Environment | Water Resources Branch

South McQuesten River Cumulative Impacts Study

Water Resources Branch

January 2023

The Water Resources Branch (WRB) strives for water stewardship in the Yukon and is committed to responsible and collaborative monitoring, management, protection and conservation of the territory's valuable water resources. One of WRB's responsibilities is to conduct assessments of water bodies or watersheds that may be impacted by various activities. Watershed assessments are conducted to improve knowledge of water in and around specific development projects. The intention is to identify emerging issues and share understanding of existing water conditions to support input into assessment, licensing and post-licensing processes.

The opinions and recommendations expressed in this report are based on field observations and relevant scientific data, reports, interpretations and analyses that are available to WRB. However, we strive to recognize diverse ways of knowing and being and to create space to learn from both Indigenous and scientific perspectives, side-by-side.

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List of Acronyms:

CMME: Canadian Council of Ministers of the Environment

CABIN: Canadian Aquatic Biominitoring Network

CMI: Compliance and Monitoring Branch (Yukon Government)

COPC: Contaminant of Potential Concern

ECCC: Environment and Climate Change Canada

EPT: Ephemeroptera Plecoptera Tricoptera

EQS: Effluent Quality Standard

FNNND: First Nation of Na-Cho Nyäk Dun

TSS: Total Suspended Solids

WQI : Water Quality Index

WQO: Water Quality Objectives

WRB: Water Resources Branch

1 Executive Summary

Water Resources Branch (WRB) conducted an information review on the South McQuesten River (Et'o Nyäk Tagé) watershed, located north of Mayo, Yukon in the Traditional Territory of the Na-Cho Nyäk Dun people. The purpose of this review was to:

- examine the potential cumulative impacts on water quality;
- assess monitoring data by looking at water quality evolution along the river and trends over the last 10 years; and
- develop water quality objectives for this river and initiate monitoring of a tributary, Cache Creek.

The South McQuesten River (the "River") watershed is used extensively for a variety of activities, including hunting, trapping, fishing, recreation, quartz mining and placer mining. As a result, there is a lot of information that has been produced over the years, especially on water quality. There are 122 known active water monitoring stations (and 84 currently inactive) in the watershed, including eight in the main stem of the River. The South McQuesten River (main stem downstream of McQuesten Lake) is classified as an Area of Special Consideration under the *Fish Habitat Management System* (FMHS) *for Yukon Placer Mining*, a regulatory regime established in 2008 under the federal *Fisheries Act* (Fisheries and Ocean Canada, 2010). Under this classification, a Water Quality Objective of 25 mg/L of total suspended solids (TSS) was established for both, the South McQuesten River and the McQuesten River, for operations on the main stem of the River.

Besides mining, roads and wildfire also have the potential to impact surface water. Many roads have been established and cross the South McQuesten River and its tributaries. Roads can contribute hydrocarbons and TSS to surface water. Multiple wildfires were reported in the watershed between 1940 and 2020, which may have contributed nitrogen, organic carbon and TSS to surface water as well.

There are three quartz mining operations (Alexco Resources Corporation, Elsa Reclamation and Development Company and Victoria Gold Corp), 12 permitted quartz mining exploration projects, 15 placer mining operations and two miscellaneous licences authorizing use and discharge of water in the South McQuesten River watershed. Nine of the licenced placer mines are located along Haggart Creek. In addition, there are 953 placer mining claims (eight Class 1 permitted placer exploration projects and 945 placer claims) in the South McQuesten River watershed.

The Water Quality Index (WQI) is classified as marginal for the South McQuesten River, potentially due to high mineralisation in the area but also because parameters affecting the WQI include copper and turbidity. Copper and turbidity are high, potentially due to increased development and wildfires in the watershed.

Trend tests were conducted to detect changes over time at the long-term monitoring station in the South McQuesten River. Turbidity and copper, along with other parameters are showing a significant increase over the last ten years. On the other hand, a significant decreasing trend is observed for arsenic and pH at the long-term monitoring station, which is located upstream of the Haggart Creek tributary.

Haggart Creek is generally displaying a very different chemistry from the South McQuesten River. Cache Creek is the most upstream tributary to the South McQuesten River and had very high aluminum and copper. Cache Creek also contributes significant concentrations of zinc into the South McQuesten River.

Generally, cadmium and copper concentrations are decreasing along the main stem of the river, due to dilution. Arsenic, on the other hand, behaves differently and increases as the water progresses downstream because of arsenic contributions from various creeks, including Haggart Creek.

Lead concentration was the highest downstream of Christal Creek and Flat Creek. Lead concentrations then decrease as the River continues downstream.

The biotic indices and community composition of the benthic invertebrates within the South McQuesten River indicate that the water quality can be considered good. There is representation from a variety of species that are sensitive to extended periods of exposure to poor water quality conditions. Also, the benthic community structure is not dominated by taxa with high tolerance to poor water quality conditions.

Water Quality Objectives (WQO) were developed, based on the methodology presented in the Yukon *Guide for Developing Water Quality Objectives and Effluent Quality Standards for Quartz Mining Projects* (Yukon Government 2021, the "Guide"). This Guide is intended for quartz mining projects, but in this project, we use the Guide in a different context and apply it to a river, not to a specific mining project. However, a number of methodologies described in the Guide apply well to a watershed. As outlined in the Guide, we held a multi-stakeholder meeting to discuss the values and interests of groups in the area. Based on this engagement, the non-degradation approach was selected for the South McQuesten River. This approach aims to maintain the baseline water quality. The rationale for this selection and in-depth description of the Water

Quality Objectives can found in Appendix A: Water Quality Objective Derivation for the South McQuesten River, Yukon.

During the process of developing WQO, fourteen parameters were selected as contaminants of potential concern at the long-term monitoring station, including total aluminum, arsenic, cadmium, cobalt, copper, iron, lead, silver, tin, thallium, vanadium, zinc and fluoride. Preliminary Average and Maximum WQO were identified for the South McQuesten River at the long-term monitoring station; however, they apply only to clear flow conditions when turbidity is lower than 4 Nephelometric Turbidity Units [NTU]. A process to validate the WQO is proposed, along with recommended approaches to monitor for attainment of the WQO. The evaluation of attainment is complex; therefore, four statistical triggers are proposed to compare the observed water quality with the WQOs.

To support adequate and sustainable management of the South McQuesten River, WRB has 14 recommendations. WRB also recognises that sustainable management, including upholding the vision and values underlying legislation such as the *Waters Act* and the Umbrella Final Agreement, cannot be done in isolation and requires meaningful collaboration amongst governments and strong ongoing engagement with stakeholders.

The recommendations are:

1. Study the potential impact of placer mining in the watershed on the main stem of the McQuesten River;
2. Monitor turbidity, TSS and Settleable Solids on a monthly basis in the South McQuesten River downstream of all placer mining activities;
3. Limit the release of nitrogen in the South McQuesten River by implementing relevant management actions;
4. Control the release of lead in Flat Creek and Christal Creek;
5. Monitor attainment of the WQOs at the long-term monitoring station in the South McQuesten River once established;
6. Monitor dissolved metals at the long-term monitoring station and align with monitoring recommendations listed in the *Yukon Guide for Developing Water Quality Objectives and Effluent Quality Standards for Quartz Mining Projects*;
7. Conduct physical evaluation of the watershed for potential permafrost degradation and slumping;
8. Monitor mercury in the South McQuesten River;

9. Assess trends in precipitation and consider monitoring flow at the long-term monitoring station;
10. Monitor water isotopes;
11. Monitor water quality in Cache Creek on a monthly basis all year round;
12. Conduct trends analysis for arsenic in Haggart Creek;
13. Conduct trends analysis for cerium across the Yukon; and
14. Conduct a correlation analysis to determine the relationship between water quality and flow.

2 Acknowledgement

The Government of Yukon - Department of Environment wishes to acknowledge the contributions of our partners in the information presented in this study. First of all, the monitoring work which generated the data used in this study was undertaken by a number of organizations and individuals. We wish to recognize Bruce McGregor, who conducted the monthly monitoring at the long-term monitoring stations in the South McQuesten River and Haggart Creek for years. Bruce has now passed the monitoring over to the First Nation of Na-Cho Nyäk Dun (FNNND) in 2021 and we look forward to working with the FNNND government. Alexco Resources Corp., Elsa Reclamation and Development Company Ltd. and Victoria Gold Corp. have also generated an impressive amount of data through monitoring of their sites. This data is critical to help us understand how the watershed evolves.

We also wish to acknowledge our partner in the operation of the long-term water quality monitoring network, Environment and Climate Change Canada (ECCC), who has not only analyzed all the samples from the network, reviewed and reported the data year after year, but has also conducted the trends analysis presented in this report. Our understanding of this area of the Yukon would not be the same without the partnership with ECCC and the contributions of knowledgeable staff.

Finally, we wish to recognize the dedicated work from our consultants, Bill Slater and Amy Wiebe and her team at Minnow Environmental Inc. for the development of the Water Quality Objectives (WQO) presented in this report. After years of developing a methodology applicable to mine sites, these individuals have pushed the scientific thinking further to apply the methodologies to a watershed. This was no small feat and we are proud to present this work.

3 Methodology

3.1 Watershed Overview

3.1.1 Fisheries

Reports on the fisheries within the South McQuesten River were obtained online. In addition, Na-Cho Nyäk Dun staff shared oral information on fisheries with WRB during a meeting held on November 16, 2020.

3.1.2 Wildfires

GeoYukon.ca was used to identify historical wildfires in the watershed under the biophysical and fire history query. ArcGIS was used to produce a map figure of all documented fires.

3.1.3 Road Network

GeoYukon.ca was used to locate the road and trail network within the associated watershed. Transportation, roads and trails layers were activated to determine the type and location of stream crossing (e.g., bridges and culverts). This database is not exhaustive and only has culvert information for the Silver Trail highway and bridges identified for the smaller roads. The data available did not provide the total number of stream crossings within the watershed. Roads within the watershed were also cross-referenced with Yukon511 and Google Maps. A site visit in February 2021 by WRB staff provided the opportunity to visually confirm the presence of the bridges located on roads 311 and 325, as well as a double culvert at the Cache Creek crossing.

ArcGIS was used to produce a map of the road network and indicate where the bridge and culverts were located for the stream crossings.

3.1.4 Authorized Water Use

GeoYukon and ArcGIS were used to identify the active water licences within the South McQuesten watershed. The Environmental Monitoring – Water Licences map layer in GeoYukon was activated and used to identify the type of water licence, licence number and licence holder. The identified licences were cross-referenced and mapped with the corporate spatial warehouse layer in ArcGIS. Additional information for each licence, such as discharge locations and monitoring sites associated with the licence, was obtained using Waterline.

3.2 Water Quality

3.2.1 Water Quality Monitoring

Numerous environmental monitoring programs throughout the South McQuesten River watershed have contributed data including surface water quality, groundwater quality and level, snow and meteorological data. Water samples have been collected from multiple locations throughout the watershed under various licensees. Surface water samples were obtained at each location using grab sampling. Typically, water sampling in the Yukon follows Canadian Council of Ministers of the Environment (CCME) protocols (CCME, 2011) or British Columbia (BC) field sampling manual (Government of BC, 2013). There are two monitoring sites, YT09DD0008 and YT09DD0014, which are monitored through a Canada – Yukon agreement. Sample collection at these two sites follow the Canada – BC protocol (ECCC and BC MOE. 2019).

All water quality data associated with monitoring stations operated by Water Resources Branch (WRB) or its partners was obtained from the Government of Yukon's EQWin database. Analytical data from water quality stations monitored by Licensees was submitted by the Licensees to the Yukon Water Board and is available on Waterline under each licences. From there, the data is then transferred to EQWin for later retrieval. The location of the sample sites were identified using GeoYukon. Data correlated to monitoring sites operated within ECCC's Long-Term Monitoring Network was retrieved from the ECCC Freshwater Quality Monitoring and Surveillance – Online Data portal. All sample stations were mapped in ArcGIS.

3.2.2 Water Quality Index

The water quality data was used to calculate the Water Quality Index (WQI) to help interpret the health of the system. There are multiple ways to define an index of water quality and the index presented in this report is based on the methodology established by the Canadian Council of Minsters of the Environment (CCME 2017). As described by CCME, the WQI "*provides a convenient means of summarizing complex water quality data and facilitating its communication to a general audience. The Index incorporates three elements: scope - the number of parameters not meeting water quality guidelines; frequency - the number of times these guidelines are not met; and amplitude - the amount by which the guidelines are not met. The index produces a number between 0 (worst water quality) and 100 (best water quality).*" The WQI for the South McQuesten River was calculated by ECCC using data collected over three years at the long-term monitoring station YT09DD0008.

3.2.3 Aquatic Ecosystem Quality Using Aquatic Benthic Macro Invertebrates

Aquatic benthic macroinvertebrates were sampled late in the open water season at two stations on the South McQuesten. One of the sample stations (YPS-390) is located upstream of the confluence with the North McQuesten River. This site was sampled in July 2009 and 2017. The second sample location (SMQ01) is located at the long-term water quality station. This site was sampled in August 2009 and 2019.

The procedure used for the biological monitoring of the benthic invertebrates followed Canadian Aquatic Benthic Invertebrate Network (CABIN) sampling methods for sampling in streams and rivers (Environment Canada, 2012). The samples were shipped to a taxonomist and identified to the genus or species level where possible according to the CABIN protocols (Environment Canada, 2014a). Taxonomy data was validated by a second taxonomist using the CABIN validation protocols by auditing 10 per cent of all invertebrate samples for sorting efficiency and correct identification (Environment Canada, 2014b). A full CABIN assessment summary has not been completed for this watershed. However, biotic indices were calculated for each sample event based on the reported taxonomy on the CABIN website to provide a general observation of the biotic health of the stream (Table 1).

Table 1. Biotic indices calculated for the sample locations on the South McQuesten River.

Site ID	YPS-390		SMQ01	
Sample Date	July 2009	July 2017	August 2009	August 2019
Sampling Device	Kick Net (400 um mesh)			
Community Metric				
Abundance	X	X	X	X
Richness	X	X	X	X
Simpson's Diversity	X	X	X	X
Shannon-Wiener Diversity	X	X	X	X
Pielou Evenness	X	X	X	X
% EPT Individuals	X	X	X	X
% Ephemeroptera	X	X	X	X
% Plecoptera	X	X	X	X
% Tricoptera	X	X	X	X
% Chironomidae	X	X	X	X
% of top 5 dominant taxa	X	X	X	X

Note: E – Ephemeroptera (mayflies); P = Plecoptera (stoneflies); T = Tricoptera (caddisflies)

3.3 Trends Analysis

Water quality data from the long-term monitoring station, called YT09DD0008, was analyzed to observe any temporal trends by Environment and Climate Change Canada. Fifty-one water quality parameters were analyzed for this station. Table 2 presents the detection limit and the number of samples considered for the analysis along with the number of censored values (values below the detection limit). The complete trend report is available upon request from water.resources@yukon.ca.

Table 2. List of parameters monitored at the long-term monitoring station and used to calculate trends

Parameter	unit	MDL (max)	n[1]	Parameter	unit	MDL (max)	n[1]
General Chemistry							
Alkalinity (as CaCO3)	mg/L	0.5	105	Water Temperature	(°C)	-10	102
pH	pH units	0.01	105	Turbidity	NTU	0.05	105
Specific Conductance	µS/cm	2	104	-	-	-	-
Anions and Nutrients							
Calcium - Dissolved	mg/L	0.1	105	Nitrogen - Total Dissolved (as N)	mg/L	0.02	99
Carbon - Dissolved Inorganic	mg/L	0.5	103	Nitrogen - Total (as N)	mg/L	0.02	101

Parameter	unit	MDL (max)	n[1]	Parameter	unit	MDL (max)	n[1]
Carbon - Dissolved Organic	mg/L	0.5	103(2)	Phosphorus - Total (as P)	mg/L	0.0005	100
Chloride	mg/L	0.1	105(1)	Potassium - Dissolved	mg/L	0.1	105
Hardness (as CaCO3)	mg/L	0.661	105	Sodium - Dissolved	mg/L	0.1	105
Fluoride	mg/L	0.01	101	Sulphate	mg/L	5	103
Magnesium - Dissolved	mg/L	0.1	105	Silicon	mg/L	0.05	105
Nitrate (as N)	mg/L	0.005	101(9)	-	-	-	-
Metals – Total							
Antimony	µg/L	0.001	102	Manganese	µg/L	0.05	103
Arsenic	µg/L	0.01	103	Molybdenum	µg/L	0.005	103
Barium	µg/L	0.05	103	Nickel	µg/L	0.02	103
Beryllium	µg/L	0.001	102(1)	Niobium	µg/L	0.002	103(86)
Boron	µg/L	0.5	103(2)	Platinum	µg/L	0.001	103(98)
Cadmium	µg/L	0.001	103	Rubidium	µg/L	0.01	103
Cerium	µg/L	0.002	103	Selenium	µg/L	0.05	103
Cesium	µg/L	0.005	103(65)	Silver	µg/L	0.001	102
Chromium	µg/L	0.02	101(2)	Strontium	µg/L	0.05	103
Cobalt	µg/L	0.002	103	Thallium	µg/L	0.001	102(2)
Copper	µg/L	0.05	102	Tin	µg/L	0.005	102(86)
Gallium	µg/L	0.001	103	Tungsten	µg/L	0.001	99(31)
Iron	µg/L	0.5	103	Uranium	µg/L	0.0005	103
Lanthanum	µg/L	0.001	103	Vanadium	µg/L	0.01	102
Lead	µg/L	0.005	103	Yttrium	µg/L	0.001	103
Lithium	µg/L	0.2	103	Zinc	µg/L	0.2	103

Note: MDL (max) = maximum method detection limit; n = number of samples in the site-parameter dataset; 1 = bracketed numbers represent the number of values censored at maximum detection limit

The water quality data was downloaded from Environment and Climate Change Canada's ENVIRODAT database using ecwqEnvirodat R package (not publicly available). All statistical analyses were completed using R (version 4.0.3) statistical software (R Core Team 2018). Figures were produced using ggplot 2 and plotly (Wickham 2016 and Sievert 2018 respectively). Seasonal Kendall trend analysis used the rkt package (Marchetto 2017).

The trends analysis was conducted by Environment Canada for data in water samples collected over 10 years (2009-2018). The Seasonal Kendall test was used to assess direction and significance, while the seasonal Sen slope estimate was used to assess the magnitude of the trend (Hirsch et al. 1982, Sen 1968, Hirsch and Slack 1984). The

Seasonal Kendall analysis can be applied to non-parametric data sets when the method detection limit is the same over the observed period. For this analysis, the highest detection limit for each individual parameter was adjusted to equal half the highest detection limit value.

Robust regression on order statistics (ROS) using the NADA for R package was used to calculate summary statistics (Lee 2013). Each parameter was included in the trend analysis when the following criteria were satisfied:

1) Data available over the entire 10 year period (2009-2018).
2) Included seasonal coverage where the first and last two years of the observed period had data for at least eight of the 12 months and the six middle years had data for at least 44 of the 72 months.
3) Data below the analytical method detection limit can not exceed 80 per cent.

Trends in the data for each parameter were identified within the data based on statistical significance (two-sided p-value <0.1) and the direction of the trend. Significant trends in the data was determined using the corrected p-value to account for correlation between subsequent seasons. Three trend categories were used to classify each parameter:

1) Increasing trend: there is a positive increase in the parameter concentration or value that is significantly different from zero.
2) No evidence of trend: not sufficient evidence to conclude presence of an increasing or decreasing trend.
3) Decreasing trend: there is a decline in the concentration or value of the parameter that is significantly different from zero.

The direction of the trend was determined based on the sign of the sum of the individual Kendall Score.

Estimated annual percent trend was calculated as a percent of the median of the first two years of data where there was sufficient data to make an unbiased slow estimate. Parameters that had more than five percent of values below the laboratory detection limit were not calculated.

3.4 Water Quality Objectives

Government of Yukon collaborated with Slater Environmental Consulting and Minnow Environmental Inc. to develop Water Quality Objectives for the South McQuesten watershed using methods outlined in the draft *Yukon Guide for Developing Water*

Quality Objectives and Effluent Quality Standards for Quartz Mining Projects (Yukon government 2021). The WQO development process was split into two phases. Phase 1 consisted of initial data review, data analysis, identification of any contaminants of potential concern and conducting stakeholders and rightholders engagement activities. Phase 1 was completed for the South McQuesten River in January 2021. Phase 2 included the development of the numerical WQOs and recommendations to validate the WQOs and monitor attainment. Staff from Government of Yukon and the contractors met regularly to discuss decision points throughout the project. This work was completed in March 2022. The methodology used for this work is described in the report titled "Water Quality Objective Derivation for the South McQuesten River, Yukon" (March 2022) presented in Appendix A.

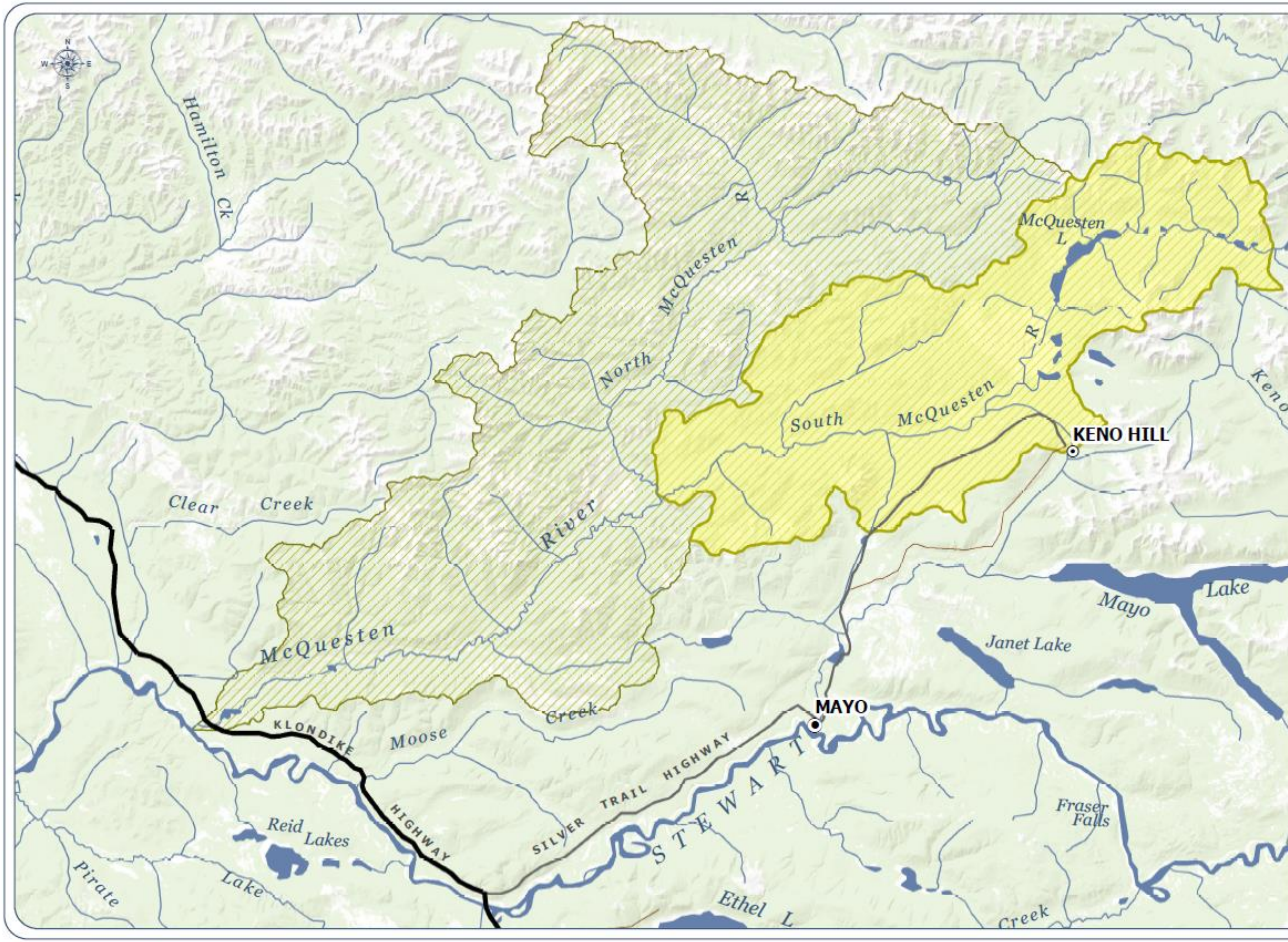
4 Watershed Overview

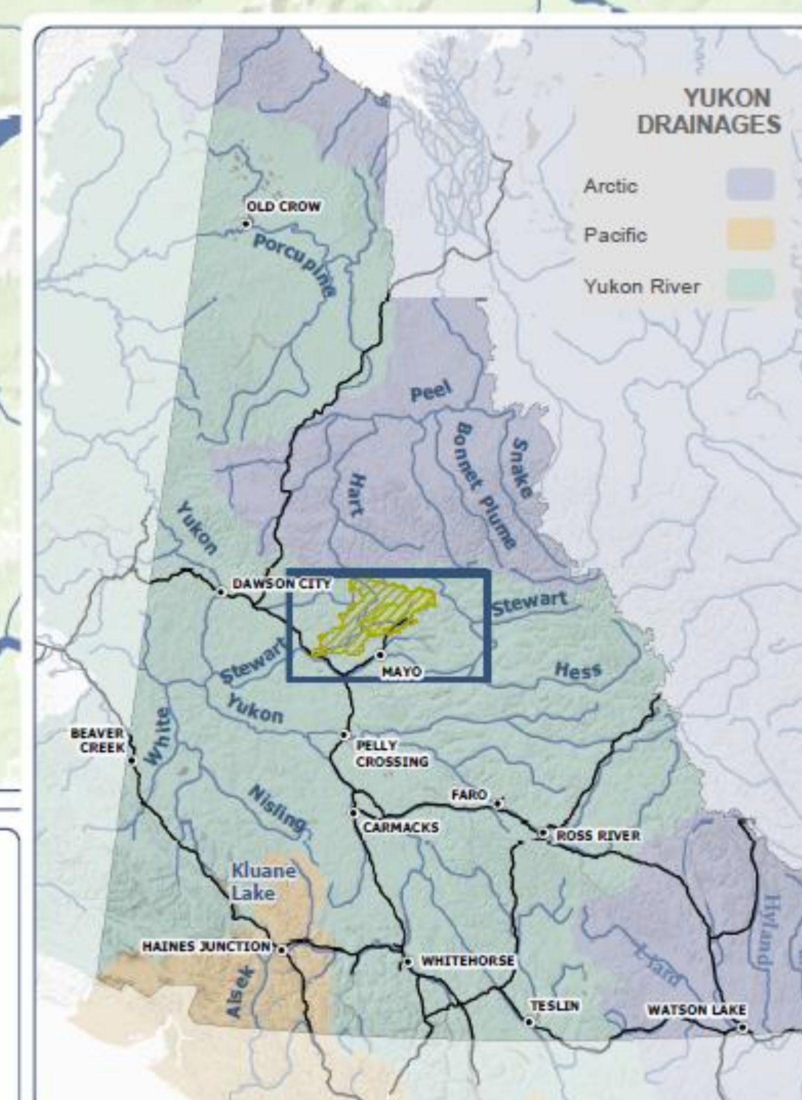
4.1 Watershed Description

One of the WRB staff was fortunate to paddle a section of the South McQuesten River and the McQuesten River and described it as a "peaceful and pleasant river, with abundant wildlife. This river deserves heightened attention from the paddler and can be playing pranks at times."

