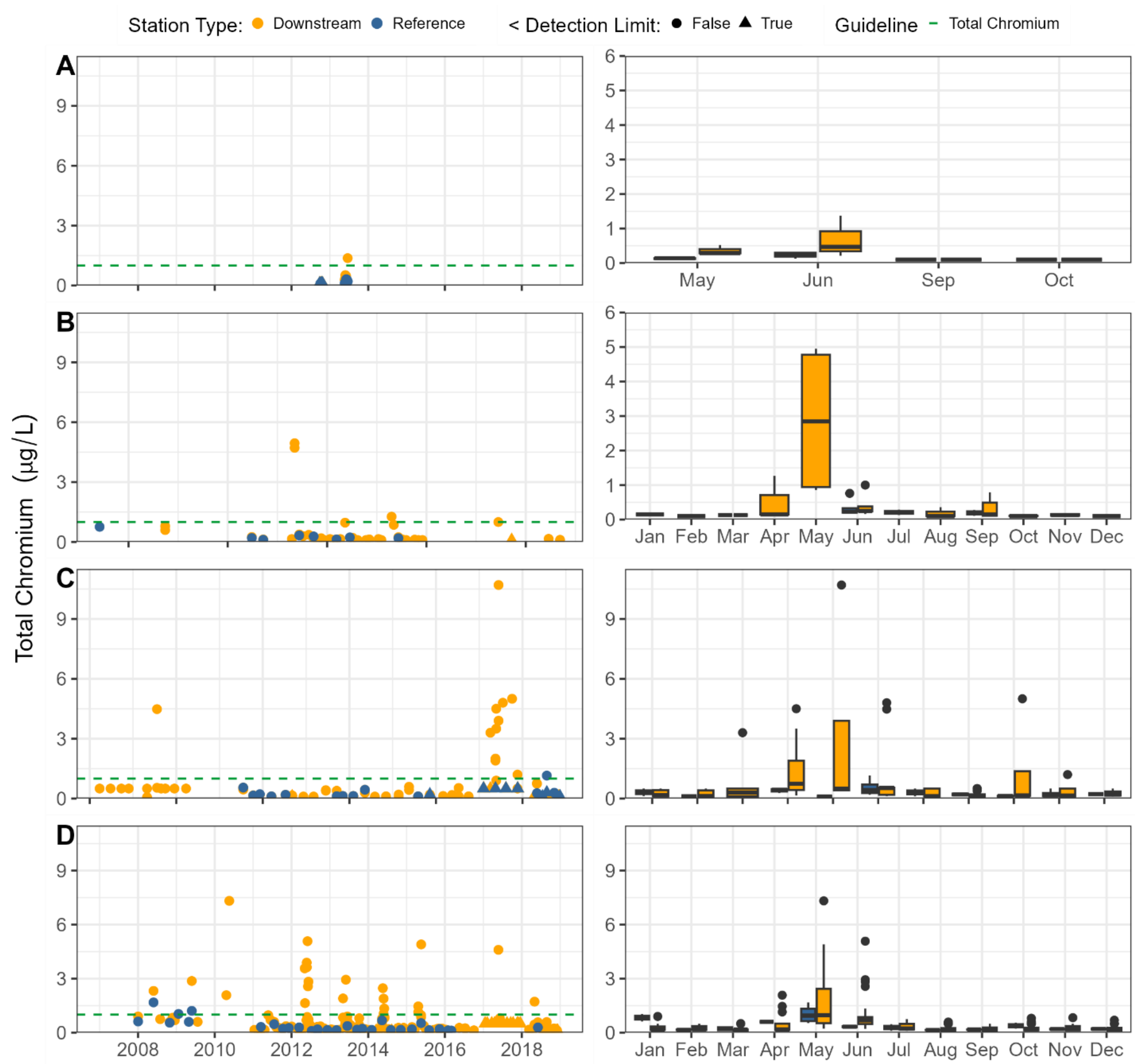

*Figure 66. Total chromium concentrations measured in Wolverine River watershed between 2008 and 2018 in Bullmoose Creek **(A)**, Mast Creek **(B)**, Perry Creek **(C)**, and the Wolverine River **(D)**. Graphs on the left include individual values. Graphs on the right group values by month (black dots represent outliers). Each graph includes a pooled station dataset for the waterbody. The green dashed line represents the working water quality guideline of 1 µg/L for Cr(VI) for the protection of aquatic life.*

Copper

Copper (Cu) is an essential metal for all organisms; however, it has long been a concern in B.C. due to mining activities and other anthropogenic sources. Elevated Cu concentrations can adversely affect aquatic life, with chronic exposure impacting the growth, reproduction, and survival of fish, amphibians, and invertebrates. The B.C. aquatic life WQG is based on dissolved Cu and determined using a biotic ligand model to consider site-specific factors such as pH, DOC, and water hardness (ENV 2019). This WQG is the most conservative for dissolved Cu and was utilized in this assessment. Challenges arose in comparing current conditions with the WQG due to insufficient information for proper calculation. Guideline values were determined where data were available.

Murray River

The Murray River samples exhibited relatively high MDLs associated with dissolved Cu, resulting in a high frequency of non-detects at many stations (Table 21, Figure 67). Generally, there was an increase in the average and 95th percentile dissolved Cu concentrations from upstream to downstream in the Murray River mainstem, with the highest values observed at CC-010 and the lowest values observed at MOE-070 and HD-028. The highest maximum concentration was recorded at HD-033 (5.4 µg/L). Where WQGs could be calculated, they were mostly met (Azimuth 2021).

Table 21. Summary statistics for dissolved copper (µg/L) at select sites on the Murray River mainstem. Sites are presented in an upstream to downstream order.

Site	Average	Min	Max	95th %ile	n	% < MDL
MOE-070	0.238	0.0590	0.926	0.371	52	0
HD-004	0.394	0.0825	2.43	0.790	98	64
HD-014	0.386	0.0747	1.37	0.887	104	78
HD-023	0.499	0.117	3.03	0.940	65	59
HD-028	0.0979	0.000464	1.39	0.471	50	92
HD-027	0.426	0.0555	2.71	0.980	116	70
HD-033	0.452	0.0571	5.40	0.961	100	74
HD-021	0.358	0.0661	1.11	0.954	93	76
CC-023	0.424	0.129	0.95	0.881	23	52
HD-040	0.296	0.0501	1.10	0.709	30	17
MOE-067	0.412	0.163	1.95	0.915	44	0
CC-010	0.750	0.312	1.72	1.46	17	0

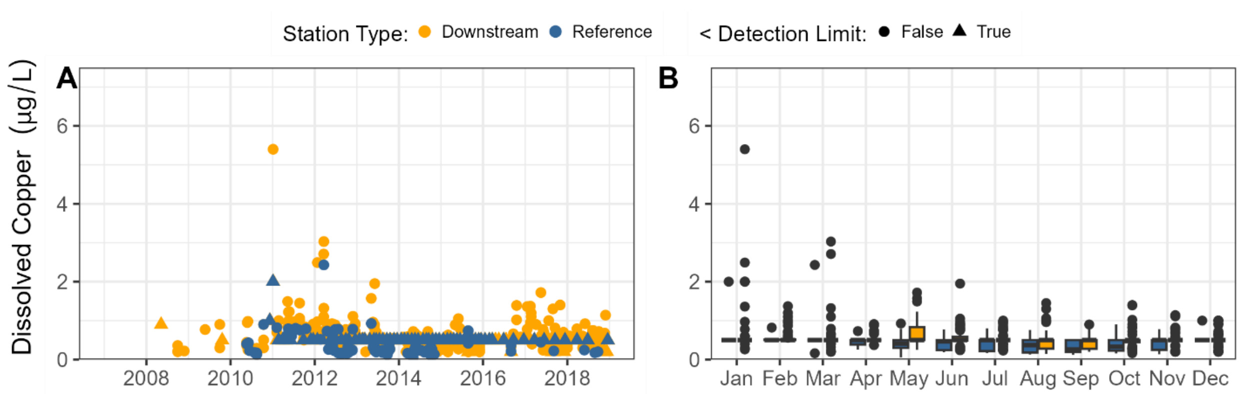

*Figure 67. Dissolved copper concentrations in the Murray River from 2008 to 2018. **A:** All values plotted individually. **B**: Values pooled by month (black dots represent outliers). Each graph includes a pooled station dataset for each waterbody.*

Mining Region

Dissolved Cu was not affected by seasonality and most values were below WQG in the mining region (Table 22, Figures 68 – 75). Average dissolved Cu concentrations ranged from 0.43 to 2.34 µg/L. Maximum reported concentrations for most sites were below 8.8 µg/L, with the exception of Perry Creek which had highest average (2.32 µg/L) and 95th percentile (11.2 µg/L) concentrations. The unusually high dissolved Cu values in Perry Creek occurred at stations CC-006 and, to lesser extent, CC-027 in 2017 on several occasions (Figure 71). Although CC-006 is located upstream of the Wolverine mine it is not considered a reference site because it is influenced by other upgradient landscape activities including clearcutting and oil and gas exploration which could explain the elevated Cu levels observed in 2017.

Dissolved Cu exhibited no significant seasonality, and most values remained below the water quality guideline (WQG) in the mining region (Table 22, Figures 68 – 75). Average dissolved Cu concentrations ranged from 0.43 to 2.34 µg/L. 95th percentile concentrations for most sites were below 1.8 µg/L, with the exception of Perry Creek, which had the highest 95th percentile (11.2 µg/L) concentrations. The unusually high dissolved Cu values in Perry Creek occurred at stations CC-006 and, to a lesser extent, CC-027 in 2017 on several occasions (Figure 71). Although CC-006 is located upstream of the Wolverine mine, it is not considered a reference site because it is influenced by other upgradient landscape activities, including clearcutting and oil and gas exploration, which could explain the elevated Cu levels observed in 2017.

Table 22. Dissolved copper data summary statistics for the waterbodies in the mining region of the KSWGSMR.

Watershed	Waterbody	Average	Min	Max	95th %ile	N
M19 Creek	M19 Creek	0.68	0.46	2.78	1.14	126
M20 Creek	M20 Creek	0.85	0.24	8.80	1.80	218
Flatbed Creek	Gordon Creek	0.62	0.20	4.90	1.20	304
	Babcock Creek	0.71	0.20	5.90	1.31	240
	Flatbed Creek	0.85	0.20	6.20	1.55	148
Wolverine River	Mast Creek	0.78	0.20	2.00	1.50	34
	Perry Creek	2.34	0.10	78.10	11.20	131
	Wolverine River	0.43	0.10	3.00	0.73	306

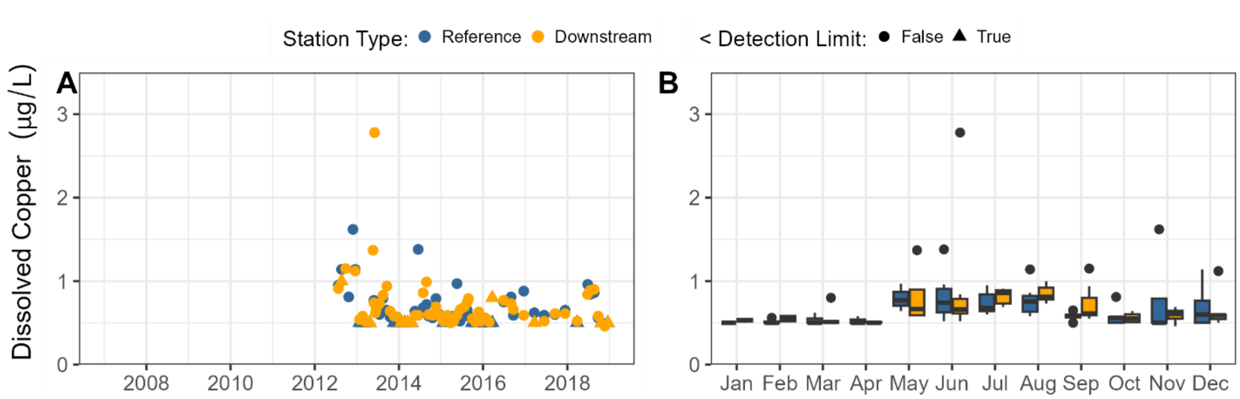

Figure 68. Dissolved copper concentrations in the M19 Creek watershed from 2008 to 2018. ***A:*** *All values plotted individually.* ***B****: Values pooled by month (black dots represent outliers). Each graph includes a pooled station dataset for each waterbody.*

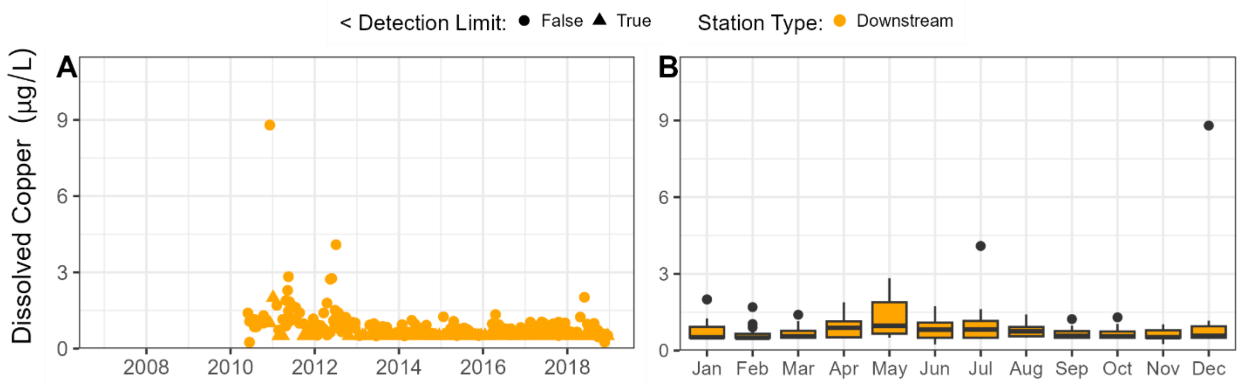

*Figure 69. Dissolved copper concentrations in M20 Creek watershed from 2008 to 2018. **A:** All values plotted individually. **B**: Values pooled by month (black dots represent outliers). Each graph includes a pooled station dataset for each waterbody.*

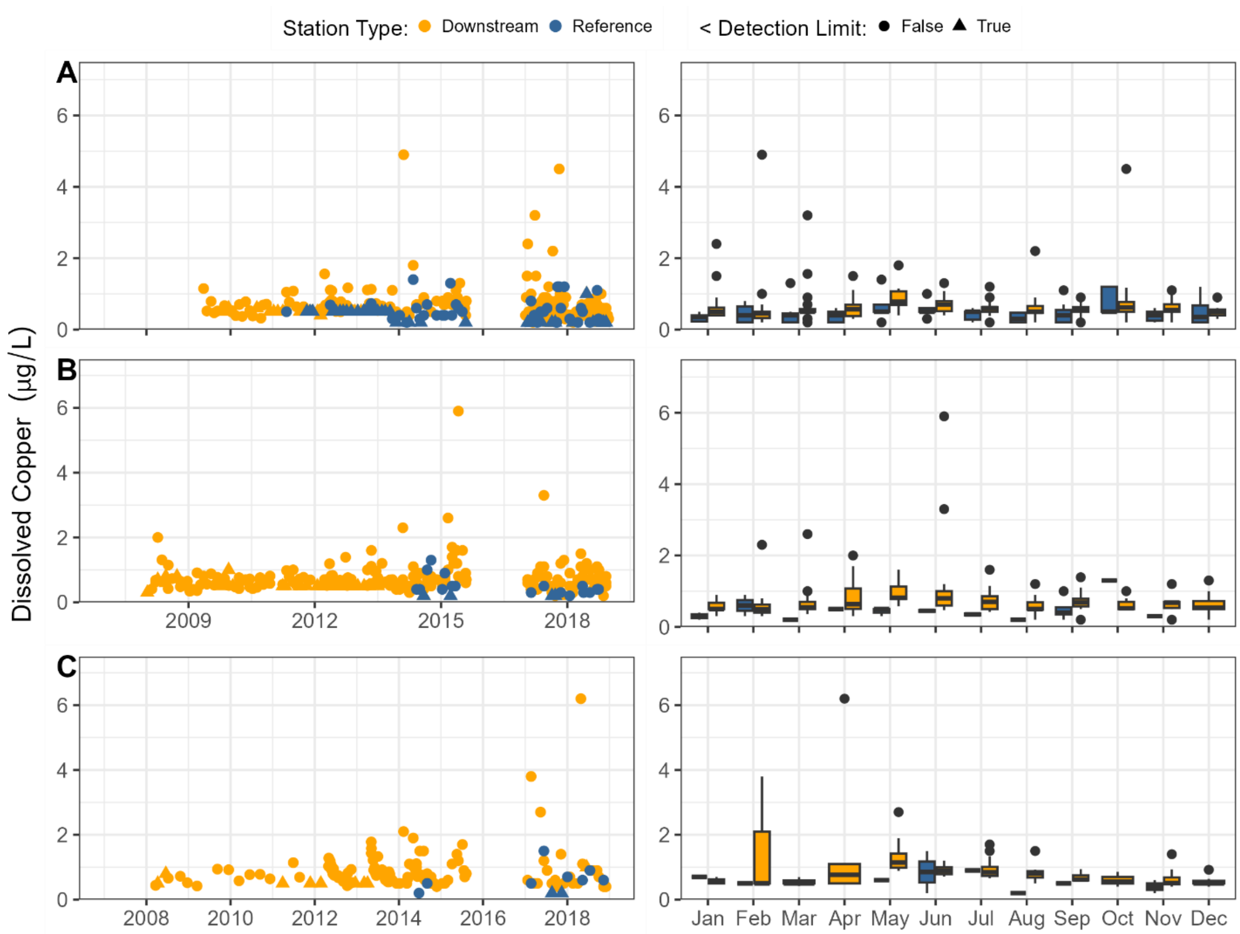

*Figure 70. Dissolved copper concentrations measured in Flatbed Creek watershed between 2008 and 2018 in Gordon Creek **(A)**, Babcock Creek **(B)**, and Flatbed Creek **(C)**. Graphs on the left include individual values. Graphs on the right group values by month (black dots represent outliers). Each graph includes a pooled station dataset for the waterbody.*

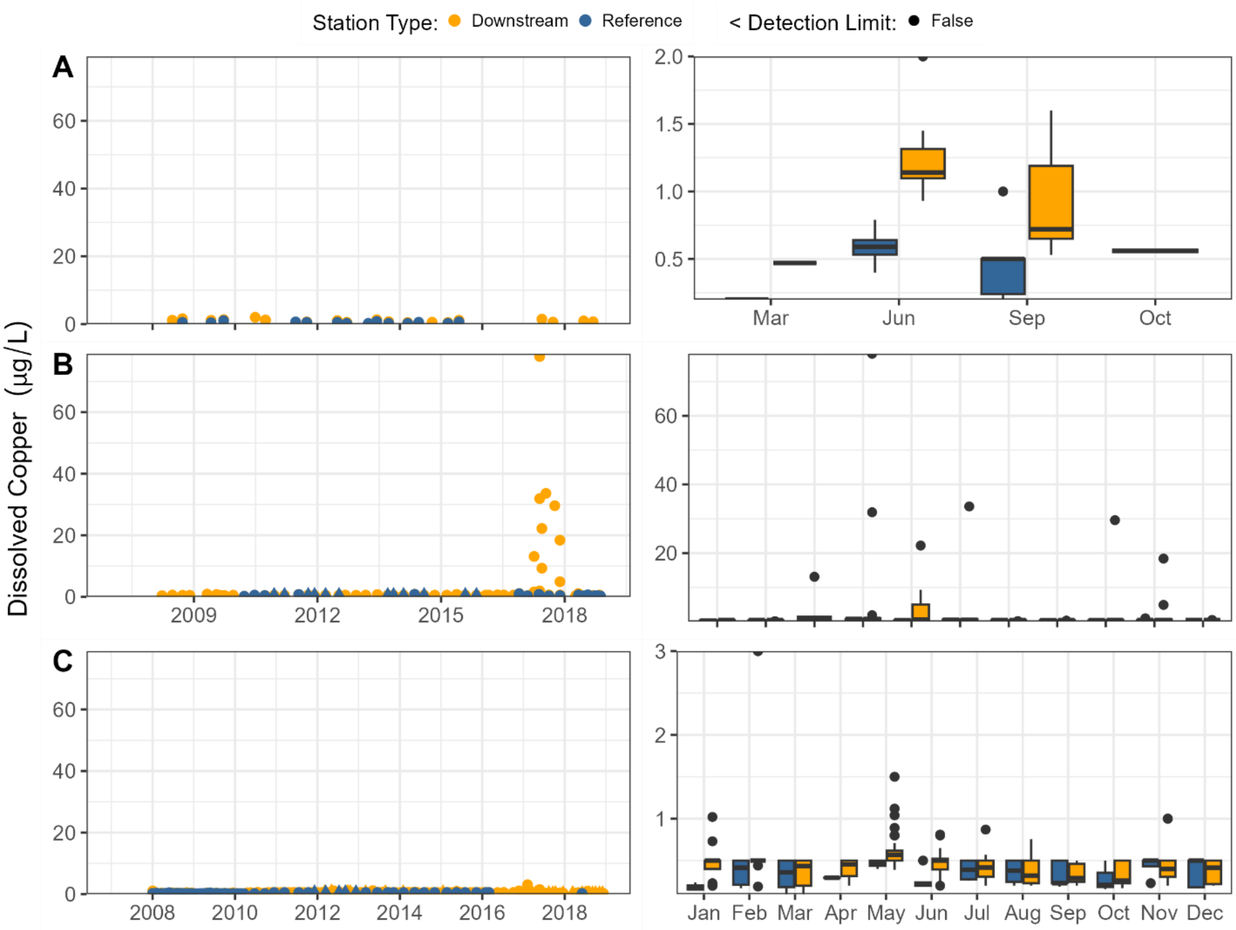

*Figure 71. Dissolved copper concentrations measured in Wolverine River watershed between 2008 and 2018 in Mast Creek **(A)**, Perry Creek **(B)**, and the Wolverine River **(C)**. Data for Bullmoose Creek were not available. Graphs on the left include individual values. Graphs on the right group values by month (black dots represent outliers). Each graph includes a pooled station dataset for the waterbody.*

Iron

Iron (Fe) is an essential element for all forms of life and plays an important role in the metabolic processes of many organisms, but is potentially toxic at higher concentrations. Iron pyrites are common in coal seams and anthropogenic sources of iron in surface water are often related to mining activities (ENV 2008). Because it is most conservative, the total B.C. Fe WQG of 0.3 mg/L to protect the aesthetic quality of drinking water was selected for this assessment (ENV 2020). The B.C. dissolved Fe WQG of 0.35 mg/L for the protection of aquatic life was also used to assess the data (ENV 2008). The dissolved Fe fraction is more biologically relevant because of its importance to aquatic life (ENV 2008).

Murray River

Total Iron

Iron (Fe) is an essential element for all forms of life and plays a crucial role in the metabolic processes of many organisms. However, it can become toxic at higher concentrations. Iron pyrites are commonly found in coal seams, and anthropogenic sources of iron in surface water are often associated with mining activities (ENV 2008). For this assessment, the most conservative total B.C. Fe WQG of 0.3 mg/L was selected to protect the aesthetic quality of drinking water (ENV 2020). Additionally, the B.C. dissolved Fe WQG of 0.35 mg/L, designed to safeguard aquatic life, was utilized to evaluate the data (ENV 2008). The dissolved Fe fraction is considered more biologically relevant due to its significance to aquatic organisms (ENV 2008).

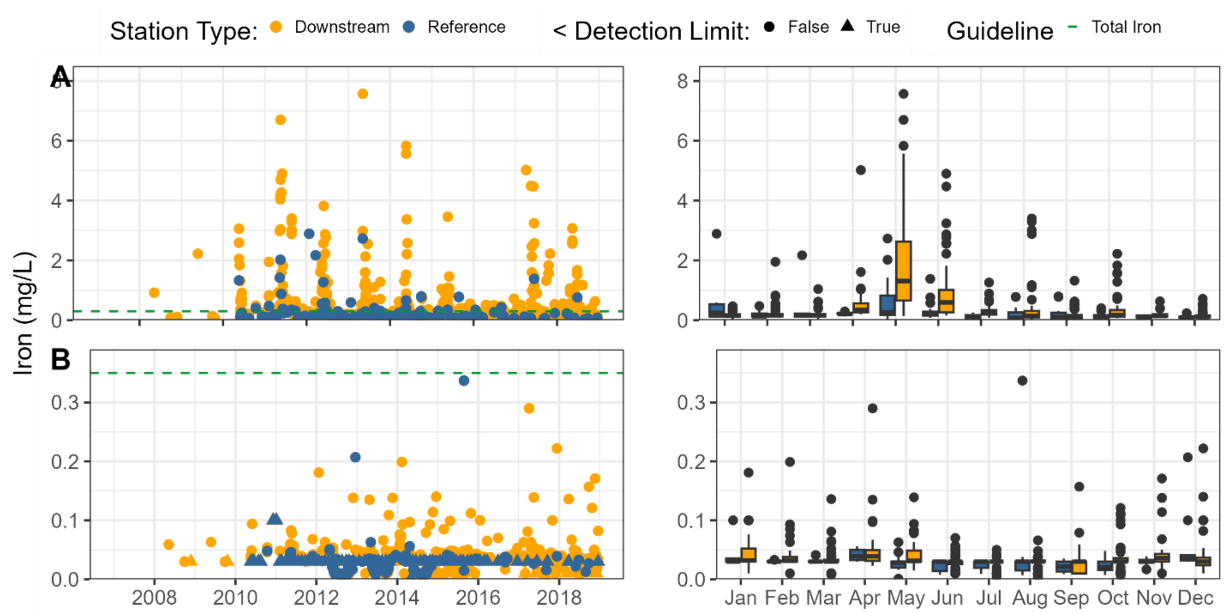

*Figure 72. Total iron **(A)** and dissolved iron **(B)** concentrations in the Murray River from 2008 to 2018. Graphs on the left present individual values and graphs on the right present values grouped by month (black dots represent outliers). The green dashed line in **A** represents the total iron guideline (0.3 mg/L) to protect the aesthetic quality of drinking water, and in **B** it represents the dissolved iron guideline (0.35 mg/L) for the protection of aquatic life.*

Table 23. Summary statistics for total iron (mg/L) at select sites on the Murray River mainstem. Sites are presented in an upstream to downstream order. Shaded rows represent reference stations.

Site	Average	Min	Max	95th %ile	% WQG Exceedance	n
MOE-070	0.232	0.001	2.730	0.711	12	52
HD-004	0.322	0.030	2.890	1.338	27	98
HD-014	0.310	0.025	4.040	0.978	26	104
HD-023	0.563	0.030	3.040	2.138	43	65
HD-028	0.237	0.090	1.030	0.799	12	50
HD-027	0.560	0.083	6.700	2.240	37	116
HD-033	0.407	0.056	4.700	1.191	31	100
HD-021	0.481	0.072	4.170	1.524	34	93
CC-023	0.890	0.037	4.900	3.401	35	23
HD-040	0.439	0.057	3.240	1.694	30	30
MOE-067	1.198	0.050	7.570	5.308	52	44
CC-010	1.677	0.076	5.020	5.020	29	17

Dissolved Iron

Dissolved iron data for the Murray River are summarized in Table 24 and depicted in Figure 72. The highest average concentrations were observed at HD-021 and CC-010. The highest maximum concentration was recorded at the background site HD-004 (0.337 mg/L) in August 2015. The results for dissolved Fe were influenced by the frequency of censored (<MDL) data, which ranged from 31% to 73%. It's noteworthy that all reported results were below the aquatic life water quality guideline (WQG) of 0.35 mg/L.

Table 24. Summary statistics for dissolved iron (mg/L) at select sites on the Murray River mainstem. Sites are presented in an upstream to downstream order. Shaded rows represent reference stations.

Site	Average	Min	Max	95th %ile	% < MDL	n
MOE-070	0.017	0.001	0.063	0.040	2	52
HD-004	0.041	0.015	0.337	0.063	71	98
HD-014	0.033	0.017	0.062	0.043	65	104
HD-023	0.035	0.030	0.070	0.062	63	65
HD-028	0.035	0.030	0.100	0.047	51	50
HD-027	0.035	0.030	0.100	0.055	58	116
HD-033	0.036	0.030	0.100	0.056	63	100
HD-021	0.064	0.030	0.222	0.147	31	93
CC-023	0.035	0.010	0.066	0.063	43	23
HD-040	0.032	0.030	0.050	0.039	73	30
MOE-067	0.019	0.003	0.054	0.042	0	44
CC-010	0.062	0.008	0.290	0.290	29	17

Mining Region

Total Iron

The total iron data for the mining region are summarized in Table 25 and depicted in Figures 73 – 76. Among the nine waterbodies included in this assessment, M20 Creek exhibited the highest total iron concentrations, with most results exceeding the WQG value of 0.3 mg/L (Figure 75). WQG exceedances were observed in other waterbodies across the mining region and were frequently associated with seasonally elevated TSS during freshet (Azimuth 2021). Higher total iron concentrations were noted in downstream stations compared to reference stations in many of the mining streams, including Babcock Creek and Flatbed Creek (Figure 75), as well as the Wolverine River (Figure 76).

Table 25. Total iron summary statistics for the waterbodies in the mining region of the KSWGSMR.

Watershed	Waterbody	Average	Min	Max	95th %ile	N
M19 Creek	M19 Creek	0.16	0.03	1.39	0.40	110
M20 Creek	M20 Creek	1.54	0.03	30.10	6.40	219
Flatbed Creek	Gordon Creek	0.46	0.01	7.57	2.44	298
	Babcock Creek	0.24	0.01	4.80	0.88	350
	Flatbed Creek	0.66	0.04	13.00	3.02	239
Wolverine River	Bullmoose Creek	0.21	0.00	2.05	0.61	29
	Mast Creek	0.34	0.01	4.57	0.81	53
	Perry Creek	0.16	0.01	3.56	0.45	77
	Wolverine River	0.29	0.03	5.07	1.19	320

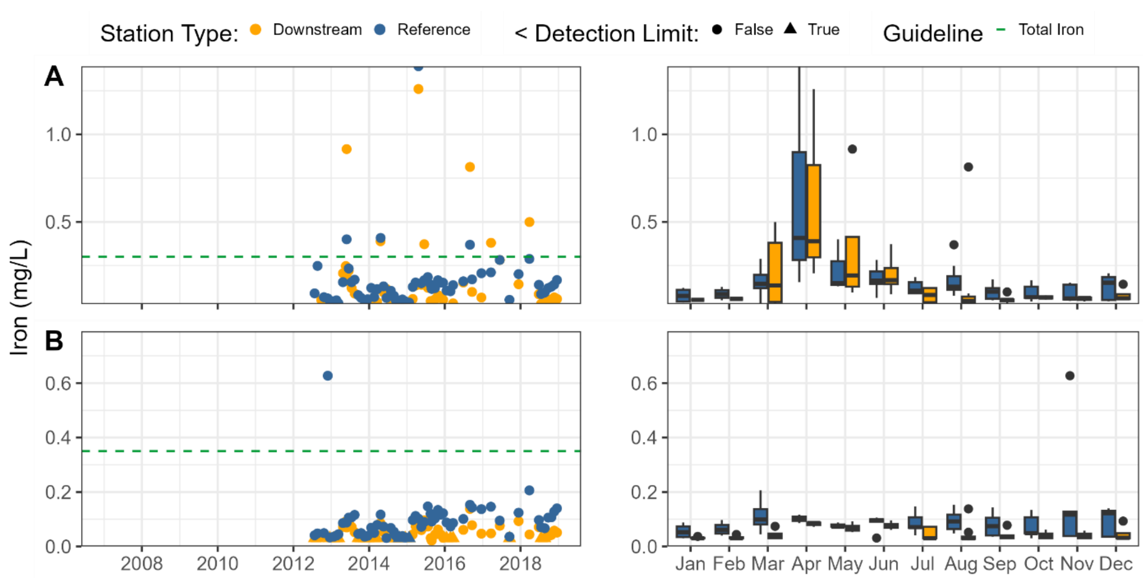

*Figure 73. Total iron **(A)** and dissolved iron **(B)** concentrations in M19 Creek watershed from 2008 to 2018. Graphs on the left present individual values and graphs on the right present values grouped by month (black dots represent outliers). The green dashed line represents the total iron guideline (0.3 mg/L) to protect the aesthetic quality of drinking water **(A)**, and the dissolved iron guideline (0.35 mg/L) for the protection of aquatic life **(B)**.*

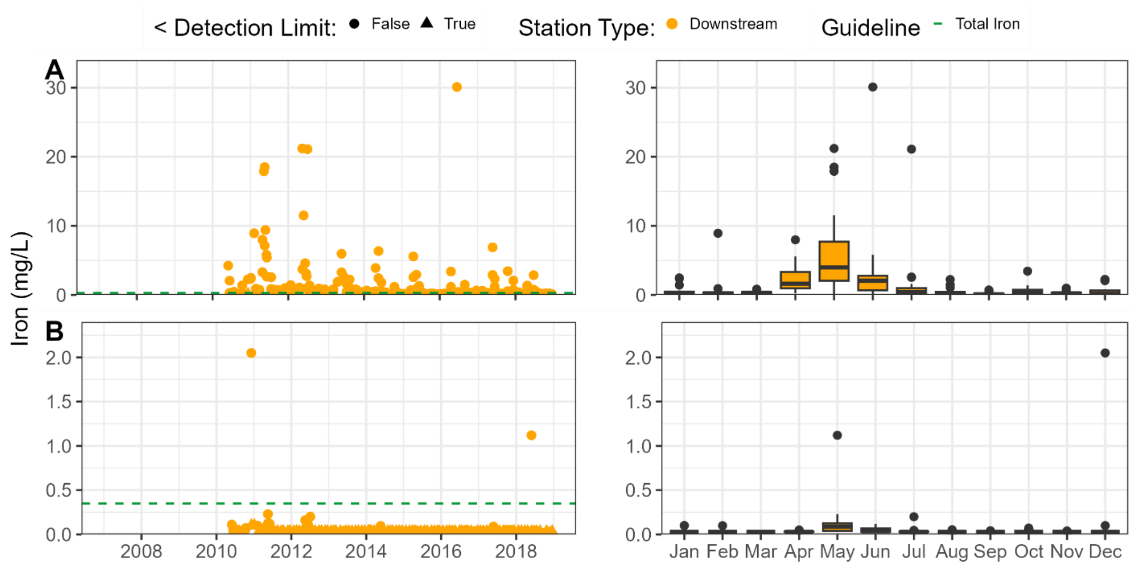

*Figure 74. Total iron **(A)** and dissolved iron **(B)** concentrations in M20 Creek watershed from 2008 to 2018**.** Graphs on the left present individual values and graphs on the right show values grouped by month (black dots represent outliers). The green dashed line represents the total iron guideline (0.3 mg/L) to protect the aesthetic quality of drinking water **(A)**, and the dissolved iron guideline (0.35 mg/L) for the protection of aquatic life **(B)**.*