The McQuesten River, traditionally named Et'o Nyäk Tagé, is located in the Na-Cho Nyäk Dun Traditional Territory, about 30 km north of Mayo. The river was named by non-Indigenous people after New Hampshire native Jack McQuesten, who came to the Yukon in 1873 during the fur trade (YukonInfo.com 2020). The McQuesten River watershed has a surface area of approximately 4,900 km^2. There are two main channels that join together to make the McQuesten River. The South McQuesten River flows southwest from McQuesten Lake, Et'o Nyäk Män, until it confluences with the North McQuesten River and forms the McQuesten River. This river discharges into the Stewart River, referred to as Nacho Nyäk gé by the First People. The Stewart River flows west until it discharges into the Yukon River (Figure 1) (FNNND 2021).

The South McQuesten watershed, between McQuesten Lake to the confluence with the North McQuesten River, contains approximately 1.7 billion m^2 and is about 70 km long. It is described as a low-energy, meandering stream with fine bed sediment, little suspended sediment and a marshy floodplain between McQuesten Lake and Haggart Creek. Downstream of Haggart Creek, the river has "higher-energy meandering stream with a sand and gravel bed and a higher suspended solids concentration" (CMI 2012). Tributaries flowing into the South McQuesten River, from upstream to downstream, include: Cache Creek, Christal Creek, Flat Creek, Shanghai Creek, Haldane Creek, North Star Creek, Bighorn Creek, Haggart Creek, Ross Creek, Goodman Creek, Seattle Creek, Rodin Creek and North McQuesten River (Figure 2). Haggart Creek is impacting the South McQuesten River significantly with its sediment input. The influx of coarse sediment from Haggart Creek has produced a large bar extending across the South McQuesten River at the confluence.





Yukon

Main Map: 1:500,000
(when printed on 11 by 17 inch paper)

0 5 10 15 20 Kilometers

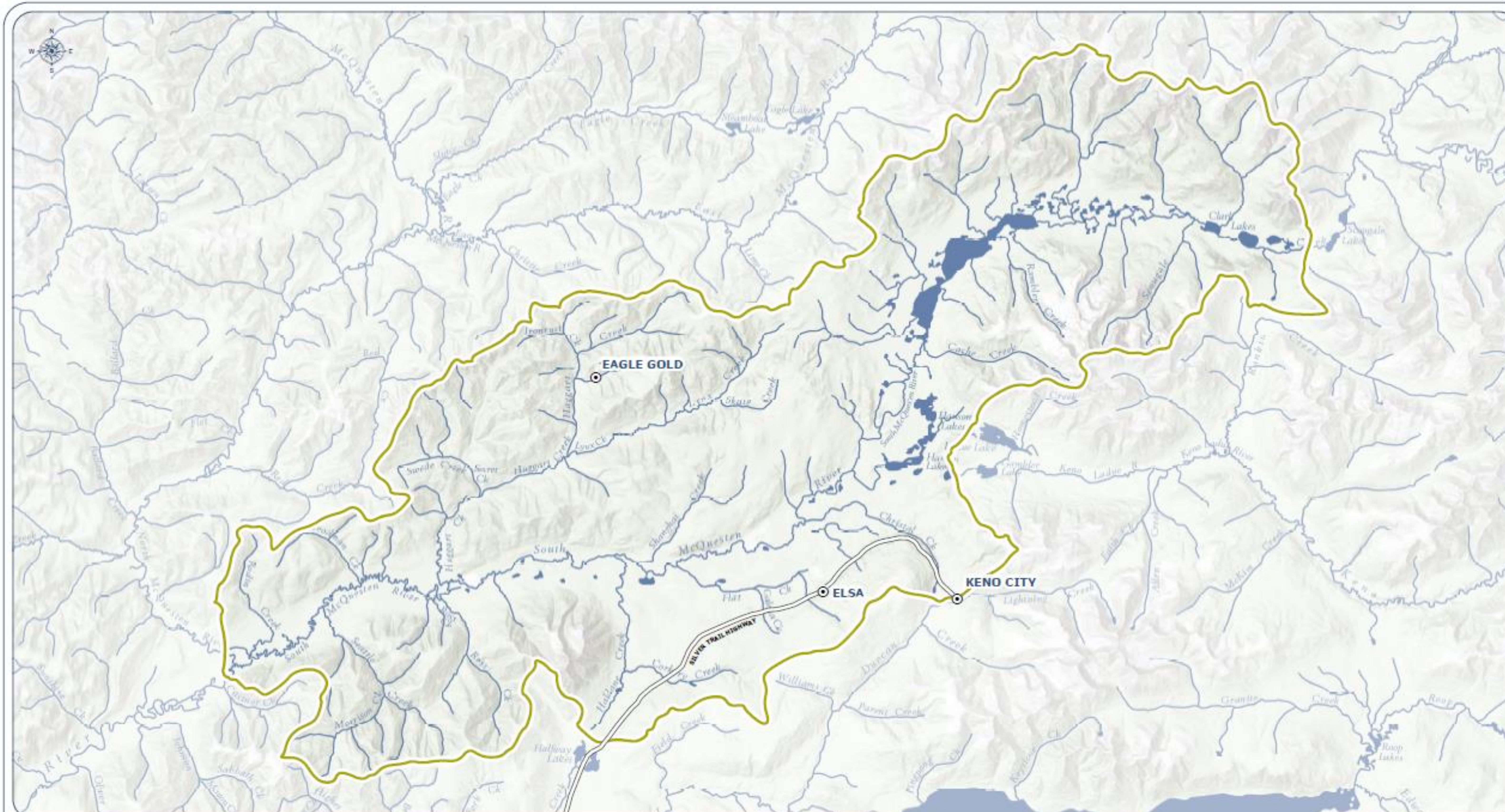
Main map watercourse and waterbody data from Topographic Data of Canada - CanVec Series at a scale of 1:100,000. Background imagery/hillshade: Sources: Esri, Airbus DS, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA, Geoland, FEMA, Intermap and the GIS user community
Sources: NRCan, Esri Canada, and Canadian Community Maps contributors..

South McQuesten Watershed

McQuesten Watershed

FIGURE 1
ET'O NYÄK TAGÉ / MCQUESTEN WATERSHED LOCATION

APRIL 2021



Yukon

1:250,000 When printed on 11 by 17 inch paper

0 5 10 15 Kilometers

Watercourse and waterbody data from Topographic Data of Canada - CanVec Series at a scale of 1:250,000. Background imagery/hillshade: Airbus,USGS,NGA,NASA,CGIAR,NCEAS,NLS,OS,NMA,Geodatastyrelsen,GSA,GSI and the GIS User Community.

South McQuesten Watershed

FIGURE 2

WATER NETWORK WITHIN THE SOUTH MCQUESTEN WATERSHED

JUNE 2021

4.2 Traditional and current use

The South McQuesten River watershed is located in the traditional territory of the Na-Cho Nyäk Dun First Nation. Staff from the FNNND government shared with WRB staff that the Na-Cho Nyäk Dun people have used the River for travelling, hunting, trapping and fishing. A number of fish camps have been set on the River. We have heard a story of people travelling on this river using "skin boats." The McQuesten River is culturally important to FNNND people.

Today, both Indigenous and non-Indigenous people use the South McQuesten and the McQuesten River for recreation, fishing, trapping and hunting. Commercial trapping and hunting concessions are allocated within the watershed.

4.3 Fisheries Overview

Twelve fish species are documented in the South McQuesten River watershed (Table 3). In addition, recent personal conversations with biologists indicated that Dolly Varden and Arctic Char may also be present in the South McQuesten River, although there is no documented confirmation. These two species have been recorded in the headwaters of the Beaver River, which is also located in the Stewart River watershed, as is the McQuesten River (Personal communications with Cameron Sinclair and Syd Cannings on November 13, 2020). Conversations with FNNND staff also informed WRB that grayling and salmon are present in the South McQuesten River and FNNND people used to fish for these species.

Table 3 Fish species documented in the South McQuesten Watershed (EDI 2005)

Category	Common Name	Scientific Name
Salmon Species	Chinook salmon	*Oncorhynchus tshawytscha*
Freshwater game fish species	Arctic grayling	*Thymallus arcticus*
	Burbot	*Lota lota*
	Northern pike	*Esox lucius*
	Round whitefish	*Prosopium cylindraceaum*
	Rainbow trout[1]	*Oncorhynchus mykiss*
	Lake whitefish	*Coregonus clupeaformis*
	Inconnu	*Stenodus leucichthys*
	Least cisco	*Coregonus sardinella*
Other fish species	Slimy sculpin	*Cottus cognatus*
	Longnose sucker	*Catostomus catostomus*
	Arctic Lamprey	*Lampetra japonica*

Note: [1] rainbow trout are an introduced species which have been documented in Hanson, Christal and Haldane Lake (small pothole lake south of Hanson Lake). However, they likely only still remain in Haldane Lake.

4.4 Fish Habitat Management System

The Fish Habitat Management System (FMHS) was established in the Yukon in 2008, in collaboration between the Government of Canada - Fisheries and Ocean Canada (DFO) and Government of Yukon. This system is based on a risk management approach to protect Chinook salmon and provides the overall management approach to deliver Watershed Authorizations for placer mines. The placer mining activities are authorized based on the type of fish habitat suitability (Yukon Placer Secretariat, 2008). The Fish Habitat Management System provides workbooks and guidance for operators as well as an Adaptive Management Program which includes the Water Quality and Aquatic Health monitoring programs.

Salmon habitat suitability was established for a number of watersheds, including the McQuesten River in 2018 (Figure 3). The main stem of the South McQuesten River between McQuesten Lake to a few kilometers upstream of Haggart Creek confluence is classified as “Areas of Special Consideration – Ecological” and “Areas of Special Consideration – Cultural.” From that point down to the Stewart River, the South McQuesten and McQuesten River is classified as fish habitat of “High Suitability.”

Areas of Special Consideration are defined as “watercourses that contain ecologically or culturally important fisheries or aquatic resources.” Watercourses designated as Areas of Special Consideration include habitats containing rare or locally significant fish species or areas which directly support subsistence, traditional, commercial or sport fisheries. Construction of new fords, diversion channels and in-stream works is not authorized in these areas. Discharged effluent directly into these streams is required to contain sediment concentration which does not exceed background levels (YPS 2010).

The Water Quality Objective for Total Suspended Solids (TSS) in a high suitability habitat is 25 mg/L. In 2012, CMI released the *Water Quality Objective Monitoring, McQuesten River Basin* report stating that on average (n=154 samples), TSS concentrations in the McQuesten River met the objectives. Exceedances of the objectives were observed five times, in June 2012 (CMI 2012). Note that prior to the FMHS, the previous regime called for Water Quality Objectives in the South McQuesten River of 12.5 or 25mg/L depending on the location (Penz and Kostaschuk 1999).

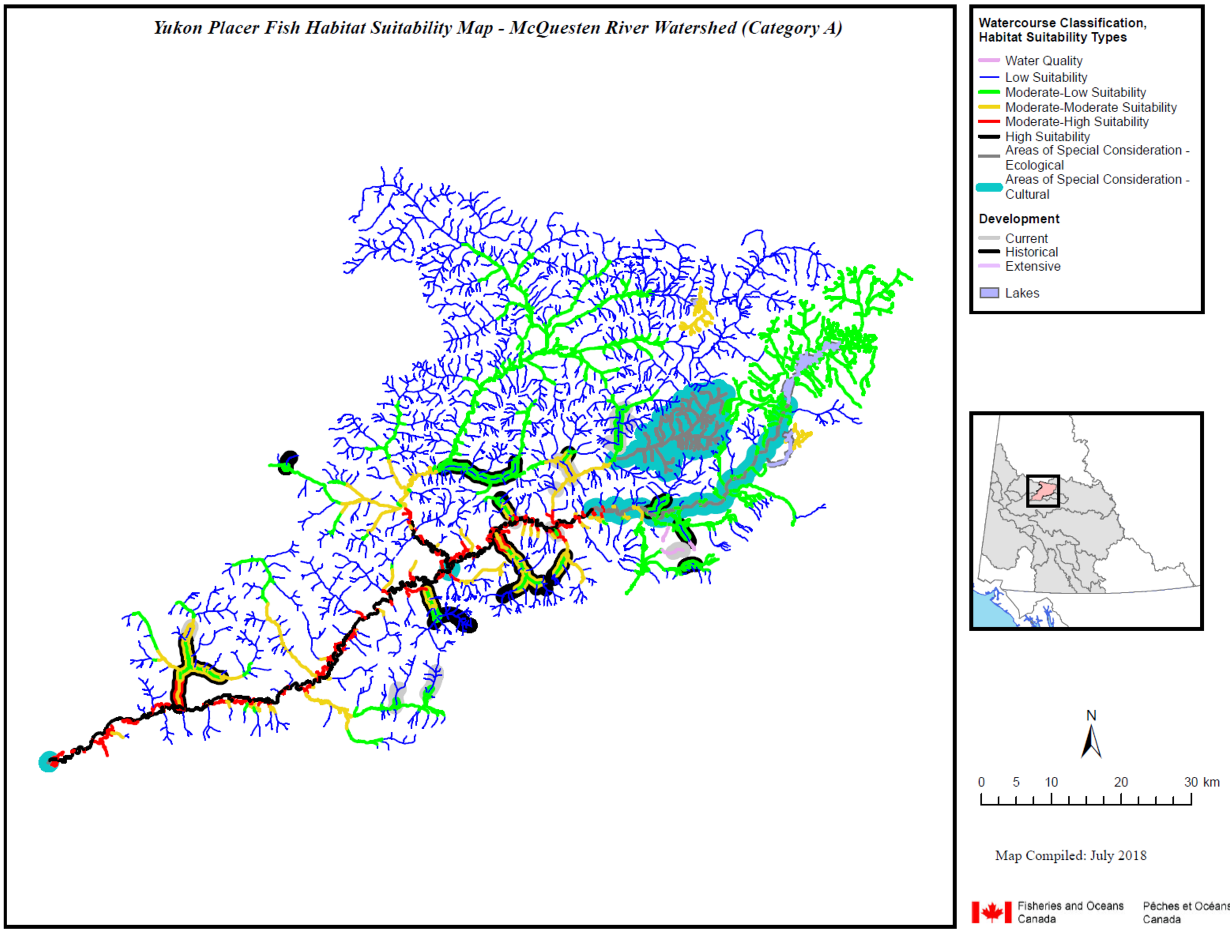


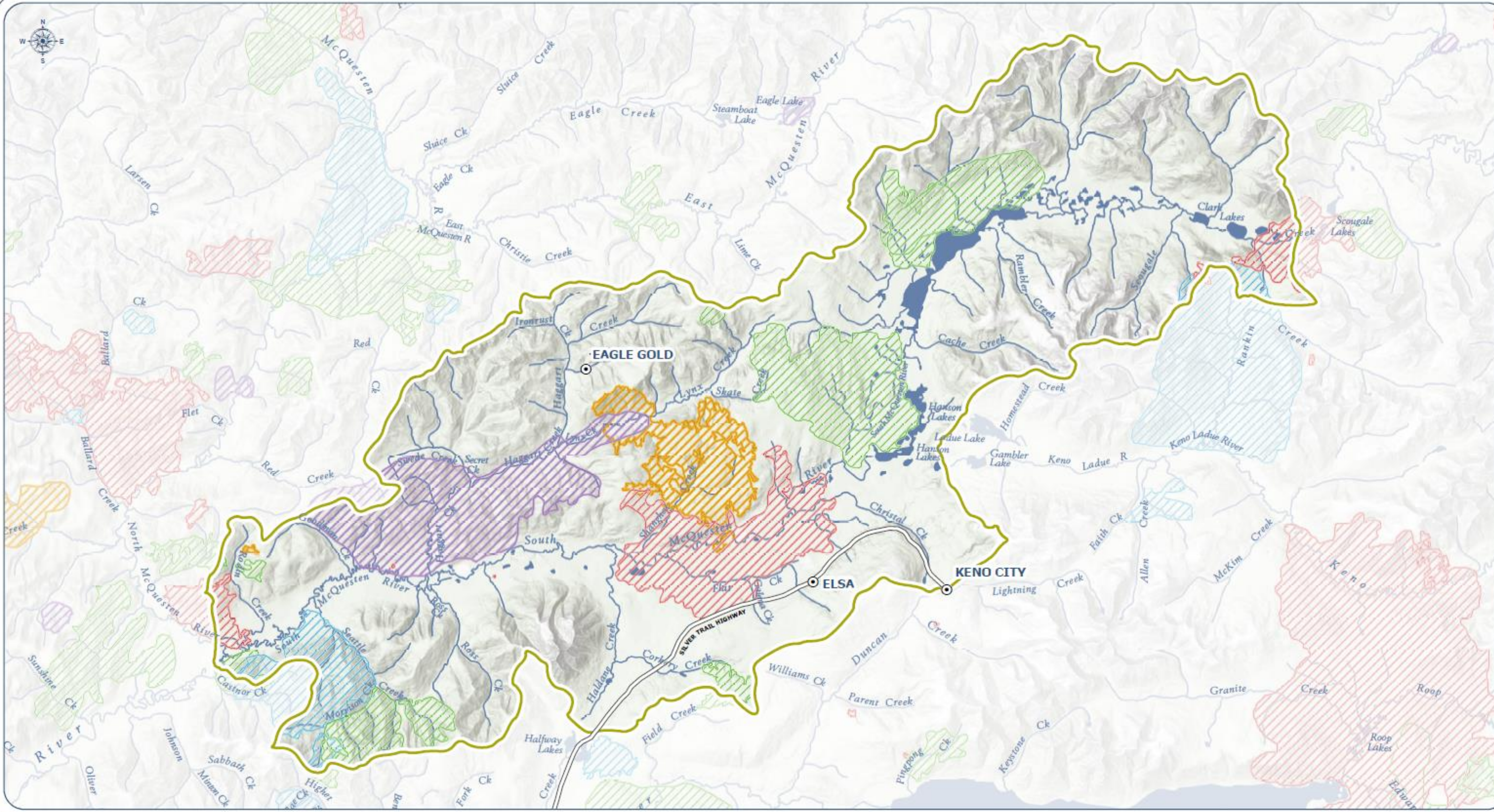
Figure 3. Fish habitat suitability within the South McQuesten River watershed based on the Fish Habitat Management System.

4.5 Wildfires

Seven wildland fires have been identified in the study area within Yukon Wildland Fire Management historic fire data (Figure 4). The earliest of these recorded fires occurred in 1955 and was the largest at 11388.3ha. In 2019, the Shanghai Creek Fire burned 8280.5ha along the River and included the water quality monitoring site YT09DD0008 which was chosen for developing Water Quality Objectives. Figure 5 and Figure 6 give a visual of the burn at the long-term station in September 2019 and February 2021.

According to the United States Geological Survey (USGS), burned areas generally produce higher levels of nitrate and organic carbon, as well as higher levels of suspended solids and increased temperatures. Trend analysis in future years using data pre-fire and post-fire will possibly indicate whether there is a change in water quality that can be attributed to the wild fire that occurred at the station in 2019 in the South

McQuesten River. This analysis was not yet available at the time of the report as several years of data post-fire is needed for this assessment.



Yukon

1:250,000 When printed on 11 by 17 inch paper

0 5 10 15 Kilometers

Watercourse and waterbody data from Topographic Data of Canada - CanVec Series at a scale of 1:250,000. Background imagery/hillshade: Airbus,USGS,NGA,NASA,CGIAR,NCEAS,NLS,OS,NMA,Geodatastyrelsen,GSA,GSI and the GIS User Community.

South McQuesten Watershed

Highway 11/Silver Trail Highway

Fire History Years

- 1940-1959
- 1960-1979
- 1980-1999
- 2000-2009
- 2010-2020

FIGURE 4

HISTORICAL FIRE AREAS IN THE SOUTH MCQUESTEN WATERSHED

JUNE 2021

Figure 5. Burned riparian vegetation at the South McQuesten River long-term water quality monitoring station observed in September 2019. Views from a) upstream and b) downstream.

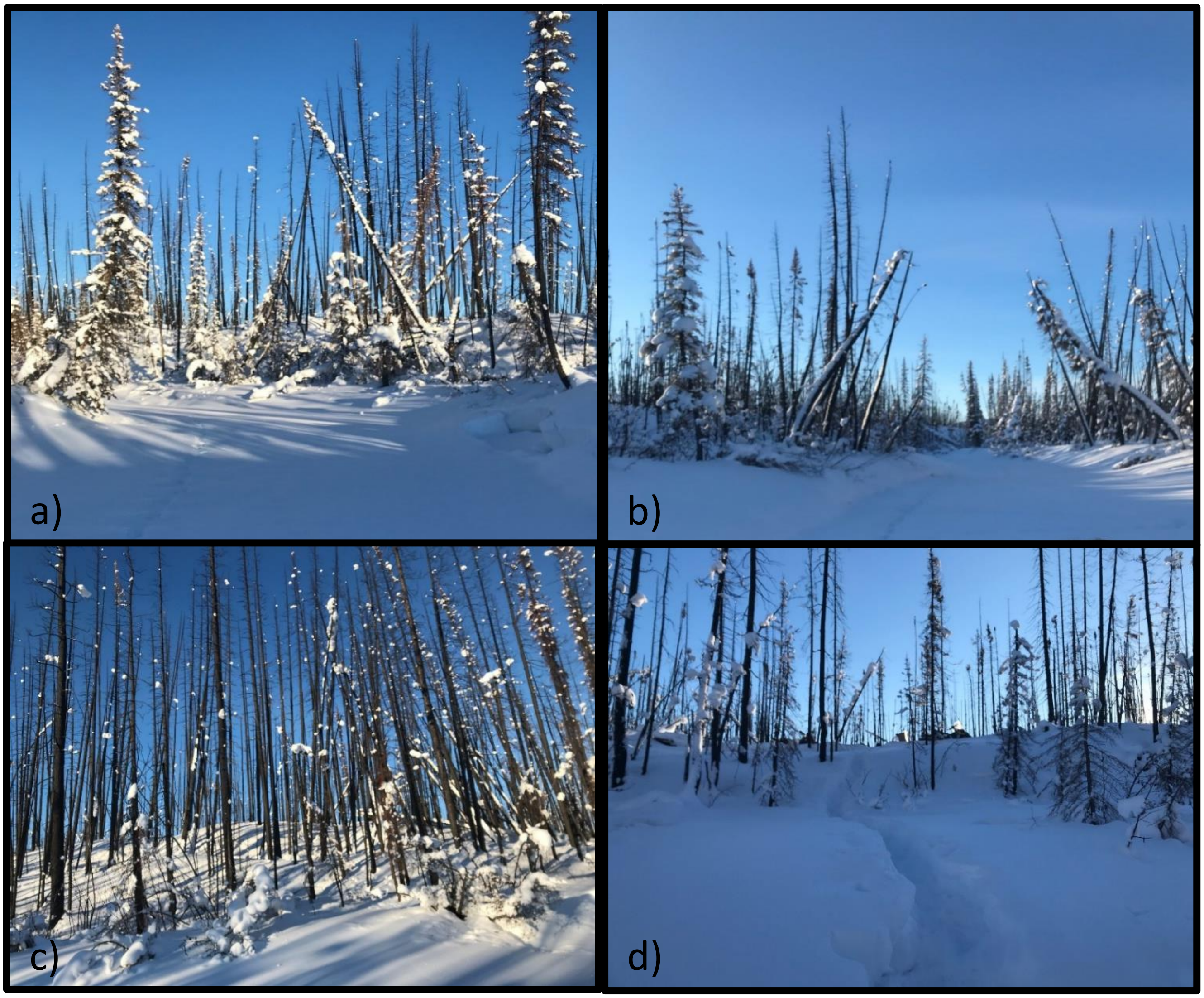


Figure 6. Burned riparian vegetation at the South McQuesten River long-term water quality monitoring station observed during February 2021. Views from a) upstream, b) downstream, c) right bank and d) left bank at the monitoring station.

4.6 Road network

There are multiple road crossings along the South McQuesten River and its tributaries. These roads and trails provide access to Keno, the mines and recreational activities throughout the watershed. Roads can contribute a source of contamination to an aquatic system such as potential hydrocarbons during a spill, increased sedimentation through dust or runoff from the road material. There are three gravel roads, Highway 11, 311 and 325, and multiple trails within the watershed (Figure 7).

Highway 11, commonly referred to as the Silver Trail, is located along the south of the South McQuesten River connecting Stewart Crossing to Keno City. This highway is paved until Mayo where it turns into a gravel road. Highway 11 enters the South McQuesten watershed at Haldane Creek headwaters, approximately 16 km southwest of Elsa, and ends at Keno. Nine tributaries of the South McQuesten River (Corkery Creek, Thompson Creek, Galena Creek, Flat Creek, Brefalt Creek, Gulch Creek, Star Creek, Sandy Creek and Christal Creek) are crossed by Highway 11. All of these creeks originate on Galena Hill and flow north until they discharge into the South McQuesten River.

There are two local roads that branch off from Highway 11 and provide further access within the watershed. Road 311 branches off between Elsa and Keno, runs northeast along the west slope of Davidson Range along the east side of the Hanson Lakes and McQuesten Lake and continues into adjacent watersheds. This road crosses Christal Creek, Cache Creek, Rambler Creek and multiple small ephemeral creeks originating on Forbes Hill and Rambler Hill within the Davidson Range. The second access road is Road 325. This road exits Highway 11 southwest of Elsa and provides access to the Eagle Gold Project. It crosses Haldane Creek and then runs along the flats along the south side of the South McQuesten River where it crosses North Star Creek and Bighorn Creek. This road crosses the South McQuesten River downstream of the Haggart Creek and South McQuesten River confluence. The road then runs northeast along the uphill side of Haggart Creek until the access road ends at the Eagle Gold Mine Project. Road 325 crosses Haggart Creek two times and multiple tributaries of Haggart Creek including Secret Creek.