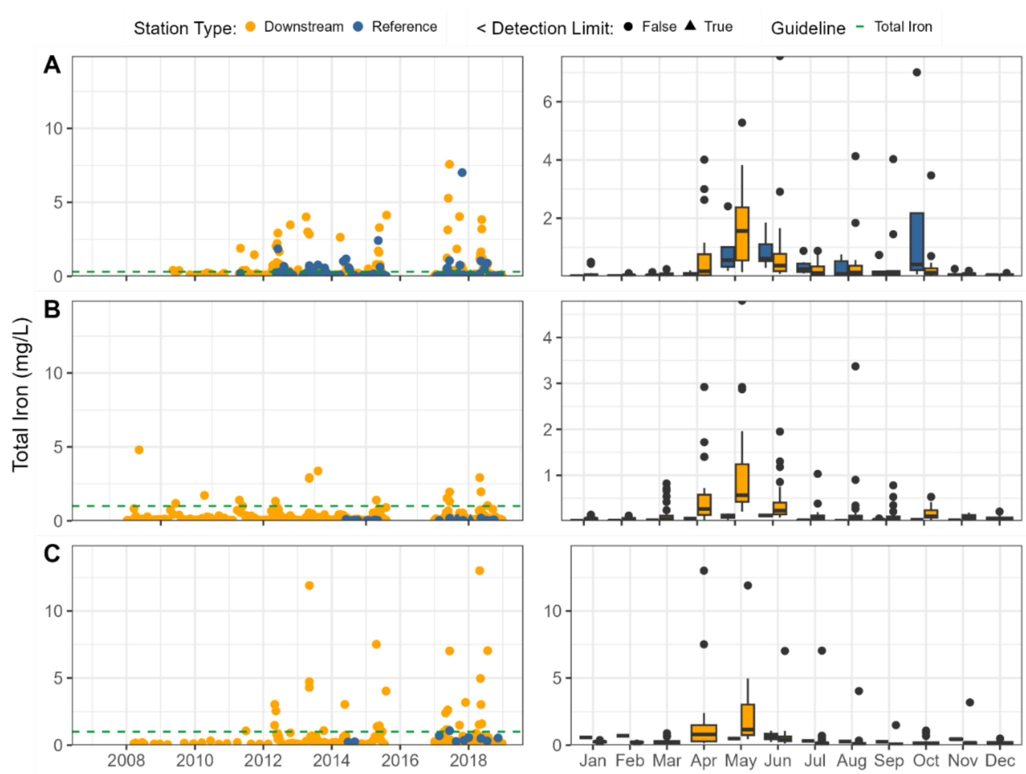

*Figure 75. Total iron concentrations measured in Flatbed Creek watershed between 2008 and 2018 in: **A** Gordon Creek, **B** Babcock Creek, **C** Flatbed Creek. Graphs on left include individual values. Graphs on right group values by month (black dots represent outliers). The green dashed line represents total iron guideline (0.3 mg/L) to protect the asthetic quality of drinking water.*

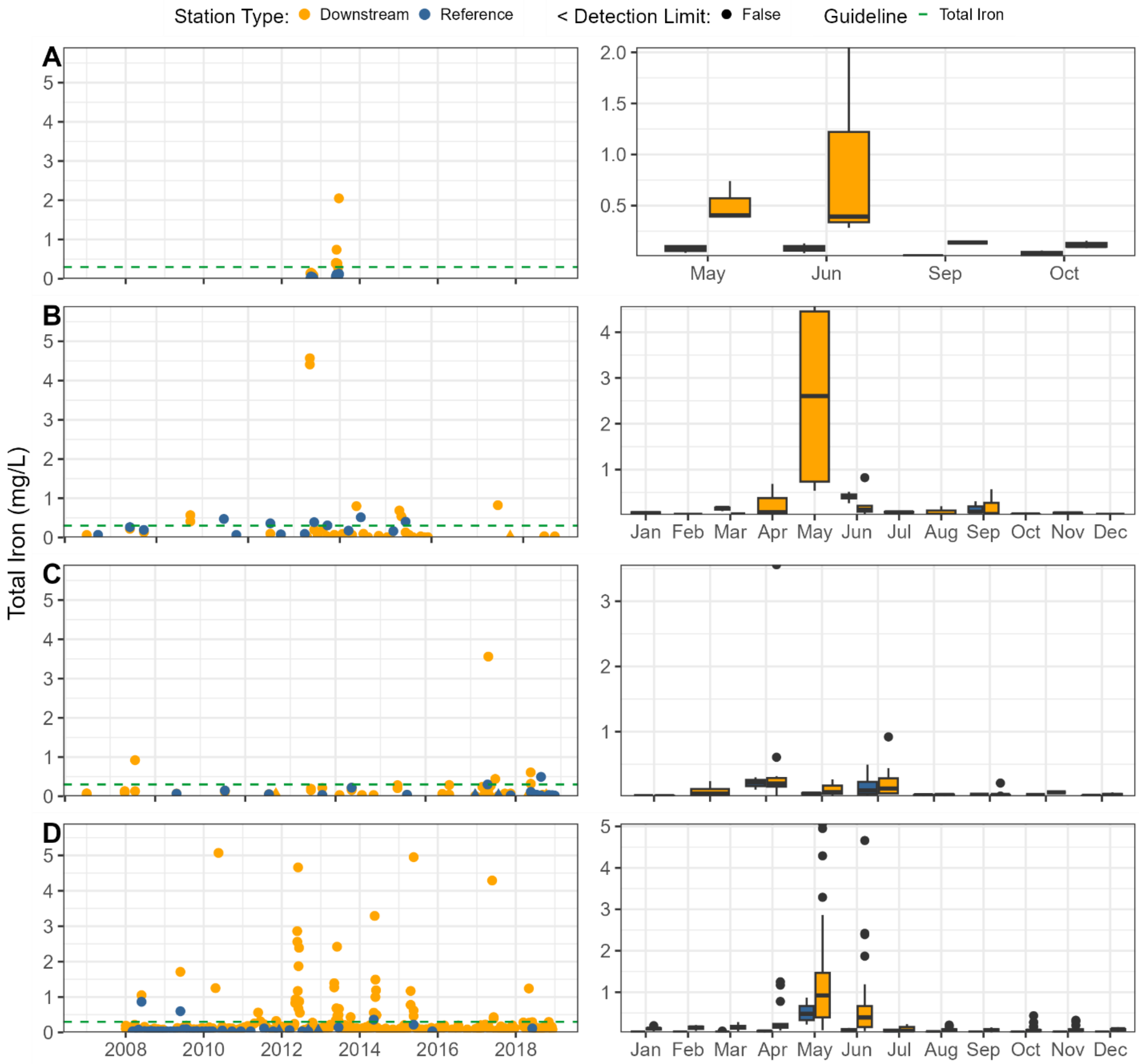

Figure 76. Total iron concentrations measured in Wolverine River watershed between 2008 and 2018 in: ***A*** *Bullmoose Creek* ***B*** *Mast Creek,* ***C*** *Perry Creek,* ***D*** *Wolverine River. Graphs on left include individual values. Graphs on right group values by month (black dots represent outliers). The green dashed line represents total iron guideline (0.3 mg/L) to protectthe asthetic quality of drinking water.*

Dissolved Iron

The dissolved iron data for the mining region are summarized in Table 26 and depicted in Figures 73 (M19 Creek), 74 (M20 Creek), 77 (Flatbed Creek watershed), and 78 (Wolverine River watershed). Generally, dissolved iron concentrations remained below the WQG level of 0.35 mg/L, with some exceptions noted in M19, M20, and Perry Creeks. There were no evident differences in dissolved iron concentrations between sites upstream and downstream of mining activities.

Table 26. Dissolved iron summary statistics for the waterbodies in the mining region. Data not available for Bullmoose Creek

Watershed	Waterbody	Average	Min	Max	95th %ile	N
M19 Creek	M19 Creek	0.07	0.02	0.63	0.14	126
M20 Creek	M20 Creek	0.05	0.01	2.05	0.11	218
Flatbed Creek	Gordon Creek	0.03	0.01	0.24	0.06	305
	Babcock Creek	0.03	0.01	0.20	0.09	255
	Flatbed Creek	0.06	0.01	0.32	0.16	148
Wolverine River	Mast Creek	0.06	0.01	0.29	0.24	34
	Perry Creek	0.03	0.01	0.37	0.08	128
	Wolverine River	0.03	0.01	0.19	0.04	307

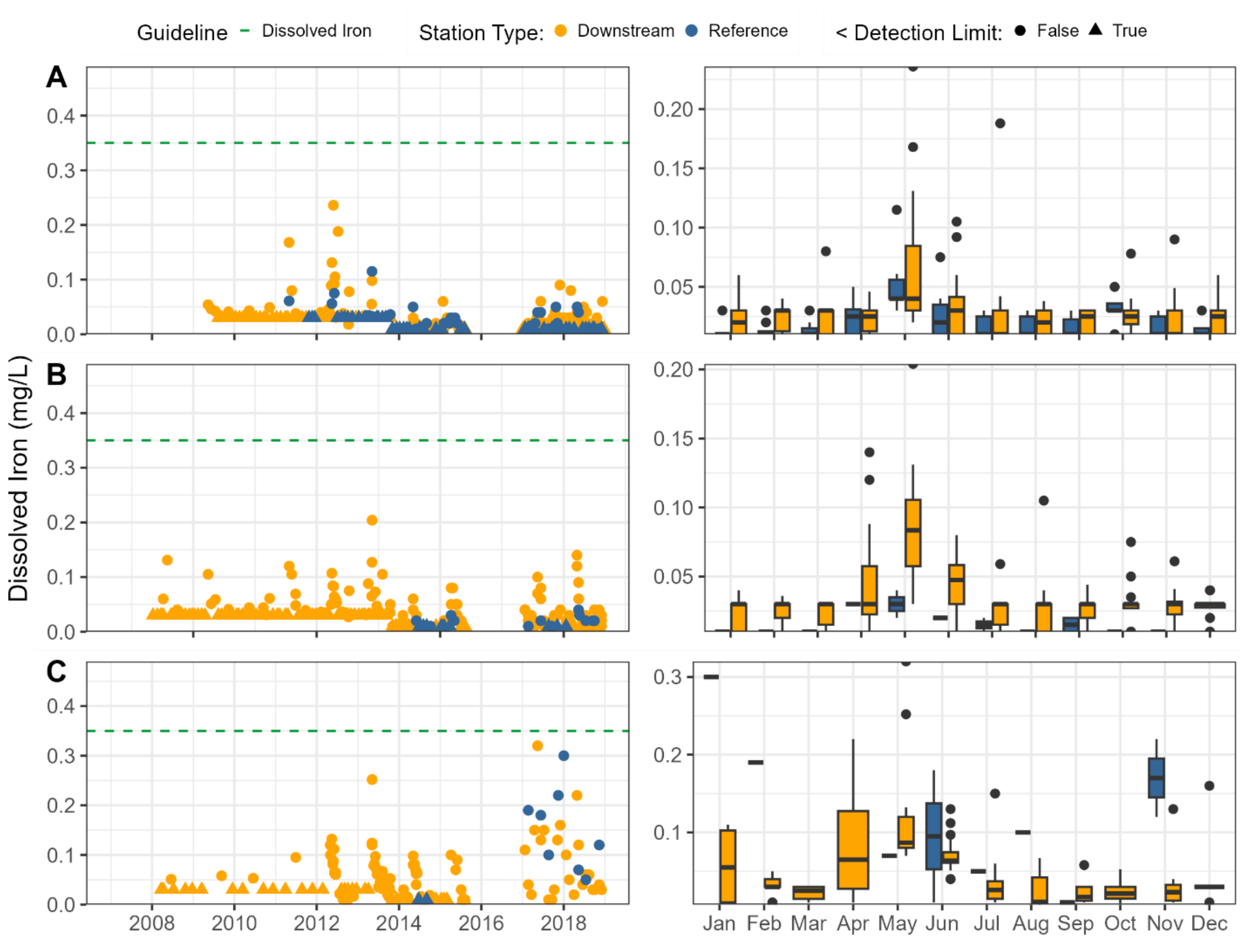

*Figure 77. Dissolved iron concentrations measured in Flatbed Creek watershed between 2008 and 2018 in: **A** Gordon Creek, **B** Babcock Creek, **C** Flatbed Creek. Graphs on left include individual values. Graphs on right group values by month (black dots represent outliers). The green dashed line represents dissolved iron guideline (0.35 mg/L) for the protection of aquatic life.*

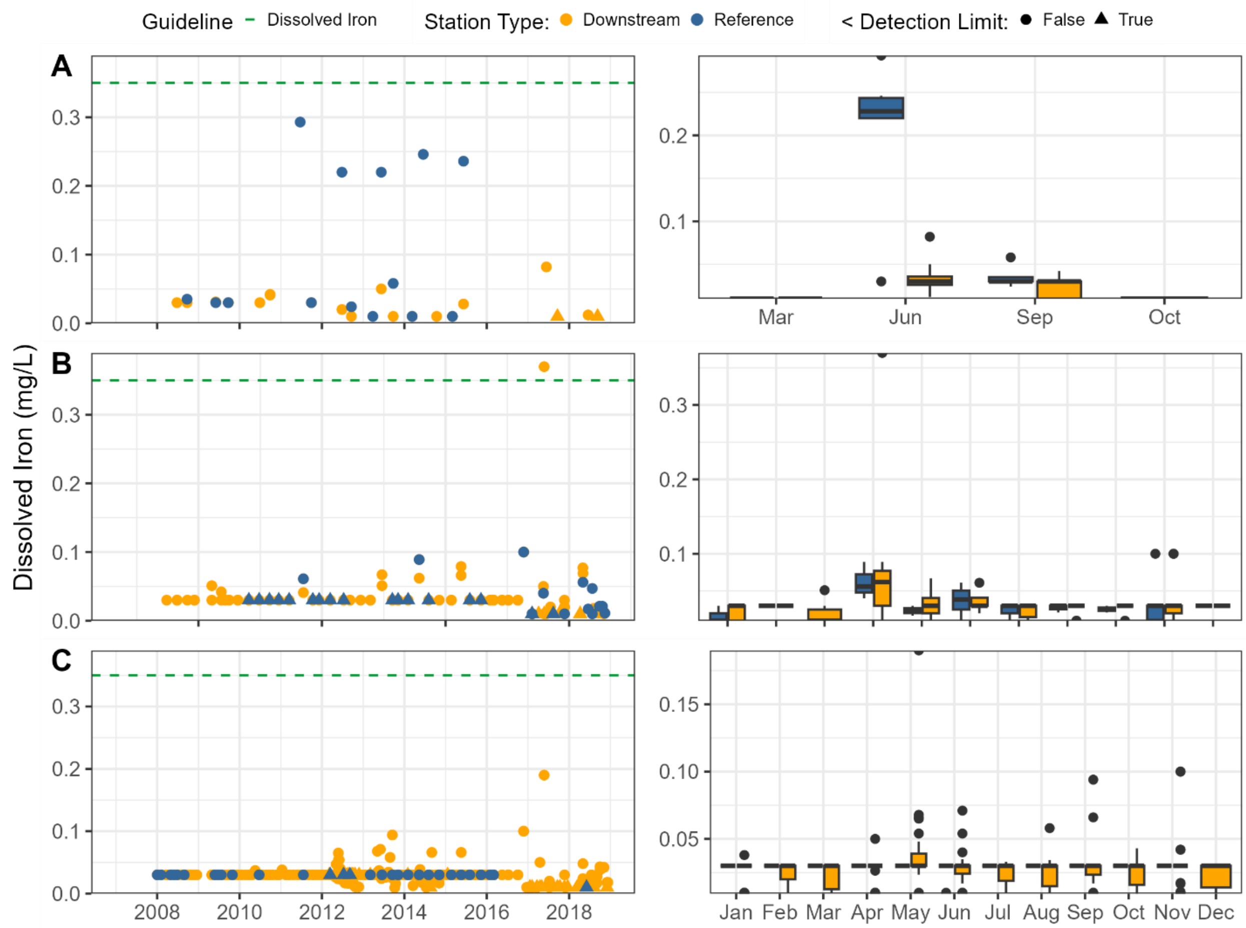

*Figure 78. Dissolved iron concentrations measured in Wolverine River watershed between 2008 and 2018 in: **A** Mast Creek, **B** Perry Creek, **C** Wolverine River. Graphs on left include individual values. Graphs on right group values by month (black dots represent outliers). The green dashed line represents total iron guideline (0.3 mg/L) to protect the asthetic quality of drinking water. Bullmoose Creek data were not available.*

Manganese

Manganese (Mn) is an essential element that plays a critical role in various physiological processes. It occurs naturally in the environment and can also be introduced through human activities (ENV 1999b). The B.C. Mn WQG for the protection of aquatic life is based on total Mn and is determined by water hardness. The long-term chronic WQGs for aquatic life protection are typically higher than the most conservative Mn BC WQG, which is an aesthetic guideline of 0.02 mg/L aimed at safeguarding drinking water quality. For this assessment, the more conservative aesthetic WQG was utilized.

Murray River

Total Mn varied seasonally with averages ranging between 0.006 mg/L at HD-040 and 0.021 mg/L at CC-010 (Table 27). The WQG of 0.02 mg/L was mostly met in the mainstem, with a few exceptions at both upstream and downstream areas, predominantly during freshet (Figure 79; Azimuth 2021). Total Mn concentrations were higher in downstream stations of the Murray River compared to the upstream (Table 27).

Table 27. Summary statistics for total manganese (mg/L) at select sites on the Murray River mainstem. Sites are presented in an upstream to downstream order. Shaded rows represent reference stations.

Site	Average	Min	Max	95th %ile	N
MOE-070	0.014	0.002	0.148	0.041	52
HD-004	0.007	0.003	0.104	0.048	98
HD-014	0.008	0.002	0.096	0.027	104
HD-023	0.012	0.001	0.077	0.054	65
HD-028	0.009	0.005	0.027	0.021	50
HD-027	0.010	0.004	0.120	0.049	116
HD-033	0.010	0.005	0.103	0.041	100
HD-021	0.010	0.004	0.099	0.042	93
CC-023	0.007	0.001	0.088	0.058	23
HD-040	0.006	0.002	0.062	0.034	30
MOE-067	0.010	0.002	0.308	0.103	44
CC-010	0.021	0.003	0.128	0.100	17

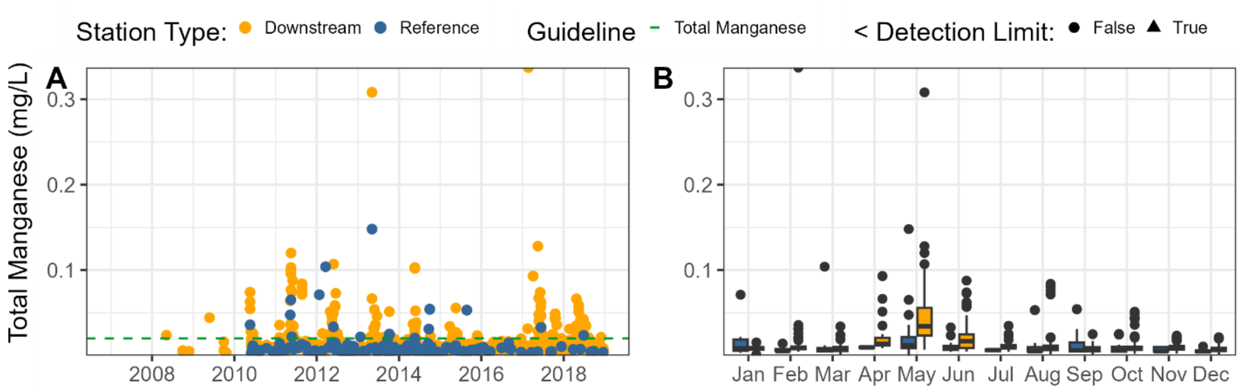

*Figure 79. Total manganese concentrations in the Murray River from 2008 to 2018: **A** values provided individually, and **B** values grouped by month (black dots represent outliers). Each graph includes pooled station dataset for each waterbody. The green dashed line represents aesthetic guideline of 0.02 mg/L to protect drinking water quality.*

Mining Region

Among the nine waterbodies in the central mining region, M20 Creek exhibited the highest average total Mn concentrations (0.029 mg/L), followed by Flatbed Creek (0.015 mg/L; see Table 28 and Figures 80 - 83). Typically, average total Mn concentrations remained below the WQG during low flow periods, although some exceedances were noted in various waterbodies across the mining region during freshet. Comparatively, total Mn levels were higher in downstream sites when contrasted with reference sites in Gordon, Flatbed, and Babcock Creeks, as well as in Bullmoose Creek and the Wolverine River. Interestingly, total Mn levels were more frequently elevated in upstream reference stations in M19 and Mast Creek compared to downstream stations (see Figure 83).

Table 28. Total manganese data summary statistics in mg/L for the waterbodies in the mining region of the KSWGSMR.

Watershed	Waterbody	Average	Min	Max	95th %ile	N
M19 Creek	M19 Creek	0.005	0.0002	0.041	0.015	126
M20 Creek	M20 Creek	0.029	0.0004	0.640	0.100	221
Flatbed Creek	Gordon Creek	0.010	0.0005	0.132	0.046	315
	Babcock Creek	0.006	0.0001	0.112	0.021	348
	Flatbed Creek	0.015	0.0020	0.229	0.046	235
Wolverine River	Bullmoose Creek	0.011	0.0005	0.061	0.029	29
	Mast Creek	0.008	0.0001	0.077	0.025	58
	Perry Creek	0.002	0.0001	0.068	0.007	130
	Wolverine River	0.012	0.0001	0.113	0.032	333

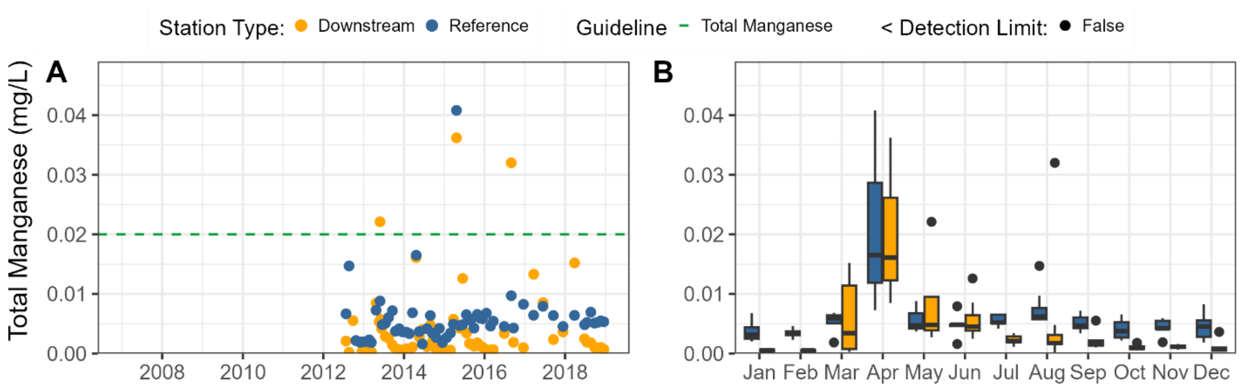

*Figure 80. Total manganese concentrations in the M19 Creek watershed from 2008 to 2018: **A** values provided individually, and **B** values grouped by month (black dots represent outliers). Each graph includes pooled station dataset for each waterbody. The green dashed line represents aesthetic guideline of 0.02 mg/L to protect drinking water quality.*

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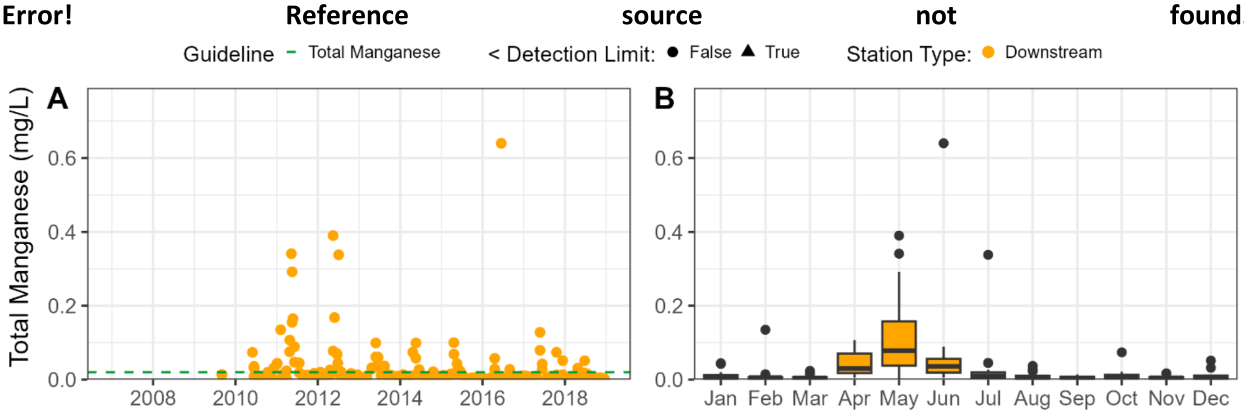

*Figure 81. Total manganese concentrations in M20 Creek watershed from 2008 to 2018: **A** values provided individually, and **B** values grouped by month (black dots represent outliers). Each graph includes pooled station dataset for each waterbody. The green dashed line represents aesthetic guideline of 0.02 mg/L to protect drinking water quality.*

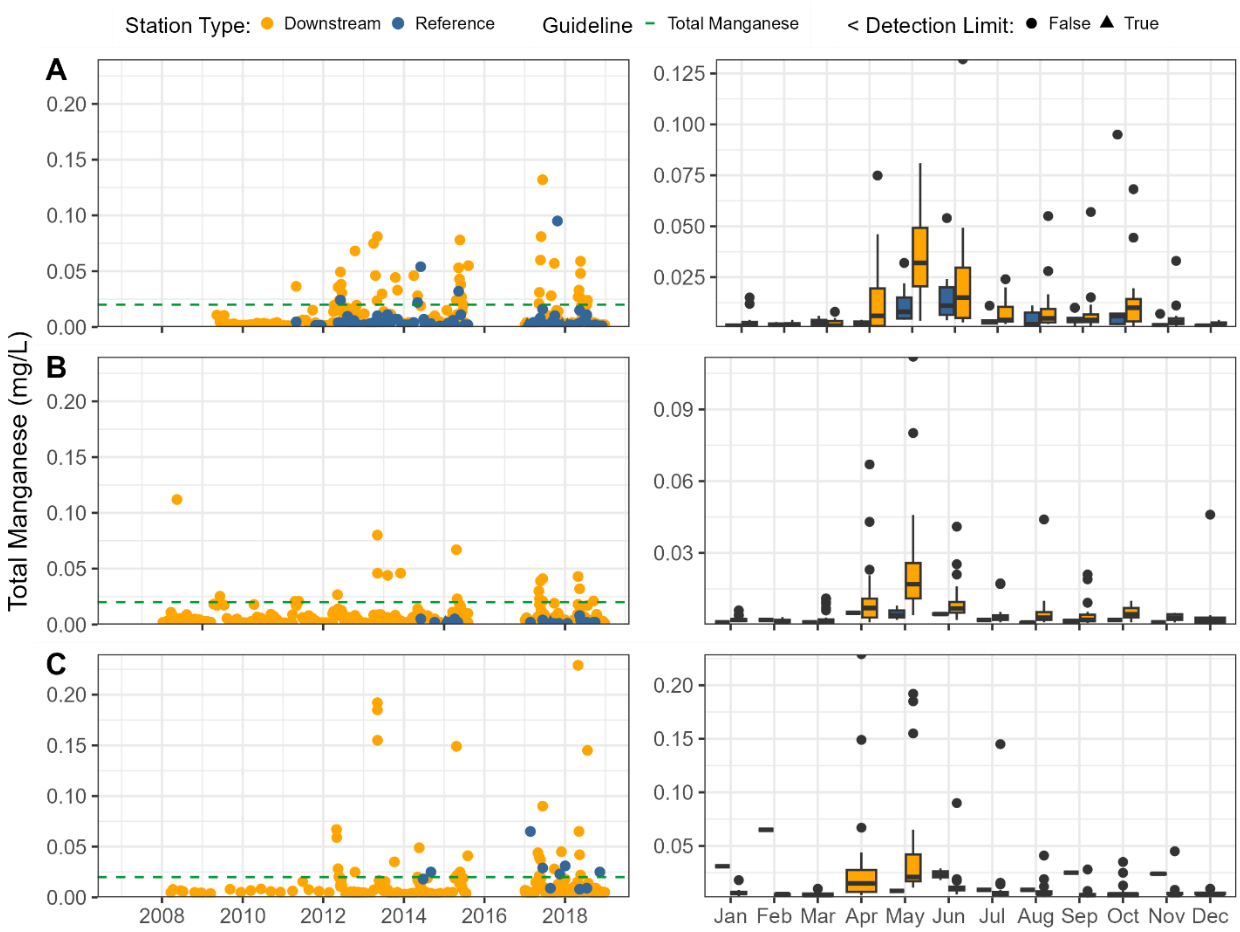

*Figure 82. Total manganese concentrations measured in Flatbed Creek watershed between 2008 and 2018 in: **A** Gordon Creek, **B** Babcock Creek, **C** Flatbed Creek. Graphs on left include individual values. Graphs on right group values by month (black dots represent outliers). The green dashed line represents aesthetic guideline of 0.02 mg/L to protect drinking water quality.*

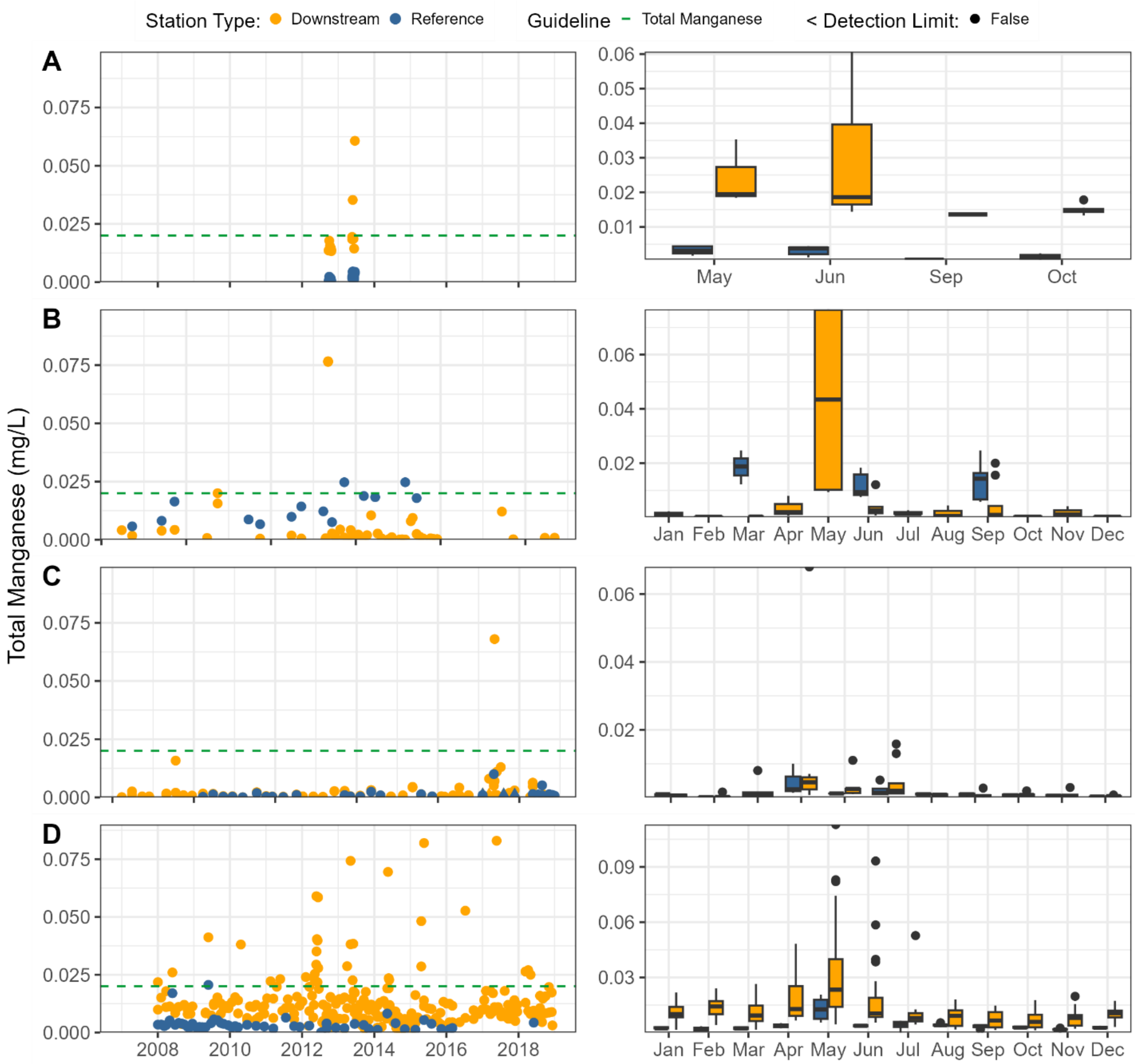

Figure 83. Total manganese measured in Wolverine River watershed between 2008 and 2018 in: ***A*** *Bullmoose Creek* ***B*** *Mast Creek,* ***C*** *Perry Creek,* ***D*** *Wolverine River. Graphs on left include individual values. Graphs on right group values by month (black dots represent outliers). The green dashed line represents aesthetic guideline of 0.02 mg/L to protect drinking water quality.*

Mercury

Mercury (Hg) is a potent neurotoxin that poses significant risks to human health, particularly to infants and children. It is commonly found in various products such as paints, scientific supplies, fungicides, and pharmaceuticals. Of particular concern is methylmercury (MeHg), which is highly toxic and has the ability to bioaccumulate and biomagnify in aquatic life (ENV 2001a). Both Hg and MeHg are detrimental to all forms of aquatic life, with chronic exposure leading to growth impairments, reproductive and developmental issues, and mortality.

In B.C., the WQG for aquatic life protection is determined based on the ratio of MeHg to total Hg. When MeHg constitutes less than 1% of the total Hg, the WQG for total Hg is set at 0.01 µg/L, with the guideline decreasing as the proportion of MeHg increases (ENV 2001a). This guideline represents the most conservative approach to regulating mercury and was utilized in the present assessment. In cases where MeHg concentrations were available, a site-specific WQG was calculated accordingly. Alternatively, if total Hg data were unavailable, dissolved Hg data were examined.

Murray River

The assessment of total Hg data was challenging due to varying MDLs over time. Although average total Hg concentrations were generally below the WQG, site HD-014 exhibited a slightly elevated average concentration of 0.0168 µg/L, exceeding the WQG of 0.01 µg/L (Table 29). Results across several sites were influenced by MDLs higher than the WQG, while others fell below the WQG or below the lowest MDL used (<0.005 µg/L; Figure 84). Notably, most exceedances occurred during periods of high freshet. The highest maximum total Hg concentration was recorded at the headwaters of the Murray River, site HD-004, reaching 0.0567 µg/L.

Three sites provided both total Hg and MeHg data, enabling the calculation of appropriate WQG values (Table 30). All results were below the calculated WQG value, with most total Hg concentrations falling below the MDL of 0.005 µg/L.

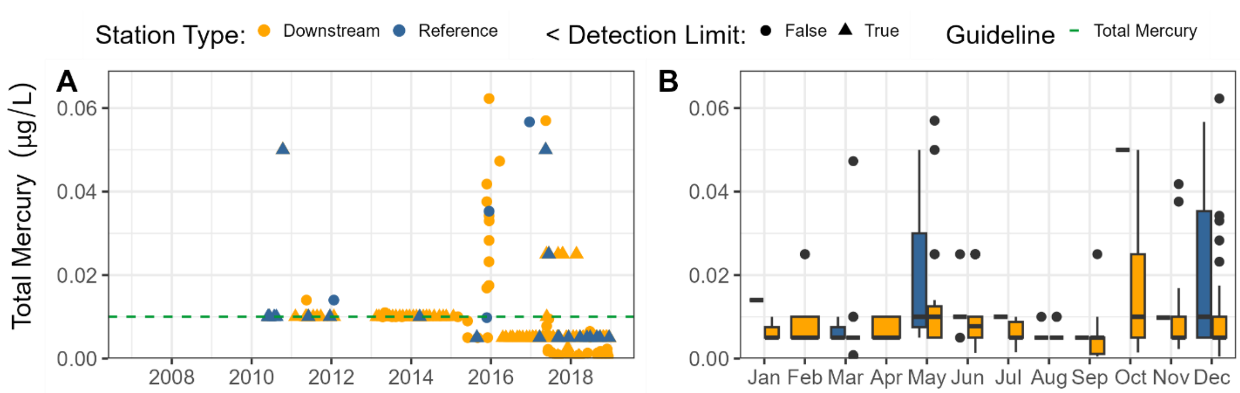

*Figure 84. Total mercury concentrations in the Murray River from 2008 to 2018: **A** values provided individually, and **B** values grouped by month (black dots represent outliers). Each graph includes pooled station dataset for each waterbody. The green dashed line represents the WQG for the protection of aquatic life of 1 µg/L, assuming MeHg concentrations are < 1%.*

Table 29. Summary statistics for total mercury (µg/L) at sites on the Murray River mainstem. Sites are presented in an upstream to downstream order. Shaded rows represent reference stations.

Site	Average	Min	Max	95th %ile	n	% < MDL
MOE-077	0.00250	0.00500	0.0500	0.0432	4	100
HD-004	0.00625	0.00014	0.0567	0.0310	25	84
TK-012	0.00316	0.00082	0.0090	0.0078	8	13
TK-014	0.00069	0.00008	0.0018	0.0017	7	57
HD-014	0.01680	0.00487	0.0473	0.0366	27	89
HD-023	0.00250	0.00250	0.0250	0.0125	34	97
HD-027	0.00174	0.00002	0.0283	0.0061	59	95
HD-033	0.00250	0.00250	0.0330	0.0258	19	95
TK-028	0.00081	0.00010	0.0022	0.0020	8	50
HD-021	0.00581	0.00005	0.0418	0.0297	15	80
CC-023	0.00250	0.00500	0.0050	0.0050	1	100
HD-040	0.00250	0.0025	0.0175	0.0160	7	86
TK-038	0.00282	4.09E-05	0.00950	0.00823	4	25
MOE-076	0.00250	0.005	0.0500	0.0432	4	100
CC-010	0.00760	0.000453	0.0570	0.0327	11	64

Table 30. Total mercury aquatic life water quality guideline values for sites on the Murray River mainstem. Sites are presented in an upstream to downstream order. Shaded rows represent reference stations.

Site	Date	MeHg (µg/L)	Total Hg (µg/L)	WQG (µg/L)
MOE-077	2018-05-29	<0.00002	<0.005	0.025
MOE-077	2018-08-28	<0.00002	<0.005	0.025
MOE-076	2018-05-29	0.00005	<0.005	0.010
MOE-076	2018-08-28	<0.00002	<0.005	0.025
CC-10	2018-06-21	0.00003	<0.005	0.018
CC-10	2018-08-10	0.00005	<0.005	0.011
CC-10	2018-10-01	0.00002	0.002	0.008
CC-10	2018-10-29	0.00002	0.002	0.006
CC-10	2018-11-29	<0.00004	0.002	0.006

Mining Region

Limited Hg data were available for waterbodies in the mining region with data missing for Gordon, Flatbed, Bullmoose Creeks and Wolverine River (Table 31; Figures 85 - 87). WQG exceedances occurred in M19 Creek, Mast Creek and M20 Creek, often due to MDLs exceeding the WQG. More recently collected data in these two creeks were below the MDL. Where data were available (i.e., M19 Creek), WQG guideline exceedances were observed in upstream reference as well as downstream sites.

Table 31. Total mercury data (µg/L) summary statistics for the waterbodies in the mining region of the KSWGSMR.

Waterbody	Average	Min	Max	95th %ile	n
M19 Creek	0.010	0.005	0.065	0.035	36
M20 Creek	0.015	0.005	0.071	0.049	83
Mast Creek	0.009	0.001	0.024	0.019	28
Perry Creek	0.005	0.005	0.005	0.005	2

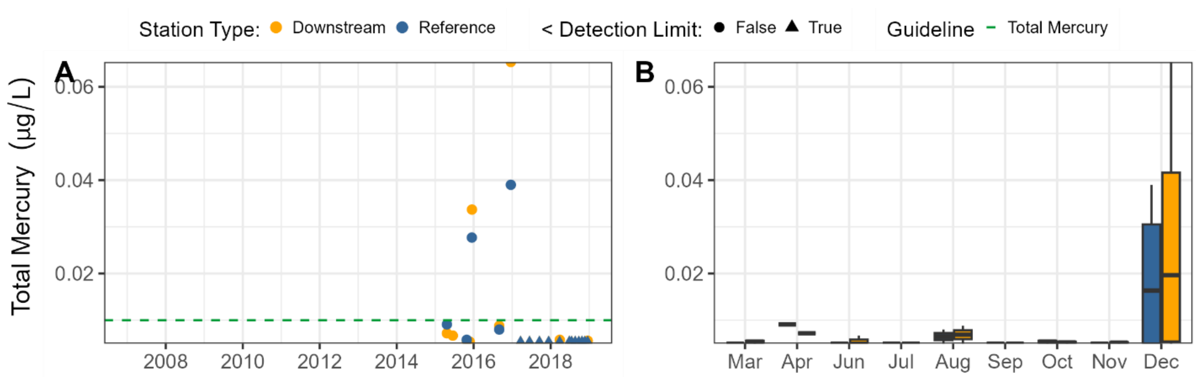

*Figure 85. Total mercury concentrations in M19 Creek watershed from 2008 to 2018: **A** values provided individually, and **B** values grouped by month (black dots represent outliers). Each graph includes pooled station dataset for each waterbody. The green dashed line represents the WQG for the protection of aquatic life of 1 µg/L, assuming MeHg concentrations are < 1%.*

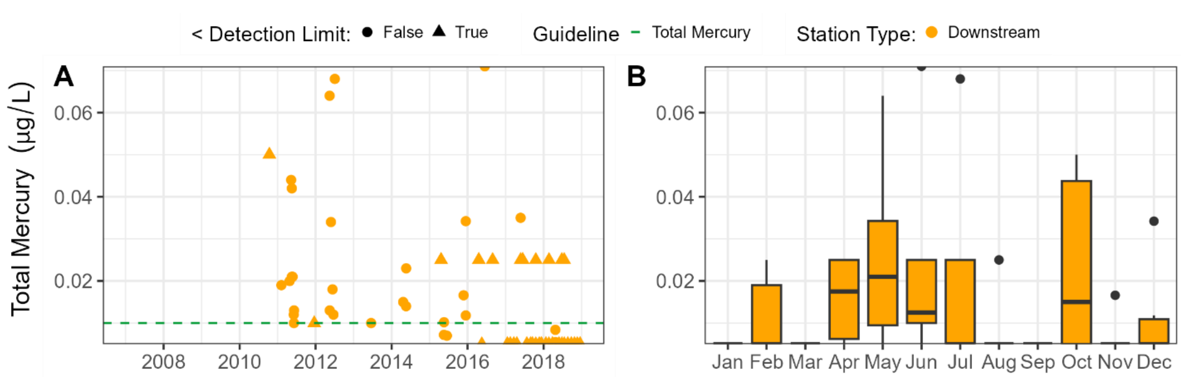

*Figure 86. Total mercury concentrations in M20 Creek watershed from 2008 to 2018: **A** values provided individually, and **B** values grouped by month (black dots represent outliers). Each graph includes pooled station dataset for each waterbody. The green dashed line represents the WQG for the protection of aquatic life of 1 µg/L, assuming MeHg concentrations are < 1%.*

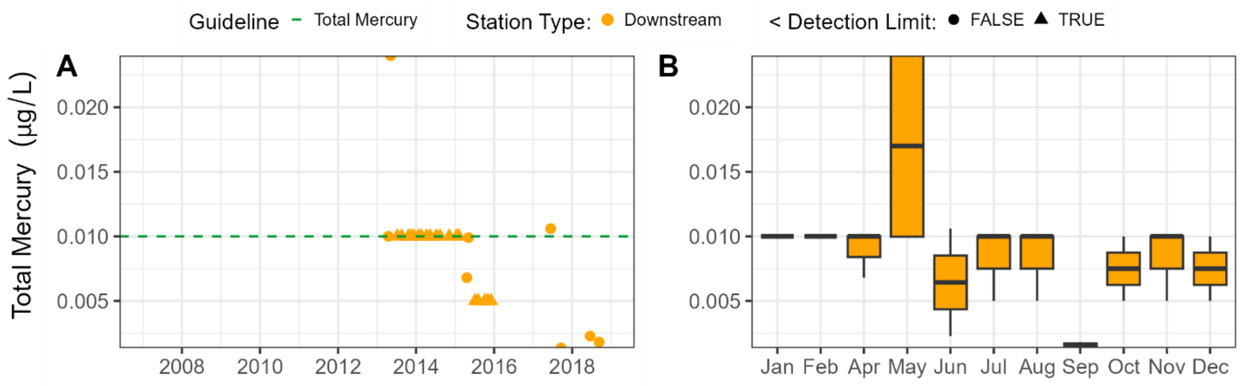

Figure 87. Total mercury concentrations in Mast Creek from 2008 to 2018: ***A*** *values provided individually, and* ***B*** *values grouped by month (black dots represent outliers). Each graph includes pooled station dataset for each waterbody. The green dashed line represents the WQG for the protection of aquatic life of 1 µg/L, assuming MeHg concentrations are < 1%.*

Selenium

Selenium (Se) is an essential trace element for many organisms, but excessive amounts can result in toxic effects. Se enters water from natural processes like erosion and human activities like mining. Se toxicity in fish results in many adverse effects including reductions in growth, behavioral changes, increased deformities, and increased mortality in early life stages. For birds that feed in aquatic environments, the most sensitive toxicity endpoint is reduced egg hatchability followed by deformities in offspring.

Se accumulates in sediments and biota in the aquatic environment and can continue to persist and cycle for many years. Se residues in aquatic life tissues can vary, even within the same species at the same site, and may not always be predictably correlated with Se in water. In many cases, low water column Se concentrations (≤ 2 µg/L) will not result in significant accumulation through the food web. However, there are instances where Se concentrations less than 1 µg/L have resulted in significant bioaccumulation and apparent chronic effects (ENV 2014).

Ingestion of elemental and organic Se compounds is not known to cause acute toxicity in humans (ENV 2014). However, there is a narrow margin between Se intake that is beneficial and that which is hazardous. Selenosis results from chronic Se intoxication and symptoms include diarrhea, nausea, fatigue, muscle aches, and hair and nail damage or loss.

The BC WQG for the protection of freshwater aquatic life is 2 µg/L; this is the most conservative BC WQG and was used in this assessment. An alert level of 1 µg/L also exists to assess water quality in lentic systems (ENV 2014).

<u>Murray River</u>

Total Se concentrations at most stations along the Murray River mainstem remained well below the WQG of 2 µg/L, with no discernible seasonal patterns observed (Table 32, Figure 88). Elevated Se concentrations were generally noted in downstream stations compared to upstream ones. The highest average total Se concentration was recorded at station CC-023, situated just downstream of inflows from the mining region's Wolverine River and Flatbed Creek, with an average of 1.38 µg/L. However, the maximum Se concentration measured at CC-023 (2.03 µg/L) slightly exceeded the WQG.

Table 32. Summary statistics for total selenium (µg/L) at select sites on the Murray River mainstem. Sites are presented in an upstream to downstream order. Shaded rows represent reference stations.

Site	Average	Min	Max	95th %ile	N
MOE-070	0.146	0.0600	0.505	0.216	52
HD-004	0.194	0.0770	0.440	0.337	84
HD-014	0.237	0.0736	1.59	0.316	87
HD-023	0.205	0.100	0.390	0.320	58
HD-028	0.198	0.120	0.330	0.302	44
HD-027	0.270	0.110	1.01	0.468	106
HD-033	0.224	0.0821	0.449	0.350	91
HD-021	0.233	0.100	0.720	0.354	80
CC-023	1.38	0.140	2.03	1.97	22
MOE-067	0.419	0.170	0.820	0.540	44
CC-010	0.549	0.376	0.800	0.800	17

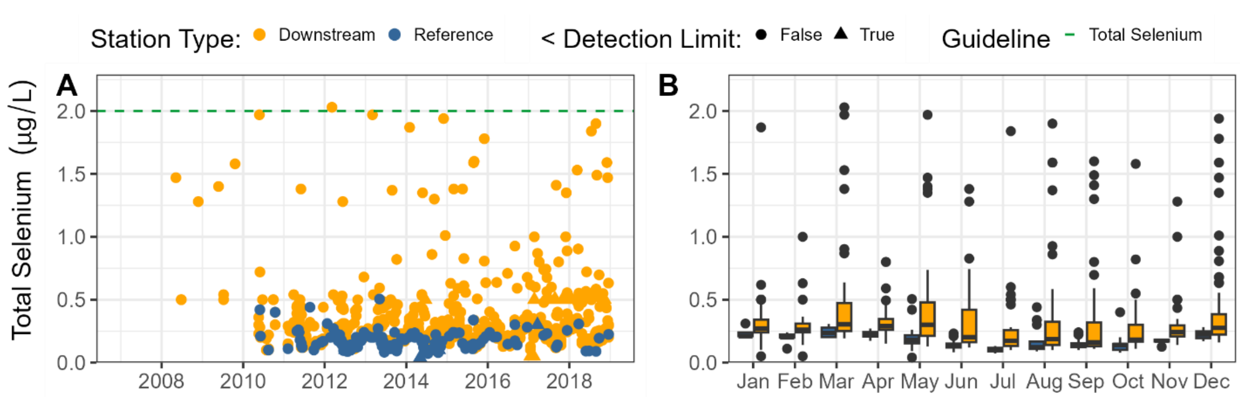

*Figure 88. Total selenium concentrations in Murray River from 2008 to 2018: **A** values provided individually, and **B** values grouped by month (black dots represent outliers). Each graph includes pooled station dataset for each waterbody. The green dashed line represents the WQG for the protection of aquatic life of 2 µg/L.*

Mining Region

At reference monitoring locations in the central mining region, total Se concentrations were predominantly below the Water Quality Guideline (WQG) of 2 µg/L (Table 33, Figures 89 – 92). However, downstream of mining operations, total Se concentrations generally exceeded the WQG, with occasional exceptions such as M19 Creek. Notably, Gordon Creek and Babcock Creek exhibited the highest total Se concentrations, reaching maximum levels of 58.4 and 24.4 µg/L, respectively. Trend analysis suggests an increasing trend in total Se levels in both waterbodies over time (Figure 91). Seasonally, lower Se levels were typically observed during freshet in most mining waterbodies, while the highest levels were observed in the summer.

Table 33. Total selenium summary statistics for the waterbodies in the mining region of the KSWGSMR.

Watershed	Waterbody	Average	Min	Max	95th %ile	N
M19 Creek	M19 Creek	0.2	0.1	0.3	0.3	116
M20 Creek	M20 Creek	1.4	0.2	4.5	2.2	215
Flatbed Creek	Gordon Creek	10.7	0.2	58.4	30.1	330
	Babcock Creek	6.2	0.5	24.4	13.0	396
	Flatbed Creek	2.2	0.5	6.5	3.9	274
Wolverine River	Bullmoose Creek	2.3	0.4	5.5	5.1	29
	Mast Creek	3.9	0.1	7.5	7.1	63
	Perry Creek	0.9	0.3	18.2	1.1	127
	Wolverine River	1.6	0.1	3.5	2.7	324

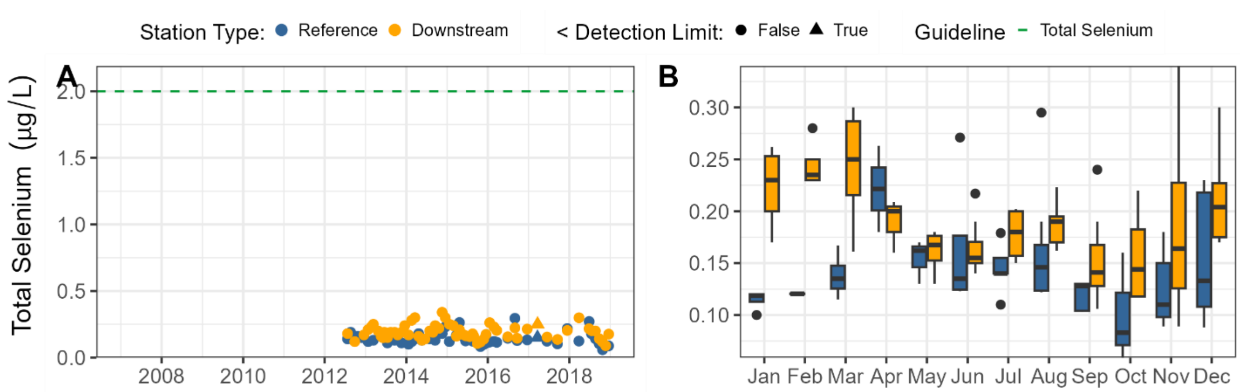

*Figure 89. Total selenium concentrations in M19 Creek watershed from 2008 to 2018: **A** values provided individually, and **B** values grouped by month (black dots represent outliers). Each graph includes pooled station dataset for each waterbody. The green dashed line represents the WQG for the protection of aquatic life of 2 µg/L.*

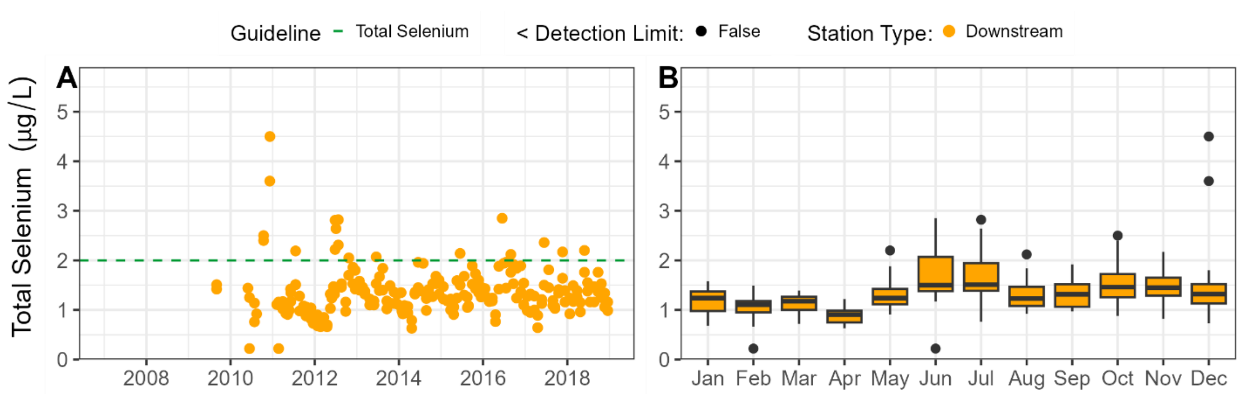

*Figure 90. Total selenium concentrations in M20 Creek watershed from 2008 to 2018: **A** values provided individually, and **B** values grouped by month (black dots represent outliers). Each graph includes pooled station dataset for each waterbody. The green dashed line represents the WQG for the protection of aquatic life of 2 µg/L.*

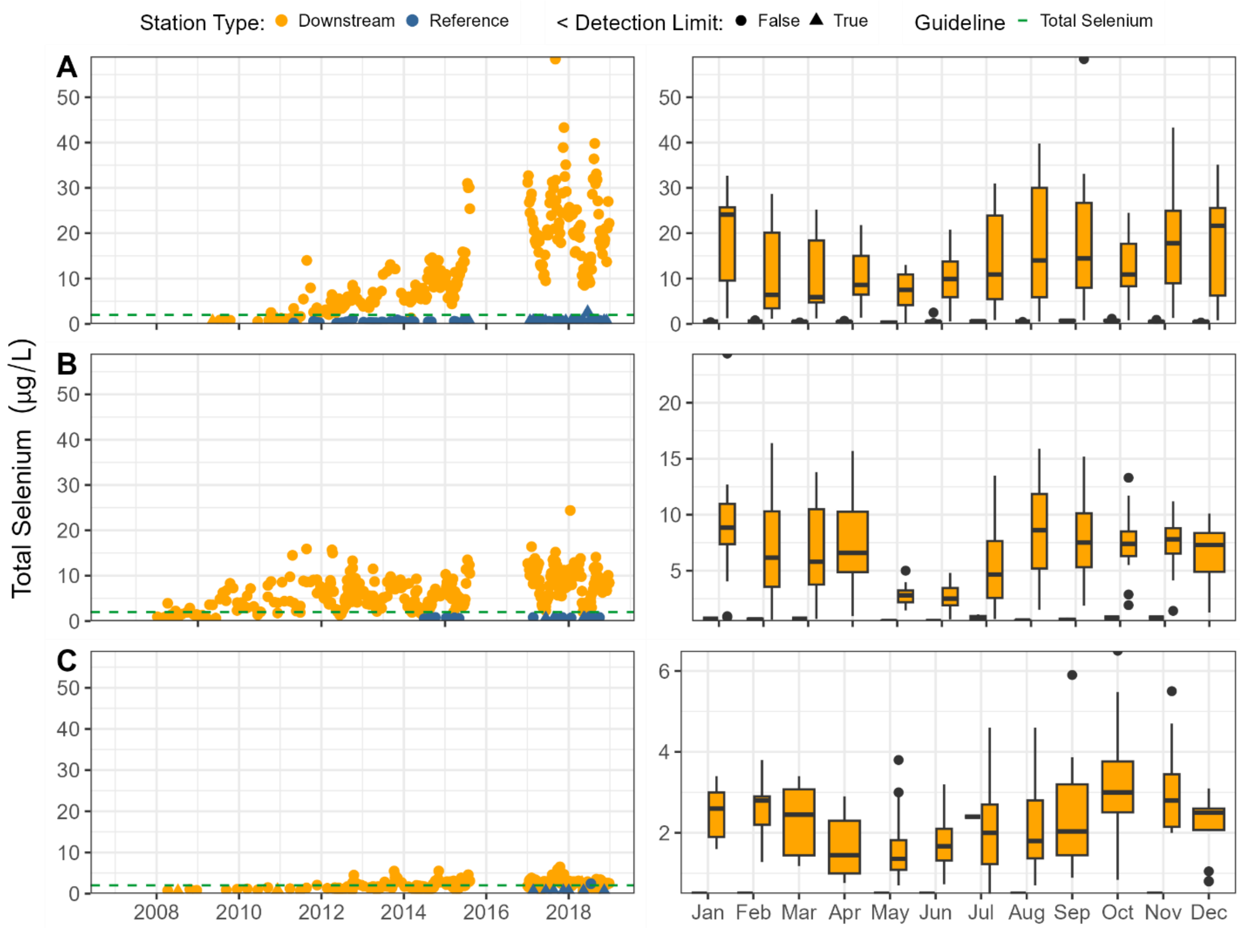

Figure 91. Total selenium concentrations measured in Flatbed Creek watershed between 2008 and 2018 in: ***A*** *Gordon Creek,* ***B*** *Babcock Creek,* ***C*** *Flatbed Creek. Graphs on left include individual values. Graphs on right group values by month (black dots represent outliers). The green dashed line represents the WQG for the protection of aquatic life of 2 µg/L.*

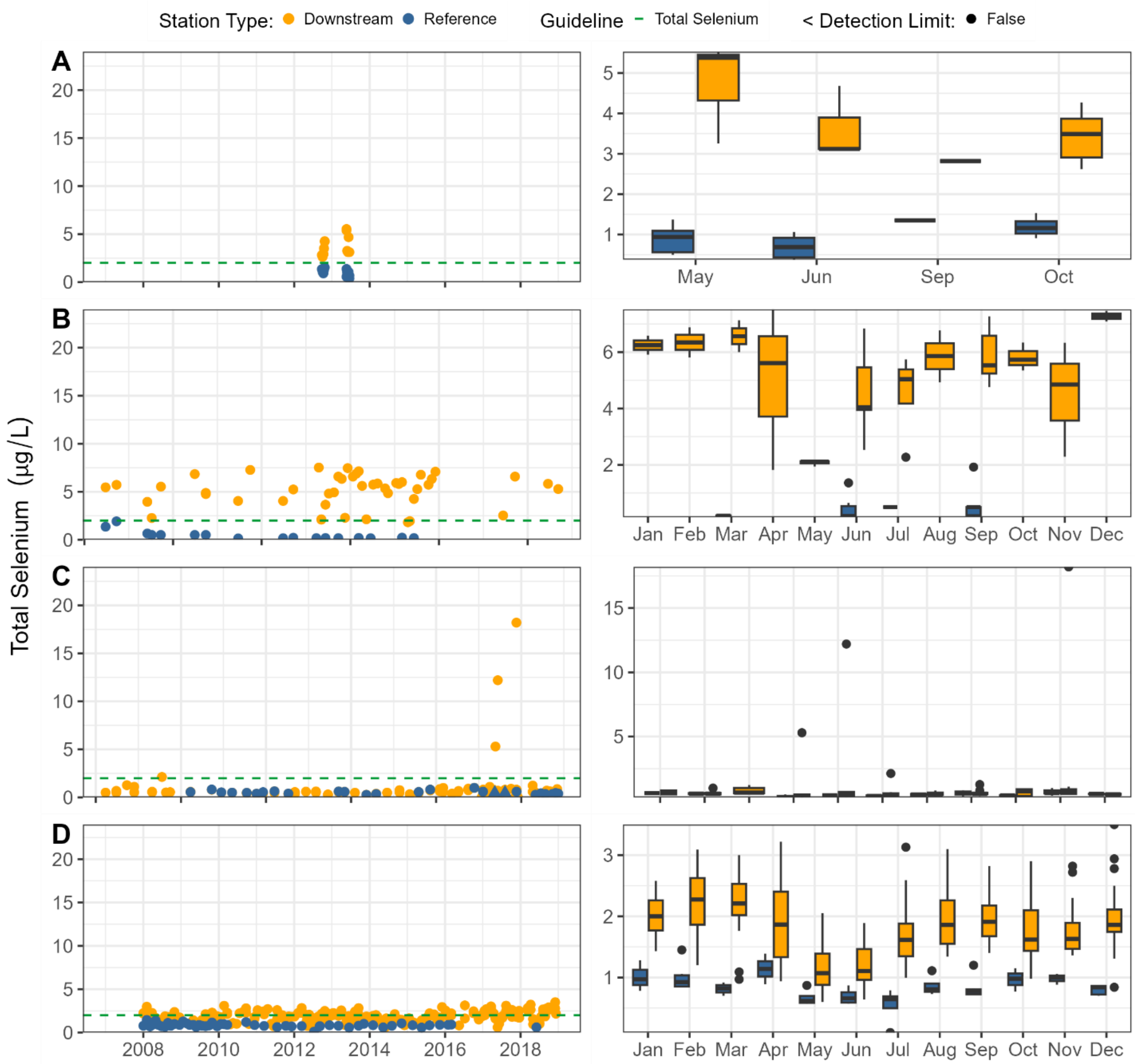

*Figure 92. Total selenium concentrations measured in Wolverine River watershed between 2008 and 2018 in: **A** Bullmoose Creek **B** Mast Creek, **C** Perry Creek, **D** Wolverine River. Graphs on left include individual values. Graphs on right group values by month (black dots represent outliers). The green dashed line represents the WQG for the protection of aquatic life of 2 µg/L.*

Silver

Silver (Ag) is a naturally occurring element. It is considered a rare metal because it is found in low concentrations in the environment compared to other metals. There is no evidence that Ag has any essential biological function in aquatic life. The risk of toxicity is related to the accidental uptake across gill surfaces leading imbalance of ions which regulate key physiological functions (CCME 2015). BC is currently updating the total Ag WQG for the protection of aquatic life, looking to adopt the CCME (2015) WQG with an assessment factor of 2 for a draft BC WQG of 0.1 µg/L. This draft WQG was used in this assessment. This draft WQG may change following its review and subsequent approval as a BC WQG.

Murray River

Total Ag data for Murray River mainstem sites were limited and are summarized in Table 34 and Figure 93. Most results were below the MDL. Older results with higher MDLs (i.e., 0.5 µg/L) were removed from the dataset. Seasonal differences in total Ag were observed with increasing concentrations during freshet. Higher concentrations were observed in downstream sites compared to upstream. WQG was not exceeded at any station between 2008 and 2018.

Table 34. Summary statistics for total silver (µg/L) at select sites on the Murray River mainstem. Sites are presented in an upstream to downstream order. Shaded rows represent reference stations.

Site	Average	Min	Max	95th %ile	n	% > MDL
MOE-070	0.00195	0.00000162	0.0370	0.0100	52	88
HD-004	0.0103	0.000587	0.0440	0.0416	25	72
HD-023	0.0117	0.000755	0.0700	0.0335	31	65
HD-027	0.0154	0.00200	0.0890	0.0337	38	58
MOE-067	0.0148	0.000251	0.0740	0.0688	44	50

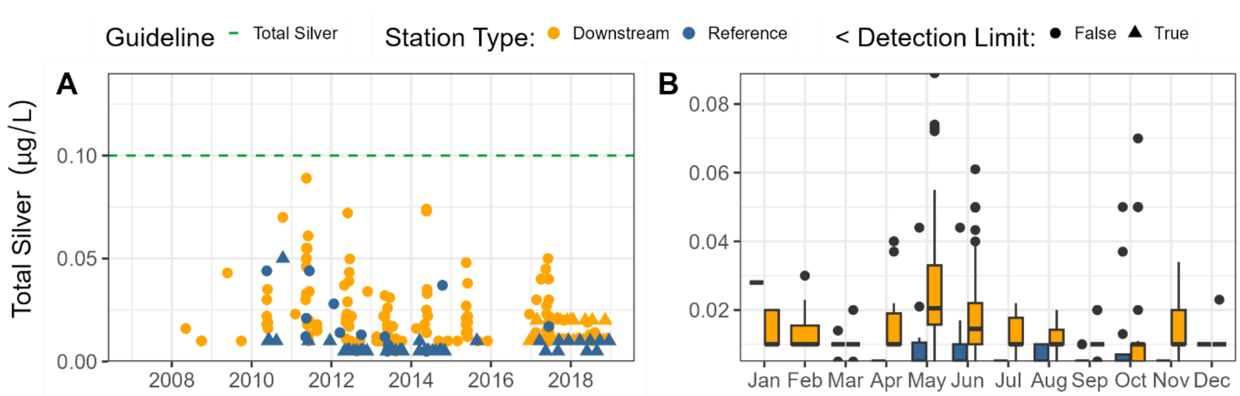

*Figure 93. Total silver concentrations in the Murray River watershed from 2008 to 2018: **A** values provided individually, and **B** values grouped by month (black dots represent outliers). Each graph includes pooled station dataset for each waterbody. The green dashed line represents the draft BC water quality guideline for the protection of aquatic life of 0.1 µg/L.*

Mining Region

Total Ag concentrations in the mining region were mostly below the WQG with average concentrations ranging between 0.007 and 0.042 µg/L (Table 35; Figures 94 - 97). Several results in M20 Creek, Gordon Creek, Flatbed Creek, Mast Creek and Wolverine River were above the draft WQG of 0.1 µg/L, primarily during freshet.

Table 35. Total silver data (µg/L) summary statistics for the waterbodies in the mining region of the KSWGSMR.