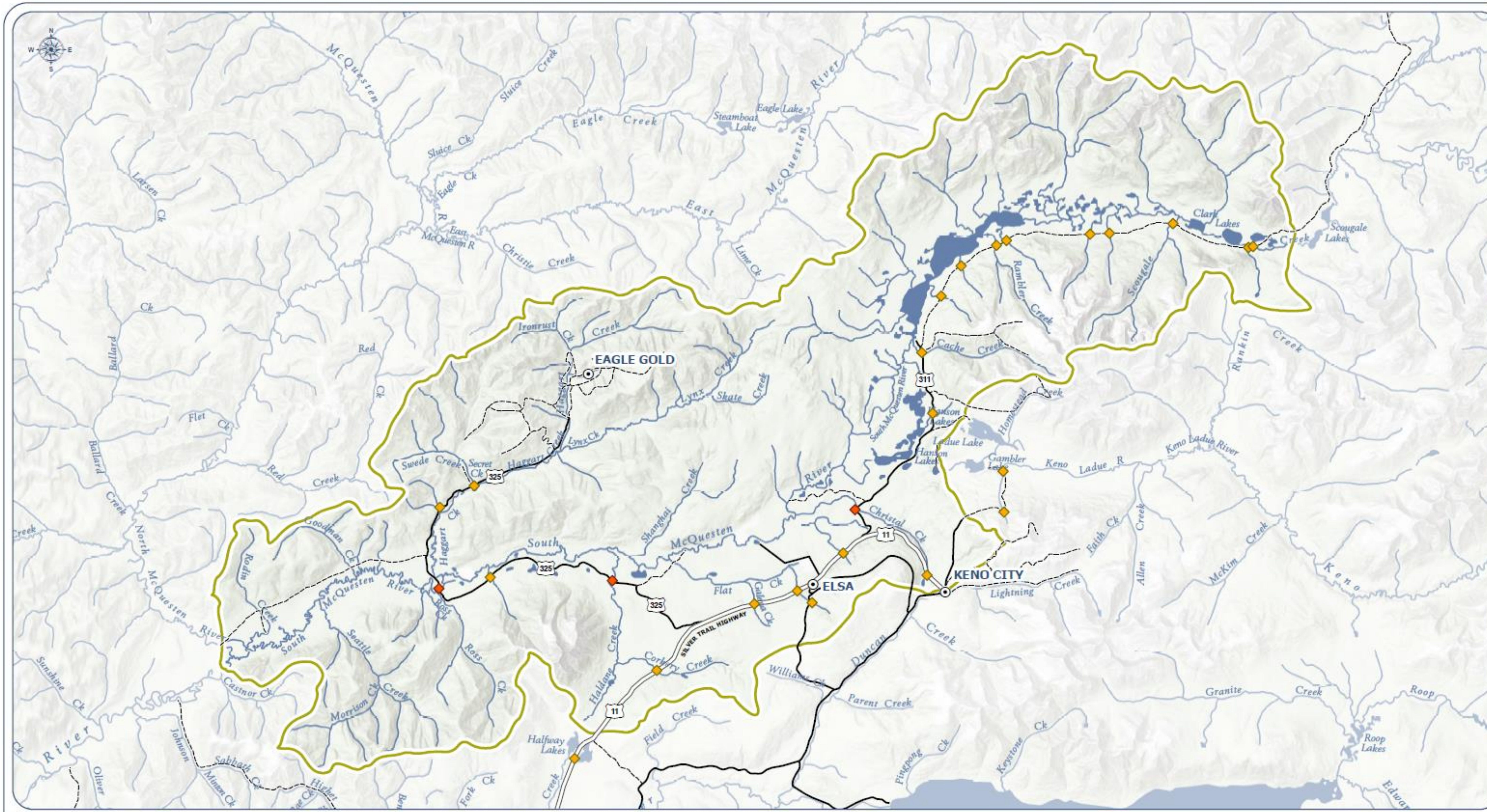
There are multiple trails within the watershed that cross tributary creeks. These trails are used for access to mines and areas for hunting and recreation. Multiple mineral exportation roads exist around Keno, Elsa and Eagle Gold mines for access to associated mining activities.

Culverts have typically been installed where the roads and trails cross the tributaries and the South McQuesten River. Culverts have also been used to assist with surface water drainage throughout the road network. However, three bridges have been installed at larger stream crossings. There is a bridge located on Road 311 at the Cristal Creek crossing and two bridges on Road 325 at the Haldane Creek and South McQuesten River crossings.

Highway 2, or the Klondike Highway, is the only major paved road that crosses the McQuesten River as a steel bridge. This river crossing is located downstream of the

North and South McQuesten River confluence. The bridge crossing is located north of Stewart Crossing before the river discharges into Stewart River.

Monument Hill and Mount Hinton are the two popular hiking trails near Keno City. However, Monument Hill is the only hiking trail located within the South McQuesten watershed. The trail is located along the summit of Keno Hill and does not cross any tributary streams.



Yukon	1:250,000 When printed on 11 by 17 inch paper 0 5 10 15 Kilometers	South McQuesten Watershed Highway 11/Silver Trail Highway Secondary/Local Road Trail Stream Crossing/Culvert(s) Bridge	**FIGURE 7** **ROAD NETWORK AND STREAM CROSSINGS WITHIN THE SOUTH MCQUESTEN WATERSHED** JUNE 2021

Watercourse and waterbody data from Topographic Data of Canada - CanVec Series at a scale of 1:250,000. Background imagery/hillshade: Airbus,USGS,NGA,NASA,CGIAR,NCEAS,NLS,OS,NMA,Geodatastyrelsen,GSA,GSI and the GIS User Community.

4.7 Authorized water use

All projects requiring a Water Use Licence are first assessed by the Yukon Environmental and Socio-economic Assessment Board (YESAB) and if the project is approved to proceed, then the proponent can apply for a Water Use Licence from the Yukon Water Board. This licence authorizes the use and deposit of waste in water. There are 21 active water use licences in the watershed, four quartz mining, 15 placer mining and two miscellaneous licences. Note that only Class 4 placer and quartz mines with a mining licence require a water licence. Smaller operations (Class 1, 2 and 3 placer mines and non-licensed quartz mines) are required to obtain a permit; however, they do not require a water licence as they are considered to have a minimal impact on the environment.

4.7.1 Quartz Mining

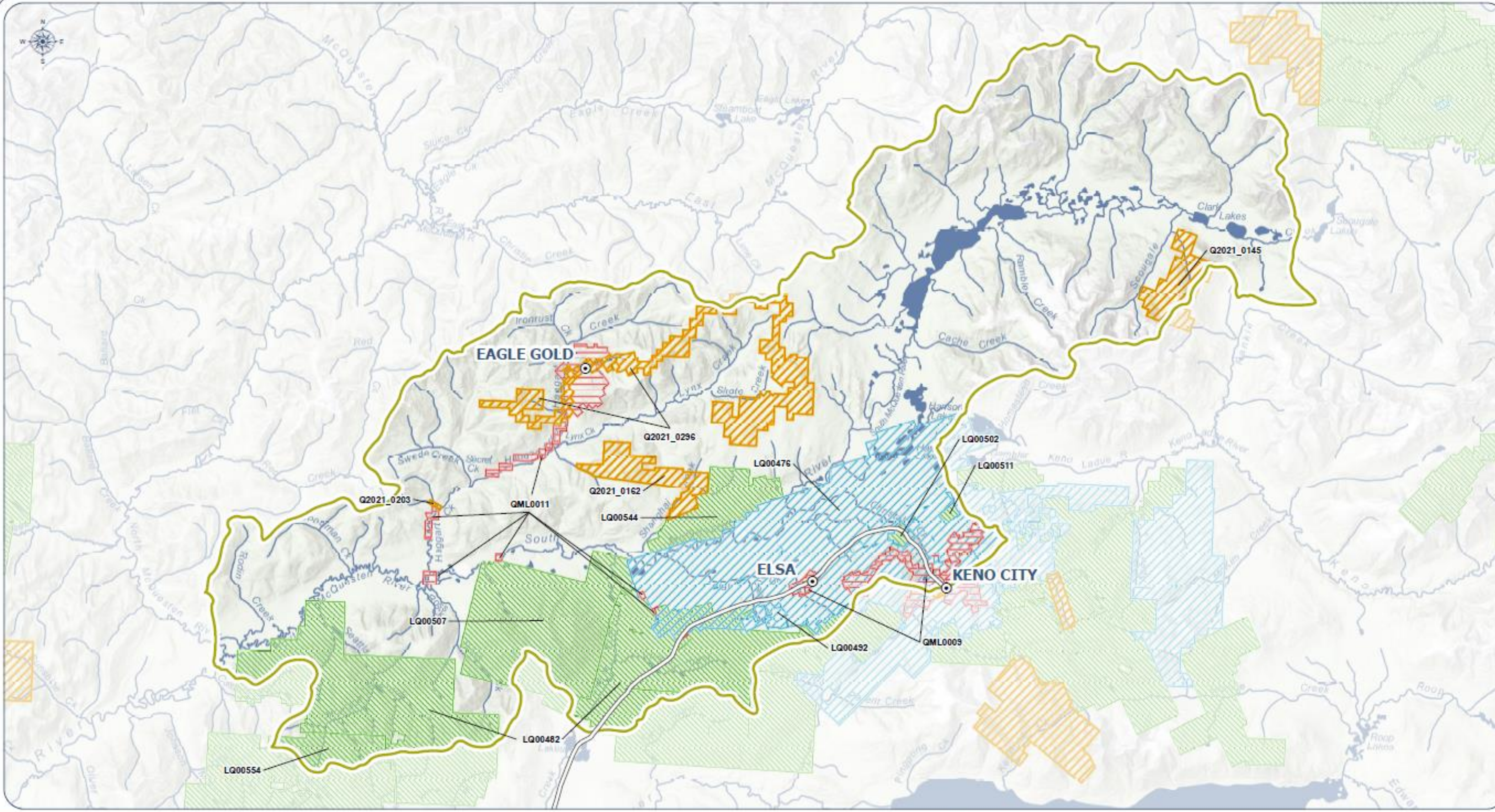
Quartz mining exploration projects are separated into four classes based on predetermined criteria to regulate the extent of impact on the environment. Class 1 projects have the smallest allowed limits whereas Class 4 projects are considered to meet at least one of the capacity limits for permitted environmental impact. These exploration projects are required to obtain a Quartz Mining Land Use Permit. There are 12 quartz exploration permits issued within the South McQuesten watershed. These consist of five Class 1, six Class 3 and one Class 4 projects (Figure 8).

Proponents are required to obtain both a Quartz Mining Land Use Licence and a Water Use Licence for a quartz mine to enter into the operation phase. The two licences are also required for quartz mines in the closure or care and maintenance phases. There are three quartz mining operations currently authorized in the area: Victoria Gold Corporation's Eagle Gold Mine, Alexco Corporation's Keno Hill operations, and the care and maintenance of the historical mining liabilities by Elsa Reclamation and Development Company, Ltd. Elsa Reclamation and Development Company Ltd. is awaiting a new Water Use Licence for upcoming reclamation and closure. This site is included under the same Quartz Mining Land Use Licence as the Keno Hill operations but has a separate Water Use Licence. Victoria Gold's operation discharges into Haggart Creek, Eagle Creek, Platinum Gulch, and Dublin Gulch. Keno Hill discharges into Lightning Creek and Thunder Gulch (tributaries of Duncan Creek) as well as Christal Creek, Christal Lake, Flat Creek and No Cash Creek. The Elsa reclamation discharges into Flat Creek and Christal Creek. These mines have active water licences to support their operation (Table 4).

The Elsa Reclamation project has submitted an extension application for their timeline to provide a decommissioning and reclamation plan to the Water Board under application QZ21-012. YESAB issued the evaluation report in February 2020 and the decision document was issued by Government of Yukon in July 2020. Currently, this project is being reviewed by the Yukon Water Board and will eventually receive a water licence.

Table 4. Active Quartz Mining Licences in the South McQuesten watershed.

Quartz Mining Licence	Water Licence	Water License Type	Licence Holder
QML0011	QZ16-016	B	Victoria Gold (Yukon) Corp., formerly StrataGold Corporation
	QZ14-041-1	A	Victoria Gold (Yukon) Corp., formerly StrataGold Corporation
QML 0009	QZ18-044	A	Alexco Keno Hill Mining Corp.
	QZ17-076	B	Elsa Reclamation and Development Company



Yukon

1:250,000 When printed on 11 by 17 inch paper

0 5 10 15 Kilometers

Watercourse and waterbody data from Topographic Data of Canada - CanVec Series at a scale of 1:250,000. Background imagery/hillshade: Airbus,USGS,NGA,NASA,CGIAR,NCEAS,NLS,OS,NMA,Geodatastyrelsen,GSA,GSI and the GIS User Community.

South McQuesten Watershed

Land Use Areas

Exploration Permit

- Class 1
- Class 3
- Class 4

Quartz Mining Licence

- Licensed Area

FIGURE 8

QUARTZ MINING LAND USE AREAS WITHIN THE SOUTH MCQUESTEN WATERSHED

NOVEMBER 2021

4.7.2 Placer mining

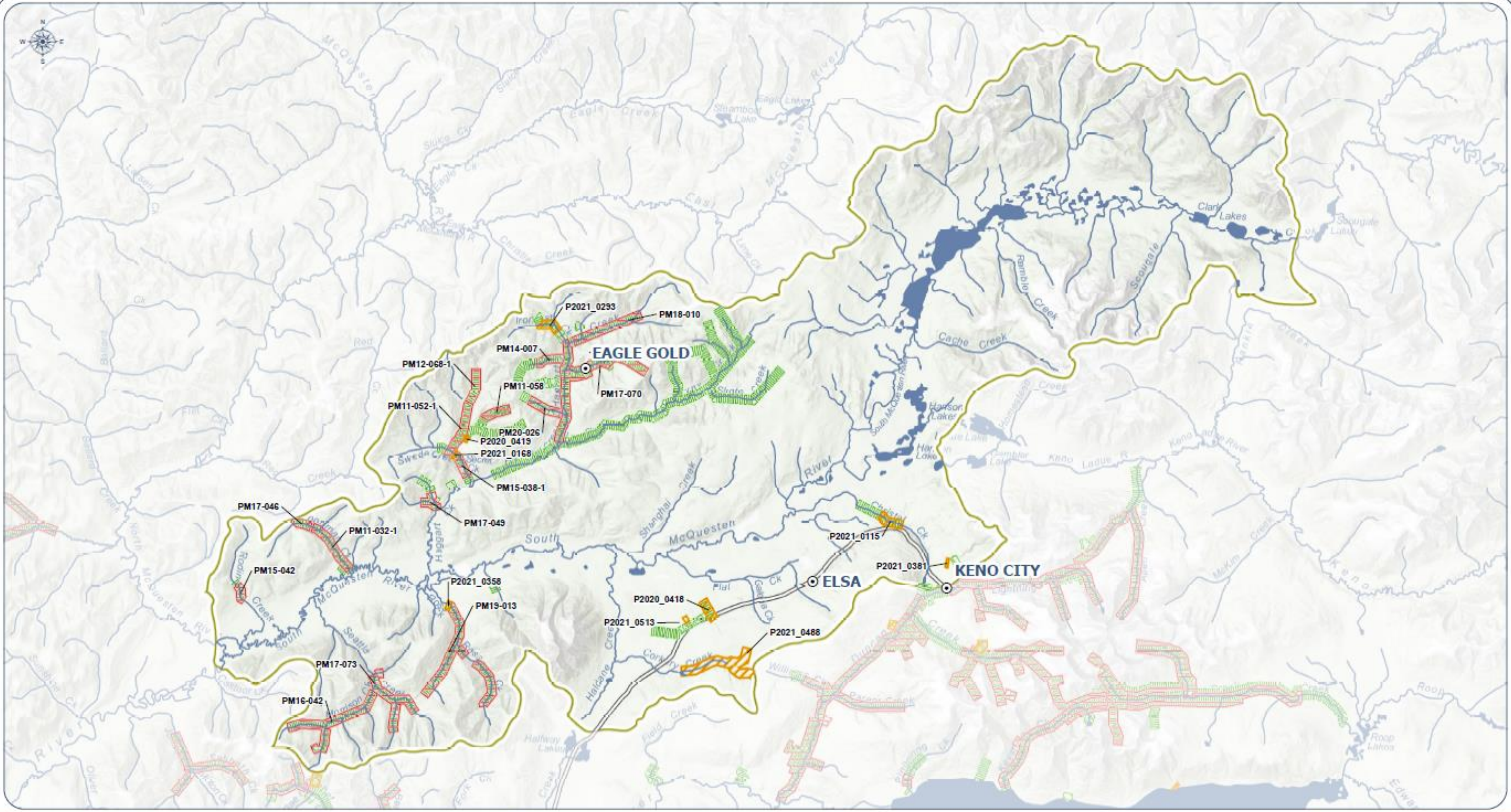
There are a number of Class 4 placer mines located in the South McQuesten River watershed. In the Yukon, the placer mines are guided by the Fish Habitat Management System, which is a joint federal and territorial government initiative and which articulates the conditions in which these mines are allowed to operate. Water licences and placer mining authorizations are delivered by the Yukon Water Board for Class 4 placer mines. For all other placer mines (Class 1, 2 and 3), the Department of Energy, Mines and Resources delivers their permits.

There are 15 Class 4 placer mining operations licensed to use and discharge water in the South McQuesten River watershed (Table 5). This includes nine placer mines with active water licences to remove and discharge water within Haggart Creek or tributaries of Haggart Creek. The remaining six active water licences for placer mines are located on Ross, Goodman, Seattle and Rodin creeks.

In addition, there are 953 placer mining claims in the South McQuesten River watershed. These consist of eight Class 1 permitted placer exploration projects and 945 placer claims pending permits (i.e. not exploited yet). There are no Class 2 and Class 3 placer mine permits in this watershed (Figure 9).

Table 5. Active Water Licences for Class 4 placer mines in the South McQuesten watershed upstream to downstream.

Main SMQ Tributary Branch	Water Licence	Licence Holder
Haggart Creek	PM18-010	Manuele Martushev
	PM14-007	O.H. Transport Inc.
	PM17-070	Victoria Gold Corp.
	PM20-026	Len Andre
	PM12-068	Vernon August Evans
	PM11-058	Travis Minelli
	PM11-052	Vernon August Evans
	PM15-038	Frank Plut
	PM17-049	Robert Van Manen
Ross Creek	PM19-013	Yukon Mining Ventures Ltd.
Goodman Creek	PM17-046	Tom Herman
	PM11-032	Gimlex Enterprises Ltd.
Seattle Creek	PM17-073	Reno Contracting Ltd.
	PM16-042	Travis Moman
Rodin Creek	PM15-042	Christopher Royden Thomas



Yukon

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0 5 10 15 Kilometers

Watercourse and waterbody data from Topographic Data of Canada - CanVec Series at a scale of 1:250,000. Background imagery/hillshade: Airbus,USGS,NGA,NASA,CGIAR,NCEAS,NLS,OS,NMA,Geodatastyrelsen,GSA,GSI and the GIS User Community.

South McQuesten Watershed

Land Use Areas

Placer Mining Claim

Land Use Permits

Class 1

Water Use Licence

Class 4

FIGURE 9

PLACER MINING LAND USE AREAS WITHIN THE SOUTH MCQUESTEN WATERSHED

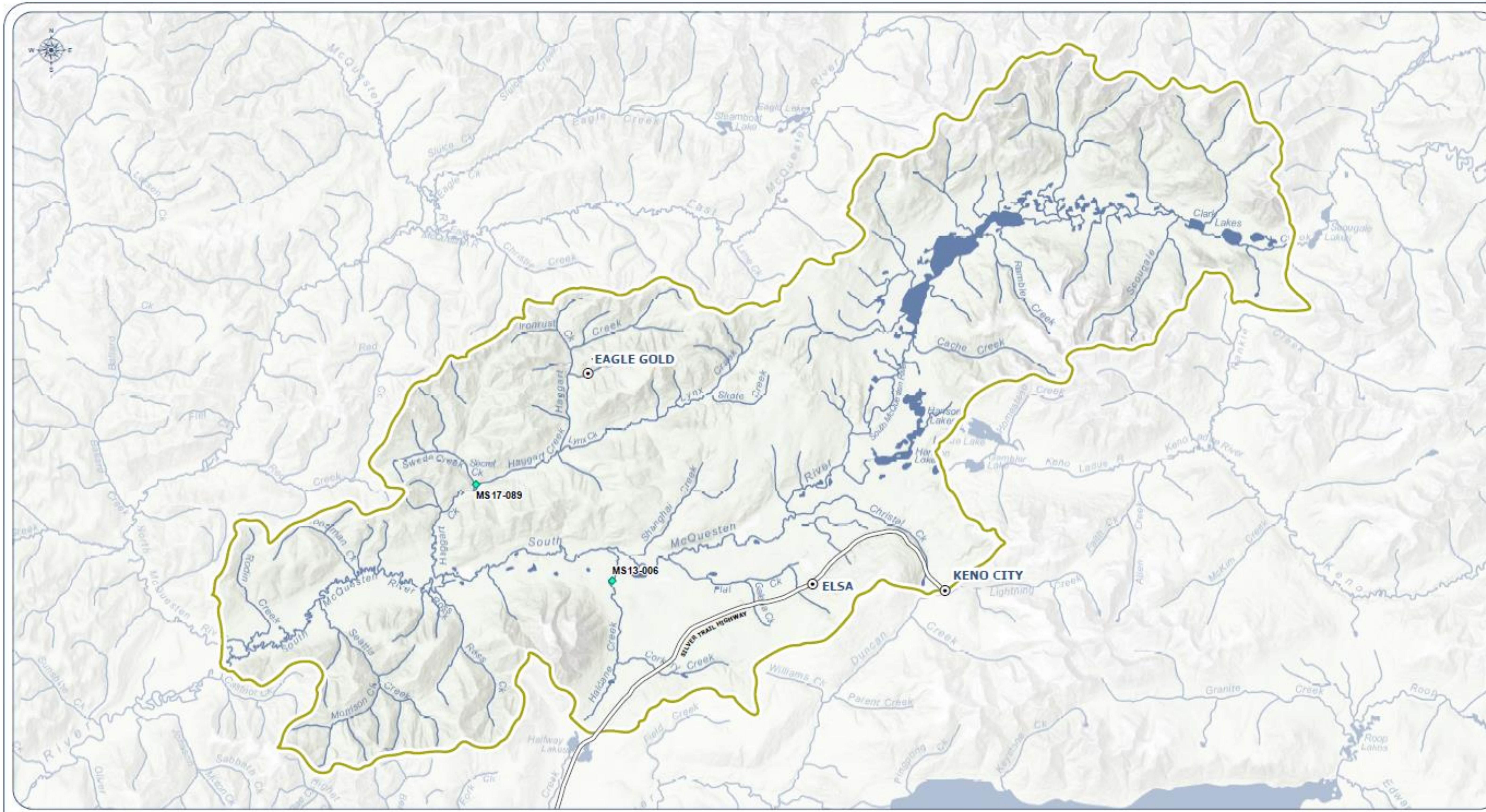
NOVEMBER 2021

4.7.3 Miscellaneous

Miscellaneous water licences cover all the licences that are not represented in the other categories. Both of the active miscellaneous licences observed within South McQuesten are related to road works (Figure 10). One of the miscellaneous licences (MS17-089) is for a culvert replacement on Swede Creek (tributary of Haggart Creek) by Victoria Gold. The other miscellaneous licence (MS13-006) is for bridge rehabilitation and long-term maintenance of the crossing on Haldane Creek by Highways and Public Works – Transportation and Engineering Branch (Table 6).

Table 6. Miscellaneous Water Licences in the South McQuesten watershed

Water Licence Number	Purpose	Licence Holder
MS17-089	Road work – culvert replacement	Victoria Gold
MS13-006	Road work - bridge rehabilitation and long-term maintenance	Highways and Public Works – Transportation and Engineering Branch



Yukon

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0 5 10 15 Kilometers

Watercourse and waterbody data from Topographic Data of Canada - CanVec Series at a scale of 1:250,000. Background imagery/hillshade: Airbus,USGS,NGA,NASA,CGIAR,NCEAS,NLS,OS,NMA,Geodatastyrelsen,GSA,GSI and the GIS User Community.