Watershed	Waterbody	Average	Min	Max	95th %ile	N
M19 Creek	M19 Creek	0.011	0.010	0.023	0.019	32
M20 Creek	M20 Creek	0.042	0.005	0.455	0.143	112
Flatbed Creek	Gordon Creek	0.026	0.010	0.323	0.061	206
	Babcock Creek	0.020	0.010	0.100	0.030	270
	Flatbed Creek	0.020	0.005	0.156	0.039	189
Wolverine River	Bullmoose Creek	0.007	0.005	0.038	0.010	29
	Mast Creek	0.019	0.010	0.111	0.057	34
	Perry Creek	0.016	0.010	0.080	0.027	79
	Wolverine River	0.014	0.005	0.101	0.035	183

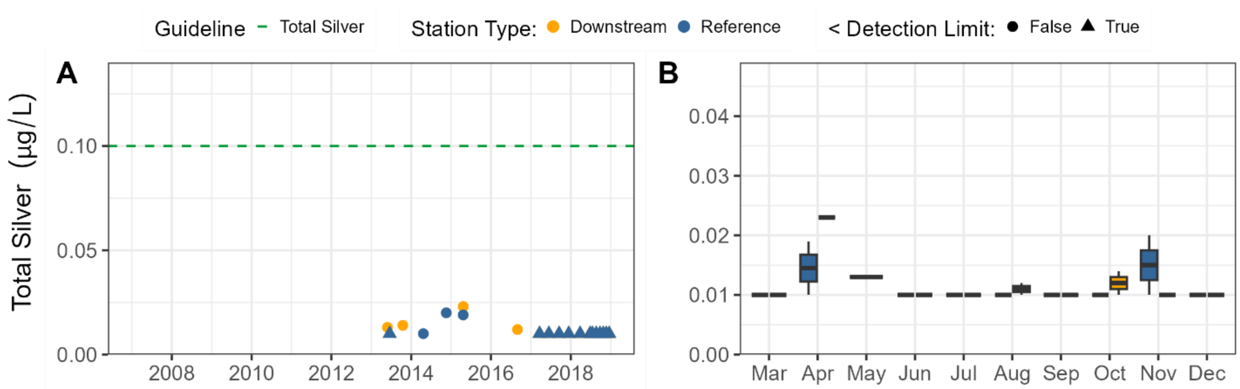

Figure 94. Total silver concentrations in the M19 watershed from 2008 to 2018: ***A*** *values provided individually, and* ***B*** *values grouped by month (black dots represent outliers). Each graph includes pooled station dataset for each waterbody. The green dashed line represents the draft BC water quality guideline for the protection of aquatic life of 0.1 µg/L.*

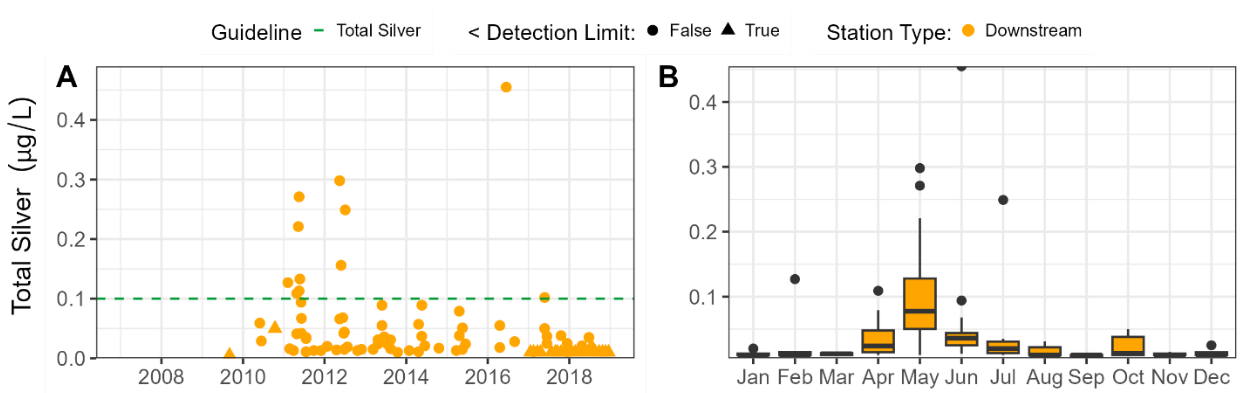

Figure 95. Total silver concentrations in M20 watershed from 2008 to 2018: ***A*** *values provided individually, and* ***B*** *values grouped by month (black dots represent outliers). Each graph includes pooled station dataset for each waterbody. The green dashed line represents the draft BC water quality guideline for the protection of aquatic life of 0.1 µg/L.*

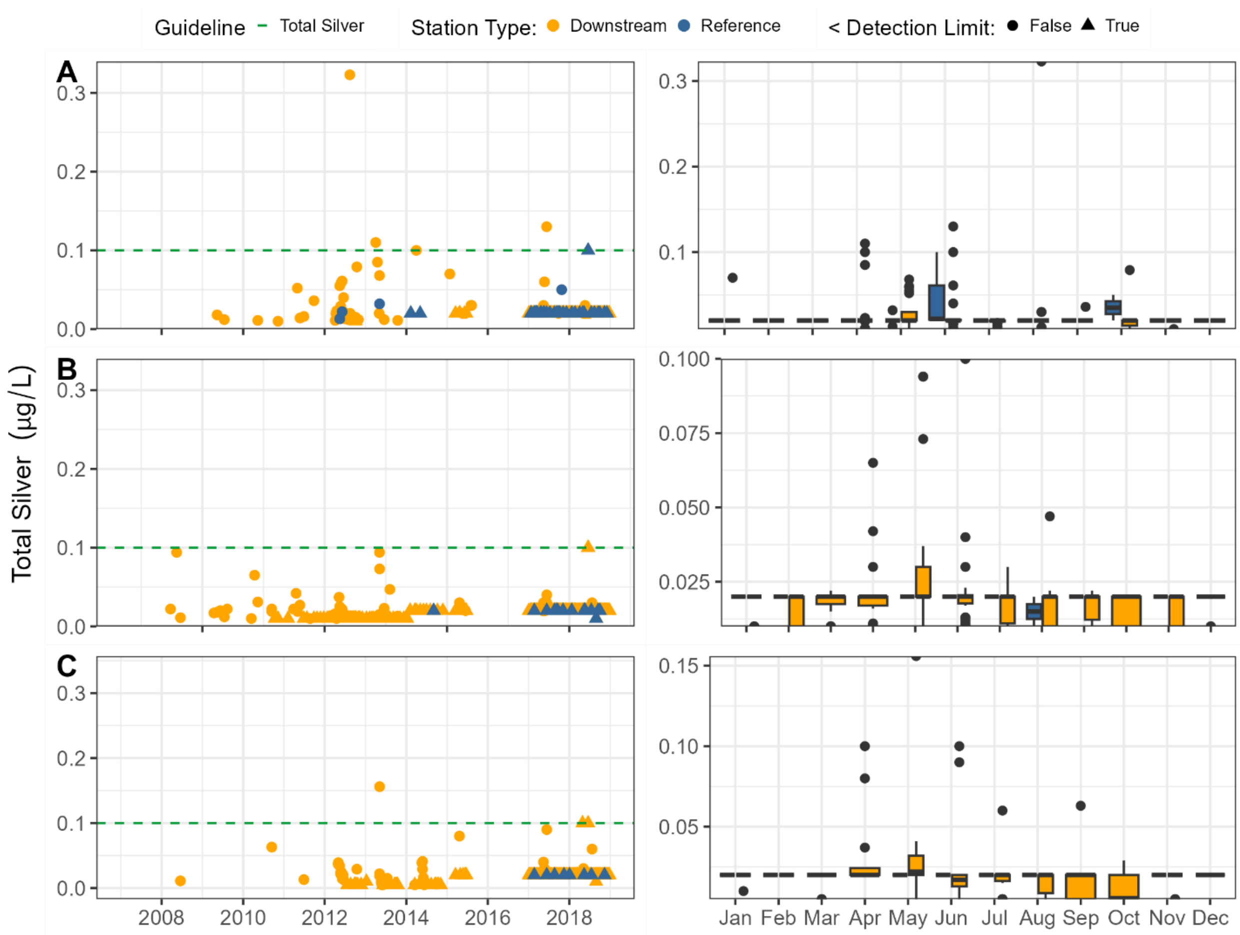

Figure 96. Total silver concentrations measured in Flatbed Creek watershed between 2008 and 2018 in: ***A*** *Gordon Creek,* ***B*** *Babcock Creek,* ***C*** *Flatbed Creek. Graphs on left include individual values. Graphs on right group values by month (black dots represent outliers). The green dashed line represents the draft BC water quality guideline for the protection of aquatic life of 0.1 µg/L.*

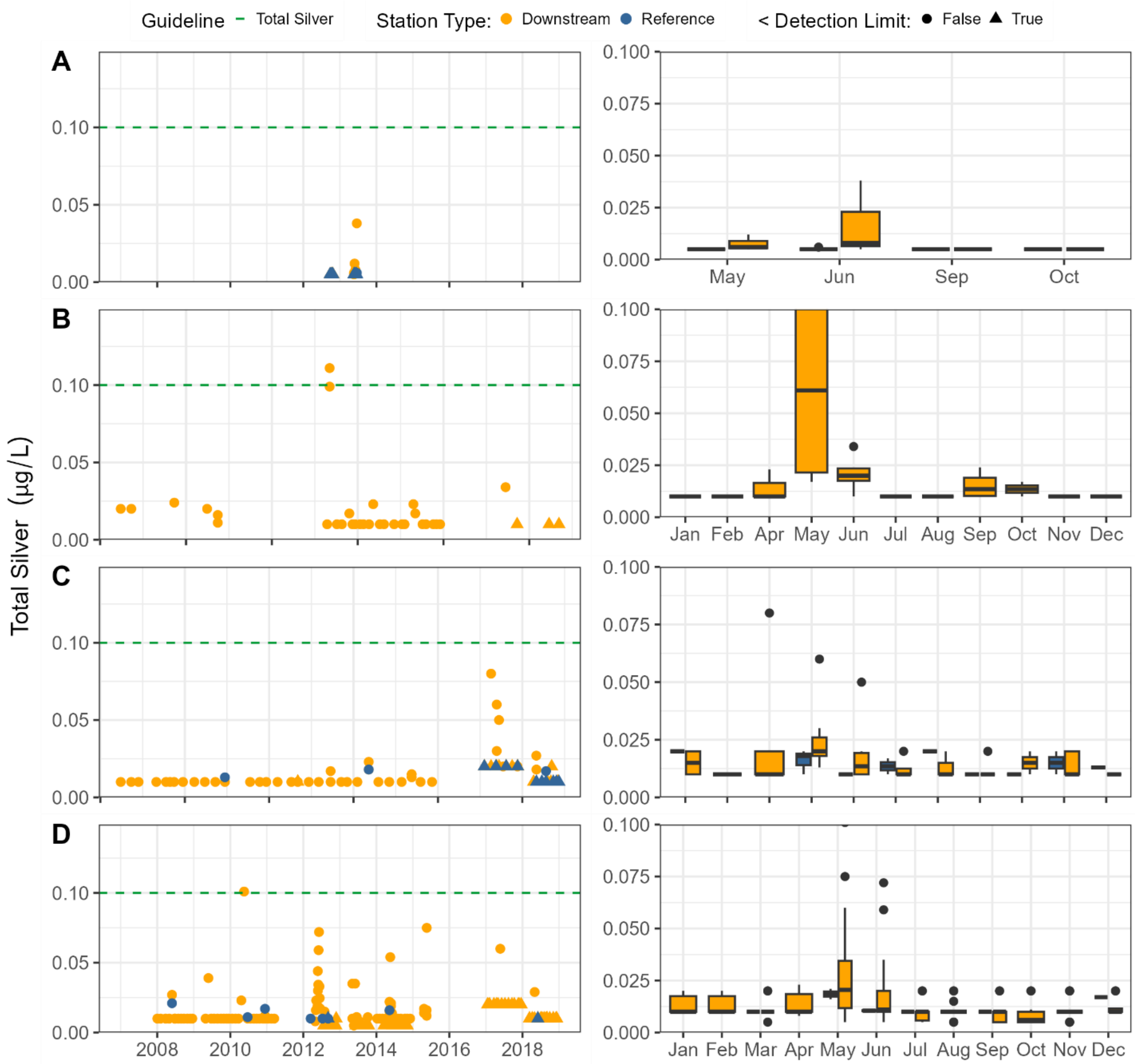

Figure 97. Total silver concentrations measured in Wolverine River watershed between 2008 and 2018 in: A Bullmoose Creek, B Perry Creek, C Wolverine River. Graphs on left include individual values. Graphs on right group values by month (black dots represent outliers). The green dashed line represents the draft BC water quality guideline for the protection of aquatic life of 0.1 µg/L.

Uranium

Uranium (U) is a metal that enters the aquatic environment through the weathering and leaching of natural deposits and industrial activities. The primary route of exposure for aquatic life is through the water column and toxic effects include survival, growth, and reproduction (CCME 2011). The most conservative BC working WQG for uranium is 8.5 µg/L to protect aquatic life (ENV 2021) and was used in this assessment. See Azimuth (2021) for further information.

Murray River

Concentrations of total U increased slightly between upstream and downstream areas of the Murray River but were well below the WQG at all times (Table 36 and Figure 98). Highest concentrations were observed at the most downstream site (CC-010) and at site CC-023 just downstream of confluence with Flatbed and Wolverine Rivers. Lower total U concentrations was observed in summer months compared to the rest of the year.

Table 36. Summary statistics for total uranium (µg/L) at select sites on the Murray River mainstem. Sites are presented in an upstream to downstream order.

Site	Average	Min	Max	95th %ile	n
MOE-070	0.171	0.0816	0.510	0.261	52
HD-004	0.209	0.0780	0.694	0.337	97
HD-014	0.239	0.0600	3.18	0.332	103
HD-023	0.227	0.118	0.368	0.349	65
HD-028	0.231	0.126	0.600	0.317	49
HD-027	0.248	0.143	0.495	0.373	116
HD-033	0.238	0.0190	0.403	0.372	100
HD-021	0.272	0.138	0.410	0.371	93
CC-023	0.505	0.182	0.793	0.784	23
HD-040	0.338	0.182	0.460	0.440	30
MOE-067	0.288	0.164	1.14	0.464	44
CC-010	0.520	0.315	0.962	0.928	17

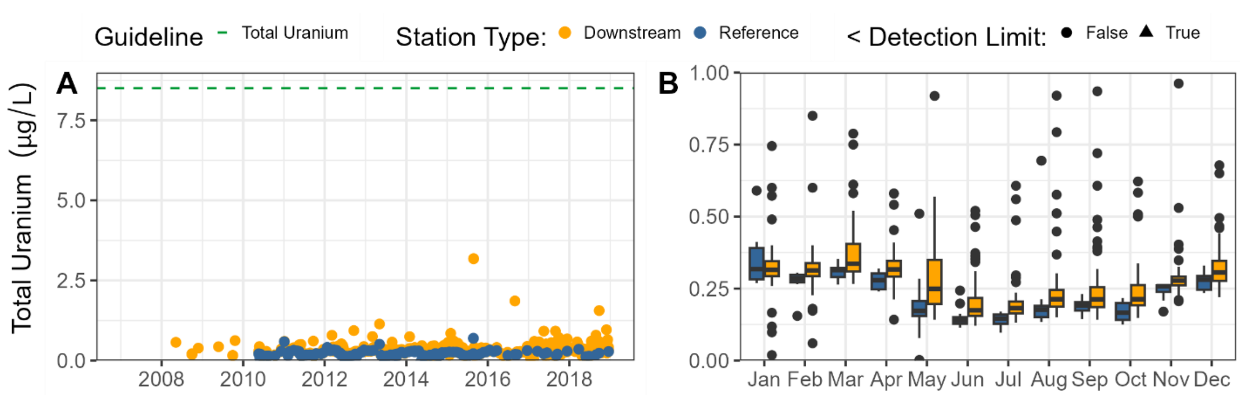

*Figure 98. Total uranium concentrations in the Murray River watershed from 2008 to 2018: **A** values provided individually, and **B** values grouped by month (black dots represent outliers). Each graph includes pooled station dataset for each waterbody. The green dashed line represents the draft BC water quality guideline for the protection of aquatic life of 8.5 µg/L.*

Mining Region

Total U concentrations in mining area creeks were below the WQG of 8.5 µg/L with averages typically lower than 1 µg/L (Table 37, Figures 99 - 102). Mast Creek, Babcock Creek and Gordon Creek had highest total U levels, which were increasing over time in Babcock and Gordon Creeks. Highest maximum total U was recorded in Mast Creek at site TK-007 (7.5 µg/L). Total U was higher downstream of mining areas compared to concentrations measured in reference areas. Total U varied seasonally with lowest concentrations observed during freshet in most mining area creeks.

Table 37. Total uranium data (µg/L) summary statistics for the waterbodies in the mining region of the KSWGSMR.

Watershed	Waterbody	Average	Min	Max	95th %ile	N
M19 Creek	M19 Creek	0.19	0.05	0.40	0.37	123
M20 Creek	M20 Creek	0.53	0.10	1.75	0.68	219
Flatbed Creek	Gordon Creek	1.19	0.01	3.81	3.21	313
	Babcock Creek	0.97	0.03	2.35	1.94	354
	Flatbed Creek	0.45	0.10	1.03	0.68	235
Wolverine River	Bullmoose Creek	0.28	0.05	0.56	0.53	29
	Mast Creek	3.34	0.13	7.50	6.22	56
	Perry Creek	0.16	0.01	1.35	0.30	125
	Wolverine River	0.66	0.01	2.85	1.19	326

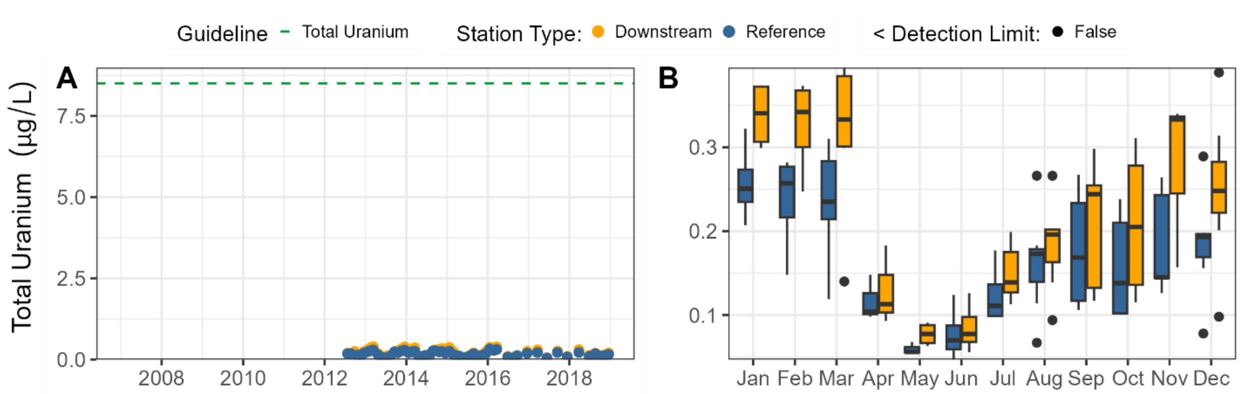

*Figure 99. Total uranium concentrations in the M19 Creek watershed from 2008 to 2018: **A** values provided individually, and **B** values grouped by month (black dots represent outliers). Each graph includes pooled station dataset for each waterbody. The green dashed line represents the draft BC water quality guideline for the protection of aquatic life of 8.5 µg/L.*

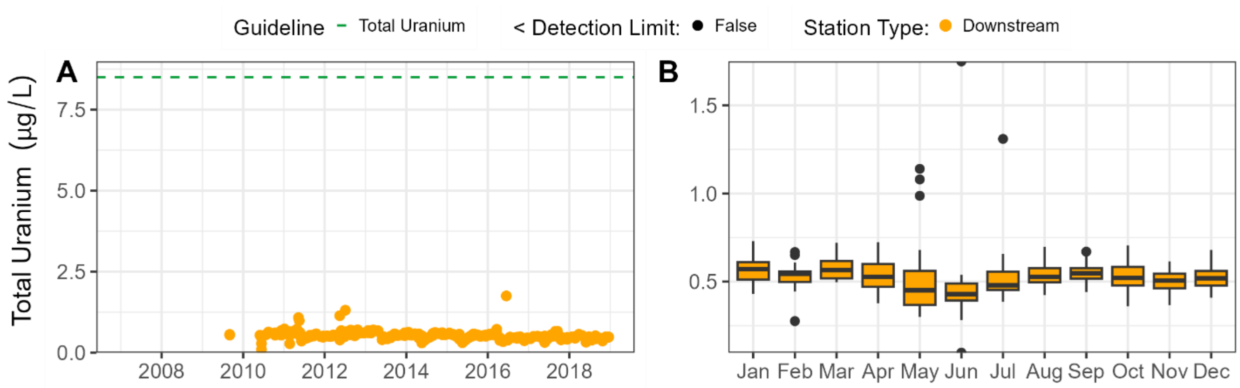

*Figure 100. Total uranium concentrations in M20 Creek watershed from 2008 to 2018: **A** values provided individually, and **B** values grouped by month (black dots represent outliers). Each graph includes pooled station dataset for each waterbody. The green dashed line represents the draft BC water quality guideline for the protection of aquatic life of 8.5 µg/L.*

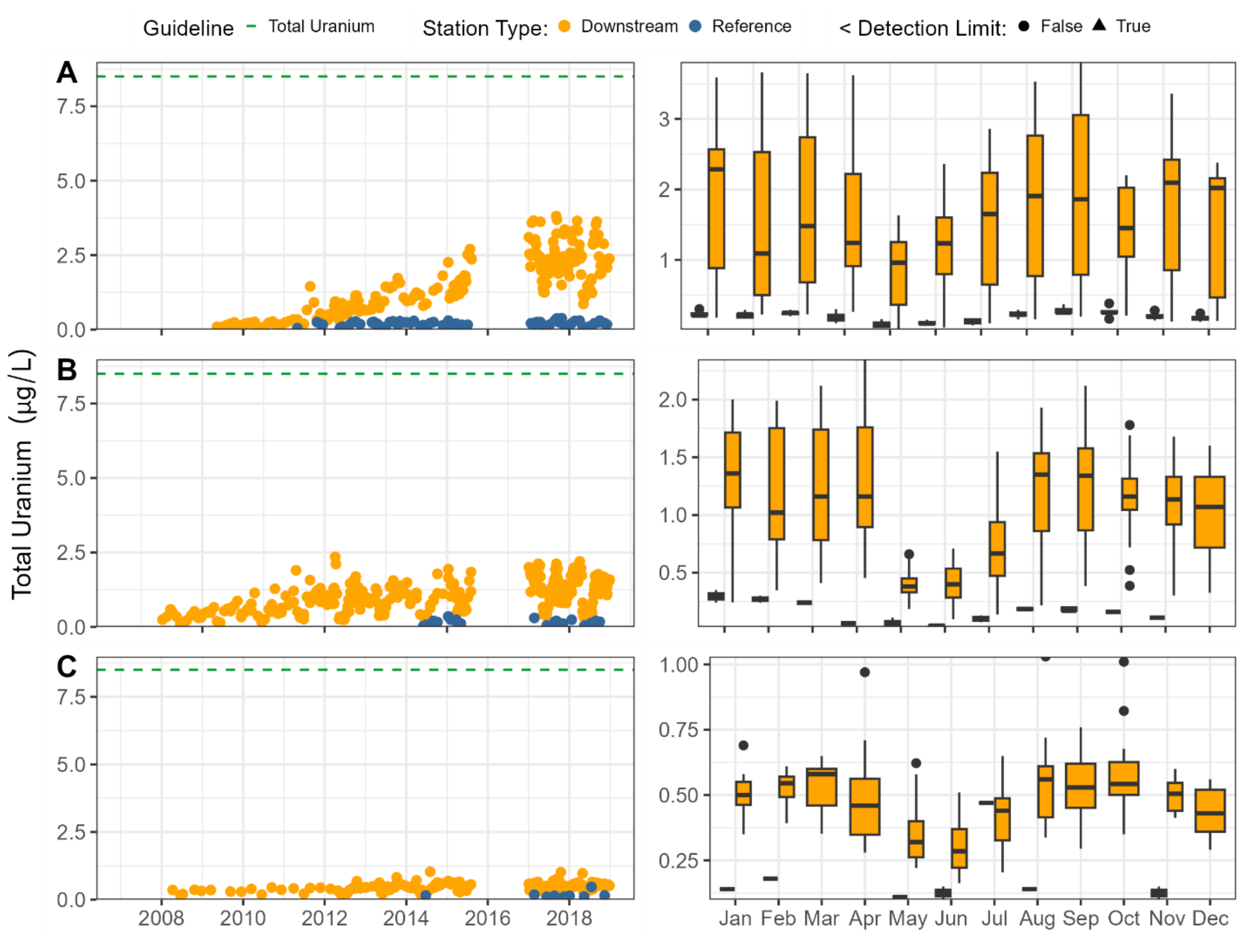

*Figure 101. Total uranium concentrations measured in Flatbed Creek watershed between 2008 and 2018 in: **A** Gordon Creek, **B** Babcock Creek, **C** Flatbed Creek. Graphs on left include individual values. Graphs on right group values by month (black dots represent outliers). The green dashed line represents the draft BC water quality guideline for the protection of aquatic life of 8.5 µg/L.*

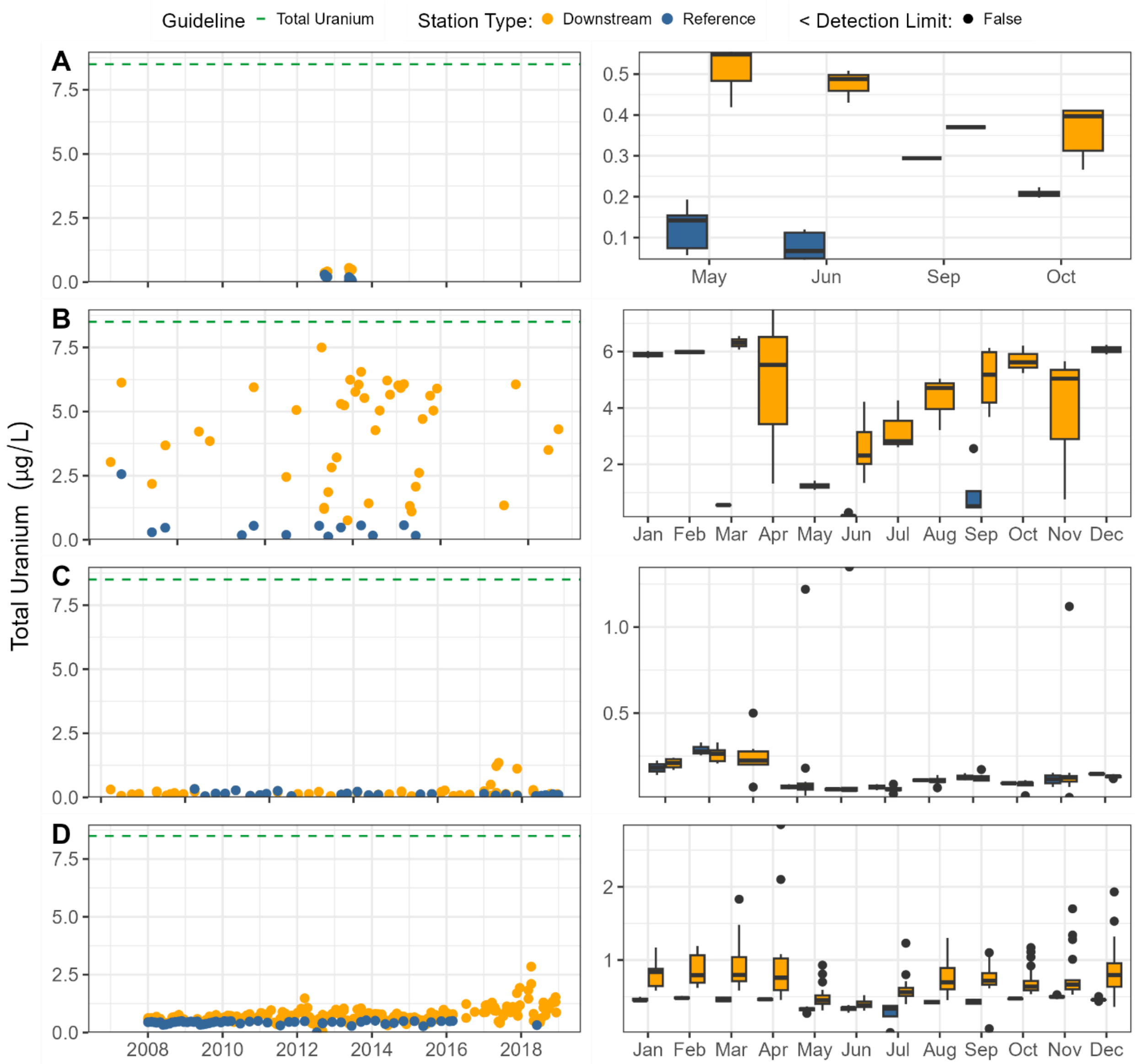

Figure 102. Total uranium concentrations measured in Wolverine River watershed between 2008 and 2018 in: ***A*** *Bullmoose Creek,* ***B*** *Mast Creek,* ***C*** *Perry Creek, and* ***D*** *Wolverine River. Graphs on left include individual values. Graphs on right group values by month (black dots represent outliers). The green dashed line represents the draft BC water quality guideline for the protection of aquatic life of 8.5 µg/L.*

Zinc

Zinc (Zn) is an essential trace element for plants and animals and plays a key role in many biological processes (ENV 1997). In fish, Zn interferes with the gill uptake of calcium causing a calcium deficiency and lethal toxicity can occur at higher concentrations. In general, salmonids appear to be more sensitive than other types of fish (CCME 2018). The BC aquatic life WQG is the most conservative benchmark for dissolved Zn (WLRS 2023b). It was difficult to compare current conditions Zn dataset with the WQG given insufficient hardness, DOC and pH information to properly calculate the WQGs. Guidelines have been calculated when data were available.

Murray River

Dissolved Zn in the Murray River increased and then decreased slightly from upstream to downstream stations with no noticeable seasonal pattern (Table 38; Figure 103). Average dissolved Zn in the Murray River ranged between 0.3 and 2.3 µg/L, and 95th percentile concentrations ranged between 0.61 and 6.22 µg/L. The highest dissolved Zn concentrations occurred at stations upstream of key mining tributary confluences (e.g., HD-23 and HD-14). When the WQG could be calculated, exceedances were not observed (Azimuth 2021).

Table 38. Summary statistics for dissolved zinc (µg/L) at select sites on the Murray River mainstem. Sites are presented in an upstream to downstream order.

Site	Average	Min	Max	95th %ile	N
MOE-070	0.32	0.0887	0.890	0.61	52
HD-004	1.37	0.0564	12.8	4.24	97
HD-014	1.52	0.0566	11.5	6.22	82
HD-023	2.25	0.0603	31.3	6.14	65
HD-027	1.43	0.0065	31.3	4.40	107
HD-033	1.77	0.299	7.2	4.34	98
HD-021	1.33	0.110	11.1	3.90	92
CC-023	0.50	1.00	3.00	3.00	23
MOE-067	0.33	0.0641	1.70	0.65	44
CC-010	1.02	0.326	2.53	2.11	17

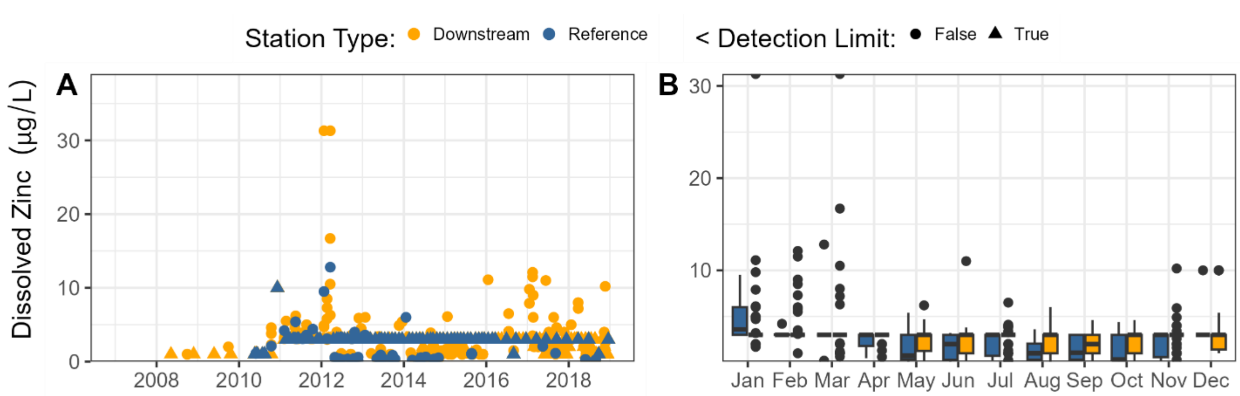

*Figure 103. Dissolved zinc concentrations in the Murray River watershed from 2008 to 2018: **A** values provided individually, and **B** values grouped by month (black dots represent outliers). Each graph includes pooled station dataset for each waterbody.*

Mining Region

Dissolved Zn in the mining region did not vary seasonally and the WQG was met most of the time (Table 39, Figures 104 – 107; Azimuth 2021). Average concentrations were slightly higher in the mining waterbodies compared to the Murray River mainstem and ranged between 1.8 µg/L in Mast Creek and 3.7 µg/L in Gordon Creek.

Table 39. Dissolved zinc data summary statistics for the waterbodies in the mining region of the KSWGSMR.

Watershed	Waterbody	Average	Min	Max	95th %ile	N
M19 Creek	M19 Creek	3.0	1.0	6.6	3.2	121
M20 Creek	M20 Creek	3.5	1.0	11.1	6.8	215
Flatbed Creek	Gordon Creek	3.7	1.0	60.0	9.0	305
	Babcock Creek	3.2	1.0	68.0	7.0	255
	Flatbed Creek	2.1	0.3	20.0	5.0	147
Wolverine River	Mast Creek	1.8	1.0	3.0	3.0	34
	Perry Creek	3.0	1.0	20.0	7.4	131
	Wolverine River	2.0	0.1	13.0	3.0	289

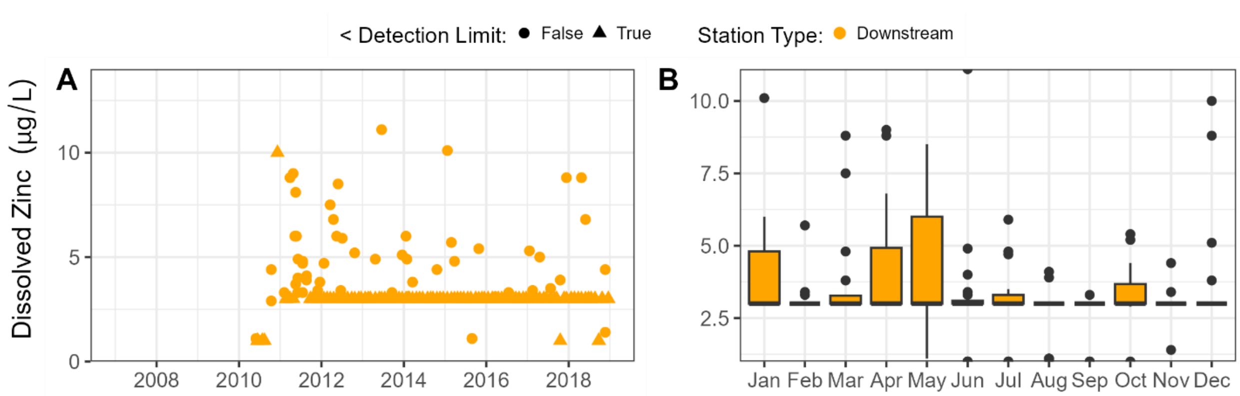

*Figure 104. Dissolved zinc concentrations in M20 Creek watershed from 2008 to 2018: **A** values provided individually, and **B** values grouped by month (black dots represent outliers). Each graph includes pooled station dataset for each waterbody.*

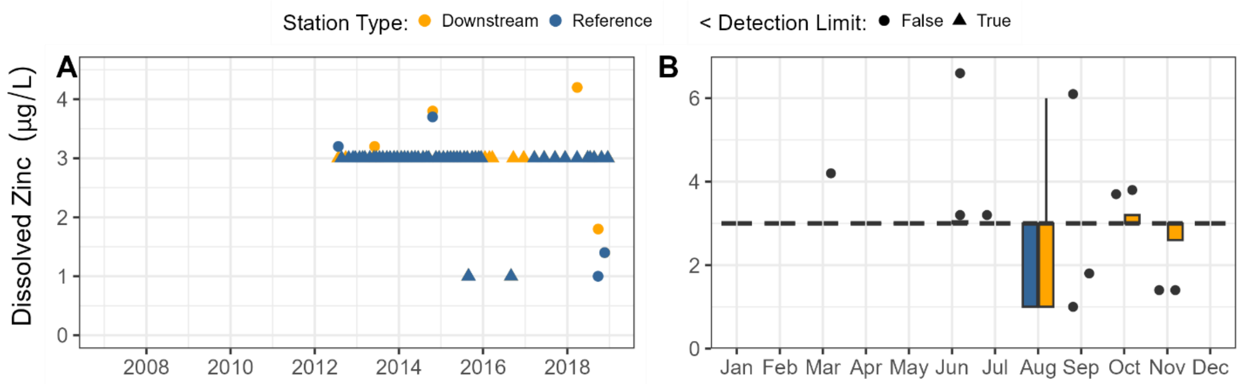

*Figure 105. Dissolved zinc concentrations in M19 Creek watershed from 2008 to 2018: **A** values provided individually, and **B** values grouped by month (black dots represent outliers). Each graph includes pooled station dataset for each waterbody.*

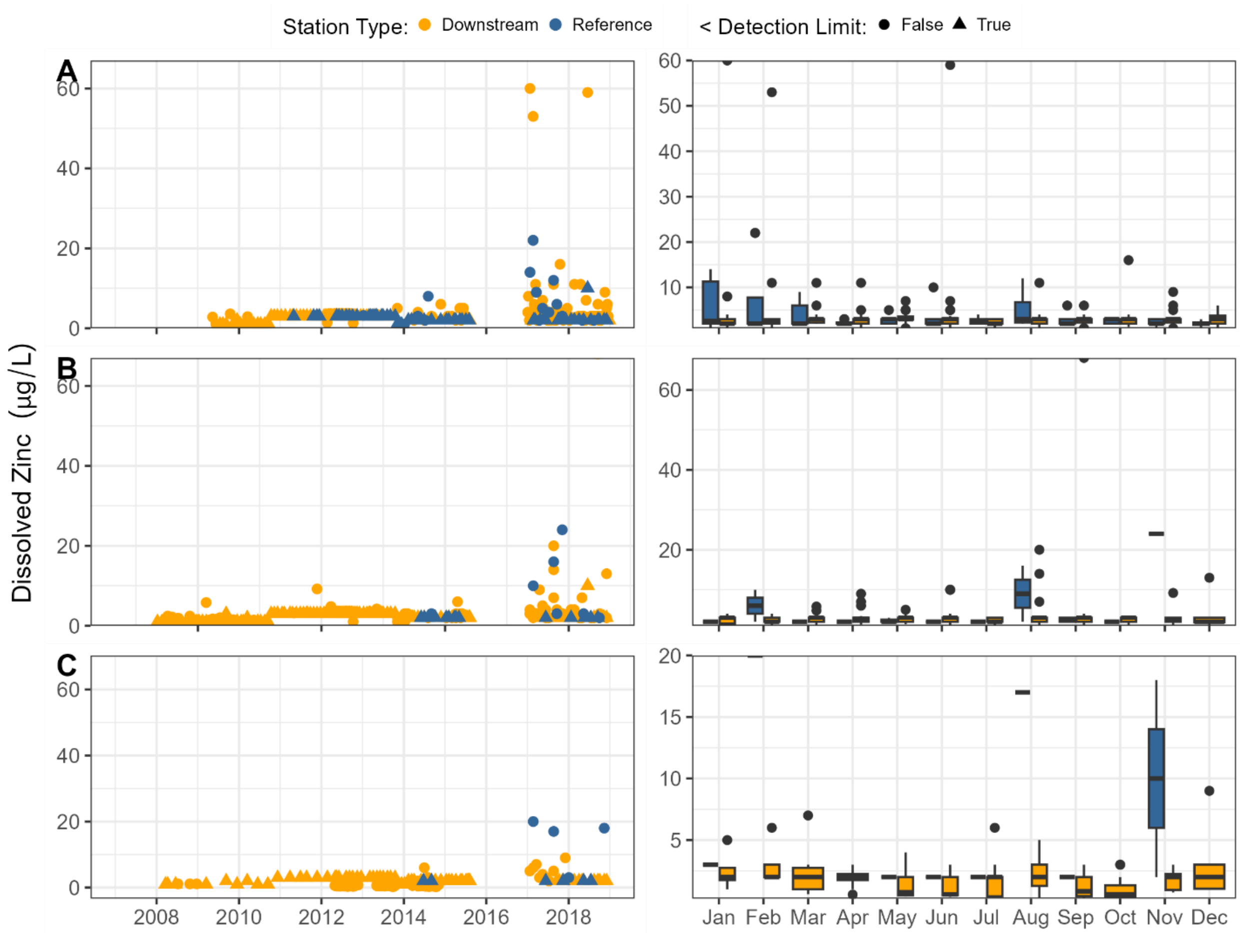

*Figure 106. Dissolved zinc concentrations measured in Flatbed Creek watershed between 2008 and 2018 in: **A** Gordon Creek, **B** Babcock Creek, **C** Flatbed Creek. Graphs on left include individual values. Graphs on right group values by month (black dots represent outliers).*

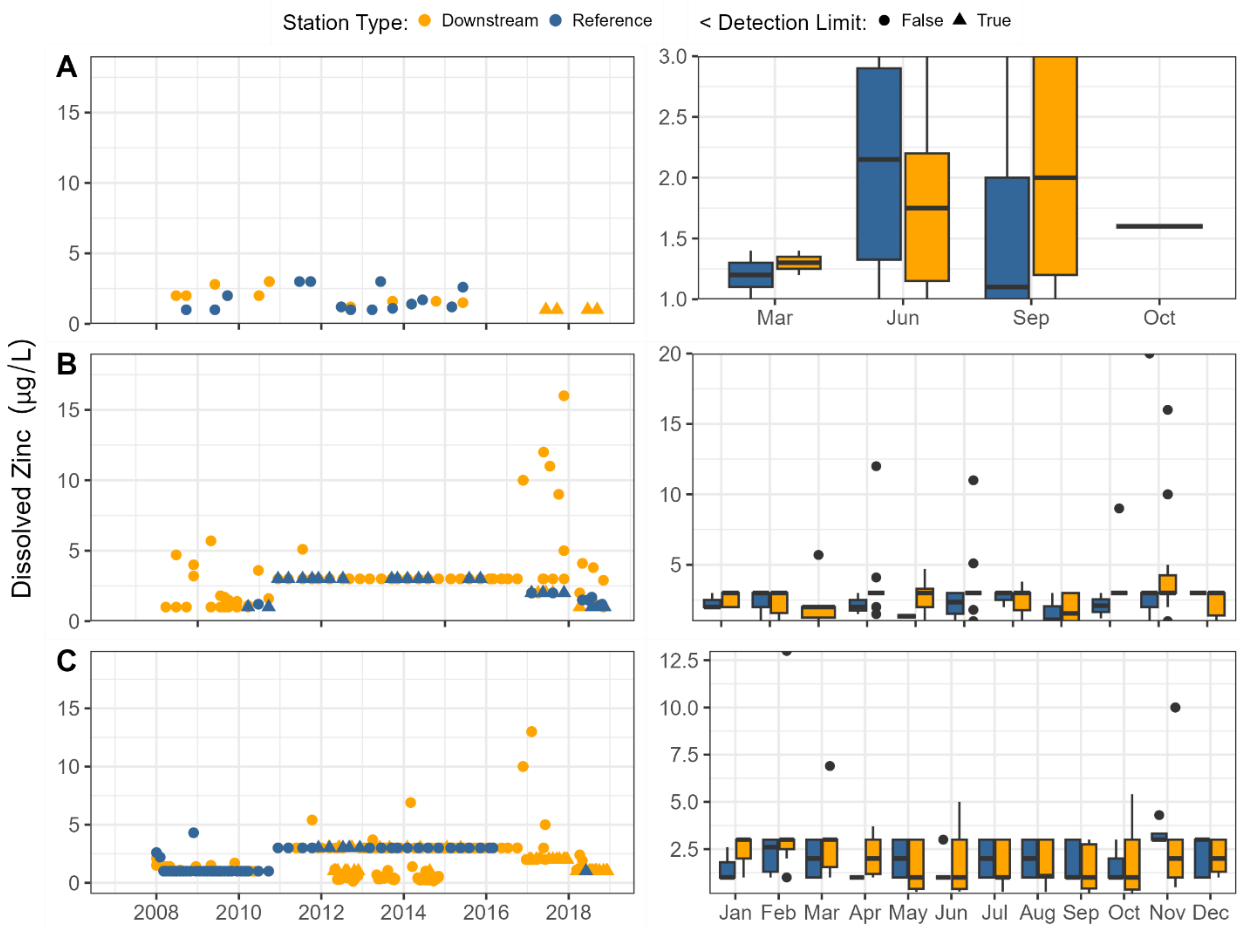

*Figure 107. Dissolved zinc concentrations measured in Wolverine River watershed between 2008 and 2018 in: **A** Mast Creek, **B** Perry Creek, **C** Wolverine River. Graphs on left include individual values. Graphs on right group values by month (black dots represent outliers).*

Microbiological Indicators

Escherichia coli (E.coli) is a fecal microbiological indicator for estimating pathogen contamination in drinking water sources. Limited *E.coli* data were available in the KSWGSMR (Table 40). Those that were available were compared to the most conservative *E.coli* guideline which is for source drinking water; 10 CFU/100 mL as the 90th percentile from a minimum of 5 samples (ENV 2020). This guideline assumes disinfection prior to human consumption.

Slight exceedances of the WQG occurred in all areas of the watershed (Table 40). The larger exceedances occurred in the lowest part of the watershed before the Murray River's confluence with the Pine River. More data are required to determine background levels of *E.coli* in the watershed. See Azimuth 2021 for further discussion.

Table 40. E.coli concentrations at locations in the KSWGSMR and number of samples from 2008 to 2018.

Location	***E.Coli*** **Range of Concentrations (CFU/100mL)**	# of samples
Murray River	<1-345	15
Downstream watersheds	<1-461	20
Upstream watersheds	1-27	3

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Appendix 3: WQO derivation and Indigenous protection levels

Introduction

This appendix explains how water quality objectives (WQOs) were derived and how they relate to the Indigenous Protection Levels. The WQOs were derived collaboratively by the government-to-government team following a five-step process:

1. Compile the water quality data for a given parameter, graph the data by sub-watershed (called watershed zone in Section 6.2.1 and used interchangeably in this appendix), and compare the data to the most sensitive water quality guideline.
2. Discuss and analyze the influences on water quality in each sub-watershed with respect to a given parameter (e.g., anthropogenic sources, naturally elevated)
3. Evaluate the Indigenous Cultural Opportunity Spectrum (ICOS) (Prince et al., 2020) for the sub-watershed (completed by the Indigenous representatives). The ICOS identifies the existing and future potential of an area to be used for the uninhibited practice of Treaty rights.
4. Identify the appropriate Indigenous Protection Level specific to the parameter and sub-watershed, considering the water quality data, the influences on water quality in the watershed, and the ICOS,
5. Define a numerical WQO based on the Indigenous Protection Level that is protective of the most sensitive water value.

While each of these process steps were undertaken largely in order, there was an iterative aspect to the process as well to ensure all concerns of each group were addressed. In these cases, the WQO derivation would return to an earlier process step and revise.

The following sections illustrate this process using the examples of dissolved copper and total selenium. These parameters were chosen as the Indigenous Protection Levels differed between sub-watersheds and therefore provide good examples of how the government-to-government group worked through each parameter to develop the WQOs. As it is challenging to accurately describe an iterative process, some of the descriptions may appear out of order. We have endeavored to identify these apparent discrepancies in the text for clarity.

Dissolved Copper

Table 1 shows the WQOs and the Indigenous Protection Levels developed for dissolved copper (see Section 6.2.4).

Table 1: Dissolved Copper WQOs

Upper Mainstem	Upper Mainstem Tributaries	Mining Region Sub-watersheds and Tributaries	Downstream Watershed
Do No Harm	**Do No Harm**	**Do No More Harm 1**	**Do No Harm**
1 µg/L	1 µg/L	B.C. WQG Aquatic Life*	1 µg/L
Notes: * The WQOs are based on a 30-day average (5 weekly samples collected in 30 days).			

Step 1 involved visualizing the available dissolved copper data. Most of the dissolved copper data were from the Murray River mainstem and the Mining Region sub-watersheds. The dissolved copper guideline is a calculated from concurrent measurements of dissolved organic carbon, hardness, and pH. Existing data for the Murray River mainstem indicates copper concentrations are consistently below the calculated B.C. water quality guideline (WQG) value (generally between 1 and 2 µg/L) and almost always below 1 µg/L and likely indicative of background concentrations. Figure 1 shows the dissolved copper data for all water quality sampling locations on the Murray River (Appendix 2, Figure 1).

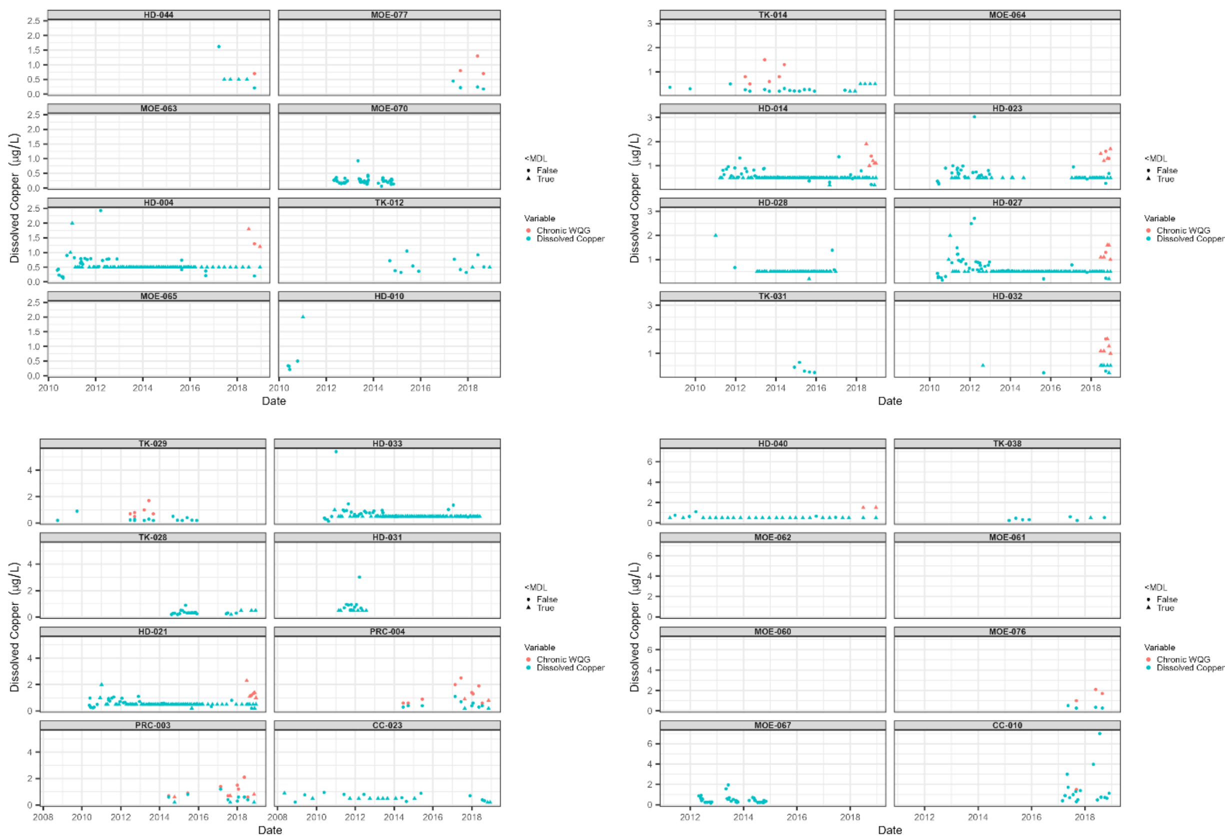

Figure 1. Dissolved copper concentrations in the Murray River. Stations are presented from upstream to downstream. Note: <MDL = less than method detection limit, WQG = B.C. water quality guideline.

Dissolved copper concentrations in the mining region sub-watershed generally met the B.C. WQG with occasional exceedances. For example, Figures 2 and 3 show the dissolved copper data compared to the WQG at select water quality sampling locations on Gordon Creek and M20 Creek, respectively (Appendix 2, Figure 2).

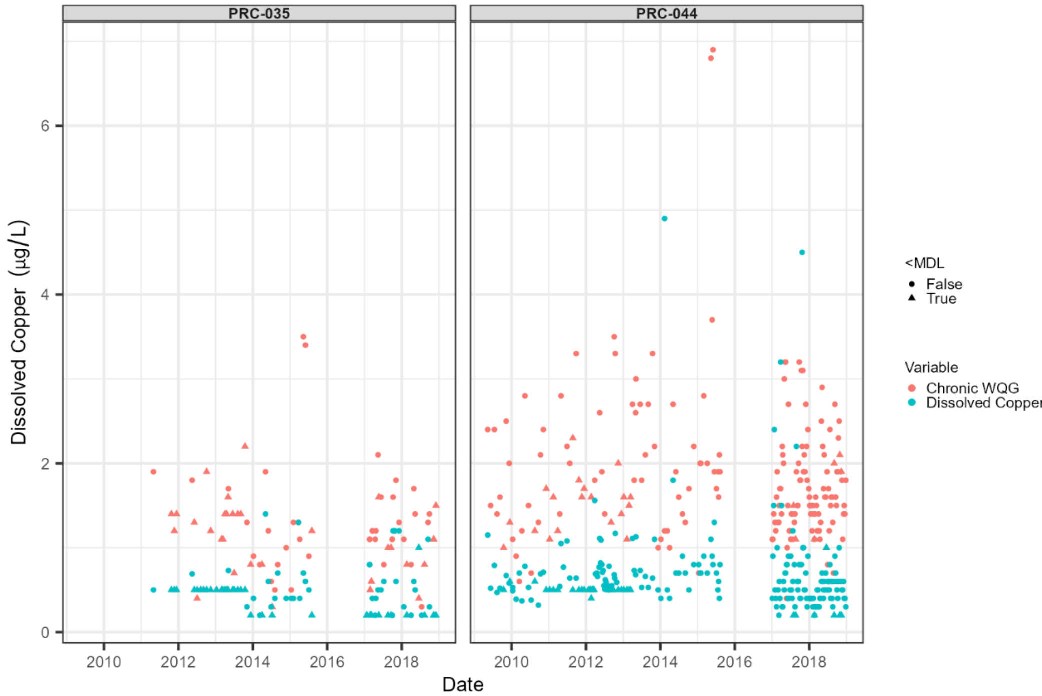

Figure 2: Dissolved copper concentrations in Gordon Creek from representative stations: PRC-035 – background, PRC-044 – downstream. Note: <MDL = less than method detection limit, WQG = B.C. water quality guideline.

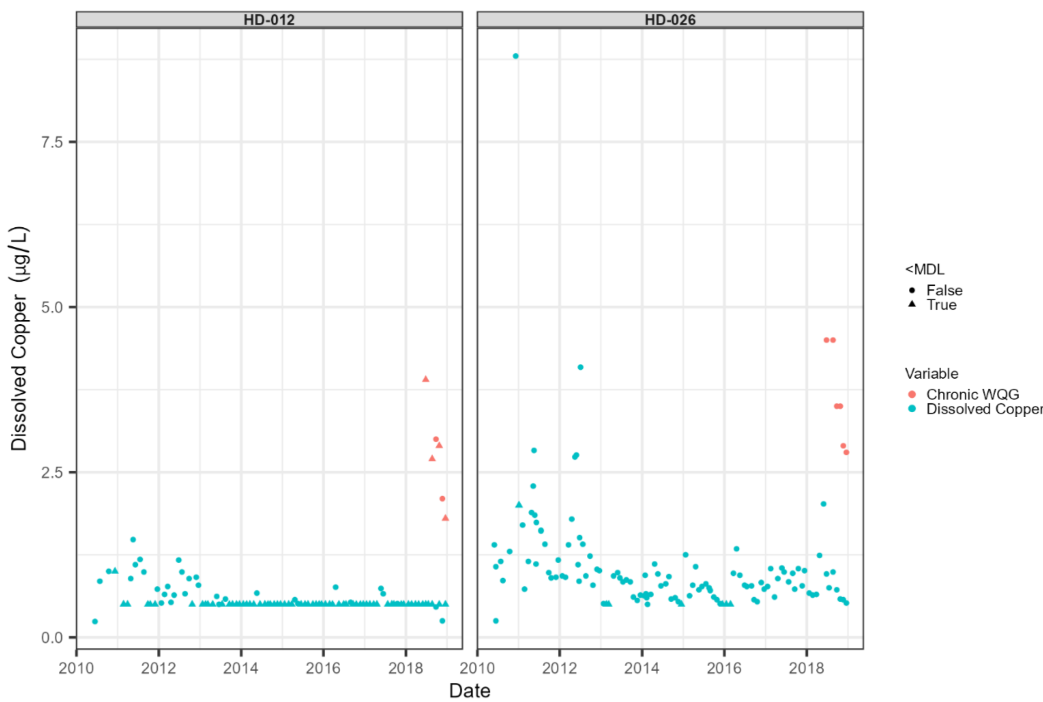

Figure 3: Dissolved copper concentrations in M20 Creek from representative stations: MOE-059 – background, HD-026 – downstream. Note: <MDL = less than method detection limit, WQG = B.C. water quality guideline.

Based on the existing dissolved copper data, the sub-watersheds for the next step of the process were divided into two groups. The Upper Mainstem, Headwater Tributaries and Downstream Watershed including the Murray Mainstem were considered together because, despite a lack of data, it was assumed the upper and downstream tributaries have similar copper concentrations to the upper and downstream mainstem. Additional monitoring is required to confirm this assumption. The Mining Region Sub-watershed and Tributaries were considered alone.

Dissolved Copper: Upper Mainstem, Headwater Tributaries, Downstream watershed including Mainstem.

The main source of dissolved copper in these areas is presumably groundwater inputs to tributaries from groundwater in contact with copper bearing rocks as there are no known anthropogenic sources of copper, and the existing conditions are likely representative of background.

Next, the ICOS was evaluated for the sub-watersheds. The current cultural use opportunity is higher in the Upper Mainstem, Headwater tributaries, and downstream watershed, as members of the Nations prefer the smaller tributaries and undisturbed areas to practice Treaty rights.

Based on this assessment, the Indigenous Protection Level of Do No Harm was assigned to each of these three sub-watersheds. Available data suggest these sites represent background conditions; where data are lacking, there is no indication that dissolved copper concentrations would be elevated due to either natural conditions or anthropogenic sources. Indigenous communities prefer the use of tributaries in this area which requires an enhanced level of protection.

An Indigenous Protection Level of Do No Harm requires maintaining existing background conditions which are well characterized throughout the Murray Mainstem. The dissolve copper WQO was assigned a value of 1 µg/L which is consistent with the B.C. guidance for background concentrations (i.e., 95th percentile + 20%)[5].

Dissolved Copper: Mining Region and Tributaries (Wolverine Sub-watershed, Flatbed Sub-watershed, M19 / M20 Creeks)

In this region, there is a known anthropogenic influence on dissolved copper likely due to enhanced leaching of copper bearing rocks from mining. The current cultural use opportunity is lower in this area due to high development and interference, however there is a desire for restoration of this area to increase cultural use opportunity. An Indigenous Protection Level of Do No More Harm 1 was applied to this area which requires maintaining the existing protective condition for dissolved copper. The B.C. WQG for dissolved copper was set as the WQO for dissolved copper in these sub-watersheds.

Total Selenium

Table 3 shows the WQOs and the Indigenous Protection Levels developed for total selenium (reproduced from Section 6.2.4).

[5] Water Quality Objectives Policy. Ministry of Environment and Climate Change Strategy. February 19, 2021.

Table 2: Total selenium WQOs.

Upper Mainstem	Upper Mainstem Tributaries	Mining Region Sub-watersheds and Tributaries	Downstream Watershed
Do No Harm	**Do No Harm 1**	**Do No More Harm 2**	**Do No Harm 1**
0.5 µg/L	1 µg/L	2 µg/L	1 µg/L
Notes: The WQOs are based on a 30-day average (5 weekly samples collected in 30 days).			

The selenium concentrations in the upper mainstem are well characterized and highlighted by station HD-004 (Figure 4; Appendix 2, Figure 1). The available data indicate very low concentrations of total selenium, generally below 0.5 µg/L, which are likely representative of background conditions. Similar to the headwater tributaries, there is little anthropogenic disturbance in area of the watershed. The current cultural opportunity is high owing to the relative undisturbed conditions. Based on this assessment the Indigenous Protection Level of Do No Harm was assigned to maintain the low total selenium concentrations and the WQO was set as 0.5 µg/L.

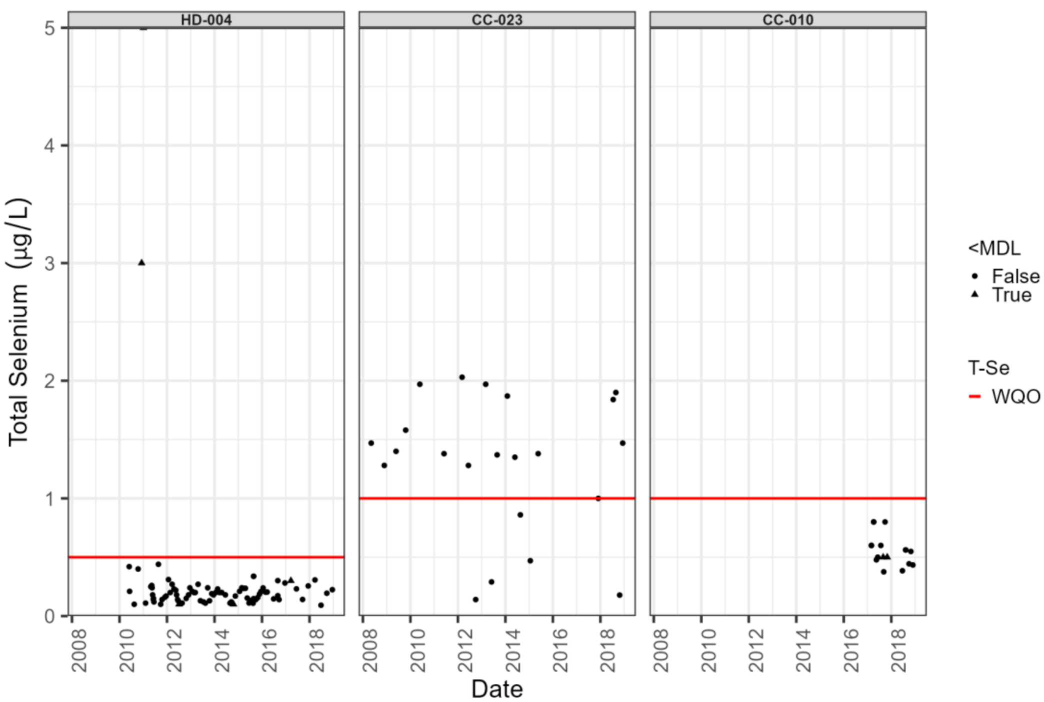

Figure 4: Total selenium concentrations in the Murray River from representative stations: HD-004 – background, CC-023 – downstream of mining region, CC-010 – downstream station before the confluence with Pine River. Note: <MDL = less than method detection limit, WQO = water quality objective.

Headwater Tributaries

There is little to no data available for the headwater tributaries. Considering the regional geology is elevated in selenium and the primary source of water to these tributaries is groundwater, it is possible that total selenium concentrations are naturally elevated in this sub-watershed. Additional data needs to be collected to confirm this. There is very little anthropogenic disturbance in this area and no anthropogenic activities were identified that could influence selenium concentrations in water. The current cultural opportunity was determined to be high because these smaller, relatively undisturbed tributaries are preferable for the practice of Treaty rights. Owing to the lack of data and possible naturally elevated selenium concentrations, the Indigenous Protection Level of Do No More Harm 1 was assigned and a corresponding WQO of 1 µg/L was set for total selenium.

Mining Region Sub-watersheds

Figures 5, 6 and 7 show data from Gordon, M20 and M19 creeks, respectively (Appendix 2, Figure 2). These data provide a good cross-section of the variability of total selenium concentrations in water throughout the mining region. Gordon Creek is heavily impacted with the highest total selenium concentration observed at 60 µg/L. M20 Creek has selenium concentrations above the WQG of 2 µg/L, likely owing to inactive mining near its headwaters. M19 Creek has very low total selenium concentrations, typically below 1 µg/L. Anthropogenic influences are very high in this area with coal mining being the primary activity. The ICOS was evaluated, and the current cultural opportunity is low based on this significant disturbance however there is a desire for restoration of the area to increase the cultural opportunity. The Indigenous Protection Level of Do No More Harm 2 was assigned recognizing the area is highly impacted and restoration is needed to reduce total selenium concentrations. The WQO was set at the BC WQG of 2 µg/L.

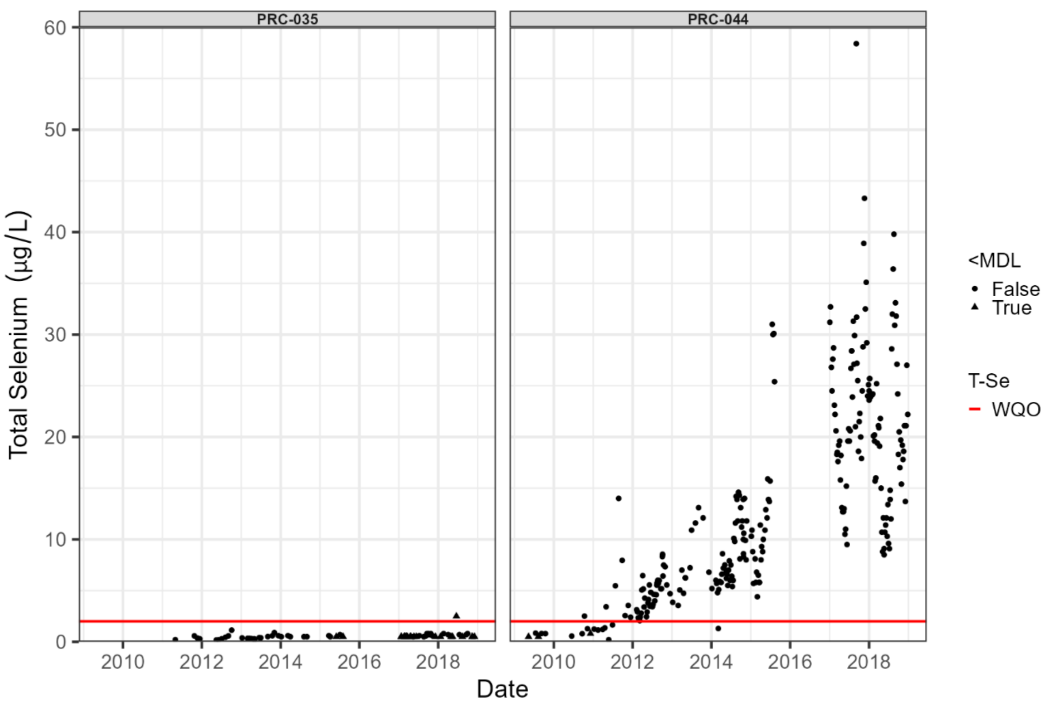

Figure 5: Total selenium concentrations in Gordon Creek from representative stations: PRC-035 – background, PRC-044 – downstream. <MDL = less than method detection limit, WQO = water quality objective.

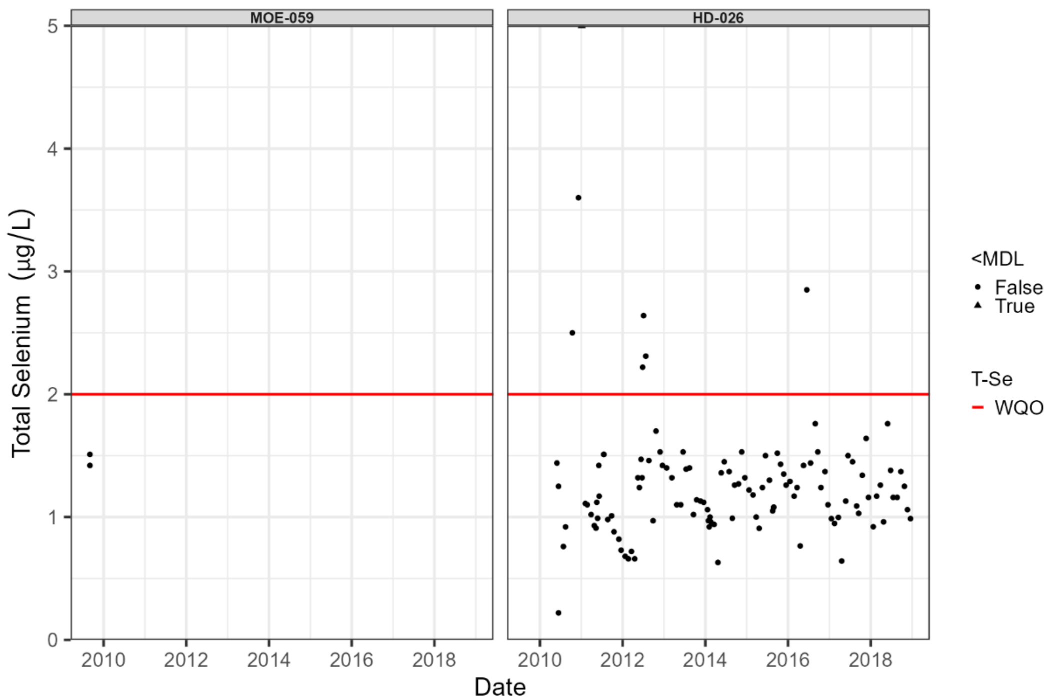

Figure 6: Total selenium concentrations in M20 Creek from representative stations: MOE-059 – background station, HD-026 – downstream. <MDL = less than method detection limit, WQO = water quality objective.

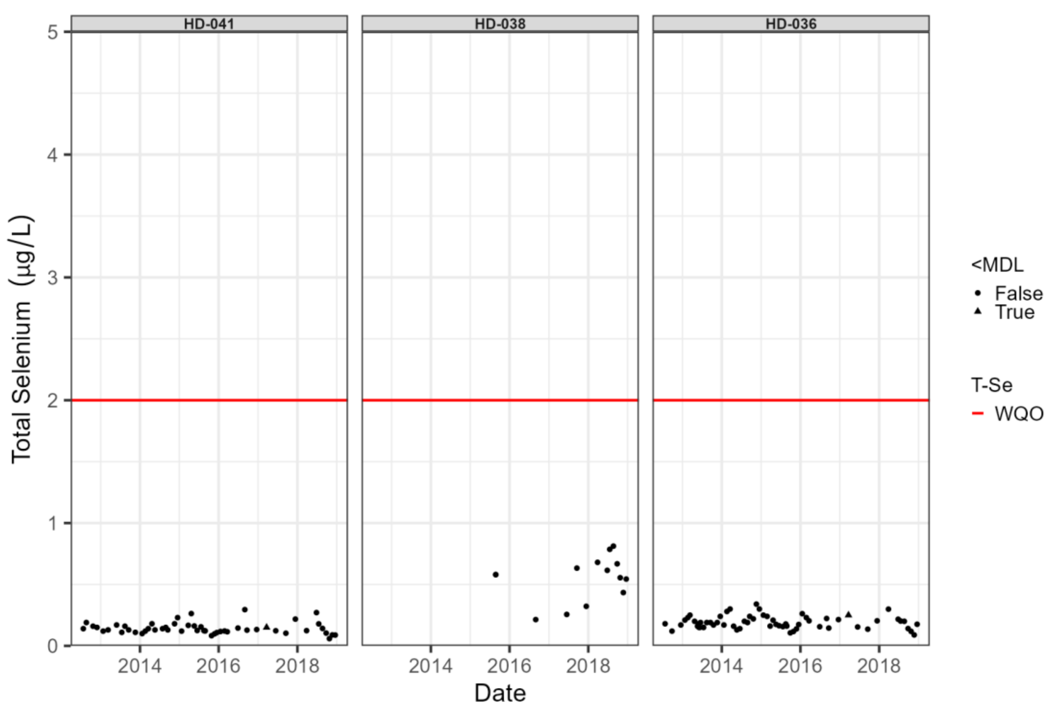

Figure 7: Total selenium concentrations in M19 Creek from representative stations: HD-041 – background station, HD-038 – highest concentrations of total selenium, HD-036 – downstream station before confluence with Murray River. <MDL = less than method detection limit, WQO = water quality objective.

Downstream Watershed including Murray River Mainstem

The total selenium data for the lower Murray River mainstem are illustrated in Figure 7. The tributaries have little to no data and this data gap will need to be addressed. The lower Murray mainstem typically had total selenium concentrations below 1 µg/L but elevated over background, likely due to upstream discharges from the mining area and other anthropogenic disturbances. The current cultural opportunity is considered moderate, but there is the desire to restore the area and increase the cultural opportunity in this zone. An Indigenous Protection Level of Do No More Harm 1 was assigned to both the downstream tributaries and the downstream mainstem to account for the lack of data in the tributaries and the anthropogenic influence from the mining region on the Murray River mainstem. The WQO was set at the BC WQG alert level of 1 µg/L, consistent with the data shown in Figure 8.