South McQuesten Watershed

Miscellaneous Water License

FIGURE 10

MISCELLANEOUS WATER USE LICENCES WITHIN THE SOUTH MCQUESTEN WATERSHED

OCTOBER 2021

5 Water quality

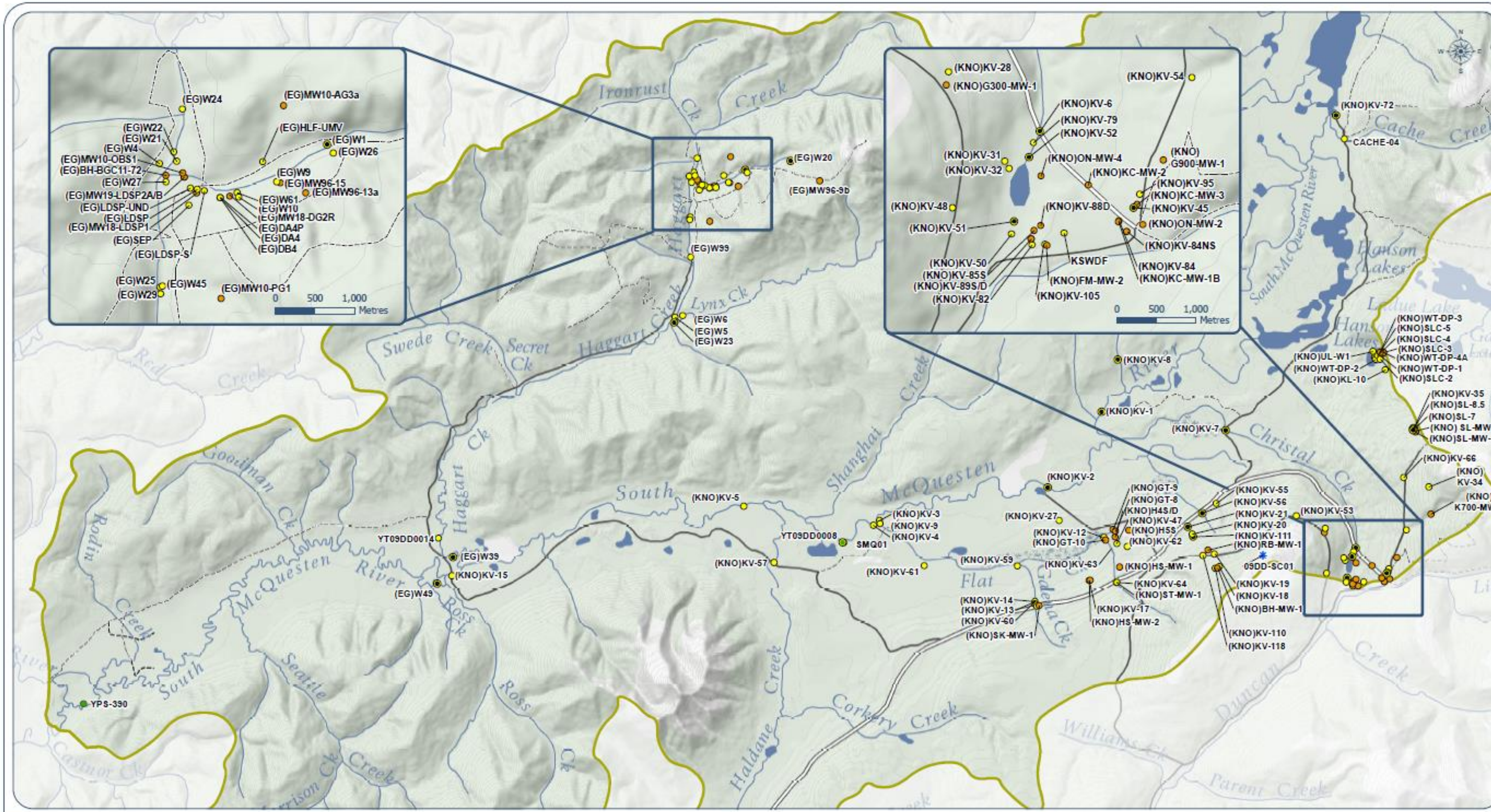
The South McQuesten watershed is monitored extensively due to mining development. Most of the monitoring sites are concentrated around mining activities to characterize baseline conditions and monitor any changes associated with human activities. The following section presents the evolution of water quality in the South McQuesten, from the headwater lake to downstream of Haggart Creek. Temporal characterization was also conducted at the long-term surface water monitoring station, comparing data at one location over multiple seasons and years to observe the variability at that station (Section 5.5).

5.1 Water quality monitoring

There are 122 active monitoring stations within the watershed with 78 surface water stations and 43 ground water stations respectively (Figure 11). Flow is measured at 21 of the surface water stations. There is one snowpack monitoring station located on Galena Hill near Elsa. There are also 84 monitoring stations considered inactive as sampling is no longer done at these locations (Figure 12).

There are eight water quality monitoring stations on the main stem of the South McQuesten River between McQuesten Lake to Haggart Creek (Table 7). Sites are monitored by Alexco Keno Hill Mining Corp., Elsa Reclamation and Development Company and Victoria Gold Corp. The long-term station YT09DD0008 is part of the Environment and Climate Change Canada Freshwater Quality Monitoring and Surveillance network. The head water lake quality, in McQuesten Lake, has also been monitored since 2011.

A number of tributaries are also monitored on a regular basis. Cache Creek, a tributary coming into the South McQuesten River just downstream of the headwater lake, was monitored opportunistically by Water Resources Branch in 2015, 2016, 2018 and 2019 due to concerns brought up by FNNND and the local residents. In 2020, monthly water sampling was initiated by WRB in Cache Creek and as of March 2021, FNNND government is taking over the monthly sampling program in partnership with WRB. Further down the South McQuesten, Crystal Creek, Flat Creek, Haggart Creek and Haldane Creek are monitored by Alexco Keno Hill Mining Corp., Elsa Reclamation and Development Company, and Victoria Gold Corp (Table 7). The data compiled for each stations is provided in Appendix B.



Yukon

Main Map: 1:135,000 (when printed on 11 by 17 inch paper)

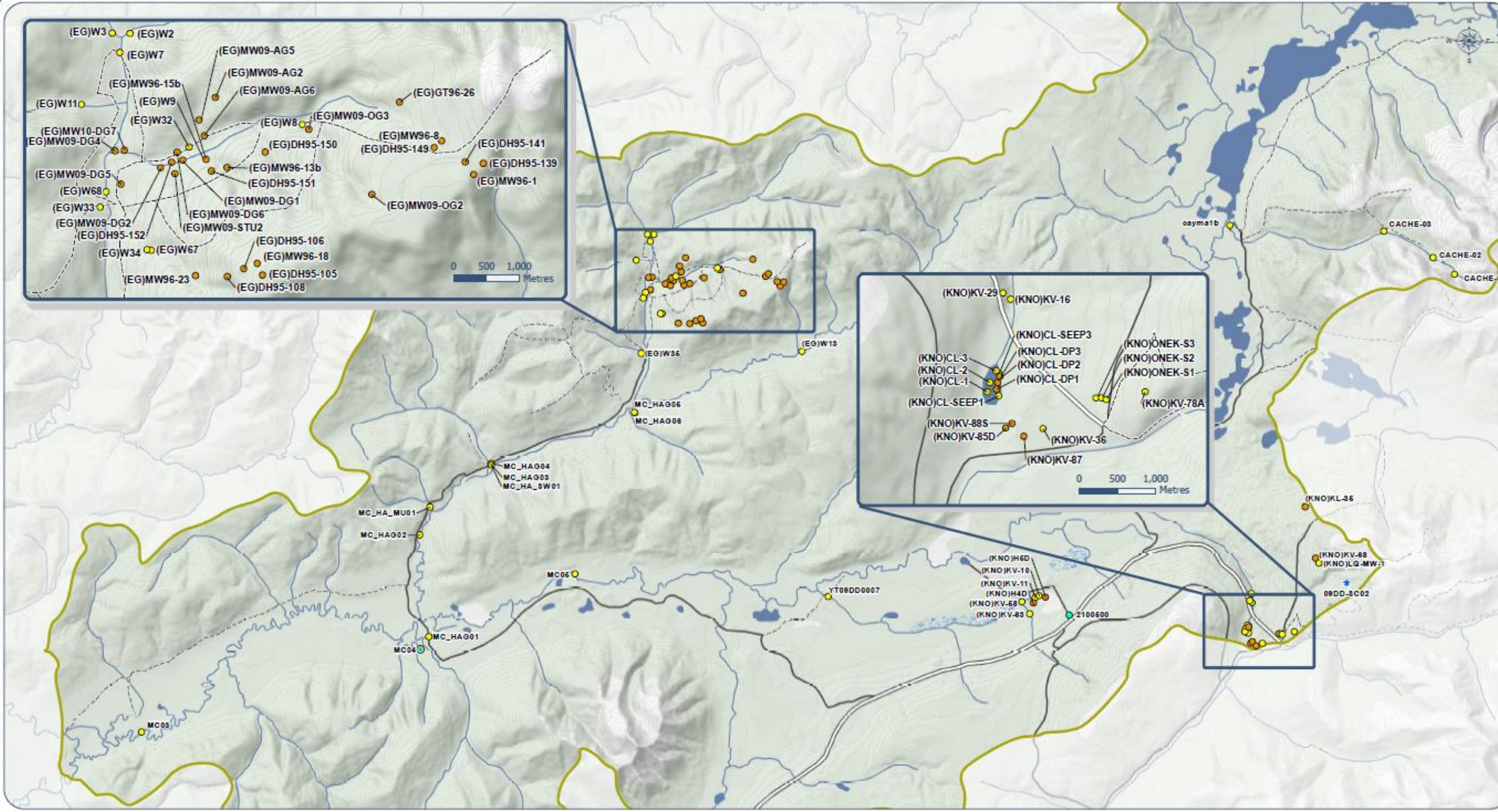
0 2.5 5 10
Kilometers

Watercourse and waterbody data from Topographic Data of Canada - CanVec Series at a scale of 1:250,000. Contours waterbody data from Topographic Data of Canada - CanVec Series at a scale of 1:50,000.

- Surface Water Quality
- Surface Water Quality and Flow
- Surface Water and Benthic Invertebrates
- Benthic Invertebrates
- Groundwater Quality
- Snowpack

FIGURE 11
ACTIVE MONITORING STATIONS IN THE SOUTH MCQUESTEN WATERSHED

JUNE 2021



Yukon

Main Map: 1:150,000 (when printed on 11 by 17 inch paper)

0 2.5 5 10

Kilometres

Watercourse and waterbody data from Topographic Data of Canada - CanVec Series at a scale of 1:250,000. Contours waterbody data from Topographic Data of Canada - CanVec Series at a scale of 1:50,000.

- Surface Water Quality
- Surface Water Quality and Meteorology
- Groundwater Quality
- Meteorology
- Snowpack

FIGURE 12
INACTIVE MONITORING STATIONS IN THE SOUTH MCQUESTENWATERSHED

JUNE 2021

Table 7 Water Quality Monitoring stations along the South McQuesten watershed from upstream to downstream.

Watercourse	Station Code	Water Licence	Northing[1]	Easting[1]	Range of Monitoring Data (YYYY - YYYY)	Flow monitoring frequency
South McQuesten at McQuesten Lake	(KNO)KV-72	QZ18-044	7104476	482492	2011 – current	Irregularly
Cache Creek	CACHE-04	N/A	7103613	482843	2015 – current	Irregularly
Christal Creek at Mouth	(KNO)KV-8	QZ18-044	7091944	474585	1998 – current	Multiple times per year 2007 to 2016, not since 2017
South McQuesten upstream of Christal Creek	(KNO)KV-1	QZ18-044	7092790	474008	1995 – current	Irregularly
South McQuesten at pumphouse	(KNO)KV-2	QZ18-044	7090036	472076	1981 – current	Irregularly
South McQuesten upstream of Flat Creek	(KNO)KV-3	QZ17-076	7088534	465846	1997 – current	Irregularly
Flat Creek upstream of South McQuesten	(KNO)KV-9	QZ17-076	7088406	465871	1981 - current	Irregularly
South McQuesten 350m downstream of Flat Creek	(KNO)KV-4	QZ17-076	7088336	465620	1981 – current	Irregularly
South McQuesten downstream of Flat Creek	YT09DD0008	N/A	7087645	464524	2005 – current	No
South McQuesten 9km downstream of Flat Creek	(KNO)KV-5	QZ17-076	7088870	460686	2004 – current	Irregularly
Haldane Creek at South McQuesten Road	(KNO)KV-57	QZ17-076	7086794	461921	2008 - current	
Haggart Creek, upstream of South McQuesten	(EG)W39	QZ14-041	7086504	449780	2011 – current	No
South McQuesten at bridge downstream of Haggart Creek	(KNO)KV-15	QZ17-076	7085805	449758	1998 - current	Irregularly
South McQuesten downstream of Haggart Creek	(EG)W49	QZ14-041	7085495	449221	2011 - current	No

[1] Coordinates are UTM Zone 8 NAD 83

5.2 Water Quality Index

The purpose of the WQI is to provide a general idea of water quality conditions at a site. The WQI for a site is calculated using data collected monthly over three years, producing a single value between 0 (poor) and 100 (excellent). These values are grouped to give an idea of the aquatic health of the site (Table 8). The natural water quality and potential concerns differ for each site and therefore different sets of parameters are measured. The set of parameters used to calculate the WQI at the South McQuesten River are arsenic, copper, lead, nitrogen, pH, phosphorous, silver, temperature and zinc.

Table 8. Water Quality Index (WQI) ratings, values, and descriptions

Rating	Description
Excellent (95-100)	Aquatic life is not threatened or impaired. Measurements never or very rarely exceed water quality guidelines.
Good (80-94)	Aquatic life is protected with only a minor degree of threat or impairment. Measurements rarely exceed water quality guidelines and, usually, by a narrow margin.
Fair (65-79)	Aquatic life is protected, but at times may be threatened or impaired. Measurements sometimes exceed water quality guidelines and, possibly, by a wide margin.
Marginal (45-64)	Aquatic life frequently may be threatened or impaired. Measurements often exceed water quality guidelines by a considerable margin.
Poor (0-44)	Aquatic life is threatened, impaired or even lost. Measurements usually exceed water quality guidelines by a considerable margin.

The WQI for the South McQuesten River has been rated as "marginal" for most of the periods it was calculated, and "fair" for a few years (Table 9). The water quality guidelines used to calculate the WQI for the South McQuesten River are generic guidelines established by CCME, the Government of Canada and the BC Ministry of Environment. In areas that are highly mineralized, such as the South McQuesten River watershed, exceedance of generic guidelines can be observed on a regular basis. Yet, some aquatic ecosystems can be healthy even when generic guidelines are exceeded. The marginal and fair WQI ratings in the South McQuesten River are likely due to a combination of naturally elevated metal concentrations found across the watershed and mining activities occurring along the river and its tributaries upstream of the long-term water quality station. The marginal score means that "water quality often exceeds guidelines by a considerable margin" and "aquatic life may be threatened or impaired" as per CCME definition (CCME 2007). Copper, zinc and temperature are the parameters which influence the WQI the most, by exceeding their respective guidelines more often.

Table 9. WQI values calculated for the South McQuesten River (2005-2019)

Time period	Index Value
2005-2007	64.4
2006-2008	64.3
2007-2009	64
2008-2010	70
2009-2011	69.5
2010-2012	70.1
2011-2013	70.4
2012-2014	70.6
2013-2015	70
2014-2016	63.8
2015-2017	63.7
2016-2018	63.5
2017-2019	64.1

5.3 Aquatic ecosystem quality interpretation using biotic sampling

Benthic invertebrates were also used to indirectly assess water quality using multiple indices. This data was obtained from ECCC at two stations along the South McQuesten River. Benthic invertebrates reflect cumulative impacts of pollution in the aquatic environment because these organisms live in the aquatic environment, do not mobilize easily within the environment and have different tolerances to the water quality. The diversity and variety of benthic macroinvertebrates provides the opportunity to determine the water quality over an extended period of time. Healthy streams with good water quality tend to contain a more abundant and wide variety of macroinvertebrate taxa. A healthy macroinvertebrate community typically reflects that the chemical and physical properties of the stream are good. On the other hand, a low benthic macroinvertebrate taxa abundance and diversity or taxa that are more pollution-tolerant tends to indicate poor water quality.

The biotic indices and community composition of the benthic invertebrates within the South McQuesten River indicate that the water quality can be considered good (Table 10, Table 10 and Figure 13). There is representation from a variety of species that are sensitive to extended periods of exposure to poor water quality conditions. Sensitive species such as Ephemeroptera, Plecoptera and Tricoptera (EPT) can be used to express a percentage of the sensitive orders to the total taxa found. A large percentage of EPT taxa indicates high water quality. %EPT values were observed higher in 2017 and 2019 compared to 2009 data at stations YPS-390 and SMQ01, which seems to indicate an improvement. Sample station SMQ01 had higher Abundance, Richness,

%EPT and % Chironomidae values than YPS-390. However, YPS-390 had higher values for some of the other observed biotic indices. Also, the benthic community structure is not dominated by taxa with high tolerance to poor water quality conditions. Using the data presented below, there is no obvious indication that would suggest that there is a change in the benthic community between the two sample sites. However, the small data set of only two sample periods makes it difficult to infer relationships amongst and between the two sites with respect to interpreting the water quality.

Table 10. Summary of the biotic indices

Site ID	**YPS-390**		**SMQ01**	
Sample Date	July 2009	July 2017	August 2009	August 2019
Community Metric				
Abundance	398	278	1233	698
Richness	23	21	26	25
Simpson's Diversity	0.92	0.89	0.90	0.87
Shannon-Wiener Diversity	2.71	2.46	2.63	2.54
Pielou Evenness	0.86	0.81	0.81	0.79
% EPT Individuals	38	51	43	66
% Ephemeroptera	17	28	9	32
% Plecoptera	14	22	14	23
% Tricoptera	7	1	20	11
% Chironomidae	11	5	15	12
% of 5 dominant taxa	54	67	57	63

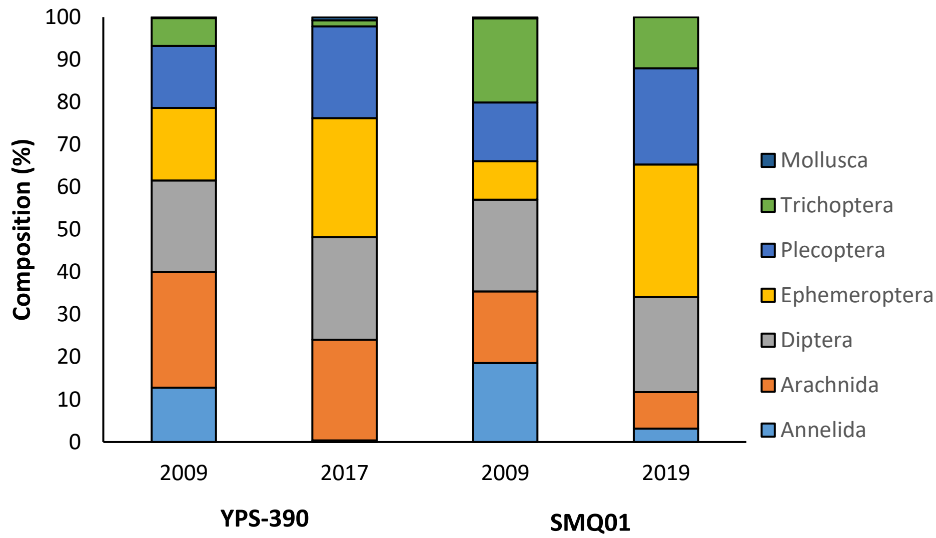


Figure 13. Summary of the composition of the major taxa during each sampling event

5.4 Water quality evolution along the South McQuesten River

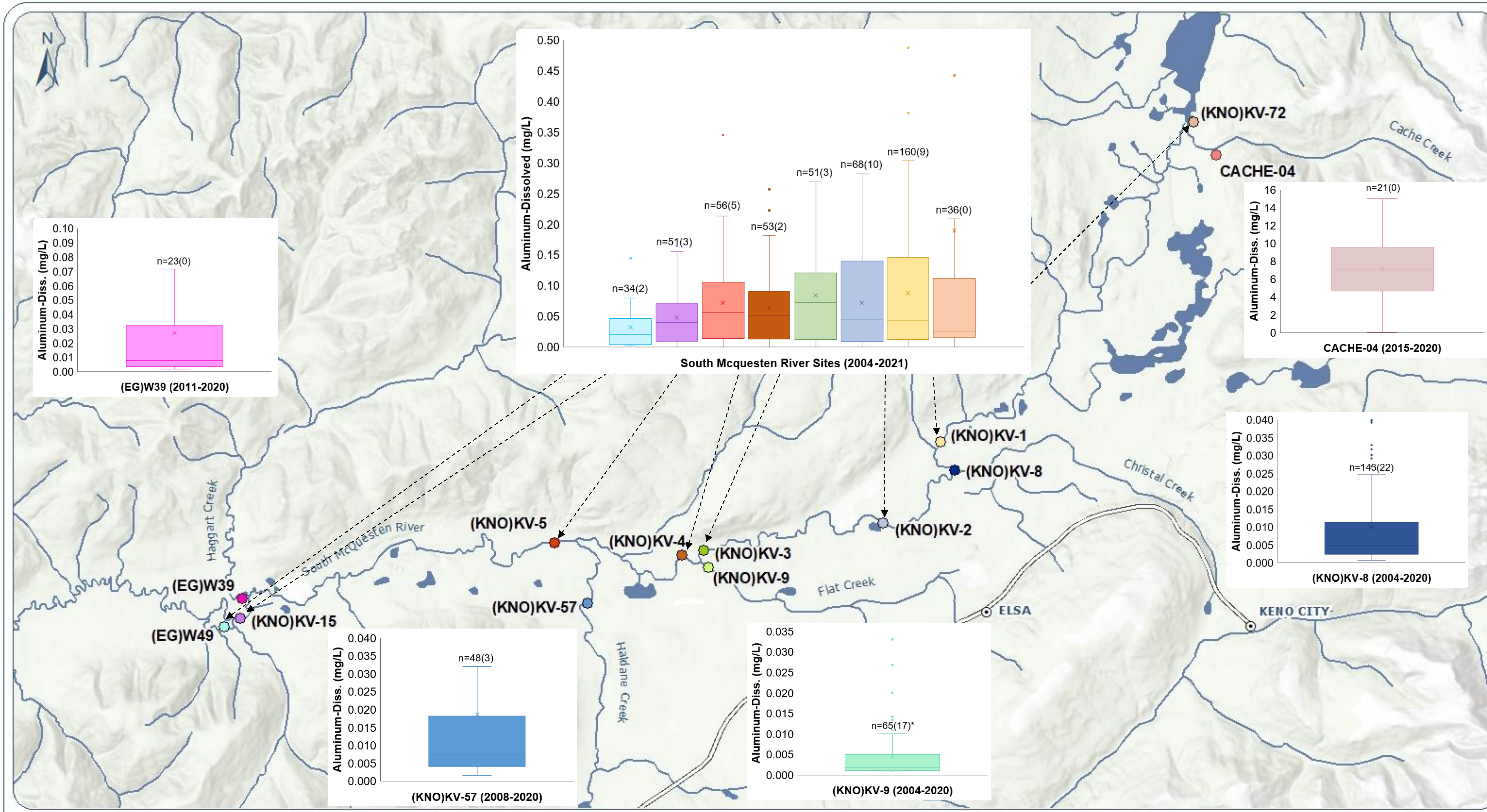
Water quality changes along the flow path of any given rivers and creeks. The evolution of aluminum, arsenic, cadmium, copper, lead, zinc, pH and sulphate is presented, from the most upstream monitoring site, the headwater lake, (KNO)KV-72, to the most downstream monitoring site of the South McQuesten River, (EG)W49, downstream of Haggart Creek.

The box plots in the sections below show the distribution of dissolved aluminum, arsenic, cadmium, copper, lead and zinc as well as pH and sulphate at a number of sites along the reach of the South McQuesten River. Each boxplot consists of three sections which represents specific ranges within the dataset. The bottom of the box represents the lower 25 per cent of the data, also called the lower quartile. Data within the box represent the middle 50 per cent range, or the interquartile range. The top of the box represents the upper 25 per cent of the data, or upper quartile. The minimum and maximum values, excluding outliers, are the bottom and top of the respective whisker. The median is represented by the line inside the box while the "X" inside the box represents the mean value. For this analysis, water quality concentrations that were less than the detection limit value were set to equal the detection limit. This was to ensure that the data was included in the analysis but reduced biased estimates of calculated values (i.e. lower quartile and medians). The "n" and bracket values indicates the number of data considered to create the box and whisker and number of data below the detection limit is indicated in brackets respectively. A "*" was included for stations where more than 20 per cent of the data was below the detection limit.

Note that the scale of the y-axis differs amongst the graphs due to varying ranges of concentrations and to support data interpretation. The frequency of sampling at the monitoring sites varies between the sample sites; therefore, the number of samples used to calculate the quartile varies. The long-term monitoring station was not included in this part of the assessment since dissolved metals were not monitored at this station.

5.4.1 Dissolved aluminum

The average concentration of dissolved aluminum increases in the South McQuesten River downstream of Cache Creek inflow until Flat Creek (Figure 14). The concentration declined downstream of the Flat Creek confluence. Cache Creek had the highest dissolved aluminum concentrations measured amongst all of the sampled locations along the South McQuesten tributaries with a mean concentration of 7.14mg/L (n = 21). Whereas Flat Creek (KNO)KV-9 tended to have the lowest concentrations amongst all the sites and over 20 per cent of the data was below the detection limit (mean concentration = 0.004mg/L, n = 65).



1:125,000 When printed on 11 by 17 inch paper

0 2.5 5 7.5 Kilometres

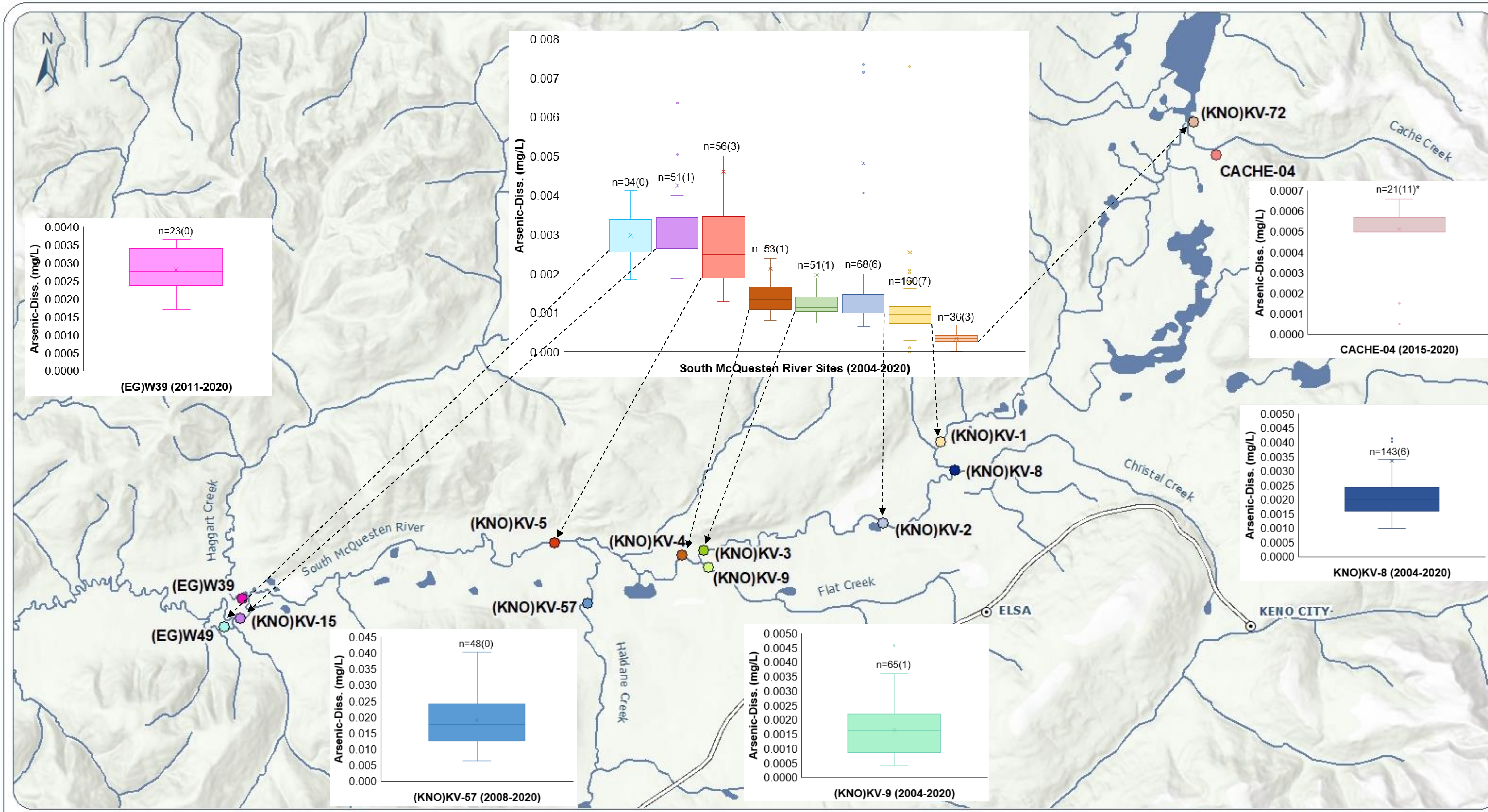
Watercourse and waterbody data from Topographic Data of Canada - CanVec Series at a scale of 1:250,000. Background imagery/hillshade: Airbus, USGS, NGA, NASA, CGIAR, NCEAS, NLS, OS, NMA, Geodatastyrelsen, GSA, GSI and the GIS User Community.