Appendix 4: Fish tissue screening benchmarks

1.1 Introduction

The recommended approach in B.C. to assessing risks to human health from eating contaminated fish is by deriving screening value benchmarks (SVs) (WLRS 2023). This approach was used to inform selenium (Se) and mercury (Hg) water quality objectives development for fish tissue in the kinosew sîpîy / whutone gah saghé / Murray River watershed (KSWGSMR).

Screening values are threshold benchmarks against which contaminant concentrations in fish tissue can be compared and assessed for potential risks to human health. If an SV is exceeded and people have been exposed to the contaminant by eating fish, informed decisions can be made regarding next steps. Screening values provide recommended safe contaminant levels in fish tissue based on conservative estimates of human fish consumption rates; they do not provide advice regarding consumption amount limits or constitute a fishing advisory.

A SV considers: the contaminant receptors (subsistence fisher, recreational fisher, the general BC population, pregnant woman, child and toddler); exposure to the contaminant (how much fish the receptors consume); and the contaminant toxicity (what is known about the contaminant and how it affects different receptors).

A subsistence (or Indigenous) toddler was identified as the most sensitive fish consumer in the watershed. Toddler characteristics such as age and body weight were defined from Health Canada (2021a), exposure was calculated through fish ingestion rates from Richardson (1997), and toxicity was defined through toxicological reference values prescribed by Health Canada (2021b). Further details on the methodology and equations used are provided in WLRS (2023).

The limited fish and invertebrate tissue data available across the KSWGSMR show toddler SV exceedances across sampling locations and waterbodies. More fish tissue monitoring data is needed to understand the extent and frequency of SV exceedances and the potential human health risks. As data is collected, discussions with health experts will be required to interpret monitoring data to understand implications on human consumption of fish in the KSWGSMR.

Selenium and Hg SV calculations are shown below. These SV's informed the water quality objectives derived for Se and Hg. The SV inputs of toddler body weight and toddler subsistence fish ingestion rate are not specific to those in the KSWGSMR (the TDI is a standard input from Health Canada 2021b and not a customizable SV input).

1.2 Selenium screening value

The receptor characteristics and SV calculation inputs for selenium are in Table 1. The Se SV calculation is presented below.

Table 1. Receptor characteristics and resulting screening values in wet weight and dry weight for a toddler subsistence fisher in the KSWGSMR.

	Selenium - screening value calculation inputs				
Consumption Pattern	**Ingestion Rate (g/day)**	**Tolerable Daily Intake (µg/kg body weight/day)**	**Body Weight (kg)**	**Screening Value (µg/g wet weight)**	**Screening Value (µg/g dry weight)**
Toddler[1] Subsistence[2] Fisher	95.0	6.00	16.5	1.04	4.17

[1] Based on Richardson 1997, a toddler is defined as 7 months to <5 years old.
[2] Based on Richardson 1997, a subsistence fisher is defined as an Indigenous fish consumer.

Selenium screening value calculation

Screening values are calculated using Health Canada's (2021a) recommended general equation (Equation 1) for calculating the ingested contaminant dose via consumption of contaminated food.

$$Dose = \frac{(\sum(C_{Foodi} \times IR_{Foodi} \times RAF_{Orali} \times D_i)) \times D_2}{BW \times 365 \times LE} \qquad \text{(Equation 1)}$$

Where:

Dose = predicted intake of contaminant (µg/kg BW/day)
C_{Foodi} = concentration of contaminant in food *i* (µg/kg)
IR_{Foodi} = human receptor ingestion rate for food *i* (g/day)
RAF_{Orali} = relative absorption factor from the gastrointestinal tract for contaminant *i* (unitless)
D_i = days per year during which consumption of food *i* will occur
D_2 = total years exposed to site (only used for assessment of carcinogens)
BW = mean body weight of human receptor (kg)
365 = total days per year (constant)
LE = life expectancy (only used for assessment of carcinogens)

Assumptions:

Fish are consumed daily throughout the year: D_i *= 365 days*
RAF_{Orali} *= 1. Unless site-specific data have been collected, oral exposures should be assumed to have a relative absorption of 100% (Health Canada 2021b)*

The noncarcinogen example calculation provided below is for the ingestion of Se by an Indigenous toddler fish consumer. The example uses Equation 1 for calculating the ingested contaminant dose via consumption of contaminated food.

Equation 1 is rearranged to solve for C_{Foodi} (Equation 2). The equation is simplified as the D_2 and *LE* variables are not used in the noncarcinogen calculation. Equation 1 is simplified further as it is assumed that food ingestion occurs every day of the year, therefore D_1 and 365 cancel each other out.

$$C_{Foodi} = \frac{Dose \times BW}{IR_{Foodi} \times RAF_{Orali}} \quad \text{(Equation 2)}$$

C_{Foodi} is equal to SV_n when the appropriate tolerable daily intake (*TDI)* is substituted for the *Dose*. Substituting the variables SV_n for C_{Foodi} and *TDI* (the safe or acceptable contaminant dose) for the *Dose* gives Equation 3. An AF was not added in this calculation to account for other exposures from Se given the SV was for the most conservative receptor (a subsistence toddler) and the resulting SV may already be at or below background conditions.

$$SV_n = \frac{TDI \times BW}{IR_{Foodi} \times RAF_{Orali}} \quad \text{(Equation 3)}$$

Where:

- SV_n = screening value for effects of Se (µg/g) (wet weight or dry weight). Based on edible portions of tissue. Wet weight to dry weight conversion based on 75% moisture content.
- *TDI* = tolerable daily intake for Se toddler = 6.00 µg/kg BW/day (Health Canada 2021b)
- *BW* = body weight = 16.5 kg
- IR_{Foodi} = ingestion rate = 95.0 g/day
- RAF_{Orali} = relative absorption factor from the gastrointestinal tract for Se = 100%

$$SV_{Se} = \frac{6.00\ \frac{\mu g}{kg}\text{day} \ \times 16.5\ \text{kg}}{95.0\frac{g}{day}\ \times 1}$$

$$SV_{Se} = 1.04\ \mu g/g \text{ wet weight}$$

$$SV_{Se} = \frac{100}{100-75} \times 1.04\ \mu g/g = 4.17\ \mu g/g \text{ dry weight}$$

This SV indicates that concentrations of selenium over 4.17 µg/g dry weight in fish tissue have the potential to pose a risk to Indigenous toddler fish consumers.

1.3 Mercury screening value

The receptor characteristics and SV calculation inputs for Hg are in Table 2. The Hg SV calculation is presented below.

Table 2. Receptor characteristics and resulting screening values in wet weight and dry weight for a toddler subsistence fisher in the KSWGSMR.

	Methyl mercury - screening value calculation inputs				
Consumption Pattern	**Ingestion Rate (g/day)**	**Tolerable Daily Intake (µg/kg body weight/day)**	**Body Weight (kg)**	**Screening Value (µg/g wet weight)**	**Screening Value (µg/g dry weight)**
Toddler[1] Subsistence[2] Fisher	95.0	0.20	16.5	0.035	0.14

[1] Based on Richardson 1997, a toddler is defined as 7 months to <5 years old.
[2] Based on Richardson 1997, a subsistence fisher is defined as an Indigenous fish consumer.

Mercury screening value calculation

Screening values are calculated using Health Canada's (2021a) recommended general equation (Equation 1) for calculating the ingested contaminant dose via consumption of contaminated food.

$$Dose = \frac{(\sum(C_{Foodi} \times IR_{Foodi} \times RAF_{Orali} \times D_i)) \times D_2}{BW \times 365 \times LE} \quad \text{(Equation 1)}$$

Where:

$Dose$ = predicted intake of contaminant (µg/kg BW/day)
C_{Foodi} = concentration of contaminant in food *i* (µg/kg)
IR_{Foodi} = human receptor ingestion rate for food *i* (g/day)
RAF_{Orali} = relative absorption factor from the gastrointestinal tract for contaminant *i* (unitless)
D_i = days per year during which consumption of food *i* will occur
D_2 = total years exposed to site (<u>only</u> used for assessment of carcinogens)
BW = mean body weight of human receptor (kg)
365 = total days per year (constant)
LE = life expectancy (<u>only</u> used for assessment of carcinogens)

Assumptions:

Fish are consumed daily throughout the year: D_i = 365 days
RAF_{Orali} = 1. Unless site-specific data have been collected, oral exposures should be assumed to have a relative absorption of 100% (Health Canada 2021b)

The noncarcinogen example calculation provided below is for the ingestion of methylmercury (MeHg) by an Indigenous toddler fish consumer. Health Canada has two methylmercury TDI values; one specific to women of child-bearing age, infants and children < 12 years, and one for non-sensitive adults of the general population. The example uses Equation 1 for calculating the ingested contaminant dose via consumption of contaminated food.

Equation 1 is rearranged to solve for C_{Foodi} (Equation 2). The equation is simplified as the D_2 and *LE* variables are not used in the noncarcinogen calculation. Equation 1 is simplified further as it is assumed that food ingestion occurs every day of the year, therefore D_1 and 365 cancel each other out.

$$C_{Foodi} = \frac{Dose \times BW}{IR_{Foodi} \times RAF_{Orali}} \quad \text{(Equation 2)}$$

C_{Foodi} is equal to SV_n when the appropriate *TDI* is substituted for the *Dose*. Substituting the variables SV_n for C_{Foodi} and *TDI* (the safe or acceptable contaminant dose) for the *Dose* gives Equation 3. An allocation factor was not used in this calculation given that fish is the primary source of mercury ingestion in humans.

$$SV_n = \frac{TDI \times BW}{IR_{Foodi} \times RAF_{Orali}} \quad \text{(Equation 3)}$$

Where:

SV_n = screening value for noncarcinogenic effects of methylmercury (µg/g) (wet weight or dry weight). Based on edible portions of tissue. Wet weight to dry weight conversion based on 75% moisture content.

TDI = tolerable daily intake for methylmercury= 0.2 µg/kg BW/day (Health Canada 2021b)
BW = body weight = 16.5 kg
IR_{Foodi} = ingestion rate = 95.0 g/day
RAF_{Orali} = relative absorption factor from the gastrointestinal tract for MeHg = 100%

$$SV_{MeHg} = \frac{0.2 \ \frac{\mu g}{kg}\text{day} \ \times 16.5 \text{ kg}}{95.0 \frac{g}{day} \ \times 1}$$

$$SV_{MeHg} = 0.035 \ \mu\text{g/g wet weight}$$

$$SV_{MeHg} = \frac{100}{100 - 75} \times 0.035 \ \mu\text{g/g} = 0.14 \ \mu\text{g/g dry weight}$$

This SV indicates that concentrations of methylmercury over 0.14 µg/g dry weight in fish tissue have the potential to pose a risk to Indigenous toddler fish consumers.

1.4 References

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Appendix 5: CABIN Technical Appendix

kinosew sîpîy / whutone gah saghé / Murray River watershed: Biomonitoring Assessment to Support Water Quality Objectives

Environmental Monitoring and Analysis Branch

PROVINCE OF BRITISH COLUMBIA

MAY 2023

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4. Conuma Resources Limited
5. Bullmoose Operating Corporation
6. Environment and Climate Change Canada

Acronyms

BEAST	Benthic Assessment of Sediment
BC	Bray Curtis Dissimilarity
CABIN	Canadian Aquatic Biomonitoring Network
ECCC	Environment and Climate Change Canada
EEM	Environmental Effects Monitoring
ENV	B.C. Ministry of Environment and Climate Change Strategy
KSWGSMR	kinosew sîpîy / whutone gah saghé / Murray River watershed
O:E	Observed:Expected
RCA	Reference Condition Approach
E_D	Simpson's Evenness Index
SD	Standard Deviation
WQO	Water Quality Objectives

Contents

1. INTRODUCTION

1.1.CABIN

ENV collaborates with Environment and Climate Change Canada (ECCC) to promote the use of the nationally standardized Canadian Aquatic Biomonitoring Network (CABIN) program in B.C. CABIN provides a consistent, scientifically defensible approach using benthic macroinvertebrate communities to assess freshwater ecosystems. Data are collected by certified samplers following standard field methods and analyzed using ECCC's laboratory protocols, which ensures the consistency and quality of data (Environment Canada 2012a; Environment Canada 2014). All data are stored in the CABIN database, which is managed by ECCC.

CABIN promotes a study design called the reference condition approach (RCA) that uses data from numerous reference sites (i.e., minimally affected by human activities or other stressors) to build models that characterize the natural range of variation in benthic macroinvertebrate communities (Reynoldson et al, 1995). CABIN models are available on the ECCC website[6] and are accessible to those that have completed the appropriate level of CABIN training and certification. Test sites (i.e., potentially impacted sites) can be analyzed using these models to determine if the benthic community is similar to reference sites with similar environmental attributes. If the benthic community at the test site is different, it is assumed to have been influenced by human activities or other stressors.

1.1.1. Peace Basin CABIN Model

A CABIN model is available for the Peace River Basin (Reynoldson, 2020), which includes the kinosew sîpîy / whutone gah saghé / Murray River watershed (KSWGSMR). The model was developed using data from 113 reference sites sampled between 2006 and 2018. There are 6 habitat predictor variables that differentiate 4 groups of benthic communities in reference condition. These predictor variables include:

- Topography: Slope 30-50% (%)
- Bedrock geology: Glacial sediment blanket (%)
- Climate: precipitation May (mm), total annual precipitation (mm), minimum temperature February (^{o}C)
- Channel: vegetation – shrubs (present/absent)

1.2.Objectives

This assessment was completed to support development of water quality objectives (WQOs) for the KSWGSMR. The objectives of this assessment are to:

1. Assess test sites in the KSWGSMR using the Peace Basin CABIN model;
2. Determine if there are temporal and spatial patterns in benthic macroinvertebrate communities;

[6] https://www.canada.ca/en/environment-climate-change/services/canadian-aquatic-biomonitoring-network/database.html

3. Assess the cause of differences in benthic macroinvertebrate communities, if observed; and
4. Determine if current conditions within the KSWGSMR support healthy benthic macroinvertebrate communities.

2. METHODS

2.1. Site Selection

To determine the scope of available CABIN data, ENV obtained a comprehensive list of all CABIN sites located within the Upper Peace watershed from ECCC. Sites were retained for analyses if they were:

- Located on the Murray River or within a key tributary influenced by stressors (e.g., mining).
- Strategically located. This assessment focused on sites that were located upstream and downstream of stressors and/or key tributaries, where possible. All sites located at the base of key tributaries were retained as they reflect the cumulative inputs from the upstream watershed.
- Sampled within the last 10 years. Sites with more recent data were targeted to characterize current stream conditions.

2.2. Data Assessment

Available test site data were checked for accuracy and completeness as CABIN models are unable to analyze sites that are missing key data (i.e., predictor variables and taxonomy). This involved exporting the test site data from the CABIN database and ensuring all relevent data were present.

Test sites were then classified by the Peace Basin CABIN model. This calculates the probability of each site belonging to the 4 model reference groups based on similarities in the predictor variables.

Once classified, sites were compared to the corresponding reference group in ordination space to characterize the degree of divergence. CABIN uses three ellipses that describe the distribution of reference sites within the cloud. Site status was determined based on the position of the test site within the ordination space (Table 1).

Table 1. *Ordination ellipses used to establish test site status in CABIN.*

Category	Description
Similar to Reference (R)	Within the 90% ellipse
Mildly Divergent (MD)	Within the 90% and 99% ellipses
Divergent (D)	Within the 99% and 99.9% ellipses
Highly Divergent (HD)	Outside of the 99.9% ellipse

River Invertebrate Prediction and Classification System (RIVPAC) values were also calculated using presence/absence data to compare taxa that are observed (O) at a site to those expected (E) to be present (O:E ratios). This comparison is based on the weighted probability of the taxa occurring in the 4 different reference groups. O:E ratios were based on taxa expected to occur with a probability of >70%. A low O:E value indicates there are fewer taxa than expected, suggesting that stressors are influencing the benthic community. A high O:E value (i.e., >1) indicates there are more taxa than expected and that the site may have nutrient enrichment or may be a diversity hotspot.

Metrics were also calculated to describe the community structure and function and help interpret the ordination results. This included benthic community endpoints recommended in federal Environmental Effects Monitoring (EEM) guidance documents (Environment Canada, 2010; Environment Canada, 2012b) and other metrics to provide more information about the benthic community's response to a range of stressors. The selected metrics included:

- **Bray-Curtis Dissimilarity (BCD).** BCD is a measure of the dissimilarity between a test site and the reference group median. This value ranges from 0 (similar to reference) to a maximum of 1 (entirely different from reference).
- **Total invertebrate abundance**. Abundance increases in areas with nutrient enrichment, which increases productivity in lower trophic levels. Abundance may decrease in areas with environmental stressors (Resh and Jackson, 1993).
- **Simpson's Evenness Index (E_D).** This measures the relative abundance of different taxa that make up the benthic community. A lower value indicates that the community is dominated by few species (i.e., low diversity), which may indicate the presence of environmental stress. A higher value indicates that several different species have similar abundance, suggesting the presence of a healthy, diverse community (Morris et al, 2014).
- **Total number of taxa**. This value provides an important overall measurement of taxonomic diversity, with the health of the community reflected by the variety of taxa present (Plafkin et al, 1989).

- **% Ephemeroptera taxa.** Ephemeroptera (mayflies) taxa are sensitive to pollution, with the diversity of mayfly taxa expected to decline in response to most types of anthropogenic stressors.
- **% Ephemeroptera that are Baetidae.** This particular family is tolerant to organic pollution; therefore, a higher proportion of this taxa suggests the presence of organic stressors (Czerniawska-Kusza, 2005).
- **Number of Ephemeroptera, Plecoptera, Trichoptera (EPT) taxa.** These taxa are known to be generally sensitive to pollution, with diversity expected to decline in response to stressors.

Metrics values for each site were compared with the mean and standard deviation (SD) of the associated reference group to determine if the benthic community was within the natural range found at reference sites. Test site values > 2 SD from the mean were considered significantly different from the reference group, indicating that stressors were affecting the community. Where possible, metrics for sites on the same stream were compared spatially to determine if there were any upstream to downstream differences. Metrics were also reviewed to assess any spatial or temporal shifts in the benthic community.

3. RESULTS

3.1. Site Selection

The data export provided from ECCC contained data from 210 CABIN samples collected from 93 different test sites within the Murray River watershed (Appendix A). Using the criteria outlined in Section 2.1, a total of 48 test sites were selected for analysis to support the WQOs (Table 2, Figure 1). These sites were available from 7 different CABIN projects, including:

BC-PRC Trend EEM-Golder

BC-Murray River Baseline -EDI

BC-Conuma-Wolverine and Hermann-Hatfield

BC MOE-Omineca/Peace Region

BC-WE Wolverine EEM-Golder

BC-Bullmoose Mine EEM and RA-Golder

EC-Fed/Prov WQ Monitoring Stations

Table 2. *CABIN test sites selected for the Murray WQO assessment.*

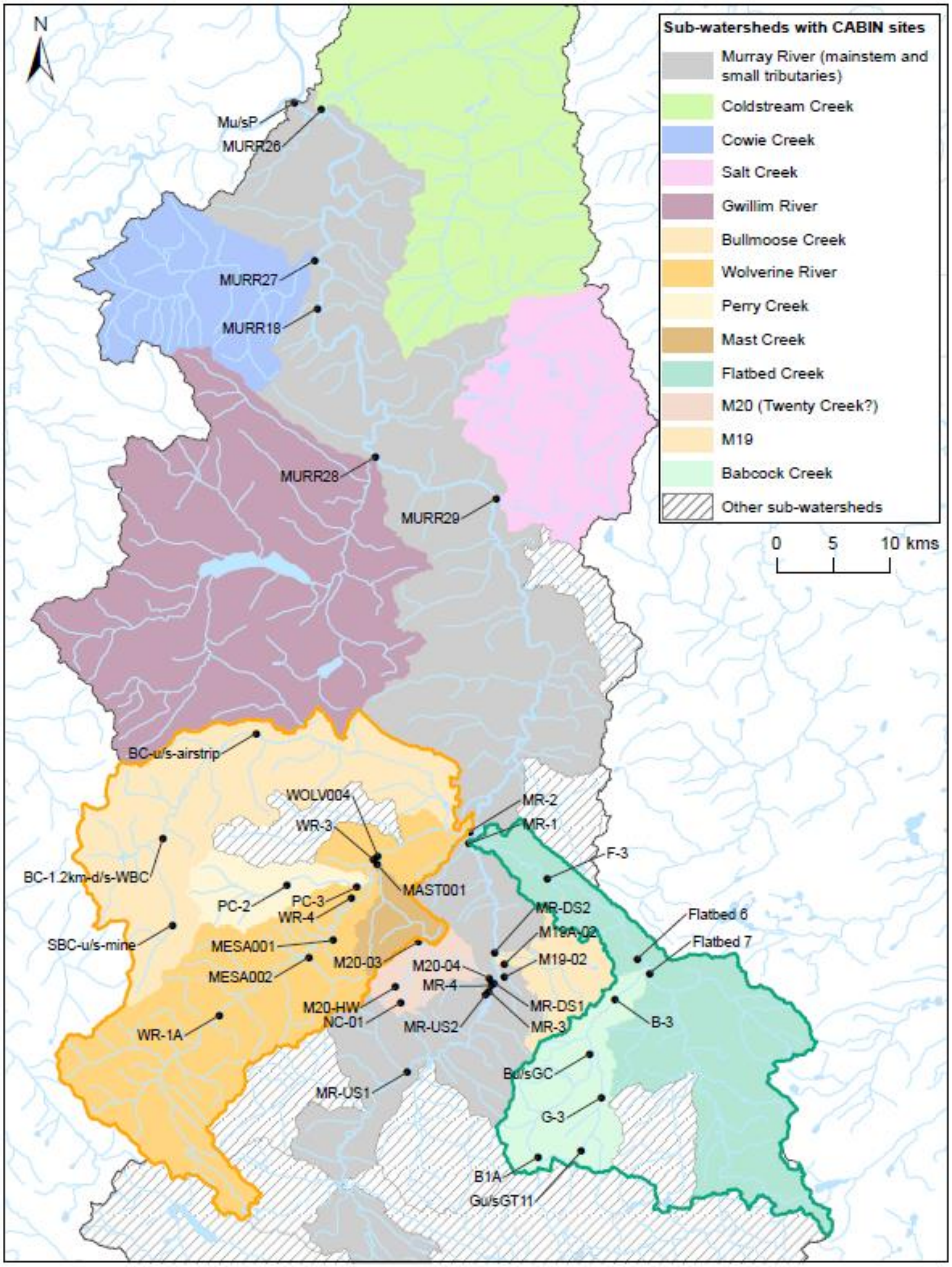
Study	Site	Years Monitored	Waterbody	Latitude	Longitude	Notes
Flatbed Watershed						
BC-PRC Trend EEM-Golder	B1A	2015/17/19	Babcock	54.87053	-120.98	PR in 2015.
BC-PRC Trend EEM-Golder	B-3	2009/11/12/13/15/17/19	Babcock	54.99083	-120.858	Missing 2009/11/13 taxonomy.
BC-PRC Trend EEM-Golder	Bu/sGC	2015/17/19	Babcock	54.94901	-120.899	
BC-PRC Trend EEM-Golder	G-3	2012/13/15/17/19	Gordon	54.91413	-120.887	Missing 2013 taxonomy.
BC-PRC Trend EEM-Golder	Gu/sGT11	2015/17/19	Gordon	54.87253	-120.92	PR in 2015.
BC-PRC Trend EEM-Golder	F-3	2012/13/15/17/19	Flatbed	55.08928	-120.94	Missing 2012/13 taxonomy.
BC-PRC Trend EEM-Golder	Flatbed 6	2012/13/15/17/19	Flatbed	55.02104	-120.824	Missing 2013 taxonomy.
BC-PRC Trend EEM-Golder	Flatbed 7	2012/13/15/17/19	Flatbed	55.00913	-120.808	PR in 2012/15. Missing 2013 taxonomy.
M19 Watershed						
BC-Murray River Baseline -EDI	M19-02	2012/13/14	M19	55.01423	-121.009	Missing 2013 taxonomy.
BC-Murray River Baseline -EDI	M19A-02	2014/15	M19A	55.02418	-121.008	
M20 Watershed						
BC-Conuma-Wolverine and Hermann-Hatfield	M20-HW	2019	M20	55.01228	-121.159	
BC-Conuma-Wolverine and Hermann-Hatfield	NC-01	2019	Nabors	54.99987	-121.153	
BC-Murray River Baseline -EDI	M20-03	2011	M20	55.04694	-121.124	PR in 2011.
BC-Conuma-Wolverine and Hermann-Hatfield	M20-03	2019	M20	55.04651	-121.125	
BC-Murray River Baseline -EDI	M20-04	2011/12/13/14	M20	55.01194	-121.026	Missing 2013 taxonomy
BC-Conuma-Wolverine and Hermann-Hatfield	M20-04	2019	M20	55.01177	-121.025	
Other Tributaries						
BC MOE-Omineca/Peace Region	MAST001	2009	Mast	55.11278	-121.175	
BC MOE-Omineca/Peace Region	MESA001	2009	W11	55.05222	-121.241	
BC MOE-Omineca/Peace Region	MESA002	2009	W9	55.04061	-121.276	
Wolverine Watershed						
BC-WE Wolverine EEM-Golder	PC-2	2012/14	Perry	55.09792	-121.3	
BC-Conuma-Wolverine and Hermann-Hatfield	PC-2	2019	Perry	55.09801	-121.3	

Study	Site	Years Monitored	Waterbody	Latitude	Longitude	Notes
BC-WE Wolverine EEM-Golder	PC-3	2012/14	Perry	55.09284	-121.204	
BC-Conuma-Wolverine and Hermann-Hatfield	PC-3	2019	Perry	55.09293	-121.204	
BC-WE Wolverine EEM-Golder	WR-1A	2012	Wolverine	54.99936	-121.405	PR in 2012
BC-Conuma-Wolverine and Hermann-Hatfield	WR-1A	2019	Wolverine	55.01657	-121.368	
BC-WE Wolverine EEM-Golder	WR-4	2012/14	Wolverine	55.08508	-121.212	
BC-Conuma-Wolverine and Hermann-Hatfield	WR-4	2019	Wolverine	55.08519	-121.212	
BC-WE Wolverine EEM-Golder	WR-3	2012/14	Wolverine	55.11414	-121.178	
BC-Conuma-Wolverine and Hermann-Hatfield	WR-3	2019	Wolverine	55.11409	-121.178	
BC MOE-Omineca/Peace Region	WOLV004	2009	Wolverine	55.11639	-121.171	
BC-Bullmoose Mine EEM and RA-Golder	BC-1.2km-d/s-WBC	2017/18	Bullmoose	55.14129	-121.467	
BC-Bullmoose Mine EEM and RA-Golder	BC-u/s-airstrip	2017/18	Bullmoose	55.21958	-121.328	
BC-Bullmoose Mine EEM and RA-Golder	SBC-u/s-mine	2017/18	South Bullmoose	55.07326	-121.461	PR in 2018.
BC-Bullmoose Mine EEM and RA-Golder	WBC u/s SP3	2018	West Bullmoose	55.12751	-121.522	PR in 2018.
Murray River Mainstem						
BC-Conuma-Wolverine and Hermann-Hatfield	MR-US1	2019	Murray	54.9446	-121.151	
BC-Conuma-Wolverine and Hermann-Hatfield	MR-US2	2019	Murray	55.00339	-121.032	
BC-Murray River Baseline -EDI	MR-3	2012/13/14	Murray	55.00429	-121.031	PR in 2012. Missing 2013 taxonomy.
BC-Conuma-Wolverine and Hermann-Hatfield	MR-DS1	2019	Murray	55.01043	-121.023	
BC-Murray River Baseline -EDI	MR-4	2011/12/13/14	Murray	55.0103	-121.023	Missing 2013 taxonomy.
BC-Conuma-Wolverine and Hermann-Hatfield	Mu/sP	2019	Murray	55.71436	-121.217	
EC-Fed/Prov WQ Monitoring Stations	MURR18	2018	Murray	55.55138	-121.203	
BC-Conuma-Wolverine and Hermann-Hatfield	MR-DS2	2019	Murray	55.03461	-121.019	
BC-PRC Trend EEM-Golder	MR-1	2015/17/19	Murray	55.12138	-121.045	PR in 2015.
BC-PRC Trend EEM-Golder	MR-2	2015/17/19	Murray	55.13074	-121.042	
Lower Murray Tributaries						
BC MOE-Omineca/Peace Region	MURR26	2018	Coldstream	55.70712	-121.179	

Study	Site	Years Monitored	Waterbody	Latitude	Longitude	Notes
BC MOE-Omineca/Peace Region	MURR27	2018	Cowie	55.58929	-121.203	
BC MOE-Omineca/Peace Region	MURR28	2018	Gwilliam	55.43118	-121.137	
BC MOE-Omineca/Peace Region	MURR29	2018	Salt	55.39175	-120.973	

Notes: PR = potential reference

Figure 1. *CABIN test sites selected to support the Murray River WQO.*



3.2. Data Review

Prior to analyzing data from relevant CABIN sites, the data was reviewed for completeness. This assessment found:

- Some samples were missing taxonomy data. These were excluded from the data analysis (Table 2).
- Many of the samples were missing GIS-based habitat data, which are required as predictor variables to match the test sites with the appropriate model reference group. GIS data was generated following guidance provided in Steeves (2021) and uploaded to the respective CABIN project.
- Some background sites were incorrectly uploaded with "potential reference" site status (Table 2). While many of the sites were upstream of major stressors (e.g., mines), they did not meet reference site criteria established for the Peace River Basin and should have been assigned "test" status. It is not possible to analyze potential reference sites using the CABIN model without changing the site status, which was not within the scope of this project.

3.3. Data Assessment

3.3.1. Flatbed Watershed

Eight sites were assessed in the Flatbed River watershed, including 5 sites within Babcock and Gordon Creeks and 3 sites on the Flatbed River. These sites were sampled between 2012 and 2019 and included (Figure 2):

- Gordon Creek (Gu/sGT11, G-3)
- Babcock Creek (B1A, Bu/sGC, B-3)
- Flatbed River (Flatbed 7, Flatbed 6, F-3)

Sites on Gordon and Babcock Creeks were assigned to reference Group 2, and sites on Flatbed Creek were assigned to reference Group 4 (Appendix B). Detailed findings are summarized in Appendix C.

The upstream background sites on both Babcock and Gordon Creek were both Similar to Reference on both sampling events. Changes were noted in both tributaries downstream of the Trend Roman mine, with Mildly Divergent and Divergent status found between 2015 and 2018 (Table 3). The difference in the benthic communities may be related to the significantly higher total abundance and the proportion of more tolerant Ephemeroptera (Baetidae) in some years, possibly a result of changes in water chemistry and increased nutrients downstream of the mine. In 2019, all sites except for Bu/sGC were Similar to Reference, suggesting an improvement in site conditions.

Within the Flatbed River, the benthic community was generally in good condition (e.g., Mildly Divergent or Similar to Reference), except for the site upstream of Babcock Creek ("Flatbed 7") in 2018, which was Divergent, suggesting the influence of an upstream stressor. This site had several metrics that were significantly different from the reference group including a significantly lower proportion of Ephemeroptera, and significantly higher abundance and number of taxa, suggesting enrichment from upstream sources.

The most recent monitoring data from 2019 suggests that conditions within the Flatbed River watershed and tributaries have improved over time, with all sites "Similar to Reference", except for Bu/sGC. This indicates that current conditions in this watershed support healthy benthic communities.

Table 3. *Site assessment results for CABIN sites in the Flatbed River watershed.*

Site	2012	2015	2017	2019
B1A			R	R
Bu/sGC		MD	D	MD
Gu/sGT11			R	R
G-3	D	D	MD	R
B-3	MD	MD	MD	R
Flatbed 7			D	R
Flatbed 6	R	MD	R	R
F-3		MD	MD	R

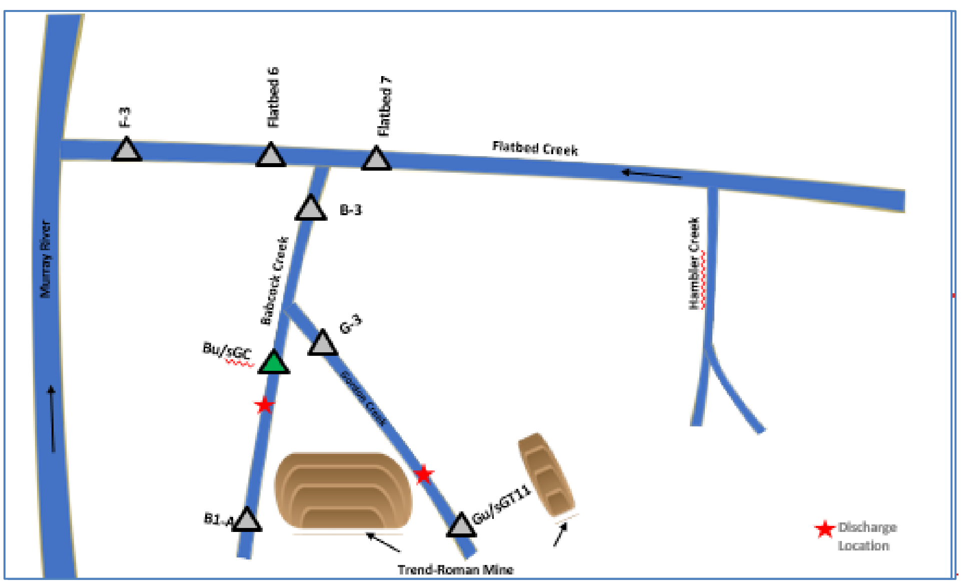


Figure 2. *Conceptual diagram of the Flatbed River watershed showing the most recent (2019) CABIN site assessment result. Grey = similar to reference, Green = mildly divergent.*

3.3.2. M19 and M20 Creeks

Two sites were assessed in M19 Creek, including M19-02 and M19A-02 (Figure 3), with data available between 2012 and 2015. Both sites were assigned to reference Group 4 (Appendix B). The most recent data from both sites on M19 Creek showed the benthic community was Divergent (Table 4), with a significantly lower proportion of sensitive Ephemeroptera taxa and higher proportion of chironomids when compared to the reference Group 4 (Appenix C). However, the information available in the CABIN database showed that these streams are very shallow, with no visible flow and intermittent water. As a result, these findings may be a result of the atypical habitat sampled in these waterbodies, which may not be represented in the reference streams. Further assessment is needed to determine if the differences in the benthic community are a result of the type of habitat present.

Four sites were assessed in the M20 watershed, including 1 site on Nabors Creek (NC-01) and 3 sites on M20 Creek (M20-HW, M20-03, M20-04) (Figure 3). Data were available between 2011 and 2019, with all sites assigned to reference Group 2. Detailed findings are summarized in Appendix C. The data from all available years found that benthic communities in this creek are Mildly Divergent or Similar to Reference (Table 4), indicating that conditions in this waterbody supports healthy benthic communities.

Table 3. *Ordination results for CABIN sites in M19 and M20 watersheds.*

	2011	2012	2014	2015	2019
M19 Creek					
M19-02		MD	D	-	-
M19A-02		-	D	D	-
M20 Creek	-	-	-	-	-
M20-HW	-	-	-	-	R
NC-01	-	-	-	-	MD
M20-03	-	-	-	-	R
M20-04	MD	R	R	-	R

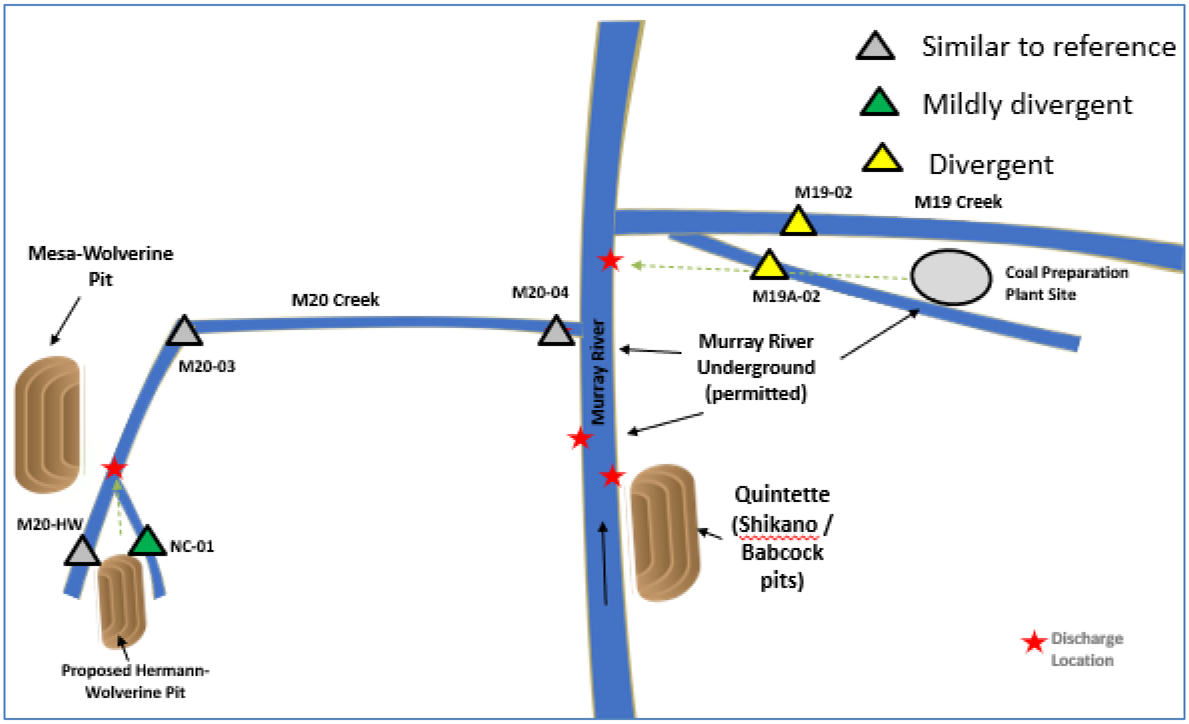


Figure 3. *Conceptual diagram showing the most recent CABIN site assessment result for M19 (2014/15) and M20 (2019) Creeks.*

3.3.3. Wolverine River Watershed

Within the Wolverine River watershed, CABIN samples were collected within Perry Creek, Bullmoose Creek, Mast and Mesa Creeks, and the Wolverine mainstem. Results are summarized below, and detailed findings are summarized in Appendix C.

1.4.1.1 Perry Creek

Two sites were assessed on Perry Creek (PC-2 and PC-3) (Figure 4), with data available between 2012 and 2019. PC-3 was assigned to reference Group 2 and PC-2 was initially assigned to two different reference groups (i.e., 2014 = Group 1 and 2019 = Group 2). Based on a review of predictor variables, it was determined that the group assignment in 2014 was due to an error in the field data (i.e., presence/absence of shrubs in the riparian); As such, the 2014 sample was reassigned to Group 2.

The upstream site (PC-2) was Mildly Divergent in 2014 and 2019. The downstream site (PC-3) was also Mildly Divergent in 2012 and 2014 but became Divergent in 2019 (Table 4). In all years, the proportion of more tolerant Baetid mayflies at the downstream site was higher than the upstream site and significantly higher than reference Group 2. Of note, there appeared to be an overall decline in taxonomic diversity at this site over time, with the RIVPACS value and number of taxa both declining each year the site was assessed (Appendix C). Further monitoring and assessment is recommended within this watershed as the benthic data suggests that stressors are influencing the community.

1.4.1.2 Bullmoose Creek

Three sites were assessed on Bullmoose Creek (SBC-u/s-mine, BC-1.2km-d/s-WBC, BC-u/s-airstrip) (Figure 4). Limited data were available from 2017 and 2018 (Appendix B), with all samples assigned to reference Group 2. There were no data available for the lower portion of the watershed (approximately 20 km in length).

Benthic communities in this creek were Similar to Reference or Mildly Divergent, indicating that conditions in this watershed generally supported a healthy benthic community (Table 4). It was noted that BC-1.2km-d/s-WBC had significantly higher abundance in 2017, which may indicate elevated nutrients and productivity related to the Bullmoose Mine (Appendix C).

1.4.1.3 Other tributaries

Limited data were available for other small tributaries on the Wolverine River, including Mast (MAST001), W11 (MESA001), and W9 (MESA002) Creeks, (Figure 4). These sites were assessed in 2009 only and assigned to Group 3, 1, and 2, respectively (Appendix B).

The benthic community in Mast Creek was Similar to Reference, with all metrics within the range found for reference Group 3. Both W11 and W9 Creeks were Mildly Divergent but had a few metrics that were significantly different from their respective reference groups, including % Ephemeroptera, which were almost completely absent from these 2 sites (Table 4; Appendix C). More recent CABIN data would help determine the cause of these differences and characterize the current state of aquatic biota in these systems.

1.4.1.4 Wolverine River Mainstem

Four sites were assessed on the Wolverine River (WR-1A, WR-4, WR-3, and WOLV004) (Figure 4). Data is available between 2009 and 2019, with all sites assigned to reference Group 2 (Appendix B).

The site upstream of the Wolverine mine was Mildly Divergent in 2019, possibly due to the significantly higher abundance and increased number of taxa at this site compared to reference Group 2. Moving downstream, sites WR-4 and WR-3 were sampled in 2012, 2014, and 2019 and the data suggest conditions at these sites appear to be declining, as both sites shifted from Mildly Divergent to Divergent in the most recent monitoring (Table 4). Based on the selected metrics (Appendix C), it is unclear what aspects of the community are making these sites different. Further assessment recommended to determine the cause of this difference.

There were limited CABIN data available for the lower reach of the Wolverine River downstream of WR-3. There is one station below Mast Creek that was Mildly Divergent in 2009. However, there are no recent CABIN data available between WR-3 and the 10 km downstream reach to the confluence with the Murray River, which makes it difficult to characterize conditions and assess the cumulative effects of stressors on aquatic biota in this watershed.

Table 4. *Ordination results for CABIN sites in the Wolverine River watershed.*

Site	2009	2012	2014	2017	2018	2019
Perry Creek	-	-	-	-	-	-
PC-2	-	-	MD	-	-	MD
PC-3	-	MD	MD	-	-	D
Bullmoose Creek						
SBC-u/s-mine	-	-	-	R	-	-
BC-1.2km-d/s-WBC	-	-	-	MD	MD	-
BC-u/s-airstrip	-	-	-	R	MD	-
Other tributaries						
MAST001	R	-	-	-	-	-
MESA001	MD	-	-	-	-	-
MESA002	MD	-	-	-	-	-
Wolverine River						
WR-1A	-	-	-	-	-	MD
WR-4	-	MD	MD	-	-	D
WR-3	-	MD	MD	-	-	D
WOLV004	MD	-	-	-	-	-

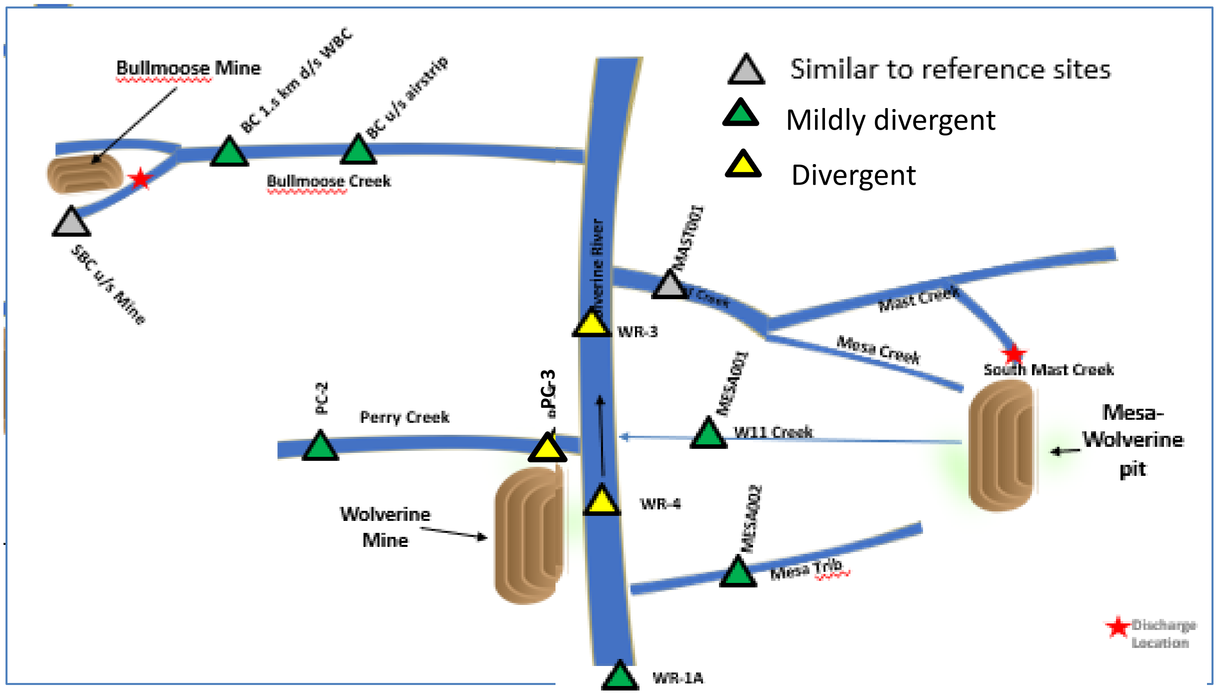


Figure 4. *Conceptual diagram showing the most recent CABIN site assessment result for Perry Creek (2019), Bullmoose Creek (2018), Mast/Mesa/W11 Creeks (2009), and the Wolverine River (2019).*

3.3.4. Lower Murray Tributaries

Limited data were available for tributaries in the Lower Murray watershed. Sampling was conducted on Salt (MURR29), Gwillam (MURR28), Cowie (MURR27), and Coldstream (MURR26) Creeks (Figure 5). These sites were sampled in 2018 and were all assigned to reference Group 3 (Appendix B).

The benthic communities were all Similar to Reference, except for Coldstream Creek, which was Mildly Divergent (Table 5). Both Coldstream and Salt Creeks contained a significantly higher proportion of the sensitive Ephemeroptera taxa when compared to reference Group 3 (Appendix C). Overall, these tributaries appear to support healthy benthic communities, although there is only one year of data available.

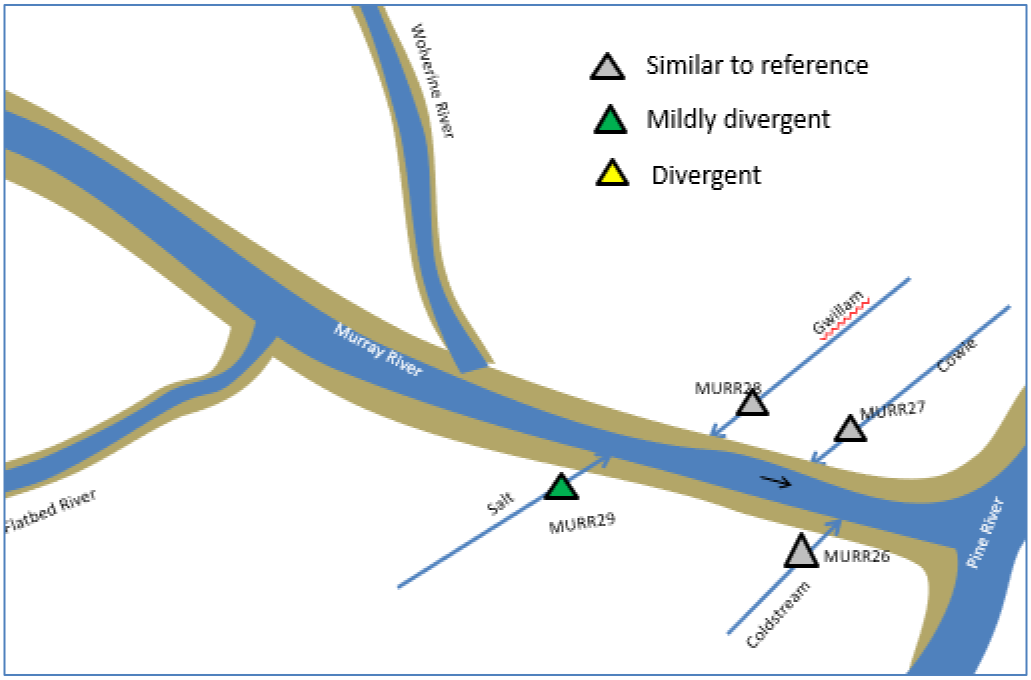


Figure 5. *Conceptual diagram showing the most recent CABIN site assessment (2018) for major tributaries on the lower Murray River.*

3.3.5. Murray Mainstem

Ten sites were sampled in the Murray Mainstem assessment, which included a gradient of sites from the upper Murray River to the confluence with the Pine River (Figure 6):

- MR-US1: Upstream of Barbour Creek
- MR-US2/MR-3: Both sites in similar locations upstream of M20 Creek
- MR-DS1/MR-4: Both sites in similar locations downstream M20 Creek
- MR-DS2: Downstream M19 Creek
- MR-1: Upstream Flatbed River
- MR-2: Downstream Flatbed River, Upstream Wolverine River
- MURR18: Lower Murray, Upstream Cowie
- Mu/sP: At confluence with Pine River.

Sites were sampled between 2011 and 2019 and were assigned to Group 2 (Appendix B). Results within the Murray River were variable, with no clear temporal or spatial patterns evident (Table 6). Overall, all sites in the Upper Murray contain communities that are diverse with sensitive taxa present. Differences between the sites may be related to localized water quality or habitat conditions. Detailed findings are summarized in Appendix C, with a summary of key highlights below:

- The 3 sites located upstream of M20 Creek were Similar to Reference in each monitoring event, indicating the upper Murray River supports healthy benthic communities.

- Sites MR-DS1/MR-4, both located downstream of M20 Creek, fluctuated between Mildly Divergent and Divergent between 2011 and 2019. This site may be influenced by upstream stressors, although the cause of differences is not clear based on the selected metrics. Note that the lower site within M20 Creek (M20-04) was Mildly Divergent or Similar to Reference during the same monitoring events, suggesting that differences noted in the Murray River are not related to surface flow from M20 Creek over the same period.
- Site MR-DS2, downstream of M19 Creek was Similar to Reference in 2019, suggesting differences observed at the upstream sites may be localized.
- Site MR-1, located upstream of Flatbed Creek was Divergent in both 2017 and 2019, likely related to the higher proportion of Chironomidae, as well as the significantly higher total abundance. It is not clear if this difference is related to habitat present at this site, or if this is a response to upstream stressors. Further assessment is recommended. The benthic community downstream of Flatbed Creek at site MR-2, was Mildly Divergent and Similar to Reference, suggesting any differences may be localized.
- There is very sparse CABIN data available in the lower Murray River, with no sites located between MR-2 and MURR18, a distance of approximately 50 km that also includes inputs from the Wolverine River.
- Site MURR18 was sampled in 2018 only and was Similar to Reference.
- Site Mu/SP, located near the confluence with the Pine River, was Divergent in 2019. The select metrics were not significantly different from the reference group; further sampling and assessment are recommended to determine the cause of divergence.

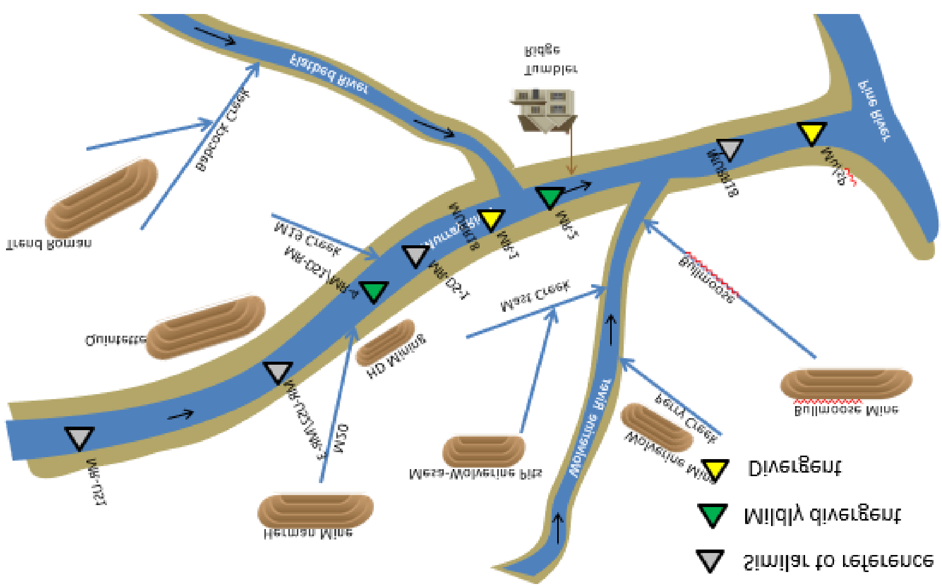


Figure 6. *Conceptual diagram and the 2018/19 assessment results for CABIN sites located on the mainstem Murray River.*

Table 6. *Ordination results for CABIN sites on lower Murray River tributaries and the Murray River mainstem sampled between 2011 and 2019.*

	2011	2012	2014	2015	2017	2018	2019
Lower Murray Tribs							
MURR26	-	-	-	-	-	MD	-
MURR27	-	-	-	-	-	R	-
MURR28	-	-	-	-	-	R	-
MURR29	-	-	-	-	-	R	-
Murray Mainstem							
MR-US1	-	-	-	-	-	-	R
MR-3/MR-US2	-	-	R	-	-	-	R
MR-4 /MR-DS1	D	MD	D	-	-	-	MD
MR-DS2	-	-	-	-	-	-	R
MR-1	-	-	-	-	D	-	D
MR-2	-	-	-	MD	R	-	MD
MURR18	-	-	-	-	-	R	-
Mu/sP	-	-	-	-	-	-	D

4. CONCLUSIONS AND RECOMMENDATIONS

Benthic macroinvertebrate communities are an important addition to the WQO process, as they integrate the effects of upstream stressors and provide a direct measure of the condition of aquatic biota. CABIN data from a total of 48 test sites within the Murray River and its tributaries were analyzed using the Peace River Basin CABIN model.

A summary of key findings and recommendations for benthic monitoring and assessment are provided below:

A. Flatbed Creek

- 8 sites were assessed within Flatbed Creek, all with recent data from 2019. The results indicate that the benthic community at these sites has improved over the past decade. The most recent data (2019) included in this assessment found most sites were Similar to Reference and indicated that both Babcock and Flatbed Creeks support healthy benthic communities.

B. M19 and M20 Creeks

- 2 sites were assessed on M19 Creek between 2012 and 2015. The most recent data shows the sites are Divergent; however, this may be a result of the shallow, intermittent habitat sampled and further assessment is recommended.
- 4 sites were assessed on M20 Creek between 2011 and 2019. Most data showed that this waterbody was Similar to Reference, indicating that it supports healthy benthic communities.

C. Wolverine River Watershed

1.4.1.4.1 Perry Creek

- Data are available from 2 sites on Perry Creek between 2012 and 2019. Both sites were found to be Mildly Divergent, although declining diversity was noted at the downstream site over this period, with the most recent data showing this site as Divergent. Further monitoring and assessment is recommended to characterize and assess the effects of stressors in this waterbody.

1.4.1.4.2 Bullmoose Creek

- Limited data are available from Bullmoose Creek, with sampling conducted in 2017 and 2018 at 3 sites located in the upper portion of the watershed. The results found that benthic communities downstream of the Bullmoose Mine in this creek were Similar to Reference or Mildly Divergent, indicating that conditions generally supported a healthy benthic community. Future monitoring efforts should consider a site in the lower section near the confluence with the Murray River to monitor the cumulative effects of upstream stressors.

1.4.1.4.3 Other tributaries

- Limited data are available for Mast, W11 and W9 Creeks, with sampling only conducted in 2009. These data showed that the sites were Similar to Reference or Mildly Divergent, indicating that conditions generally supported a healthy benthic community. More recent monitoring data would help characterize the current state of aquatic biota in these tributaries.

Wolverine River Mainstem

- Data are available from 4 sites on the Wolverine River sampled between 2009 and 2019. All sites were Mildly Divergent, except for the sites adjacent to and downstream of the Wolverine Mine, which shifted to become Divergent during the most recent monitoring period. Further assessment is recommended to determine what is causing the decline in the benthic community. Future monitoring efforts should consider site(s) in the lower reaches of the Wolverine River, possibly downstream of Bullmoose Creek and near the confluence with the Murray River.

D. Lower Murray Tributaries

- Data were collected from 4 tributaries flowing to the lower Murray River in 2018, including Salt, Gwillam, Cowie, and Coldstream Creeks. All sites were Similar to Reference, except for Salt Creek, which was Mildly Divergent. The limited data available suggest that these tributaries support healthy benthic communities.

E. Murray River

- Data were assessed from 8 sites on the Murray River mainstem between 2011 and 2019. The upper 2 sites were both Similar to Reference. Variable results were found at the downstream sites, ranging from Similar to Reference to Divergent, with no clear temporal or spatial pattern. Annual monitoring at a gradient of sites along the Murray River is strongly recommended to thoroughly characterize the current state of the biological community and to monitor long-term changes within the watershed. This should consider additional sites in the lower portion of the watershed, as monitoring data were extremely limited downstream of Tumbler Ridge.

The CABIN data from the KSWGSMR highlights the value of using this approach to collect, store, and analyze biomonitoring data. This assessment was possible as a direct result of the standardized data available from 7 different CABIN projects.

Biological monitoring following the CABIN approach should continue within the KSWGSMR to provide a direct measure of the effects of stressors on the aquatic biota. CABIN sampling should be considered as part of receiving environment monitoring for all permitted discharges within the Murray River watershed. Annual CABIN sampling and assessment is also recommended as part of WQO attainment monitoring to assess cumulative effects and track long-term conditions within these watersheds. Sampling locations should consider sites located at the base of key tributaries to the Murray River, as well as sites located along the mainstem Murray River.

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Appendix A. All available CABIN sites in the KSWGSMR.

Study	Site	Site Name	Years	Sample Status	Latitude	Longitude
Flatbed Watershed						
BC-PRC Trend EEM-Golder	B1A	Babcock Creek	2015/17/19	Pot. Ref.	54.87053	-120.98
BC-PRC Trend EEM-Golder	B-2	Babcock Creek	2009/11/12/13/15/17/19	Test	54.90722	-120.963
BC-PRC Trend EEM-Golder	B-3	Babcock Creek	2009/11/12/13/15/17/19	Test	54.99083	-120.858
BC-PRC Trend EEM-Golder	B-5	Babcock Creek	2009/11/12/13/15/17/19	Pot. Ref.	54.92444	-120.923
BC-PRC Trend EEM-Golder	Bu/sGC	Babcock Creek	2015/17/19	Test	54.94901	-120.899
BC MOE-Omineca/Peace Region	MURR001	Babcock Creek	2008	Test	54.92111	-120.925
BC-PRC Trend EEM-Golder	G-2	Gordon Creek	2012/13/15/17/19	Test	54.89384	-120.895
BC-PRC Trend EEM-Golder	G-3	Gordon Creek	2012/13/15/17/19	Test	54.91413	-120.887
BC-PRC Trend EEM-Golder	Gu/sGT11	Gordon Creek	2015/17/19	Pot. Ref.	54.87253	-120.92
BC-PRC Trend EEM-Golder	G-U/S-GT12	Gordon Creek	2012/13	Pot. Ref.	54.86536	-120.928
BC-PRC Trend EEM-Golder	Gu/sGT33	Gordon Creek	2015/17/19	Test	54.887	-120.904
BC-PRC Trend EEM-Golder	GT33	Murray River	2013/15/17/19	Test	54.88686	-120.904
BC-PRC Trend EEM-Golder	F-3	Flatbed Creek	2012/13/15/17/19	Test	55.08928	-120.94
BC-PRC Trend EEM-Golder	Flatbed 6	Flatbed Creek	2012/13/15/17/19	Test	55.02104	-120.824
BC-PRC Trend EEM-Golder	Flatbed 7	Flatbed Creek	2012/13/15/17/19	Pot. Ref.	55.00913	-120.808
M19 Watershed						
BC-Murray River Baseline -EDI	M19-01	M19 Creek	2012/13/14	Test	55.02237	-120.96
BC-Murray River Baseline -EDI	M19-02	M19 Creek	2012/13/14	Test	55.01423	-121.009
BC-Murray River Baseline -EDI	M19A-01	M19A Creek	2014/15	Test	55.02186	-120.983
BC-Murray River Baseline -EDI	M19A-02	M19A Creek	2014/15	Test	55.02418	-121.008
M20 Watershed						
BC MOE-Omineca/Peace Region	M20001	M20 Creek	2009	Test	55.04694	-121.124

Study	Site	Site Name	Years	Sample Status	Latitude	Longitude
BC-Conuma-Wolverine and Hermann-H	M20-02	M20 Creek	2019	-	55.02099	-121.142
BC-Murray River Baseline -EDI	M20-03	M20 Creek	2011	Pot. Ref.	55.04694	-121.124
BC-Conuma-Wolverine and Hermann-H	M20-03	M20 Creek	2019	-	55.04651	-121.125
BC-Murray River Baseline -EDI	M20-04	M20 Creek	2011/12/13/14	Test	55.01194	-121.026
BC-Conuma-Wolverine and Hermann-H	M20-04	M20 Creek	2019	-	55.01177	-121.025
BC-Murray River Baseline -EDI	M20-05	M20 Creek	2011/12/13/14	Test	55.03139	-121.096
BC-Conuma-Wolverine and Hermann-H	M20-06	M20 Creek	2019	-	55.01343	-121.025
BC-Conuma-Wolverine and Hermann-H	M20-HW	M20 Creek	2019	-	55.01228	-121.159
BC-Conuma-Wolverine and Hermann-H	M20-LZ-02	M20 Creek	2019	-	55.0262	-121.139
BC-Conuma-Wolverine and Hermann-H	M20-SEDDS	M20 Creek	2019	-	55.03382	-121.099
BC-Conuma-Wolverine and Hermann-H	NC-01	Nabors Creek	2019	-	54.99987	-121.153
BC-Conuma-Wolverine and Hermann-H	NC-02	Nabors Creek	2019	-	55.01332	-121.139
Other Tributaries						
BC MOE-Omineca/Peace Region	MAST001	Mast Creek	2009	Test	55.11278	-121.175
BC MOE-Omineca/Peace Region	MESA001	Mesa Creek W11	2009	Test	55.05222	-121.241
BC MOE-Omineca/Peace Region	MESA002	Mesa Creek W9	2009	Test	55.04061	-121.276
Wolverine Watershed						
BC-WE Wolverine EEM-Golder	PC-01/10	Perry Creek	2012/13	Test	55.0981	-121.359

Study	Site	Site Name	Years	Sample Status	Latitude	Longitude
BC-WE Wolverine EEM-Golder	PC-05	Perry Creek	2012	Pot. Ref.	55.63664	-121.393
BC-WE Wolverine EEM-Golder	PC-1	Perry Creek	2013	Test	55.09815	-121.359
BC-WE Wolverine EEM-Golder	PC-2	Perry Creek	2012/14	Pot. Ref.	55.09792	-121.3
BC-Conuma-Wolverine and Hermann-H	PC-2	Perry Creek	2019	Test	55.09801	-121.3
BC-WE Wolverine EEM-Golder	PC-3	Perry Creek	2012/14	Test	55.09284	-121.204
BC-Conuma-Wolverine and Hermann-H	PC-3	Perry Creek	2019	Test	55.09293	-121.204
BC-WE Wolverine EEM-Golder	PC-5	Perry Creek	2012	Pot. Ref.	55.09615	-121.417
BC-WE Wolverine EEM-Golder	PC-6	Perry Creek	2013	Test	55.10018	-121.38
BC-WE Wolverine EEM-Golder	PC-9	Perry Creek	2013	Test	55.09698	-121.412
BC-WE Wolverine EEM-Golder	PC-DS	Perry Creek	2013	Test	55.09056	-121.328
BC MOE-Omineca/Peace Region	PERR001	Perry Creek	2009	Test	55.09275	-121.204
BC-WE Wolverine EEM-Golder	PC-4	Perry Creek Trib	2013	Test	55.10641	-121.381
BC-WE Wolverine EEM-Golder	TRIB_A Bridg	Perry Creek Trib (A)	2013	Test	55.09375	-121.358
BC MOE-Omineca/Peace Region	MURR002	Bull Moose River	2008	Test	55.15667	-121.461
BC-Bullmoose Mine EEM and RA-Golder	BC-1.2km-d/s-WB	Bullmoose Ck	2017/18	Test	55.14129	-121.467
BC-Bullmoose Mine EEM and RA-Golder	BC-u/s-airstrip	Bullmoose Ck	2017/18	Test	55.21958	-121.328
BC-Bullmoose Mine EEM and RA-Golder	SBC-d/s-SP2	South bullmoose Ck	2017/18	Test	55.13683	-121.485
BC-Bullmoose Mine EEM and RA-Golder	SBC-u/s-mine	South Bullmoose Ck	2017/18	Pot. Ref.	55.07326	-121.461
BC-Bullmoose Mine EEM and RA-Golder	SBC d/s Trib 3	South Bullmoose Ck	2018	Test	55.10958	-121.472

Study	Site	Site Name	Years	Sample Status	Latitude	Longitude
BC-Bullmoose Mine EEM and RA-Golder	SBC u/s Trib 3	South Bullmoose Ck	2018	Test	55.10946	-121.471
BC-Bullmoose Mine EEM and RA-Golder	WBC-d/s-SP3	West Bullmoose Ck	2017/18	Test	55.13443	-121.497
BC-Bullmoose Mine EEM and RA-Golder	WBC-d/s SP2	West Bullmoose Ck	2017/18	Test	55.13625	-121.488
BC-Bullmoose Mine EEM and RA-Golder	WBC u/s SP3	West Bullmoose Ck	2018	Test	55.12751	-121.522
BC MOE-Omineca/Peace Region	WOLV004	Wolverine River	2009	Test	55.11639	-121.171
BC-WE Wolverine EEM-Golder	WR-1	Wolverine River	2014	Test	55.04147	-121.299
BC-WE Wolverine EEM-Golder	WR-1A	Wolverine River	2012	Pot. Ref	54.99936	-121.405
BC-Conuma-Wolverine and Hermann-H	WR-1A	Wolverine River	2019	Test	55.01657	-121.368
BC-WE Wolverine EEM-Golder	WR-2	Wolverine River	2012/14	Test	55.05653	-121.245
BC-Conuma-Wolverine and Hermann-H	WR-2	Wolverine river	2019	Test	55.05646	-121.244
BC-WE Wolverine EEM-Golder	WR-3	Wolverine River	2012/14	Test	55.11414	-121.178
BC-Conuma-Wolverine and Hermann-H	WR-3	Wolverine River	2019	Test	55.11409	-121.178
BC-WE Wolverine EEM-Golder	WR-4	Wolverine River	2012/14	Test	55.08508	-121.212
BC-Conuma-Wolverine and Hermann-H	WR-4	Wolverine River	2019	Test	55.08519	-121.212
BC-WE Wolverine EEM-Golder	WR-7	Wolverine River	2012/14	Test	55.0731	-121.229
BC-Conuma-Wolverine and Hermann-H	WR-7	Wolverine River	2019	Test	55.07406	-121.235
BC-Conuma-Wolverine and Hermann-H	WR-US	Wolverine River	2019	Test	55.05123	-121.265

Study	Site	Site Name	Years	Sample Status	Latitude	Longitude
Murray River Mainstem						
BC-PRC Trend EEM-Golder	MR-1	Murray River	2015/17/19	Test	55.12138	-121.045
BC-PRC Trend EEM-Golder	MR-2	Murray River	2015/17/19	Test	55.13074	-121.042
BC-Conuma-Wolverine and Hermann-H	MR-US2	Murray River	2019	-	55.00339	-121.032
BC-Murray River Baseline -EDI	MR-3	Murray River	2012/13/14	Pot. Ref	55.00429	-121.031
BC-Conuma-Wolverine and Hermann-H	MR-DS1	Murray River	2019	-	55.01043	-121.023
BC-Murray River Baseline -EDI	MR-4	Murray River	2011/12/13/14	Test	55.0103	-121.023
BC-Murray River Baseline -EDI	MR-6	Murray River	2012/13/14	Pot. Ref	55.11271	-121.032
BC-Murray River Baseline -EDI	MR-7	Murray River	2011	Test	55.03056	-121.017
BC-Murray River Baseline -EDI	MR-7b	Murray River	2012/13/14	Test	55.03972	-121.017
BC-Murray River Baseline -EDI	MR-9	Murray River	2011/12/13/14	Test	54.96667	-121.05
BC-Murray River Baseline -EDI	MR-Ref	Murray River	2013/14/15	Test	54.91327	-121.218
BC-Conuma-Wolverine and Hermann-H	Mu/sP	Murray River	2019	Test	55.71275	-121.105
EC-Fed/Prov WQ Monitoring Stations	MURR18	Murray River	2018	Test	55.55138	-121.203
BC-Conuma-Wolverine and Hermann-H	MR-DS2	Murray River	2019	-	55.03461	-121.019
BC-Conuma-Wolverine and Hermann-H	MR-US1	Murray River	2019	-	54.9446	-121.151
Murray River Mainstem						
BC MOE-Omineca/Peace Region	MURR26	Coldstream Creek	2018	Test	55.70712	-121.179
BC MOE-Omineca/Peace Region	MURR27	Cowie Creek	2018	Test	55.58929	-121.203
BC MOE-Omineca/Peace Region	MURR28	Gwilliam River	2018	Test	55.43118	-121.137

Study	Site	Site Name	Years	Sample Status	Latitude	Longitude
BC MOE-Omineca/Peace Region	MURR29	Salt Creek	2018	Test	55.39175	-120.973
BC-Jackpine-AMEC	SR2	Salt Creek	2011	Test	55.38343	-120.951
BC-Jackpine-AMEC	SR4	Salt Creek	2011	Test	55.3771	-120.903

Appendix B. Table of probabilities for select KSMRW sites.