Figure 14.
DISSOLVED ALUMINUM CONCENTRATIONS WITHIN THE SOUTH MCQUESTEN RIVER AND TRIBUTARIES

OCTOBER 2021

5.4.2 Dissolved arsenic

Arsenic concentration increases as the water progresses downstream, with a jump in concentration between (KNO)KV-4 and (KNO)KV-5 (Figure 15). Two tributary streams discharge into the South McQuesten River between the two sample sites, Shanghai Creek and Haldane Creek. No monitoring sites are located within Shanghai Creek. However, data from (KNO)KV-57 on Haldane Creek suggest that this creek contributes to the increase in dissolved arsenic concentrations observed in the South McQuesten River downstream of the confluence (Figure 15). Haldane Creek concentrations were at least an order of magnitude higher than what was observed at other monitored sites. The mean concentrations observed at Haldane Creek and the closest upstream site (KNO)KV-4 was 0.02mg/L and 0.002mg/L respectively. Further downstream and below Haggart Creek, the mean arsenic concentration increased to 0.003 mg/L. Over half of the data at Cache Creek was below detection limit (n=21).



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Watercourse and waterbody data from Topographic Data of Canada - CanVec Series at a scale of 1:250,000. Background imagery/hillshade: Airbus, USGS, NGA, NASA, CGIAR, NCEAS, NLS, OS, NMA, Geodatastyrelsen, GSA, GSI and the GIS User Community.

Figure 15.
DISSOLVED ARSENIC CONCENTRATIONS WITHIN THE SOUTH MCQUESTEN RIVER AND TRIBUTARIES

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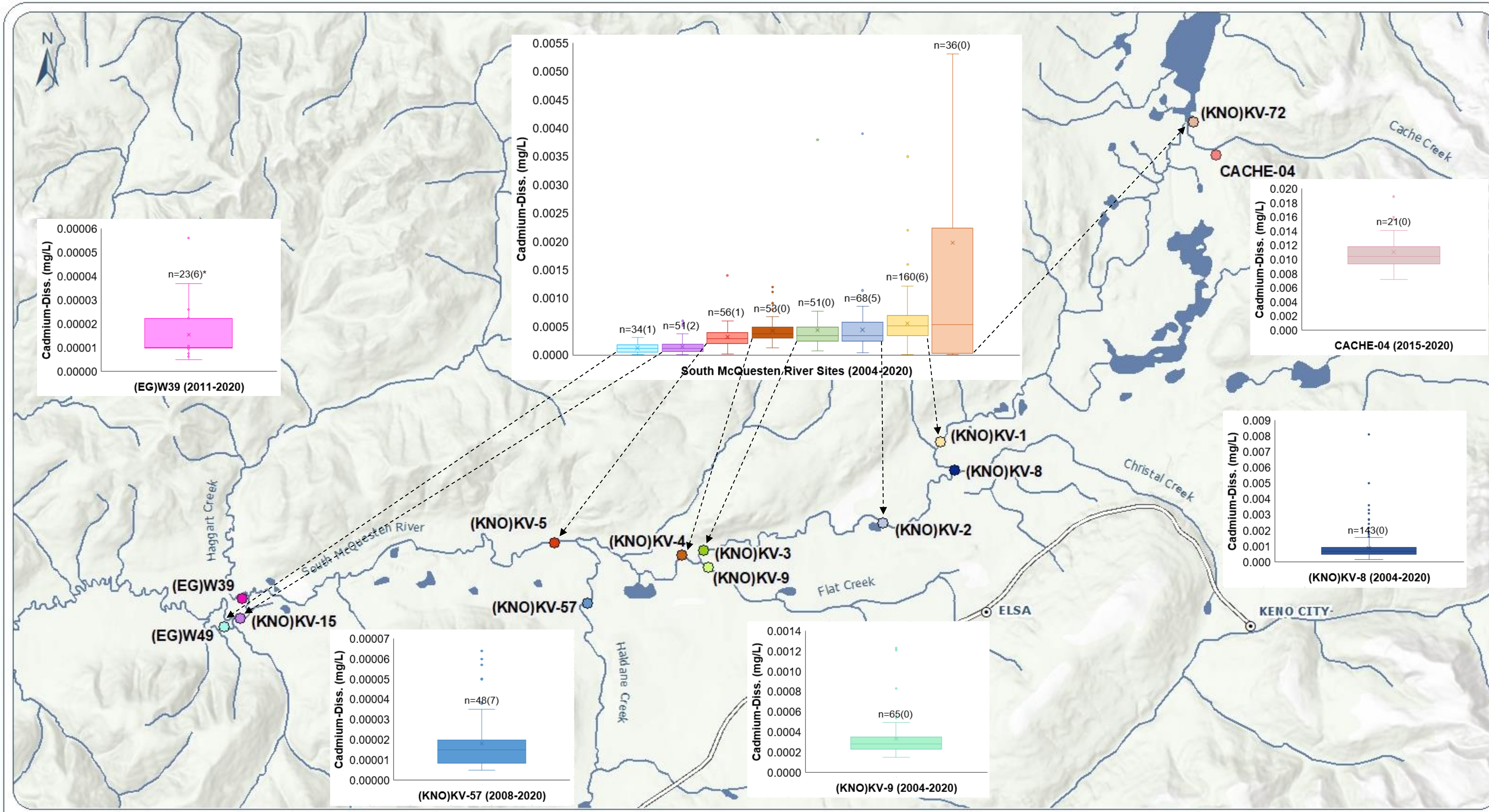
5.4.3 Dissolved cadmium

Dissolved cadmium concentrations tend to be high upstream at (KNO)KV-72 and in Cache Creek with mean concentrations of 0.002 and 0.011 mg/L respectively (Figure 16). However, the range of concentration drops once the water reaches (KNO)KV-1. There is a slight steady decline of cadmium concentration as the water progresses downstream. Christal Creek ((KNO)KV-8) also had slightly higher cadmium levels than the upstream site (KNO)KV-1 on the South McQuesten. However, the contribution of cadmium from Christal Creek is not reflected in the downstream water quality data. Haggart Creek ((EG)W39) had the lowest mean concentration of dissolved cadmium amongst the observed stations and more than 20 per cent of the data below the detection limit (mean concentration = 0.000015mg/L, n=23). The lower cadmium concentration from Haggart Creek is reflected in the downstream water quality data.



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Watercourse and waterbody data from Topographic Data of Canada - CanVec Series at a scale of 1:250,000. Background imagery/hillshade: Airbus, USGS, NGA, NASA, CGIAR, NCEAS, NLS, OS, NMA, Geodatastyrelsen, GSA, GSI and the GIS User Community.

Figure 16.
DISSOLVED CADMIUM CONCENTRATIONS WITHIN THE SOUTH MCQUESTEN RIVER AND TRIBUTARIES

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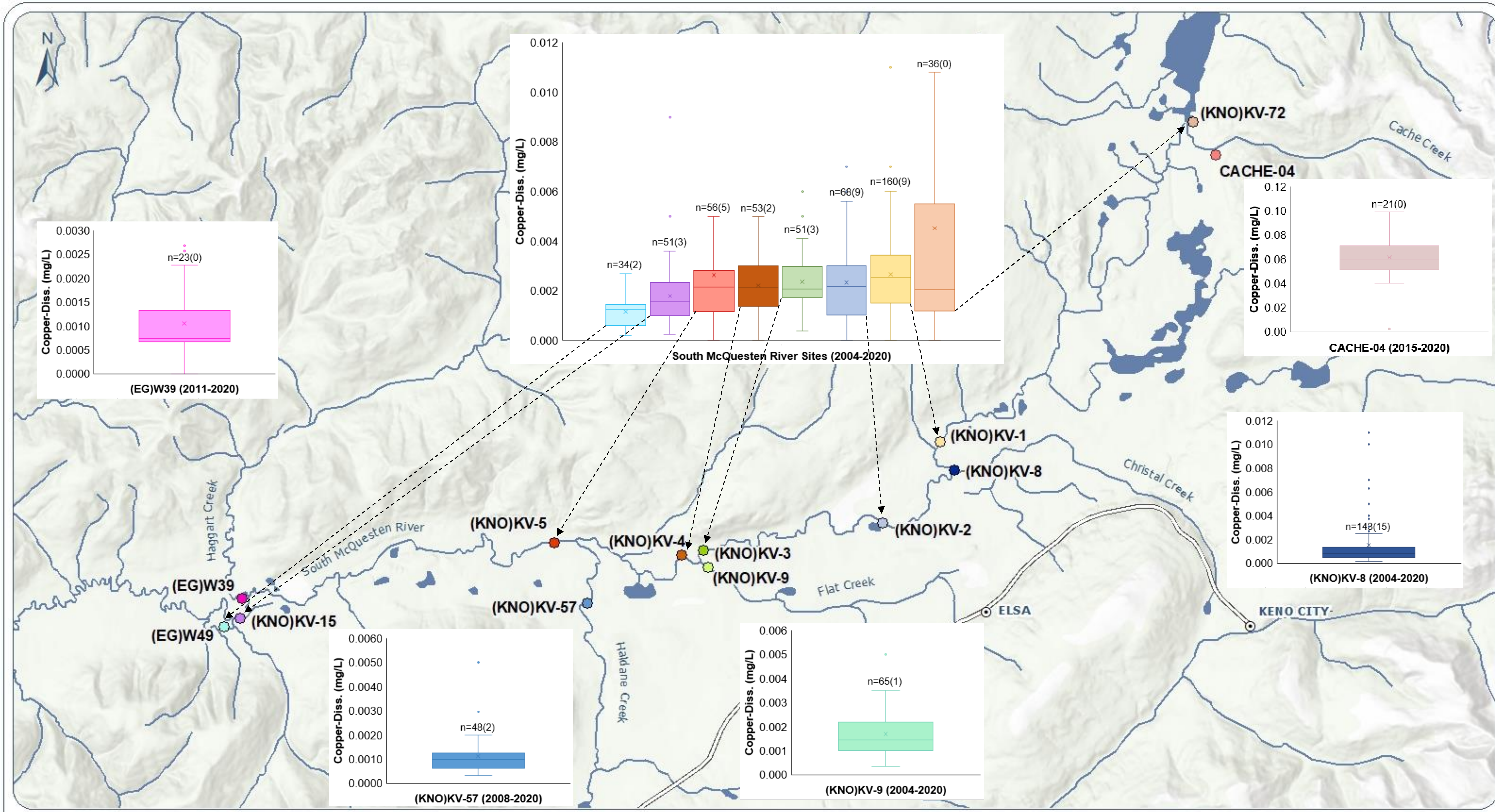
5.4.4 Dissolved copper

The concentration of dissolved copper concentrations between (KNO)KV-72 and (KNO)KV-1 reduces, after which point the concentration does not vary much as the water moves downstream until there is a small reduction starting at (KNO)KV-15 (Figure 17). Cache Creek concentrations were typically an order of magnitude higher than the other monitored sites along the South McQuesten (mean concentration = 0.06mg/L, n=21). There does not seem to be a lasting effect of the Cache Creek discharge on the main river since the concentration is greatly reduced by the time the water reaches the next downstream station at (KNO)KV-1 (mean concentration = 0.003mg/L, n=160).



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Watercourse and waterbody data from Topographic Data of Canada - CanVec Series at a scale of 1:250,000. Background imagery/hillshade: Airbus, USGS, NGA, NASA, CGIAR, NCEAS, NLS, OS, NMA, Geodatastyrelsen, GSA, GSI and the GIS User Community.

Figure 17.
DISSOLVED COPPER CONCENTRATIONS WITHIN THE SOUTH MCQUESTEN RIVER AND TRIBUTARIES

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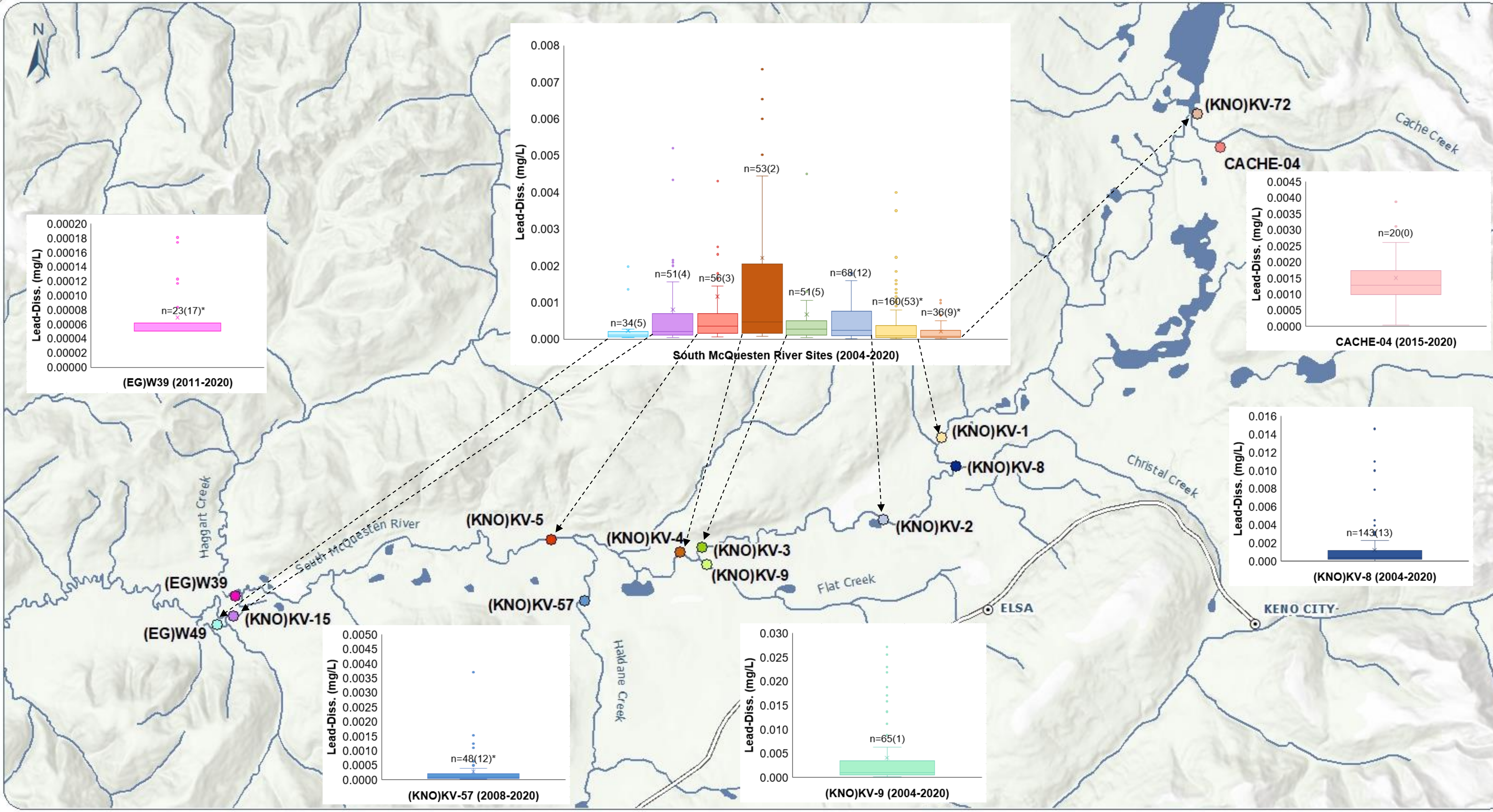
5.4.5 Dissolved lead

A large variability in the distribution of dissolved lead concentrations occurred at (KNO)KV-2 and (KNO)KV-4, which are downstream of Christal Creek and Flat Creek respectively (Figure 18). Both KV-2 and KV-4 have the highest concentrations observed along the South McQuesten monitoring stations, both having a mean concentration of 0.002mg/L (n=68 and 53 respectively). Christal Creek ((KNO)KV-8) had some of the highest measured concentration values of dissolved lead with a large distribution in the data, yet it does not seem to contribute to the concentrations observed downstream at (KNO)KV-2. The source of the lead concentration is unknown as upstream concentrations at sites (KNO)KV-1 on the main river and (KNO)KV-8 on Christal Creek typically have lower concentrations of dissolved lead (both with mean concentrations of 0.001mg/L). The higher dissolved lead concentration observed at (KNO)KV-4 may come from the high concentrations of dissolved lead from the Flat Creek discharge ((KNO)KV-9). There appears to be a reduction in dissolved lead concentration as the river continues downstream and the variability within the concentrations also progressively decreases along the river. There were a number of non-detect values and several sites with more than 20% of the data below detection limits, including KV-72, KV-1, W39 and KV-57. In particular, 17 samples out of 23 have lead (Pb) concentrations below the detection limit at EG(W39).



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Watercourse and waterbody data from Topographic Data of Canada - CanVec Series at a scale of 1:250,000. Background imagery/hillshade: Airbus, USGS, NGA, NASA, CGIAR, NCEAS, NLS, OS, NMA, Geodatastyrelsen, GSA, GSI and the GIS User Community.

Figure 18.
DISSOLVED LEAD CONCENTRATIONS WITHIN THE SOUTH MCQUESTEN RIVER AND TRIBUTARIES

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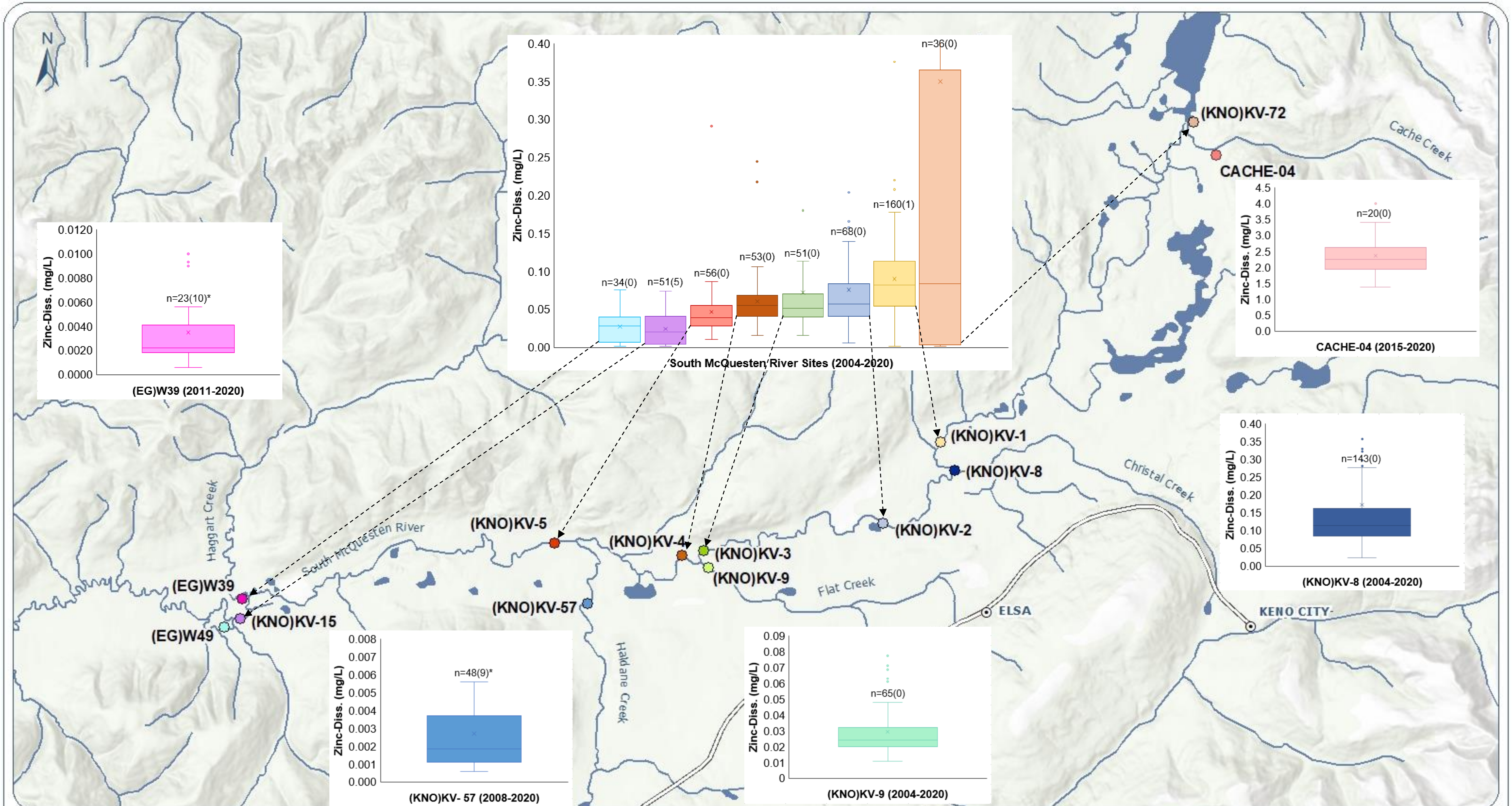
5.4.6 Dissolved zinc

Cache Creek has the highest dissolved zinc concentrations amongst the observed stations ranging between 1.39 to 4 mg/L (n=21; Figure 19). The discharge from Cache Creek likely influences the large distribution of dissolved zinc concentrations reported at (KNO)KV-72. The distribution of data and mean value decreases as the South McQuesten River progresses downstream. A small increase in mean concentration occurs between (KNO)KV-15 and (EG)W49. Station (EG)W49 is downstream of Haggart Creek; however, the Haggart Creek monitoring site ((EG)W39) has the lowest mean zinc concentration amongst all the monitoring stations and is unlikely to cause the observed small increase at (EG)W49. Haldane Creek ((KNO)KV-57) and Haggart Creek ((EG)W39) have the lowest concentrations and have more than 20 per cent of the data below the detection limit.



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Watercourse and waterbody data from Topographic Data of Canada - CanVec Series at a scale of 1:250,000. Background imagery/hillshade: Airbus, USGS, NGA, NASA, CGIAR, NCEAS, NLS, OS, NMA, Geodatastyrelsen, GSA, GSI and the GIS User Community.

Figure 19.
DISSOLVED ZINC CONCENTRATIONS WITHIN THE SOUTH MCQUESTEN RIVER AND TRIBUTARIES

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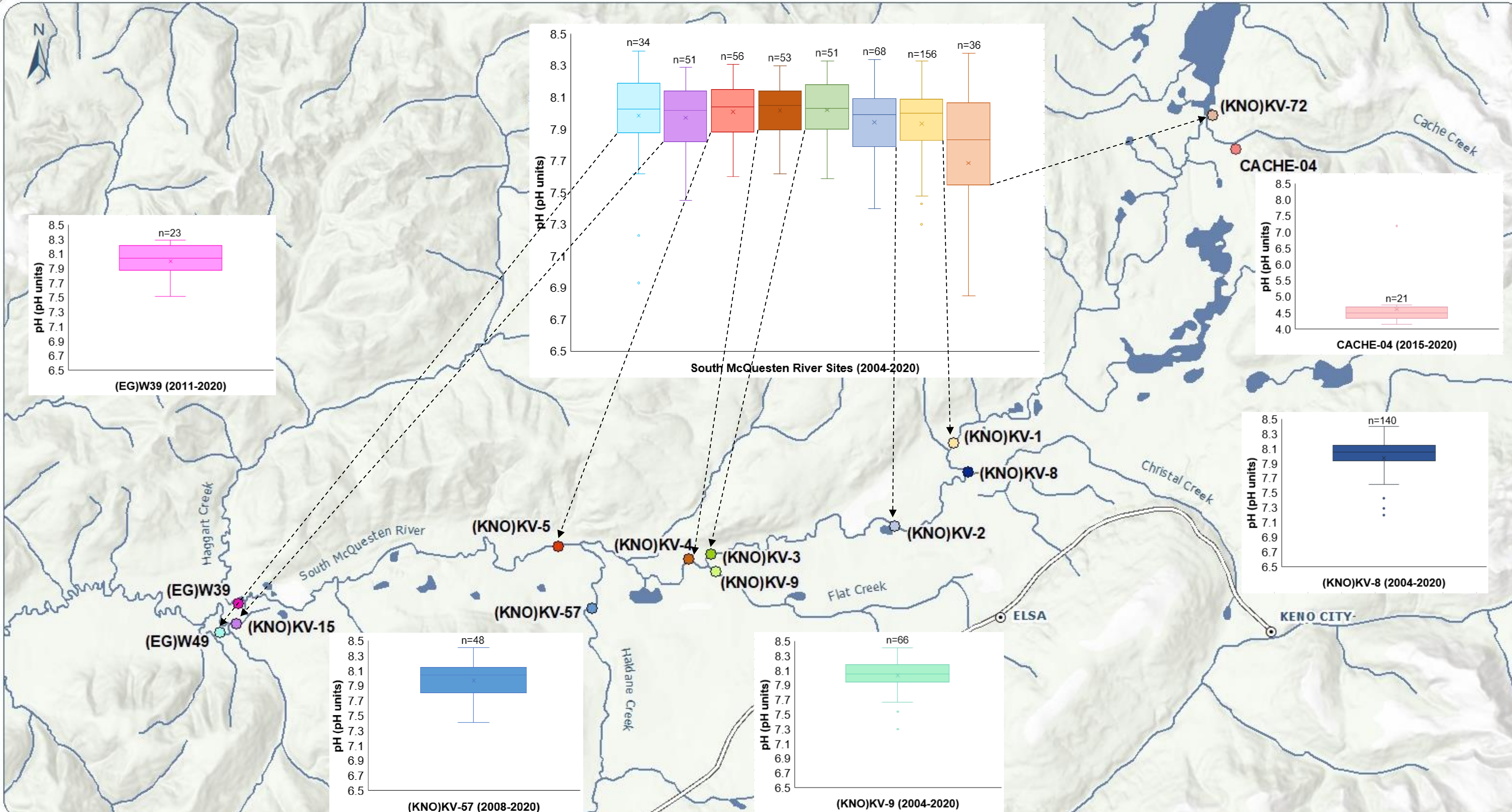
5.4.7 pH

Variability within water pH tended to be steady across the entire river with mean values ranging from 7.69 to 8.04 (Figure 20). The pH observed at KV-72 had a larger variability of pH values and the lowest mean pH at 7.69, compared to the rest of the observed values on the South McQuesten but it is not considered to be a significant difference. Cache Creek was the only tributary that had a significantly different pH, with water being acidic. The mean pH value in Cache Creek is 4.61. The acidic discharge of Cache Creek into the South McQuesten River does not seem to significantly influence the pH in the River. At (KNO)KV-1, the pH is alkaline with a mean value of 7.94 (n = 156).