Site	Group	Group 1	Group 2	Group 3	Group 4
Flatbed					
B1A	2	3%	**96%**	0%	1%
B-3	2	0%	**79%**	1%	19%
Bu/sGC	2	0%	**95%**	1%	4%
G-3	2	0%	**94%**	1%	4%
Gu/sGT11	2	31%	**62%**	1%	6%
F-3	4	0%	6%	1%	**93%**
Flatbed 6	4	0%	8%	1%	**91%**
Flatbed 7	4	0%	2%	0%	**97%**
M19					
M19-02	4	0%	1%	2%	**97%**
M19A-02	4	0%	1%	2%	**97%**
M20					
M20-HW	2	1%	**95%**	2%	2%
NC-01	2	0%	**98%**	1%	1%
M20-03	2	1%	**91%**	6%	3%
M20-04	2	0%	**59%**	36%	5%
Other Tributaries					
MAST001	3	0%	37%	**59%**	4%
MESA001	1	**100%**	0%	0%	0%
MESA002	2	3%	**93%**	1%	3%
Wolverine					
PC-2 (2014)	1	**100%**	0%	0%	0%
PC-2 (2019)	2	0%	**99%**	0%	1%
PC-3	2	1%	**97%**	1%	1%
BC-1.2km-d/s-WBC	2	1%	**98%**	0%	1%
BC-u/s-airstrip	2	1%	**97%**	1%	1%
SBC-u/s-mine	2	0%	**99%**	0%	0%
WR-1A	2	2%	**96%**	0%	2%
WR-4	2	6%	**89%**	1%	5%
WR-3	2	4%	**90%**	1%	5%
WOLV004	2	3%	**90%**	2%	5%

Site	Group	Group 1	Group 2	Group 3	Group 4
Lower Murray Tributaries					
MURR26	3	0%	0%	**99%**	1%
MURR27	3	0%	0%	**100%**	0%
MURR28	3	0%	12%	**82%**	6%
MURR29	3	0%	1%	**70%**	28%
Murray River Mainstem					
MR-US1	2	1%	**94%**	1%	5%
MR-US2	2	1%	**92%**	1%	6%
MR-3	2	1%	**92%**	1%	6%
MR-DS1	2	1%	**91%**	1%	6%
MR-4	2	1%	**91%**	1%	6%
Mu/sP	2	1%	**58%**	14%	27%
MURR18	2	1%	**58%**	14%	27%
MR-DS2	2	1%	**90%**	1%	8%
MR-1	2	1%	**88%**	2%	9%
MR-2	2	1%	**78%**	2%	18%

Appendix C. Metrics for select KSWGSMR sites.

	2012	2015	2017	2019	Mean	Std Dev	Notes
B1A (Group 2)							
Ordination	-	-	R	R	-	-	Upstream background site in Babock Creek is in reference condition with more EPT taxa than expected in 2017. Stable, in reference condition
Bray Curtis	-	-	0.34	0.40	-	-	
RIVPACS O:E (p>0.7)	-	-	1.13	1.05			
% Chironomidae	-	-	3	14	10.4	9.6	
% Ephemeroptera	-	-	67	58	46.7	16.6	
% Ephemeroptera that are Baetidae	-	-	13	11	21.4	12.7	
EPT taxa (number)	-	-	**17**	14	12.6	1.9	
Simpson's Evenness	-	-	0.27	0.26	0.32	0.11	
Total Abundance	-	-	2400	3130	3079	2739	
Total Number. of Taxa	-	-	23	20	18.2	3.0	
Bu/sGC (Group 2)							
Ordination	-	MD	D	MD	-	-	Downstream of mine inputs, u/s confluence with Gordon Creek. Some changes in the benthic community between 2015 and 2019, including an increase in % of more tolerant Ephemeroptera and a large increase in abundance relative to upstream background and reference group. Changes may be a result of changes to water chemistry, reducing the presence of more sensitive Ephemeroptera and an increase in nutrients.
Bray Curtis	-	0.80	0.86	0.74	-	-	
RIVPACS O:E (p>0.7)	-	0.97	1.05	0.97	-	-	
% Chironomidae	-	1	1	4	10.4	9.6	
% Ephemeroptera	-	44	37	57	46.7	16.6	
% Ephemeroptera that are Baetidae	-	27	**83**	**51**	21.4	12.7	
EPT taxa (number)	-	14	15	12	12.6	1.9	
Simpson's Evenness	-	0.28	0.23	0.31	0.32	0.11	
Total Abundance	-	**12940**	**12760**	**9580**	3078.9	2738.9	
Total Number. of Taxa	-	22	23	19	18.2	3.0	

	2012	2015	2017	2019	Mean	Std Dev	Notes
Gu/sGT11 (Group 2)							
Ordination	-	-	R	R	-	-	Upstream background site in Gordon Creek in reference condition; slighly more Baetidae than the reference group in 2017.
Bray Curtis	-	-	0.63	0.41	-	-	
RIVPACS O:E (p>0.7)	-	-	1.07	1.07	-	-	
% Chironomidae	-	-	1	4	10.4	9.6	
% Ephemeroptera	-	-	32	59	46.7	16.6	
% Ephemeroptera that are Baetidae	-	-	**47**	26	21.4	12.7	
EPT taxa (number)	-	-	13	14	12.6	1.9	
Simpson's Evenness	-	-	0.32	0.29	0.32	0.11	
Total Abundance	-	-	5917	658	3078.9	2738.9	
Total Number. of Taxa	-	-	18	16	18.2	3.0	
G-3 (Group 2)							
Ordination	D	D	MD	R	-	-	Site u/s confluence with Babock Creek. Some changes in benthic community relative to upstream and reference group between 2012 and 2017, including an increase in % tolerant Ephemeroptera and large increase in abundance. Conditions appear to be improving over time. Changes may indicate presence of contaminants, reducing the presence of more sensitive Ephemperoptera and an increase in nutrients.
Bray Curtis	0.68	0.87	0.81	0.51	-	-	
RIVPACS O:E (p>0.7)	1.05	0.97	0.89	0.97	-	-	
% Chironomidae	3	6	1	5	10.4	9.6	
% Ephemeroptera	35	24	25	69	46.7	16.6	
% Ephemeroptera that are Baetidae	30	**72**	**74**	34	21.4	12.7	
EPT taxa (number)	15	15	12	15	12.6	1.9	
Simpson's Evenness	0.28	0.22	0.22	0.28	0.32	0.11	
Total Abundance	7040	**20200**	**12620**	4188	3078.9	2738.9	
Total Number. of Taxa	22	25	22	18	18.2	3.0	

	2012	2015	2017	2019	Mean	Std Dev	Notes
B-3 (Group 2)							
Ordination	MD	MD	MD	R	-	-	Babcock d/s Gordon Creek. Some changes in benthic community relative to reference group between 2012 and 2017, with improved conditions in 2019. Generally in good condition, with no significant differences found within selected metrics.
Bray Curtis	0.67	0.65	0.76	0.49	-	-	
RIVPACS O:E (p>0.7)	0.94	0.85	0.94	1.13	-	-	
% Chironomidae	5	3	9	8	10.4	9.6	
% Ephemeroptera	55	46	49	51	46.7	16.6	
% Ephemeroptera that are Baetidae	58	27	37	46	21.4	12.7	
EPT taxa (number)	11	13	14	13	12.6	1.9	
Simpson's Evenness	0.28	0.42	0.27	0.26	0.32	0.11	
Total Abundance	6720	5850	8180	3780	3078.9	2738.9	
Total Number. of Taxa	20	21	21	18	18.2	3.0	
Flatbed 7 (Group 4)							
Ordination	-	-	D	R	-	-	Upstream confluence with Babcock Creek. Divergent site conditions found in 2017, with significant differences in Ephemeroptera taxa and increased abundance relative to reference group. More taxa found at this site than the reference group. Results suggest some enrichment from upstream sources in 2017.
Bray Curtis	-	-	0.77	0.40	-	-	
RIVPACS O:E (p>0.7)	-	-	0.96	0.96	-	-	
% Chironomidae	-	-	22	10	11.9	8.7	
% Ephemeroptera	-	-	**25**	68	60.0	14.5	
% Ephemeroptera that are Baetidae	-	-	**7**	59	69.7	25.5	
EPT taxa (number)	-	-	14	12	10.6	3.7	
Simpson's Evenness	-	-	0.31	0.22	0.24	0.04	
Total Abundance	-	-	**9660**	6100	3795.7	2058.5	
Total Number. of Taxa	-	-	**28**	19	16.3	5.3	

	2012	2015	2017	2019	Mean	Std Dev	Notes
Flatbed 6 (Group 4)							
Ordination	R	MD	R	R			Downstream of confluence with Babcock Creek. Benthic community similar to reference between 2012 and 2019, except for 2015. Divergence noted upstream in 2017 not reflected at this site. Evenness values > reference group, except for 2019.
Bray Curtis	0.38	0.73	0.44	0.43			
RIVPACS O:E (p>0.7)	0.96	0.96	1.10	1.10			
% Chironomidae	2	4	19	24	11.9	8.7	
% Ephemeroptera	66	36	41	57	60.0	14.5	
% Ephemeroptera that are Baetidae	56	**16**	49	94	69.7	25.5	
EPT taxa (number)	13	14	14	14	10.6	3.7	
Simpson's Evenness	0.24	**0.38**	**0.37**	**0.14**	0.24	0.04	
Total Abundance	3556	2392	3360	4940	3795.7	2058.5	
Total Number. of Taxa	22	25	23	20	16.3	5.3	
F-3 (Group 4)							
Ordination		MD	MD	R			At confluence with the Murray River. Furthest downstream site and represents the effects of cumulative stressors. Site is generally in good condition, with mildly divergent benthic community in 2015, 2017, and similar to reference in 2019. Evenness values > reference group.
Bray Curtis		0.76	0.66	0.25			
RIVPACS O:E (p>0.7)		1.10	0.96	1.10			
% Chironomidae		1	26	22	11.9	8.7	
% Ephemeroptera		38	**21**	55	60.0	14.5	
% Ephemeroptera that are Baetidae		**13**	31	90	69.7	25.5	
EPT taxa (number)		17	15	12	10.6	3.7	
Simpson's Evenness		**0.38**	**0.32**	0.21	0.24	0.04	
Total Abundance		3173	3880	2523	3795.7	2058.5	
Total Number. of Taxa		28	22	15	16.3	5.3	

	2012	2014	2015	Mean	Std Dev	Notes
M19-02 (Group 4)						
Ordination	MD	D	-			Upstream M19A-02. Only older data available (2012, 2014) that indicate declining condition. Differences may be related to higher proportion of Chironomidae and lower proportion of Ephemeroptera relative to reference group. Relatively small tributary; atypical habitat or poor site conditions?
Bray Curtis	0.55	0.74	-			
RIVPACS O:E (p>0.7)	0.96	0.96	-			
% Chironomidae	**40**	**51**	-	11.9	8.7	
% Ephemeroptera	**24**	**14**	-	60.0	14.5	
% Ephemeroptera that are Baetidae	29	20	-	69.7	25.5	
EPT taxa (number)	13	12	-	10.6	3.7	
Simpson's Evenness	0.22	**0.15**	-	0.24	0.04	
Total Abundance	2000	633	-	3795.7	2058.45	
Total Number. of Taxa	22	24	-	16.3	5.3	
M19A-02 (Group 4)						
Ordination	-	D	D	-	-	M19A Creek upstream of confluence with M19. Only older data available (2014/15). Divergence may be related to significantly lower proportion of Ephemeroptera and higher abundance (2015 only) relative to reference group. Relatively small tributary; atypical habitat or poor site conditions?
Bray Curtis	-	0.88	0.93	-	-	
RIVPACS O:E (p>0.7)	-	0.55	0.69	-	-	
% Chironomidae	-	9	**49**	11.9	8.7	
% Ephemeroptera	-	**4**	**3**	60.0	14.5	
% Ephemeroptera that are Baetidae	-	**0**	**0**	69.7	25.5	
EPT taxa (number)	-	10	9	10.6	3.7	
Simpson's Evenness	-	0.22	0.18	0.24	0.04	
Total Abundance	-	1258	**31300**	3795.7	2058.5	
Total Number. of Taxa	-	19	20	16.3	5.3	

	2011	2012	2014	2019	Mean	Std Dev	Notes
M20-HW (Group 2)							
Ordination	-	-	-	R	-	-	Upstream background site in M20 Creek - reference condition with significantly higher proportion of Ephemeroptera than reference group.
Bray Curtis	-	-	-	0.53	-	-	
RIVPACS O:E (p>0.7)	-	-	-	0.97	-	-	
% Chironomidae	-	-	-	1	10.4	9.6	
% Ephemeroptera	-	-	-	**86**	46.7	16.6	
% Ephemeroptera that are Baetidae	-	-	-	**66**	21.4	12.7	
EPT taxa (number)	-	-	-	12	12.6	1.9	
Simpson's Evenness	-	-	-	0.17	0.32	0.11	
Total Abundance	-	-	-	3360	3078.9	2738.9	
Total Number. of Taxa	-	-	-	15	18.2	3.0	
NC-01 (Group 2)							
Ordination	-	-	-	MD	-	-	Upstream background site in Nabors Creek; Mildly Divergent possibly related to proportion of Epheroptera, which is slighly lower than reference group.
Bray Curtis	-	-	-	0.55	-	-	
RIVPACS O:E (p>0.7)	-	-	-	0.97	-	-	
% Chironomidae	-	-	-	11	10.4	9.6	
% Ephemeroptera	-	-	-	**13**	46.7	16.6	
% Ephemeroptera that are Baetidae	-	-	-	7	21.4	12.7	
EPT taxa (number)	-	-	-	13	12.6	1.9	
Simpson's Evenness	-	-	-	0.26	0.32	0.11	
Total Abundance	-	-	-	2354	3078.9	2738.9	
Total Number. of Taxa	-	-	-	20	18.2	3.0	

	2011	2012	2014	2019	Mean	Std Dev	Notes
M20-03 (Group 2)							
Ordination	-	-	-	R	-	-	Downstream of Nabors Creek. Higher proportion of Ephemeroptera than reference group.
Bray Curtis	-	-	-	0.59	-	-	
RIVPACS O:E (p>0.7)	-	-	-	1.04	-	-	
% Chironomidae	-	-	-	3	10.4	9.6	
% Ephemeroptera	-	-	-	**81**	46.7	16.6	
% Ephemeroptera that are Baetidae	-	-	-	44	21.4	12.7	
EPT taxa (number)	-	-	-	10	12.6	1.9	
Simpson's Evenness	-	-	-	0.30	0.32	0.11	
Total Abundance	-	-	-	5217	3078.9	2738.9	
Total Number. of Taxa	-	-	-	14	18.2	3.0	
M20-04 (Group 2)							
Ordination	MD	R	R	R	-	-	At confluence with Murray River. Site appears to be improving over time based on Bray Curtis.
Bray Curtis	0.61	0.60	0.37	0.32	-	-	
RIVPACS O:E (p>0.7)	1.14	1.14	1.14	1.14	-	-	
% Chironomidae	19	13	13	11	10.4	9.6	
% Ephemeroptera	18	26	33	34	46.7	16.6	
% Ephemeroptera that are Baetidae	25	22	42	22	21.4	12.7	
EPT taxa (number)	12	12	15	12	12.6	1.9	
Simpson's Evenness	0.20	0.27	0.36	0.43	0.32	0.11	
Total Abundance	469	5916	2438	1465	3078.9	2738.9	
Total Number. of Taxa	19	19	26	17	18.2	3.0	

	2012	2014	2017	2018	2019	Mean	Std Dev	Notes
Perry Creek PC-2 (Group 2)								
Ordination	-	MD	-	-	MD	-	-	Forestry and oil and gas activities upstream. Mildly Divergent, possibly related to higher number Baetid mayflies.
Bray Curtis	-	0.60	-	-	0.46	-	-	
RIVPACS O:E (p>0.7)	-	1.04	-	-	0.96	-	-	
% Chironomidae	-	19	-	-	22	10.4	9.6	
% Ephemeroptera	-	49	-	-	70	46.7	16.6	
% Ephemeroptera that are Baetidae	-	29	-	-	**63**	21.4	12.7	
EPT taxa (number)	-	15	-	-	11	12.6	1.9	
Simpson's Evenness	-	0.37	-	-	0.22	0.32	0.11	
Total Abundance	-	3430	-	-	2746	3078.9	2738.9	
Total Number. of Taxa	-	20	-	-	16	18.2	3.0	
Perry Creek PC-3 (Group 2)								
Ordination	MD	MD	-	-	D	-	-	At confluence with Wolverine River, adjacent to mine site. Shift to Divergent in most recent monitoring, possibly related to Baetidae mayflies. Note # of taxa and RIVPACS score decreased over time, suggest declining condition.
Bray Curtis	0.82	0.76	-	-	0.75	-	-	
RIVPACS O:E (p>0.7)	1.13	0.81	-	-	0.64	-	-	
% Chironomidae	10	6	-	-	3	10.4	9.6	
% Ephemeroptera	43	35	-	-	80	46.7	16.6	
% Ephemeroptera that are Baetidae	**85**	**62**	-	-	**91**	21.4	12.7	
EPT taxa (number)	**18**	10	-	-	10	12.6	1.9	
Simpson's Evenness	0.19	0.49	-	-	0.14	0.32	0.11	
Total Abundance	**15168**	6780	-	-	5243	3078.9	2738.9	
Total Number. of Taxa	**28**	18	-	-	13	18.2	3.0	

	2012	2014	2017	2018	2019	Mean	Std Dev	Notes
Bullmoose Creek SBC-u/s-mine (Group2)								
Ordination	-	-	R	-	-			South Bullmoose Creek upstream of mine. Significantly higher proportion of Baetidae mayflies than reference group.
Bray Curtis	-	-	0.45	-	-			
RIVPACS O:E (p>0.7)	-	-	1.04	-	-			
% Chironomidae	-	-	4	-	-	10.4	9.6	
% Ephemeroptera	-	-	47	-	-	46.7	16.6	
% Ephemeroptera that are Baetidae	-	-	**59**	-	-	21.4	12.7	
EPT taxa (number)	-	-	13	-	-	12.6	1.9	
Simpson's Evenness	-	-	0.32	-	-	0.32	0.11	
Total Abundance	-	-	2945	-	-	3078.9	2738.9	
Total Number. of Taxa	-	-	20	-	-	18.2	3.0	
Bullmoose Creek BC-1.2 km-d/s-WBC (Group2)								
Ordination	-	-	MD	MD	-	-	-	Downstream South and West Bullmoose Creek. Mildly Divergent possibly related to significantly higher abundance (nutrients?), not observed at upstream SBC site. Improving condition based on the Bray Curtis score, although RIVPACS score declined slightly.
Bray Curtis	-	-	0.79	0.52	-	-	-	
RIVPACS O:E (p>0.7)	-	-	0.96	0.88	-	-	-	
% Chironomidae	-	-	24	12	-	10.4	9.6	
% Ephemeroptera	-	-	34	64	-	46.7	16.6	
% Ephemeroptera that are Baetidae	-	-	24	**81**	-	21.4	12.7	
% EPT Individuals	-	-	71	82	-	84.0	11.1	
EPT taxa (number)	-	-	14	11	-	12.6	1.9	
Simpson's Evenness	-	-	0.27	0.20	-	0.32	0.11	
Total Abundance	-	-	**12280**	3345	-	3078.9	2738.9	
Total Number. of Taxa	-	-	21	17	-	18.2	3.0	

	2012	2014	2017	2018	2019	Mean	Std Dev	Notes
Bullmoose Creek BC-u/s-airstrip (Group2)								
Ordination	-	-	R	MD	-	-	-	Lower Bullmoose Creek generally in good condition. RIVPACS suggests some expected taxa are missing, but no significant difference in selected metrics.
Bray Curtis	-	-	0.52	0.46	-	-	-	
RIVPACS O:E (p>0.7)	-	-	0.80	0.80	-	-	-	
% Chironomidae	-	-	4	11	-	10.4	9.6	
% Ephemeroptera	-	-	72	67	-	46.7	16.6	
% Ephemeroptera that are Baetidae	-	-	23	37	-	21.4	12.7	
% EPT Individuals	-	-	91	81	-	84.0	11.1	
EPT taxa (number)	-	-	11	12	-	12.6	1.9	
Simpson's Evenness	-	-	0.28	0.25	-	0.32	0.11	
Total Abundance	-	-	4122	2000	-	3078.9	2738.9	
Total Number. of Taxa	-	-	18	22	-	18.2	3.0	

	2009	Mean	Std Dev	Notes
MAST001 (Group 3)				
Ordination	R			Older data, may not represent current conditions.
Bray Curtis	0.59			
RIVPACS O:E (p>0.7)	0.95			
% Chironomidae	27	27.9	19.6	
% Ephemeroptera	19	16.8	12.8	
% Ephemeroptera that are Baetidae	46	49.1	33.6	
% EPT Individuals	62	53.9	20.3	
EPT taxa (number)	9	9.8	3.5	
Simpson's Evenness	0.36	0.27	0.09	
Total Abundance	2546	1565.1	946.6	
Total Number. of Taxa	17	17.3	5.3	
MESA001 (Group 1)				
Ordination	MD			Site may be d/s of tailings pond, likely highly influenced by mining. Mildly Divergent with NO Ephemeroptera taxa here.
Bray Curtis	0.59			
RIVPACS O:E (p>0.7)	0.56			
% Chironomidae	69	30.3	21.4	
% Ephemeroptera	0	30.4	17.0	
% Ephemeroptera that are Baetidae	0	35.5	29.7	
% EPT Individuals	29	59.9	22.1	
EPT taxa (number)	**7**	12.0	2.1	
Simpson's Evenness	0.15	0.22	0.09	
Total Abundance	**4100**	12741.7	3901.2	
Total Number. of Taxa	13	19.1	3.3	

	2009	Mean	Std Dev	Notes
MESA002 (Group 2)				
Ordination	MD			Site may be d/s of tailings pond, although coordiantes seem off. Only Mildly Divergent, despite significantly lower proportion of Ephereroptera, EPT individuals, EPT taxa, total taxa and higher proportion of Chironomidae.
Bray Curtis	0.76			
RIVPACS O:E (p>0.7)	0.65			
% Chironomidae	**75**	10.4	9.6	
% Ephemeroptera	**2**	46.7	16.6	
% Ephemeroptera that are Baetidae	25	21.4	12.7	
% EPT Individuals	**7**	84.0	11.1	
EPT taxa (number)	**6**	12.6	1.9	
Simpson's Evenness	0.14	0.32	0.11	
Total Abundance	687	3078.9	2738.9	
Total Number. of Taxa	**12**	18.2	3.0	

	2009	2012	2014	2019	Mean	Std Dev	Notes
WR-1A (Group 2)							
Ordination	-	-	-	MD	-	-	Upper Wolverine watershed. Site is Mildly Divergent, likely related to significantly increased number of taxa and total abundance, relative to reference group; suggests enrichment.
Bray Curtis	-	-	-	0.86	-	-	
RIVPACS O:E (p>0.7)	-	-	-	1.05			
% Chironomidae	-	-	-	17	10.4	9.6	
% Ephemeroptera	-	-	-	29	46.7	16.6	
% Ephemeroptera that are Baetidae	-	-	-	22	21.4	12.7	
EPT taxa (number)	-	-	-	15	12.6	1.9	
Simpson's Evenness	-	-	-	0.25	0.32	0.11	
Total Abundance	-	-	-	**20060**	3079	2739	
Total Number. of Taxa	-	-	-	**25**	18.2	3.0	
WR-4 (Group 2)							
Ordination	-	MD	MD	D	-	-	Site adjacent to Wolverine mine and upstream of Perry Creek. Appears to be in declining condition based on site status and.Bray Curtis; % Ephemeroptera decreasing and taxonomic richness increasing?
Bray Curtis	-	0.50	0.55	0.63	-	-	
RIVPACS O:E (p>0.7)	-	0.89	0.81	0.97	-	-	
% Chironomidae	-	1	10	9	10.4	9.6	
% Ephemeroptera	-	62	40	37	46.7	16.6	
% Ephemeroptera that are Baetidae	-	7	19	12	21.4	12.7	
EPT taxa (number)	-	11	13	12	12.6	1.9	
Simpson's Evenness	-	0.28	0.45	0.31	0.32	0.11	
Total Abundance	-	2238	1053	1928	3078.9	2738.9	
Total Number. of Taxa	-	17	21	23	18.2	3.0	

	2009	2012	2014	2019	Mean	Std Dev	Notes
WR-3 (Group 2)							
Ordination	-	MD	MD	D	-	-	Site downstream of Perry Creek. Similar status to WR-4. Declining in 2019 may be related to significantly higher proportion of Chironomids relative to reference group.
Bray Curtis	-	0.63	0.55	0.70	-	-	
RIVPACS O:E (p>0.7)	-	1.14	1.06	0.97	-	-	
% Chironomidae	-	15	5	**54**	10.4	9.6	
% Ephemeroptera	-	39	34	23	46.7	16.6	
% Ephemeroptera that are Baetidae	-	30	7	37	21.4	12.7	
EPT taxa (number)	-	15	14	12	12.6	1.9	
Simpson's Evenness	-	0.38	0.47	0.15	0.32	0.11	
Total Abundance	-	5840	2947	4571	3078.9	2738.9	
Total Number. of Taxa	-	**25**	22	21	18.2	3.0	
WOLV004 (Group 2)							
Ordination	MD	-	-	-	-	-	Furthest d/s site in Wolverine; d/s of Mast Creek. Older data, but shows the site is Mildly Divergent. Also indicates there is a high proportion of chironomids here relative to the reference group, similar to that observed at WR-3 in 2019 (natural variability?).
Bray Curtis	0.48	-	-	-	-	-	
RIVPACS O:E (p>0.7)	0.98	-	-	-	-	-	
% Chironomidae	**40**	-	-	-	10.4	9.6	
% Ephemeroptera	27	-	-	-	46.7	16.6	
% Ephemeroptera that are Baetidae	30	-	-	-	21.4	12.7	
EPT taxa (number)	11	-	-	-	12.6	1.9	
Simpson's Evenness	0.29	-	-	-	0.32	0.11	
Total Abundance	3060	-	-	-	3078.9	2738.9	
Total Number. of Taxa	17	-	-	-	18.2	3.0	

	2018	Mean	Std Dev	Notes
MURR26				
Ordination	MD			Mildy Divergent possibly related to higher proportion of Ephemeroptera relative to reference group.
Bray Curtis	0.56			
RIVPACS O:E (p>0.7)	1.16			
% Chironomidae	17	27.9	19.6	
% Ephemeroptera	**43**	16.8	12.8	
% Ephemeroptera that are Baetidae	39	49.1	33.6	
% EPT Individuals	73	53.9	20.3	
Ephemeroptera taxa	4	3.3	1.4	
EPT taxa (number)	13	9.8	3.5	
Simpson's Evenness	0.33	0.27	0.09	
Total Abundance	480	1565.1	946.6	
Total Number. of Taxa	21	17.3	5.3	
MURR27				
Ordination	MD			Mildy Divergent possibly related to higher proportion of Ephemeroptera relative to reference group.
Bray Curtis	0.56			
RIVPACS O:E (p>0.7)	1.16			
% Chironomidae	17	27.9	19.6	
% Ephemeroptera	**43**	16.8	12.8	
% Ephemeroptera that are Baetidae	39	49.1	33.6	
% EPT Individuals	73	53.9	20.3	
Ephemeroptera taxa	**4**	3.3	1.4	
EPT taxa (number)	13	9.8	3.5	
Simpson's Evenness	0.33	0.27	0.09	
Total Abundance	480	1565.1	946.6	
Total Number. of Taxa	21	17.3	5.3	

	2018	Mean	Std Dev	Notes
MURR28				
Ordination	R			
Bray Curtis	0.39			
RIVPACS O:E (p>0.7)	0.96			
% Chironomidae	38	10.4	9.6	
% Ephemeroptera	33	46.7	16.6	
% Ephemeroptera that are Baetidae	53	21.4	12.7	
% EPT Individuals	52	84.0	11.1	
Ephemeroptera taxa	**4**			
EPT taxa (number)	11	12.6	1.9	
Simpson's Evenness	0.28	0.32	0.11	
Total Abundance	1207	3078.9	2738.9	
Total Number. of Taxa	18	18.2	3.0	
MURR29				
Ordination	R			
Bray Curtis	0.54			
RIVPACS O:E (p>0.7)	1.05			
% Chironomidae	4	10.4	9.6	
% Ephemeroptera	**47**	46.7	16.6	
% Ephemeroptera that are Baetidae	49	21.4	12.7	
% EPT Individuals	92	84.0	11.1	
Ephemeroptera taxa	5			
EPT taxa (number)	11	12.6	1.9	
Simpson's Evenness	0.34	0.32	0.11	
Total Abundance	855	3078.9	2738.9	
Total Number. of Taxa	15	18.2	3.0	

	2011	2012	2014	2015	2017	2018	2019	Mean	Std. Dev.	Notes
MR-US1										
Ordination	-	-	-	-	-	-	R	-	-	
Bray Curtis	-	-	-	-	-	-	0.33	-	-	
RIVPACS O:E (p>0.7)	-	-	-	-	-	-	0.81	-	-	
% Chironomidae	-	-	-	-	-	-	4	10.4	9.6	
% Ephemeroptera	-	-	-	-	-	-	72	46.7	16.6	
% Ephemeroptera that are Baetidae	-	-	-	-	-	-	10	21.4	12.7	
EPT taxa (number)	-	-	-	-	-	-	13	12.6	1.9	
Simpson's Evenness	-	-	-	-	-	-	0.18	0.32	0.11	
Total Abundance	-	-	-	-	-	-	1097	3079	2739	
Total Number. of Taxa	-	-	-	-	-	-	22	18.2	3.0	
MR-3/MR-US2										
Ordination	-	-	R	-	-	-	R	-	-	
Bray Curtis	-	-	041	-	-	-	0.33	-	-	
RIVPACS O:E (p>0.7)	-	-	0.81	-	-	-	0.98	-	-	
% Chironomidae	-	-	15	-	-	-	7	10.4	9.6	
% Ephemeroptera	-	-	50	-	-	-	73	46.7	16.6	
% Ephemeroptera that are Baetidae	-	-	22	-	-	-	20	21.4	12.7	
EPT taxa (number)	-	-	12	-	-	-	13	12.6	1.9	
Simpson's Evenness	-	-	0.31	-	-	-	0.318	0.32	0.11	
Total Abundance	-	-	2431	-	-	-	843	3079	2739	
Total Number. of Taxa	-	-	21	-	-	-	20	18.2	3.0	

	2011	2012	2014	2015	2017	2018	2019	Mean	Std. Dev.	Notes
MR-4/MR-DS1										
Ordination	D	MD	D	-	-	-	MD	-	-	Downstream of M20 Creek; Variable status, but appears to be improving based on Bray Curtis score from 2019.
Bray Curtis	0.80	0.74	0.85	-	-	-	0.49	-	-	
RIVPACS O:E (p>0.7)	0.90	0.98	0.98	-	-	-	0.90	-	-	
% Chironomidae	5	24	11	-	-	-	3	10.4	9.6	
% Ephemeroptera	61	24	30	-	-	-	67	46.7	16.6	
% Ephemeroptera that are Baetidae	**67**	7	14	-	-	-	12	21.4	12.7	
EPT taxa (number)	12	12	14	-	-	-	12	12.6	1.9	
Simpson's Evenness	0.29	0.33	0.40	-	-	-	0.21	0.32	0.11	
Total Abundance	211	356	257	-	-	-	680	3079	2739	
Total Number. of Taxa	16	23	24	-	-	-	20	18.2	3.0	
MR-DS2										
Ordination	-	-	-	-	-	-	R	-	-	
Bray Curtis	-	-	-	-	-	-	0.70	-	-	
RIVPACS O:E (p>0.7)	-	-	-	-	-	-	0.82	-	-	
% Chironomidae	-	-	-	-	-	-	22	10.4	9.6	
% Ephemeroptera	-	-	-	-	-	-	34	46.7	16.6	
% Ephemeroptera that are Baetidae	-	-	-	-	-	-	29	21.4	12.7	
EPT taxa (number)	-	-	-	-	-	-	10	12.6	1.9	
Simpson's Evenness	-	-	-	-	-	-	0.46	0.32	0.11	
Total Abundance	-	-	-	-	-	-	6100	3079	2739	
Total Number. of Taxa	-	-	-	-	-	-	15	18.2	3.0	

	2011	2012	2014	2015	2017	2018	2019	Mean	Std. Dev.	Notes
MR-1										
Ordination	-	-	-	-	D	-	D	-	-	Upstream of Flatbed River; divergence likely related to higher proportion of Chironomidae, number of taxa, and total abundance relative to reference group.
Bray Curtis	-	-	-	-	0.61	-	0.82	-	-	
RIVPACS O:E (p>0.7)	-	-	-	-	0.98	-	0.74	-	-	
% Chironomidae	-	-	-	-	**31**	-	**51**	10.4	9.6	
% Ephemeroptera	-	-	-	-	35	-	14	46.7	16.6	
% Ephemeroptera that are Baetidae	-	-	-	-	8	-	14	21.4	12.7	
EPT taxa (number)	-	-	-	-	14	-	10	12.6	1.9	
Simpson's Evenness	-	-	-	-	0.21	-	0.16	0.32	0.11	
Total Abundance	-	-	-	-	1595	-	**11320**	3079	2739	
Total Number. of Taxa	-	-	-	-	**28**	-	21	18.2	3.0	
MR-2										
Ordination	-	-	-	MD	R	-	MD	-	-	Improved condition relative to MR-1, suggesting Divergent conditions upstream might be localized. Higher proportion of Chironomidae relative to reference group in 2019.
Bray Curtis	-	-	-	0.68	0.43	-	0.67	-	-	
RIVPACS O:E (p>0.7)	-	-	-	0.94	1.04	-	1.04	-	-	
% Chironomidae	-	-	-	7	7	-	**31**	10.4	9.6	
% Ephemeroptera	-	-	-	54	74	-	40	46.7	16.6	
% Ephemeroptera that are Baetidae	-	-	-	5	10	-	23	21.4	12.7	
EPT taxa (number)	-	-	-	13	15	-	14	12.6	1.9	
Simpson's Evenness	-	-	-	0.28	0.17	-	0.29	0.32	0.11	
Total Abundance	-	-	-	6300	2758	-	6340	3079	2739	
Total Number. of Taxa	-	-	-	23	24	-	21	18.2	3.0	

	2011	2012	2014	2015	2017	2018	2019	Mean	Std. Dev.	Notes
MURR18										
Ordination	-	-	-	-	-	R	-	-	-	
Bray Curtis	-	-	-	-	-	0.52	-	-	-	
RIVPACS O:E (p>0.7)	-	-	-	-	-	0.99	-	-	-	
% Chironomidae	-	-	-	-	-	12	-	10.4	9.6	
% Ephemeroptera	-	-	-	-	-	57	-	46.7	16.6	
% Ephemeroptera that are Baetidae	-	-	-	-	-	54	-	21.4	12.7	
EPT taxa (number)	-	-	-	-	-	11	-	12.6	1.9	
Simpson's Evenness	-	-	-	-	-	0.30	-	0.32	0.11	
Total Abundance	-	-	-	-	-	630	-	3079	2739	
Total Number. of Taxa	-	-	-	-	-	18	-	18.2	3.0	
Mu/sP										
Ordination	-	-	-	-	-	-	D	-	-	Near confluence with Pine River, represents cumulative effects in Murray River watershed. Divergent status, not clear based on selected metrics.
Bray Curtis	-	-	-	-	-	-	0.79	-	-	
RIVPACS O:E (p>0.7)	-	-	-	-	-	-	0.99	-	-	
% Chironomidae	-	-	-	-	-	-	27	10.4	9.6	
% Ephemeroptera	-	-	-	-	-	-	29	46.7	16.6	
% Ephemeroptera that are Baetidae	-	-	-	-	-	-	7	21.4	12.7	
EPT taxa (number)	-	-	-	-	-	-	15	12.6	1.9	
Simpson's Evenness	-	-	-	-	-	-	0.21	0.32	0.11	
Total Abundance	-	-	-	-	-	-	327	3079	2739	
Total Number. of Taxa	-	-	-	-	-	-	24	18.2	3.0	