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Watercourse and waterbody data from Topographic Data of Canada - CanVec Series at a scale of 1:250,000. Background imagery/hillshade: Airbus, USGS, NGA, NASA, CGIAR, NCEAS, NLS, OS, NMA, Geodatastyrelsen, GSA, GSI and the GIS User Community.

Figure 20.
pH WITHIN THE SOUTH MCQUESTEN RIVER AND TRIBUTARIES

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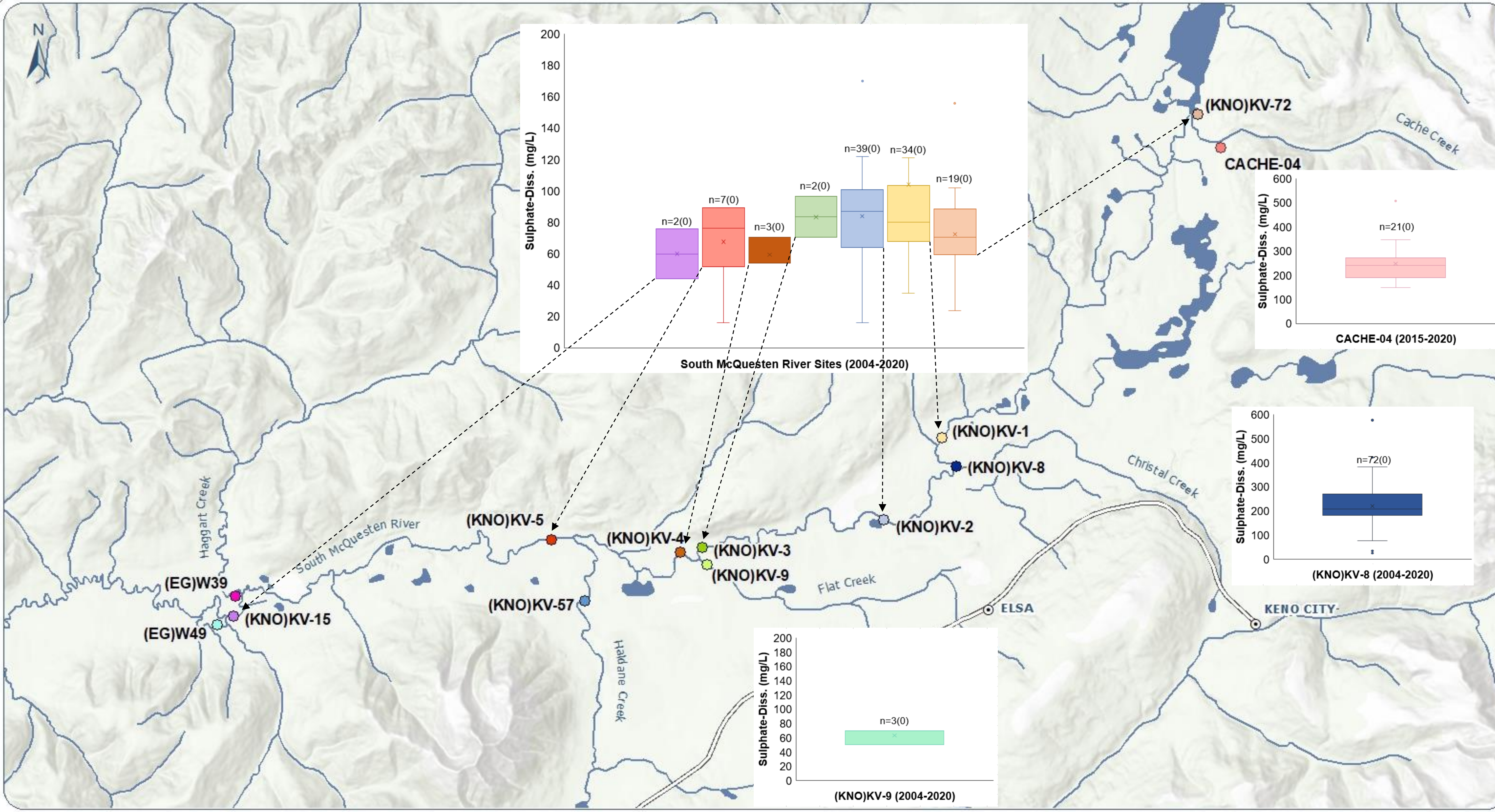
5.4.8 Sulphate

Cache and Christal Creeks had significantly higher sulphate concentrations than all of the other observed sites on the main channel and tributaries of the watershed (Figure 21). The mean concentrations were 249mg/L at Cache Creek and 218mgL at Christal Creek while the other monitoring stations have a mean sulphate concentration ranging between 59.47-104.12mg/L. The distribution of sulphate concentrations was lowest at (KNO)KV-15 on the main channel. Stations (KNO)KV-57 (EG)W39 and (EG)W49 did not have any sulphate data between 2004 to 2020 for comparison.



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Watercourse and waterbody data from Topographic Data of Canada - CanVec Series at a scale of 1:250,000. Background imagery/hillshade: Airbus, USGS, NGA, NASA, CGIAR, NCEAS, NLS, OS, NMA, Geodatastyrelsen, GSA, GSI and the GIS User Community.

Figure 21.
DISSOLVED SULPHATE CONCENTRATIONS WITHIN THE SOUTH MCQUESTEN RIVER AND TRIBUTARIES

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5.5 Trends in water quality over the last decade

Trends in water quality over the ten year period between 2009 and 2018 were analysed by ECCC for 51 water quality parameters at the long-term monitoring network station YT09DD0008, in the South McQuesten River below the Flat Creek Juncture. The complete trend report is available upon request from water.resources@yukon.ca. Figure 22 presents the annual percent trend for all 51 parameters that were analysed. Among these 51 parameters analysed, 15 parameters exhibited a significant Seasonal Kendall trend, with a p-value below 0.10. The trending parameters include pH, turbidity, nitrogen, phosphorous, chloride, arsenic, beryllium, boron, cerium, chromium, copper, lanthanum, molybdenum and yttrium.

Six parameters indicate a decreasing trend (slope <0) and nine parameters had an increasing trend (slope >0) amongst the 2009 to 2018 data (Table 11). Three parameters (total niobium, platinum and tin) did not meet the selection criteria and were excluded from further consideration in trend analysis because the data was below the method detection limit more than 80 per cent of the time.

Note that the summary table below presents the trend from year to year. The Seasonal Kendall test assumes a single (monotonic) trend across all seasons and provides a summary statistic for the entire record. There may be instances in which some months exhibit an upward trend, and others that show evidence of a downward trend, and yet the result indicates no evidence of annual trend (Hirsch et al., 1982).

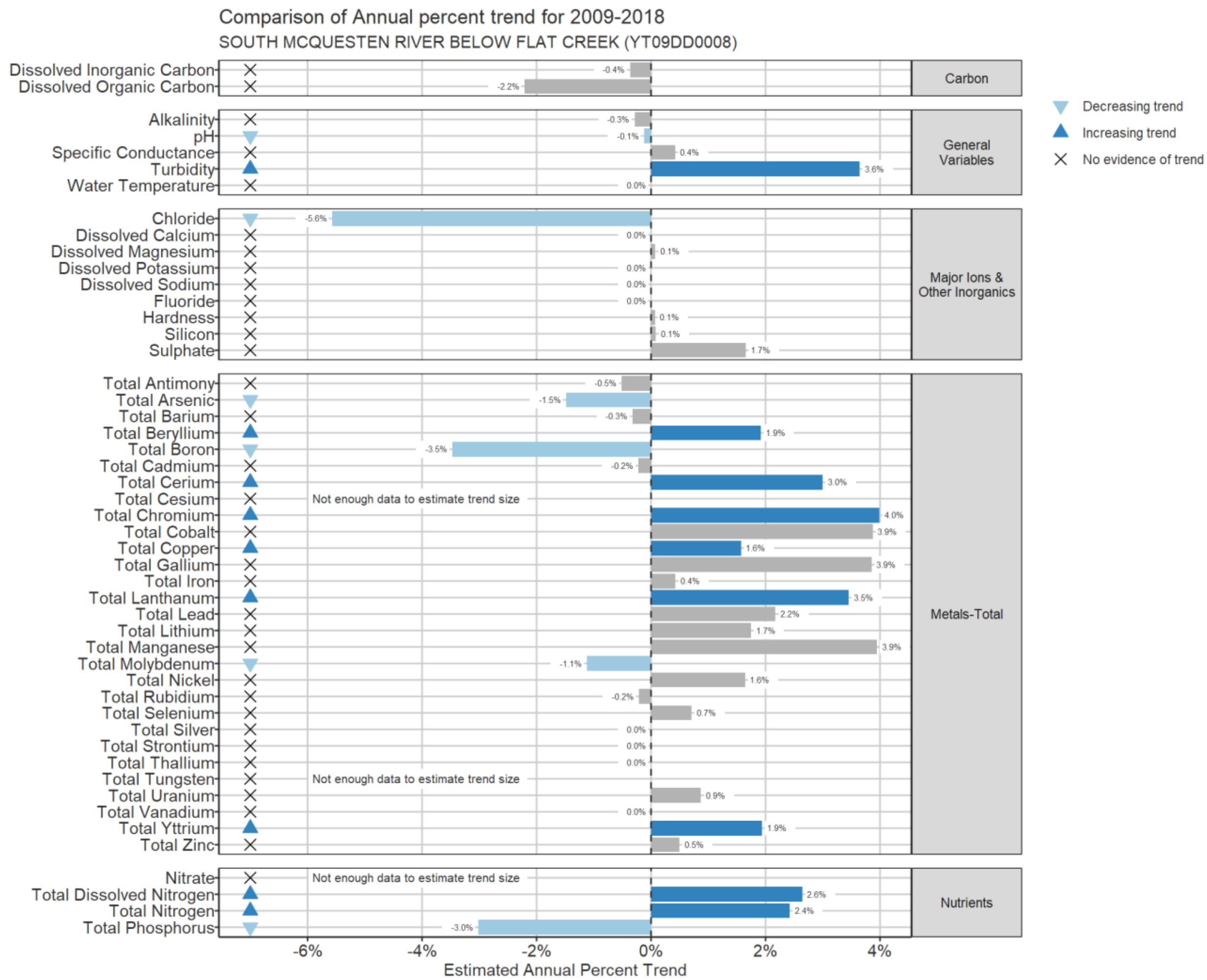


Figure 22 Comparison of annual percent trend at the long-term monitoring station (YT09DD0008) from 2009-2018 for all parameters analyzed.

Table 11. Summary statistics for parameters exhibiting significant water quality trends at the long-term monitoring station (YT09DD0008) over 10 year period (2009-2018).

Parameter	Data Record		Summary Statistics				Annual Trends from 2009-2018			
	n	%BDL	min	mean	median	Max	Slope	% Slope	p value	Trend Category
General Chemistry										
pH (pH units)	105	0	7.73	8.09	8.11	8.29	-0.010	-0.1	0.040	Decreasing
Turbidity (NTU)	105	0	0.94	5.21	1.80	83.00	0.059	3.6	0.061	Increasing
Anions and Nutrients (mg/L)										
Chloride	105	1	<0.1	0.8	0.6	2.6	-0.03	-5.8	0.036	Decreasing
Dissolved Nitrogen(as N)	99	0	0.13	0.24	0.23	0.63	0.005	2.6	0.014	Increasing
Total Nitrogen (as N)	101	0	0.14	0.26	0.25	0.68	0.005	2.4	0.036	Increasing
Total Phosphorus (as P)	100	0	0.0032	0.0123	0.0060	0.1500	-0.00020	-3.0	0.056	Decreasing
Metals – Total (µ/L)										
Arsenic	103	0	1.18	1.95	1.73	8.09	-0.025	-1.5	0.091	Decreasing
Beryllium	102	1	<0.001	0.016	0.008	0.080	0.0002	1.9	0.016	Increasing
Boron	103	1.9	<0.5	2.0	1.7	5.3	-0.06	-3.5	0.056	Decreasing
Cerium	103	0	0.018	0.541	0.352	2.410	0.0148	3.0	0.016	Increasing
Chromium	101	2	<0.020	0.149	0.070	2.240	0.0025	4.0	0.033	Increasing
Copper	102	0	0.41	3.08	2.42	10.50	0.052	1.6	0.050	Increasing
Lanthanum	103	0	0.015	0.283	0.188	1.250	0.0085	3.5	0.013	Increasing
Molybdenum	103	0	0.35	0.66	0.60	1.34	-0.006	-1.1	0.040	Decreasing
Yttrium	103	0	0.036	0.450	0.288	1.780	0.0085	1.9	0.052	Increasing

Note: n = number of samples; BDL = below (highest) detection limit; p value = p-value of trend test (p=0.1); slope = slope in units/year; %Slope = slope expressed as a percent of the median of the first two years; Trends were calculated using Seasonal Kendall test with a 90% confidence level (alpha = 0.1)

5.5.1 Parameters with significant decreasing trends

Significant downward trends are observed for pH, chloride, total phosphorus, arsenic, boron and molybdenum are displaying in the 2009-2018 period at the long-term station. The following sections present the detailed trends for each of these decreasing parameters.

5.5.1.1 pH

There is a slight downward trend exhibited in the study set for pH between 2009 and 2018 (Figure 23-Figure 25). The trend is a nominal shift of 0.010 units per year. The average pH for the final year in the data set was 8 and CCME lists pH 6.5 to 9 being optimal for long-term aquatic life exposure. While there is no apparent source driving the trend it could be related to climate change and/or development in the upper watershed having a slight acidification effect on the pH of the overall system.

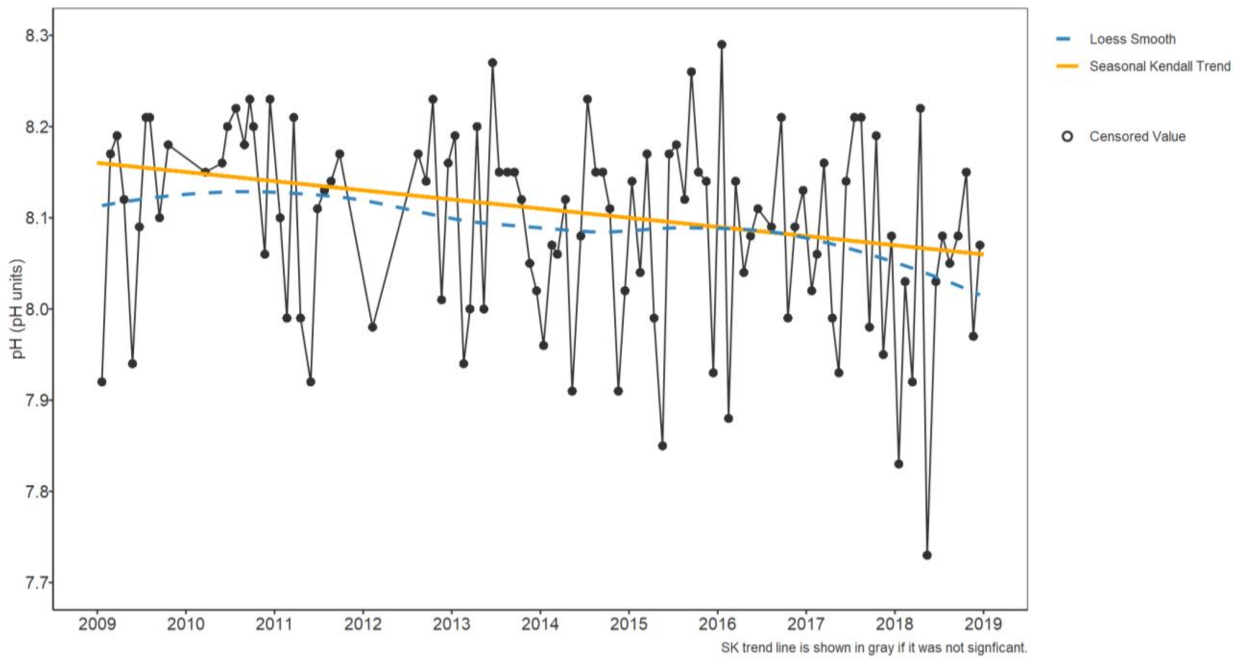


Figure 23. Distribution of pH between 2009-2018 using Seasonal Kendall Trend analysis

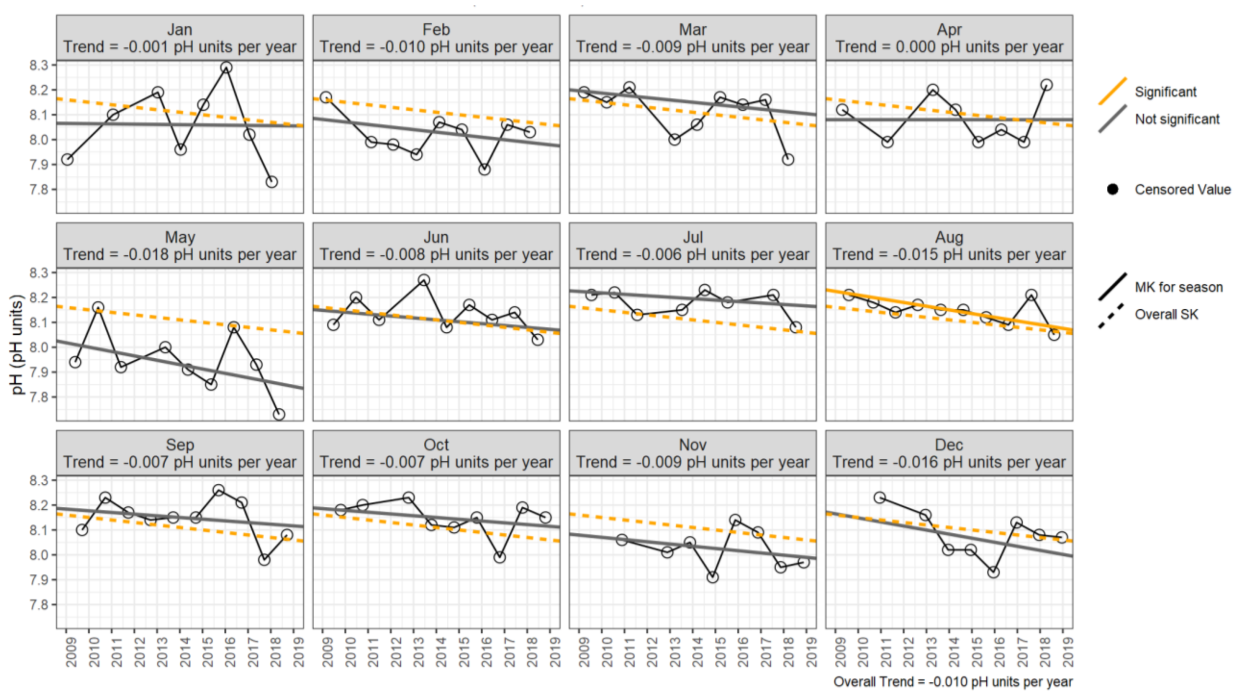


Figure 24. Monthly distribution of pH from 2009-2018 using Mann-Kendall

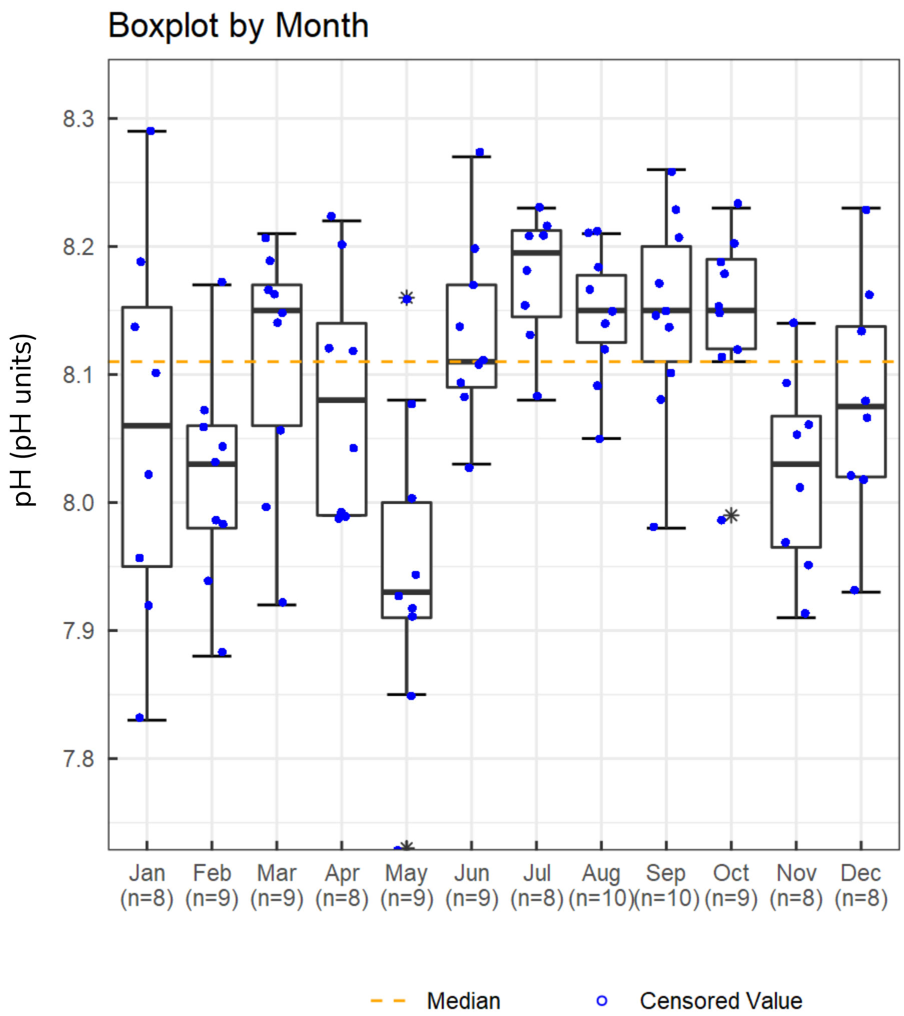


Figure 25. Monthly range of pH from 2009-2018

5.5.1.2 Chloride

The data analysis shows a decreasing trend for chloride in the system of 0.03mg/L per year (Figure 26-Figure 28). Chloride is naturally occurring and quite stable in the freshwater environment. What is usually seen in an area with a road network is an increase in chloride from the use of dust and ice control products. As chloride is an essential micronutrient for photosynthetic aquatic organisms it is possible that the uptake has increased with climate change driven effects and the increasing trend observed for nitrogen within the system. In terrestrial environments, chloride is readily acquired by biota.

The long-term chronic CCME guideline for the protection of aquatic life is 120 mg/L and the maximum chloride concentration observed at the long-term monitoring station is 2.6 mg/L.

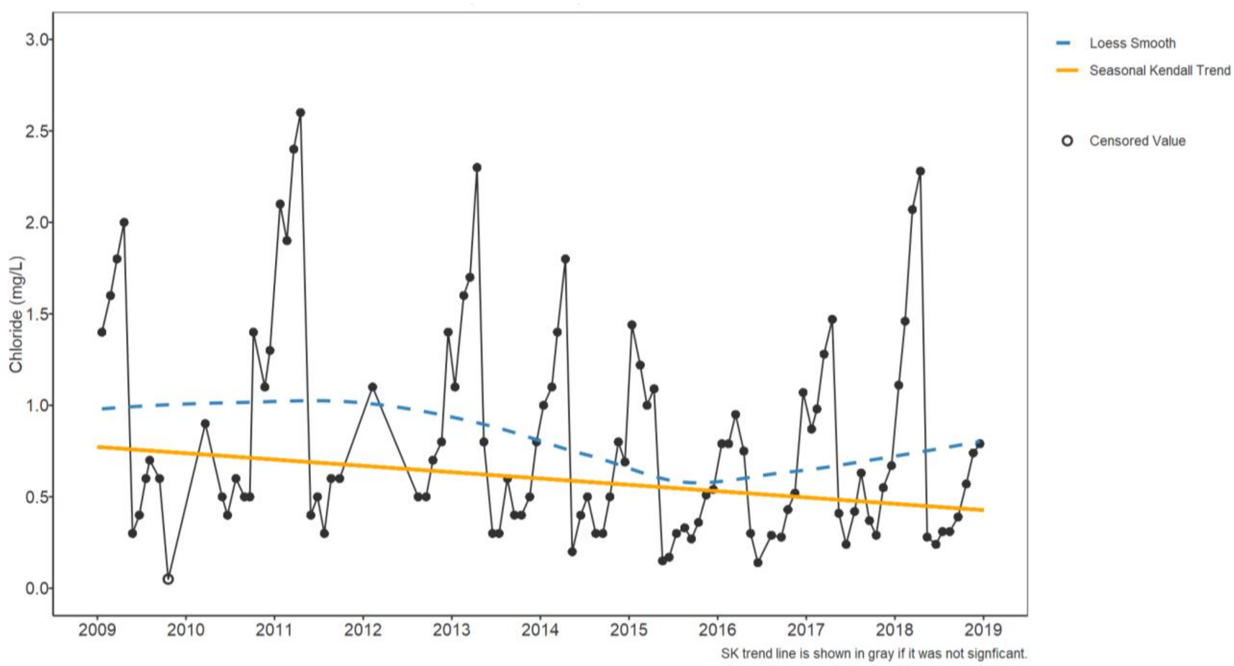


Figure 26. Distribution of chloride concentrations between 2009-2018 using Seasonal Kendall Trend analysis.

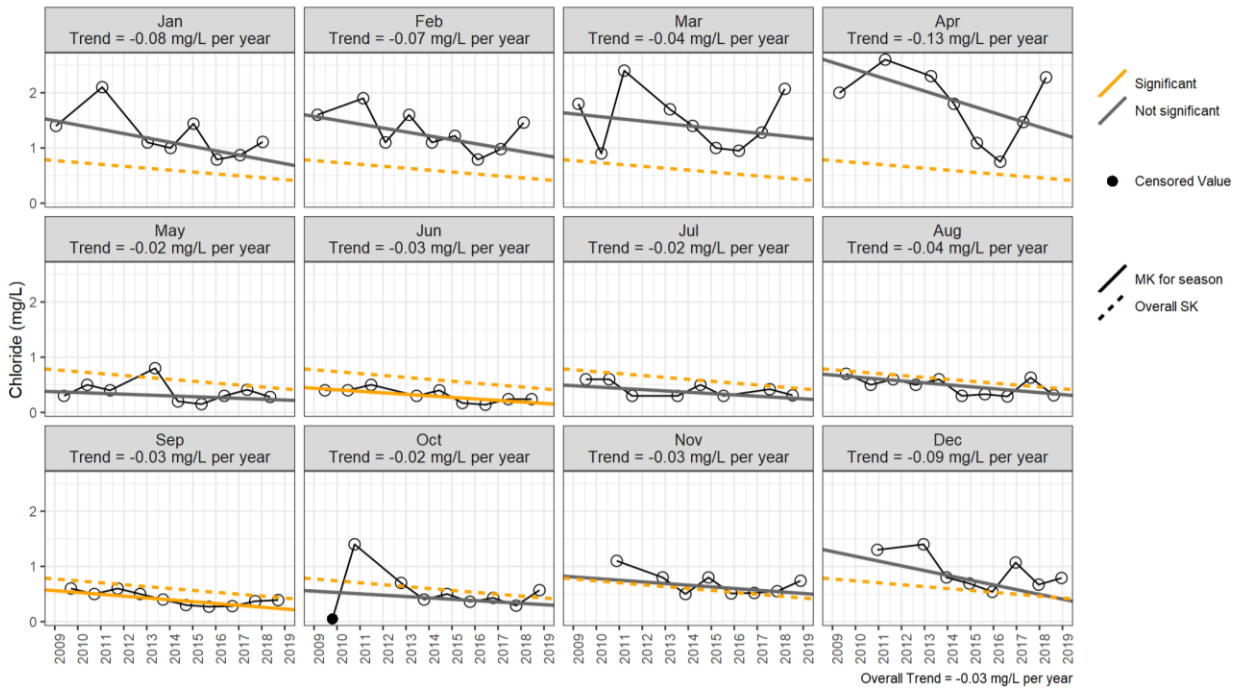


Figure 27. Monthly distribution of chloride from 2009-2018 using Mann-Kendall

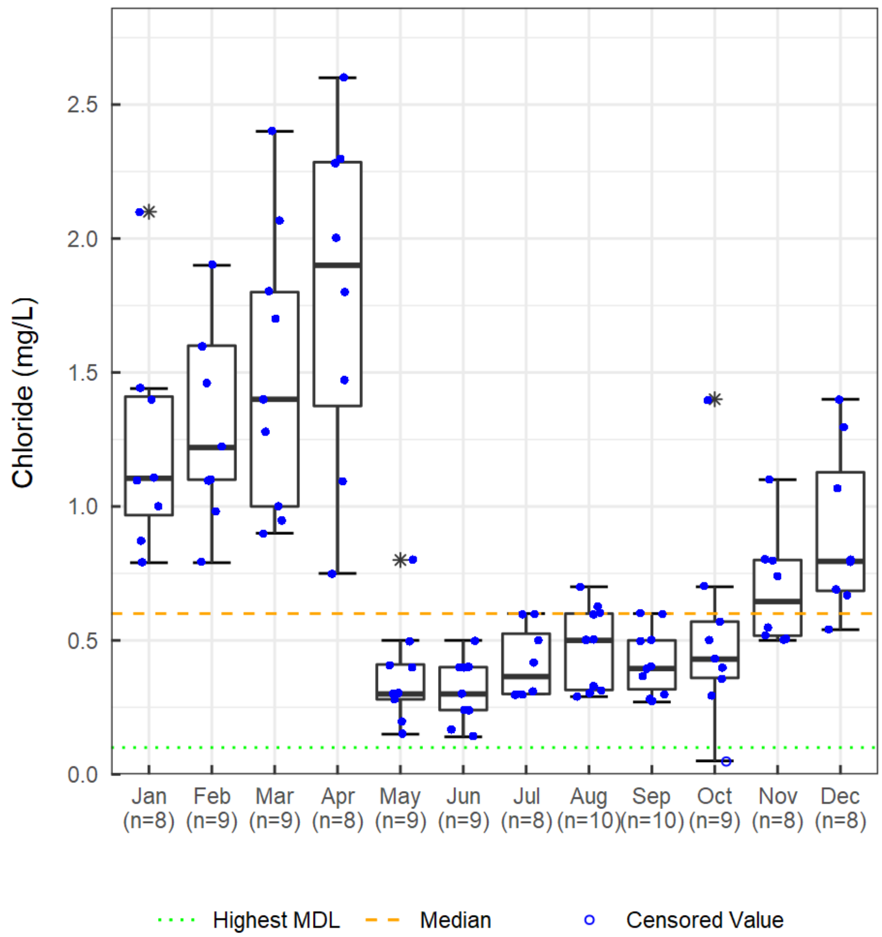


Figure 28. Monthly range of chloride from 2009-2018

5.5.1.3 Total phosphorous

The level of total phosphorous in the system shows a statistically significant decreasing trend using the Mann-Kendall test; however, the rate of decrease is very small and could be considered negligible with a decrease rate of 0.00020 mg/L per year (Figure 29-Figure 31). However, it is interesting to point out that total phosphorus concentrations are increasing significantly in the months of May over the last 10 years, during snow melt, when run-off is the highest. Phosphorous occurs naturally in aquatic systems through the erosion soils. It is a key element to life and the limiting nutrient in aquatic and terrestrial systems. In this system the maximum level of phosphorous occurs during freshet and then reduces to trace levels which would lend credence to an erosion input scenario. Wildfires may cause the increase in erosion of phosphorus and observed increase in concentration in May. On the other hand, lanthanum has an affinity for phosphorous and will form a salt with it that exhibits little solubility. Climate effects and the increasing nitrogen seen in the system may be contributing to increased aquatic plant growth in the system. This along with the increasing lanthanum levels may be contributing to the small gradual decrease in total phosphorous.

The Canadian Guidance Framework for Phosphorus (CCME 2007) presents a method to develop phosphorus guidelines for freshwater and it is based on the trophic status (ultra-oligotrophic <4 µg/L; oligotrophic 4-10 µg/L; mesotrophic 10-20 µg/L; meso-eutrophic 20-35 µg/L; eutrophic 35-100 µg/L; hyper-eutrophic >100 µg/L). The mean concentration of 0.0123 mg/L of total phosphorus generally places the South McQuesten River in the oligotrophic status, however, the observed phosphorus concentration is sometimes found in the ultra-oligotrophic status.

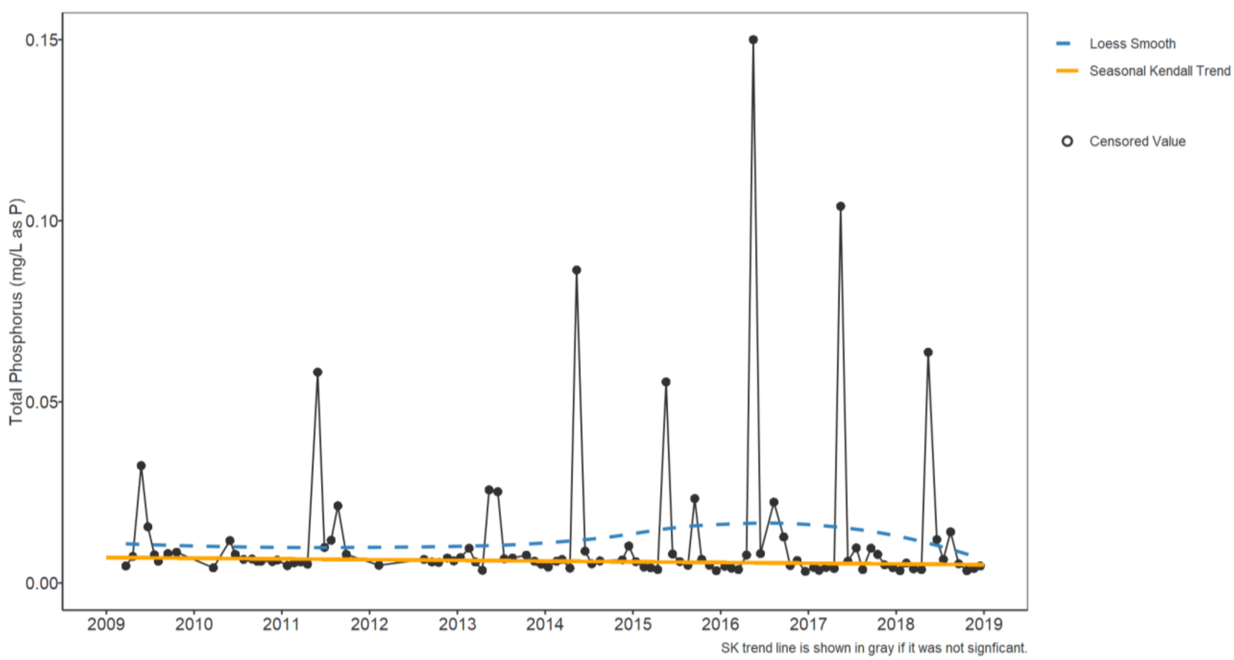


Figure 29. Distribution of total phosphorous concentrations between 2009-2018 using Seasonal Kendall Trend analysis

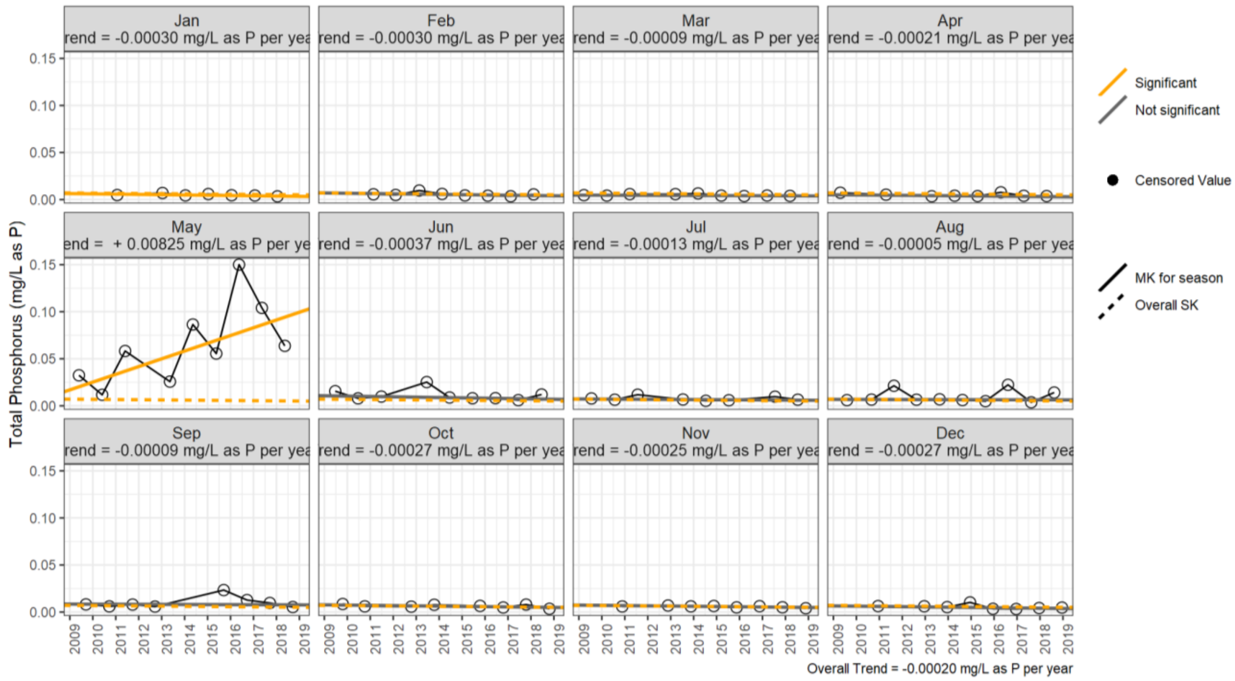


Figure 30. Monthly distribution of total phosphorous from 2009-2018 using Mann-Kendall

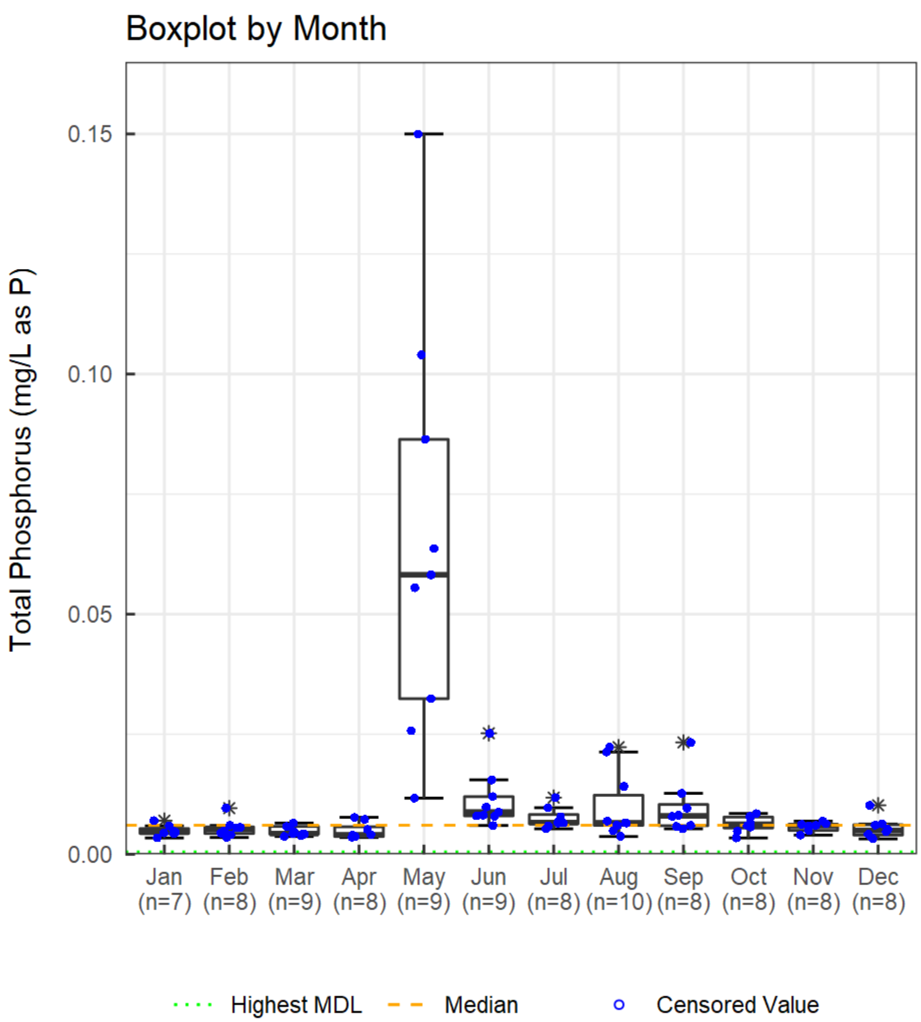


Figure 31. Monthly range of total phosphorous from 2009-2018

5.5.1.4 Arsenic

The level of total arsenic in the system is showing a decreasing trend of 0.025 µg/L per year (Figure 32). The highest levels are within the May freshet, which would indicate an association with suspended particles (Figure 33). The measured arsenic concentrations are well below the long-term CCME water quality guideline of 5 µg/L (upper limit). In May, arsenic concentrations are higher and the maximum observed was 8.09 µg/L. The overall median arsenic concentration, including the months of May, is 1.73 µg/L (Figure 34).

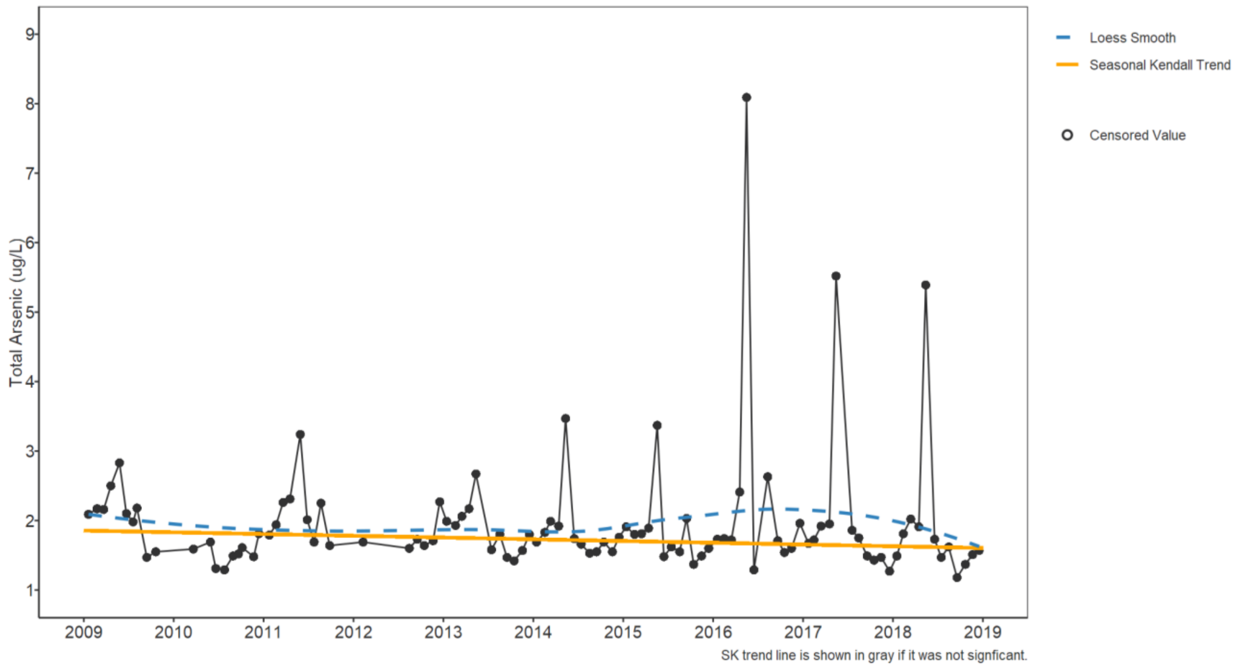


Figure 32. Distribution of total arsenic concentrations between 2009-2018 using Seasonal Kendall Trend analysis

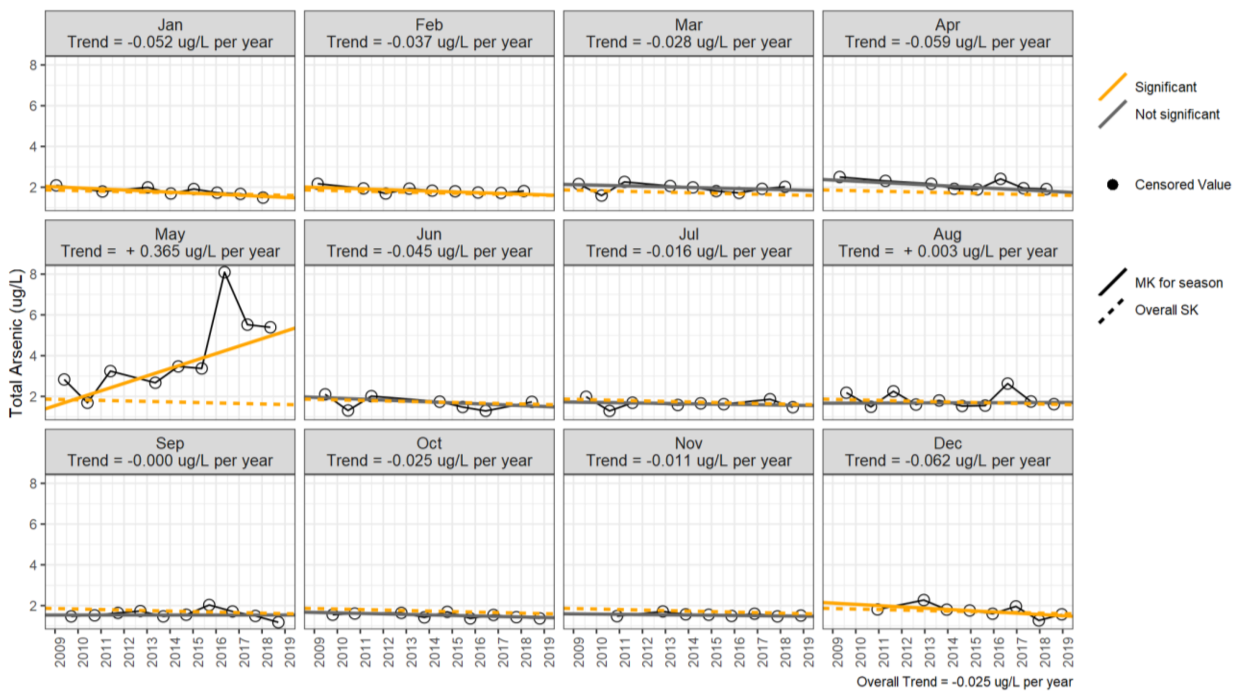


Figure 33. Monthly distribution of total arsenic from 2009-2018 using Mann-Kendall

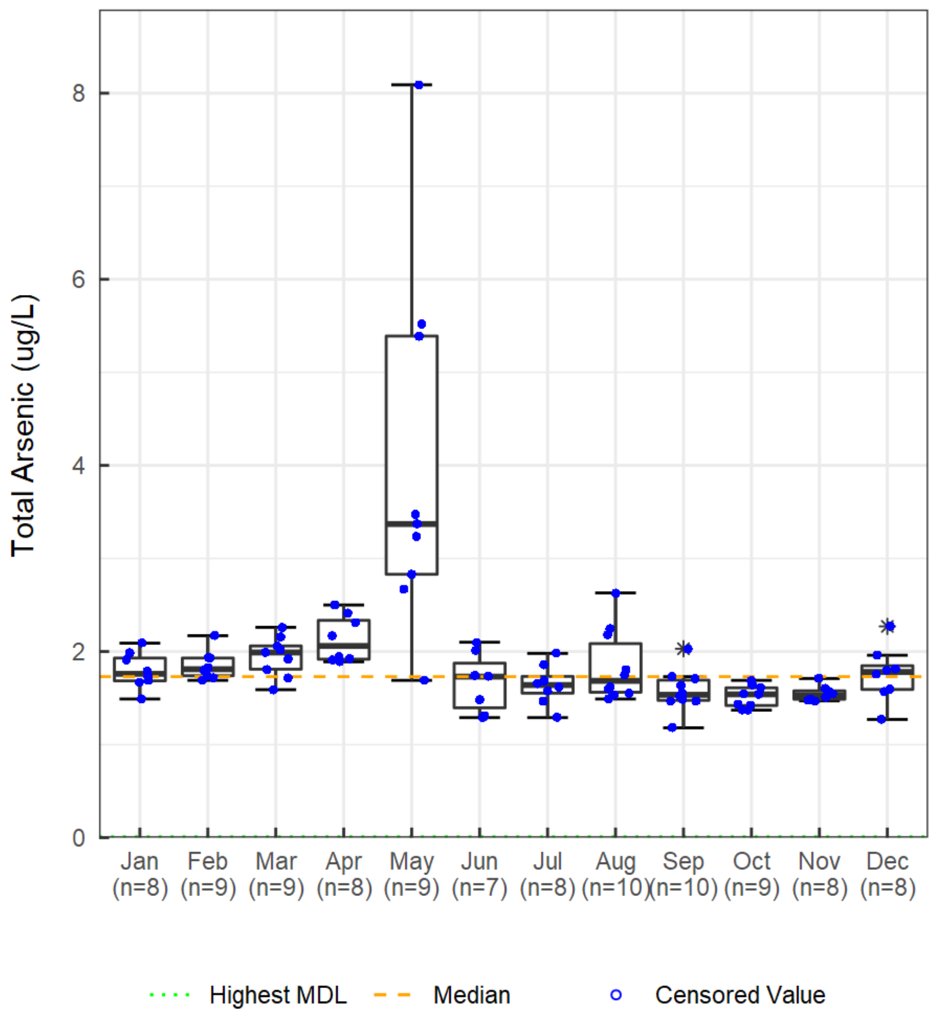


Figure 34. Monthly range of total arsenic from 2009-2018

5.5.1.5 Boron

The trace levels of total boron in the system are decreasing at a rate of 0.06μg/L per year. In non-urbanized areas, the aquatic sources of boron are typically from the erosion of borates in sedimentary rock and are reflective of local geochemistry. It does serve as a micronutrient for aquatic plants so an increase in aquatic plant production, as suggested with chloride, may be driving the reduction. The primary inputs of boron to the system are during the groundwater recharge period during winter through the pre-freshet period (Figure 35 - Figure 37). The long-term CCME water quality guideline for the protection of aquatic life is 1500 μg/L (upper limit).

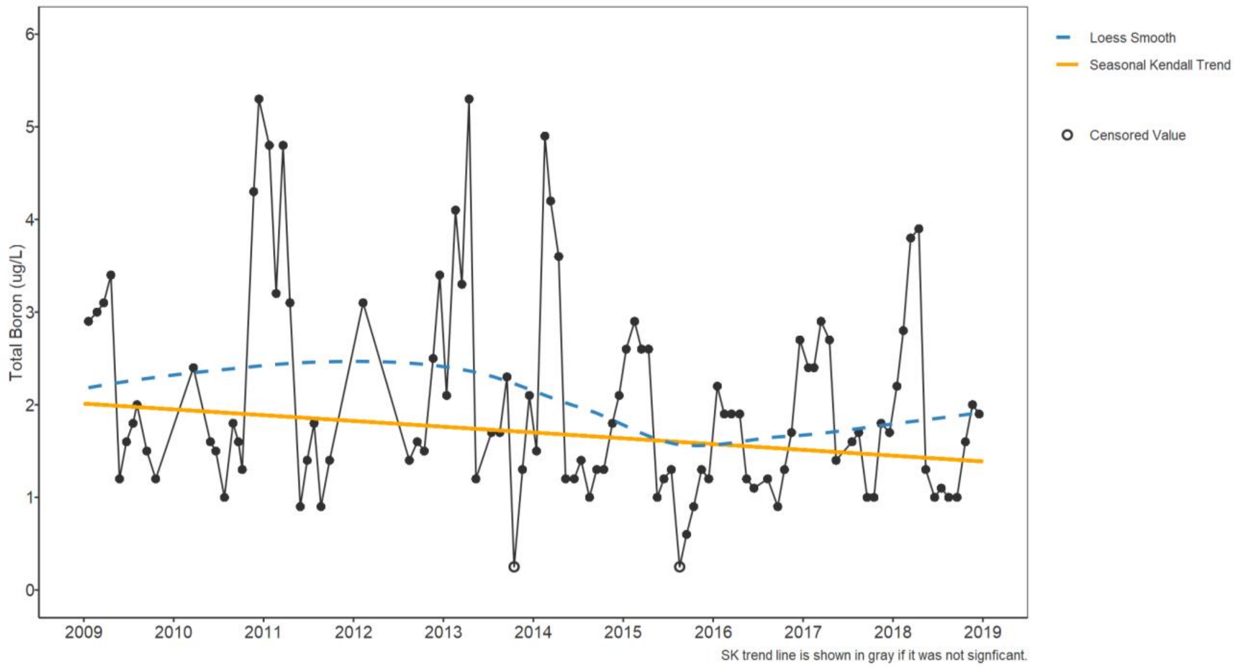


Figure 35. Distribution of total boron concentrations between 2009-2018 using Seasonal Kendall Trend analysis

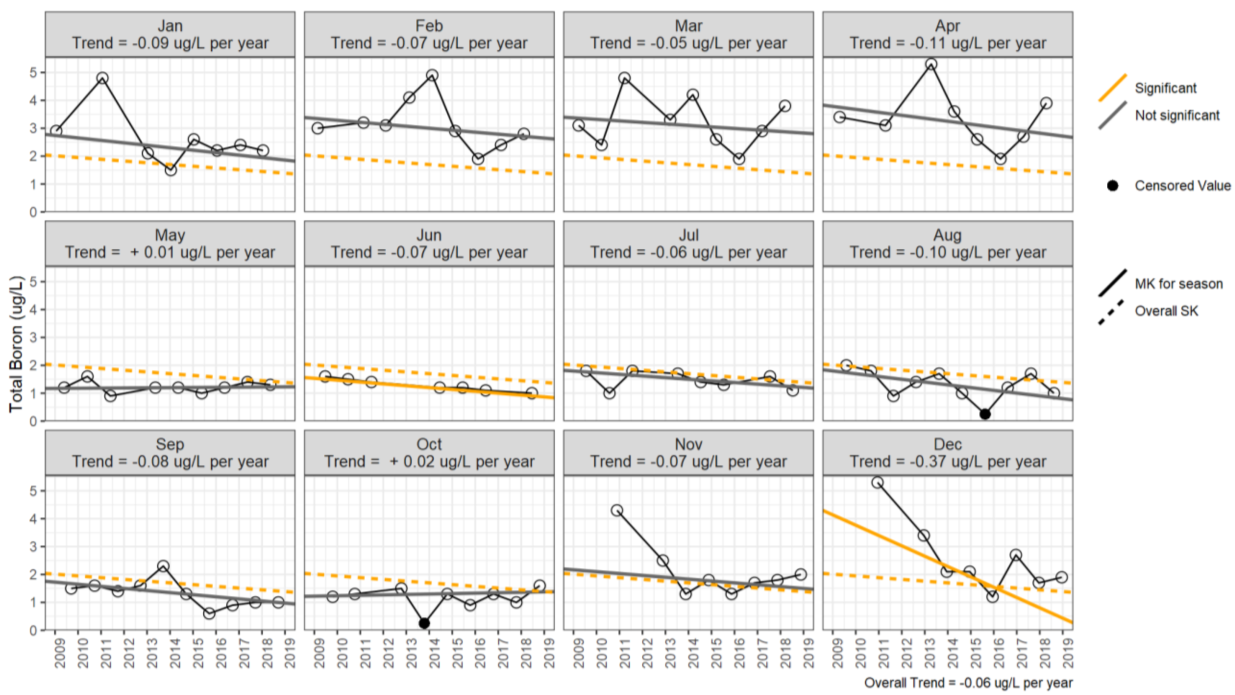


Figure 36. Monthly distribution of total boron from 2009-2018 using Mann-Kendall

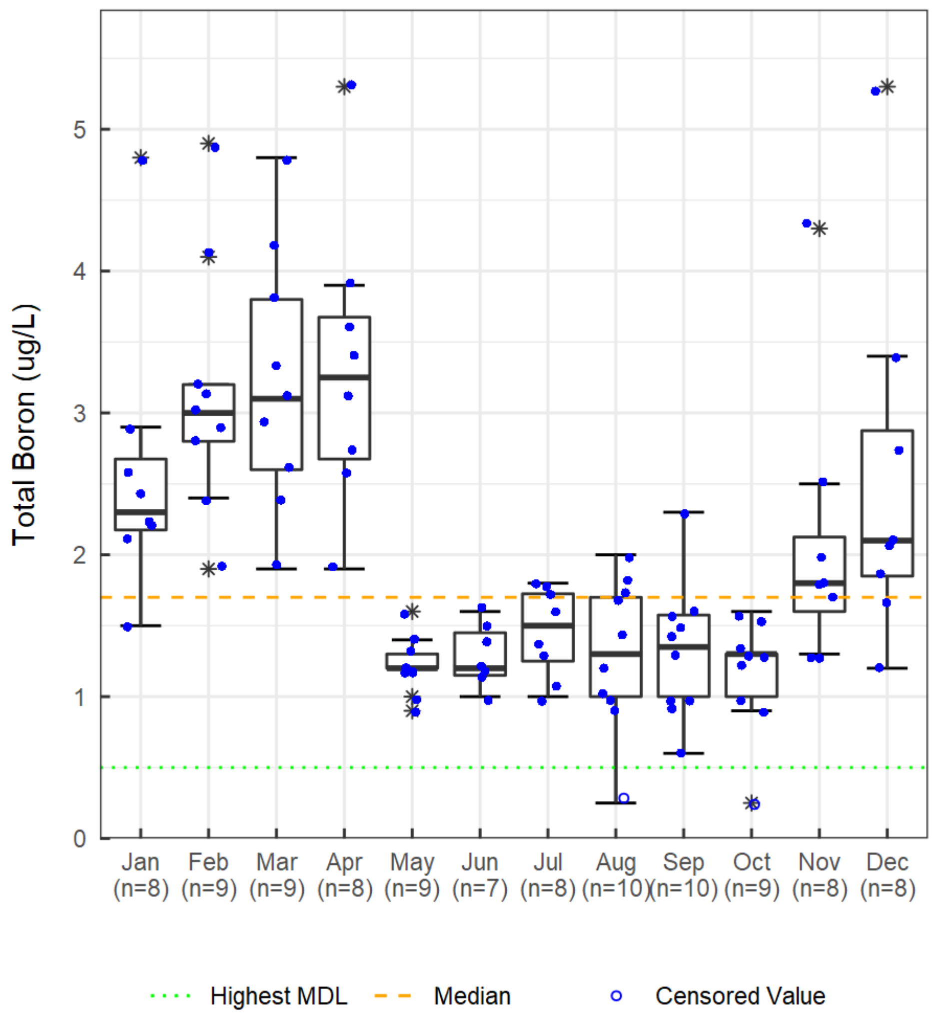


Figure 37. Monthly range of total boron from 2009-2018

5.5.1.6 Molybdenum

The level of total molybdenum in the system is trending downward at a rate of 0.006µg/L per year (Figure 38). The system demonstrates the highest levels of molybdenum during the groundwater recharge phase of the year and then drops to trace levels during the open water period (Figure 39 - Figure 40). This suggests a dissolved state for molybdenum as an influence on the system. Molybdenum is more soluble in alkaline conditions, which would correlate with the hard groundwater inputs during the winter months. It is possible that a mineralized ore body is being depleted. The existing levels of molybdenum at maximum levels near 1.4µg/L are well below the recommended CCME guideline of 73µg/L for long-term exposure.

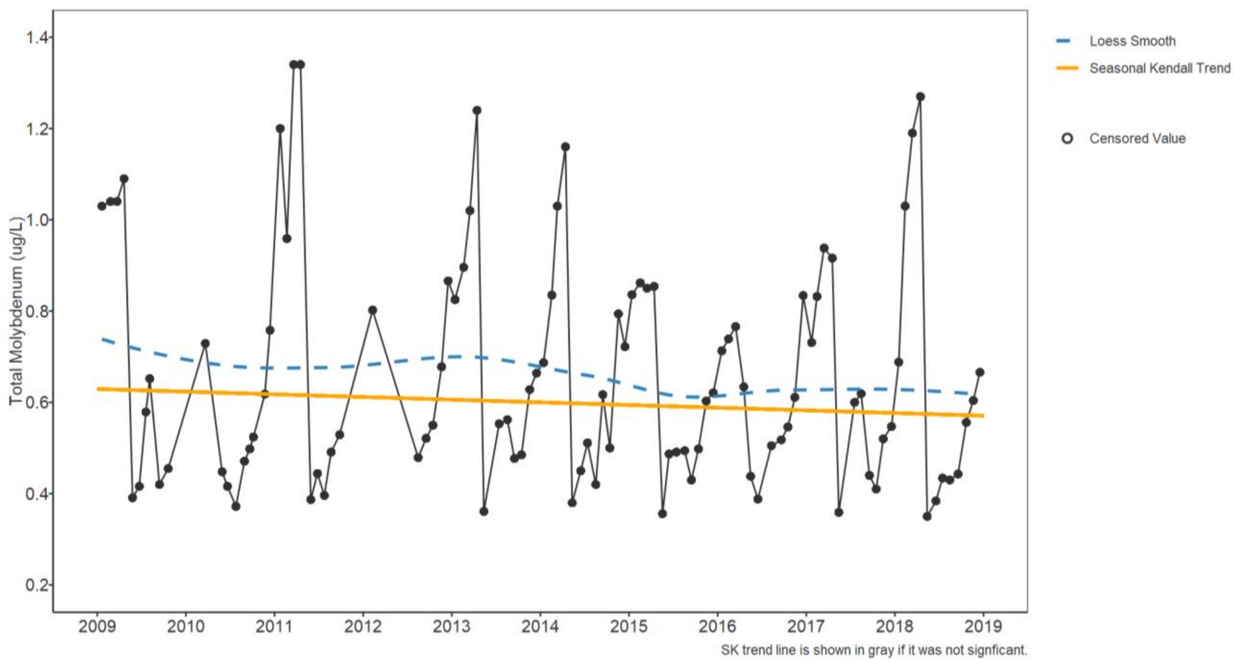


Figure 38. Distribution of total molybdenum concentrations between 2009-2018 using Seasonal Kendall Trend analysis

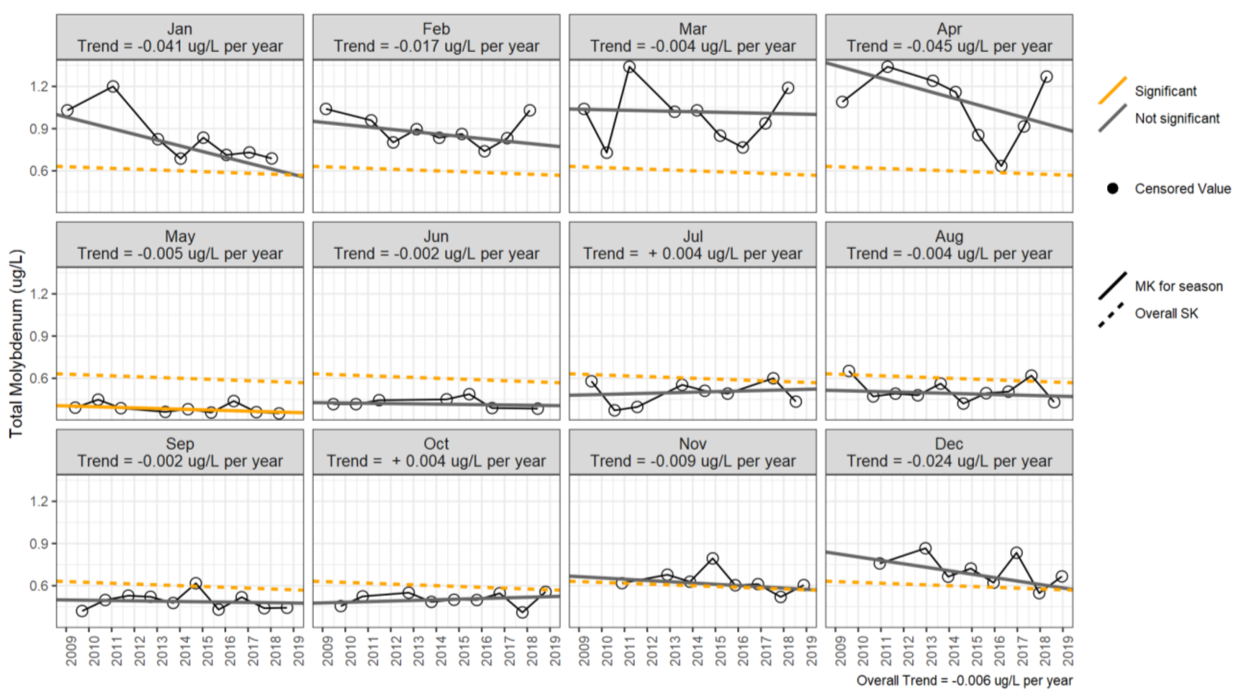


Figure 39. Monthly distribution of total molybdenum from 2009-2018 using Mann-Kendall

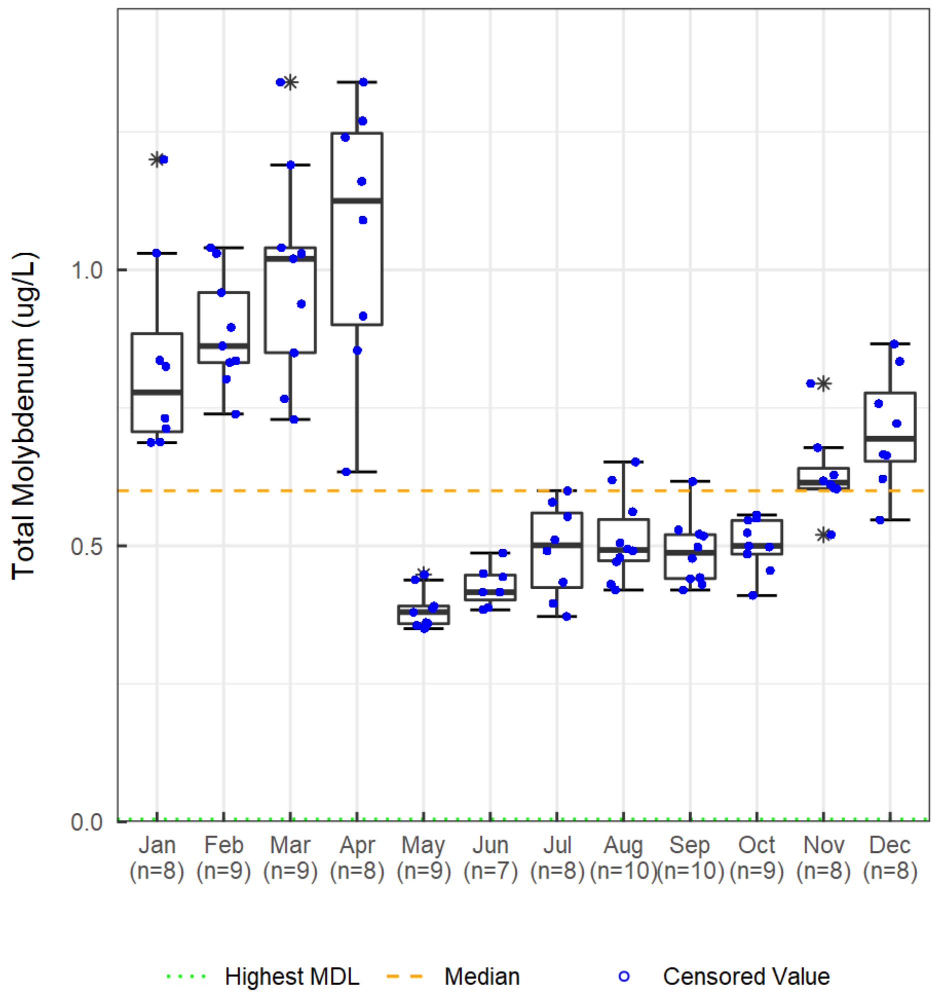


Figure 40. Monthly range of total molybdenum from 2009-2018.

5.5.2 Parameters with significant increasing trends

Turbidity, total nitrogen, total dissolved nitrogen, beryllium, cerium, chromium, copper, lanthanum and yttrium are displaying significant upward trends in the 2009-2018 period at the long-term station. The following sections present the detailed trends for each of these increasing parameters.

5.5.2.1 Turbidity

Turbidity in the system is exhibiting a slight but significant upward trend of 0.059 NTU per year. More noticeable is the upward trend of 2.928 NTU per year, specifically in the months of May in the last ten years (Figure 41). Looking at the seasonal data, as expected in Yukon rivers, the May freshet is the peak of turbidity within the system (Figure 41 - Figure 43). The rest of the seasonal data does not show levels of concern for aquatic life based on the CCME Guidelines. The cause of the slight rise is unknown but climate change effects such as permafrost degradation and slumping, along with an increase in annual precipitation, are potential sources. Increased traffic on the roads, forest fires and mining are other potential sources of particulates that can increase turbidity in water.

The narrative CCME guideline states that during high flow and when background turbidity is between 8 and 80 NTU, the increase in turbidity should not exceed 2 NTU from background levels over the long-term. The annual median turbidity value is 1.80 NTU (mean is 5.21) and the turbidity has been measured in May between approximately 5 and 80 NTU, thus exceeding the CCME narrative guideline during freshet.

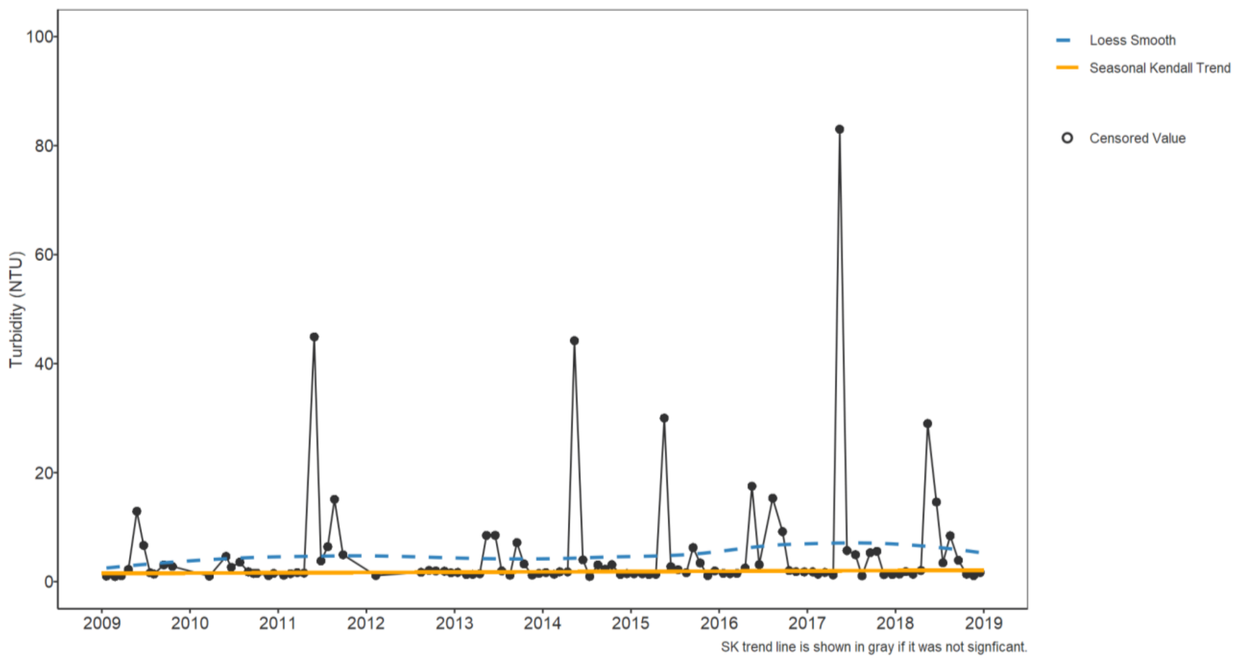


Figure 41. Distribution of turbidity between 2009-2018 using Seasonal Kendall Trend analysis

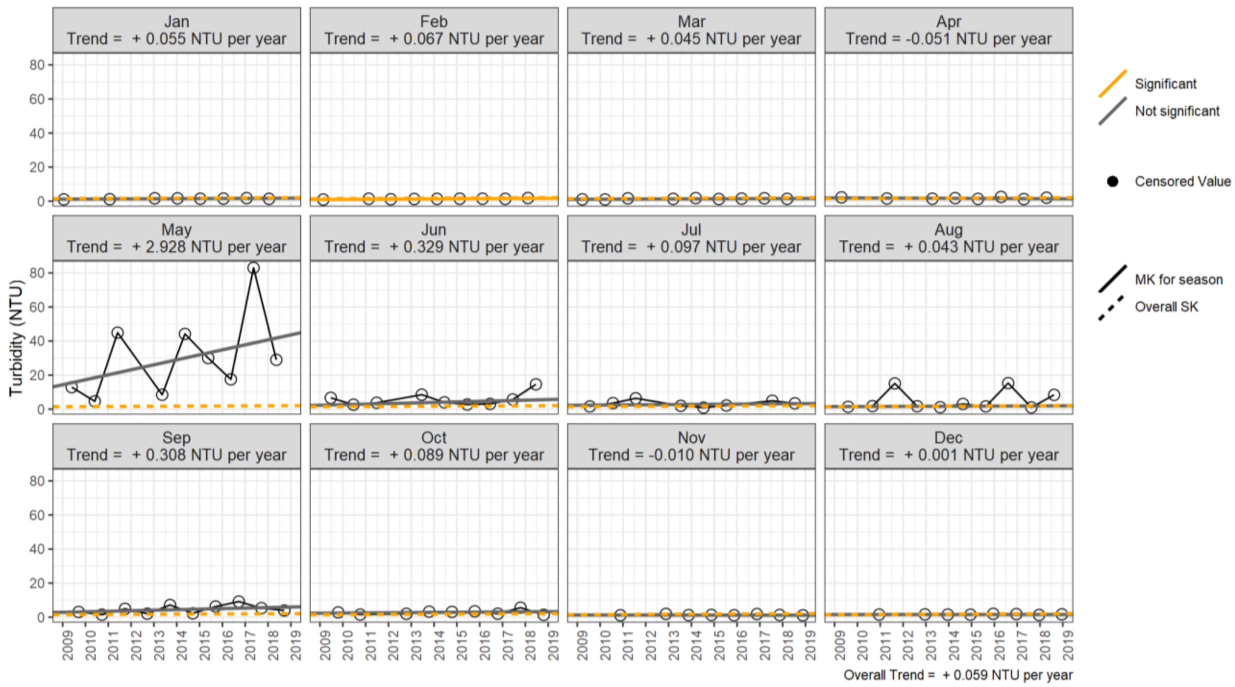


Figure 42. Monthly distribution of turbidity from 2009-2018 using Mann-Kendall

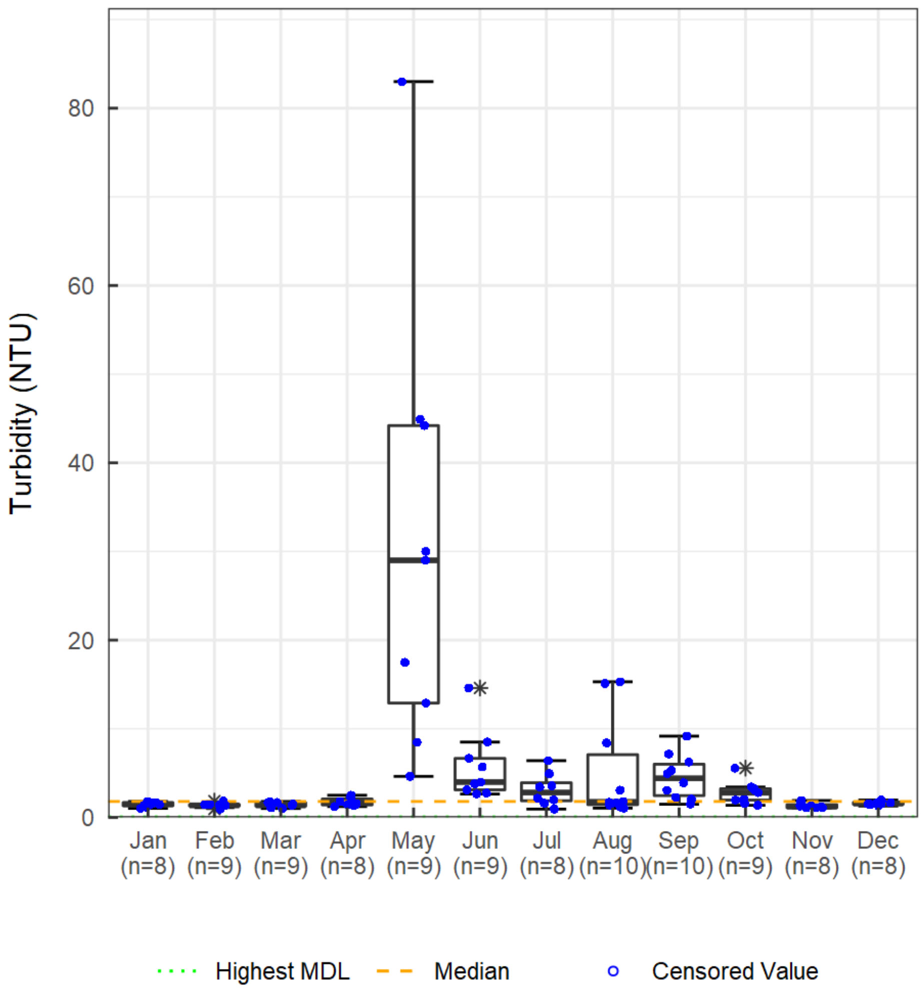


Figure 43. Monthly range of turbidity from 2009-2018

5.5.2.2 Total and dissolved nitrogen

Levels of dissolved and total nitrogen are increasing in the system at the rate of 0.005mg/L per year (Figure 44 - Figure 46). While nitrogen is the most common component of the atmosphere it does not transfer itself readily to the aquatic environment. Natural inputs of nitrogen to aquatic systems are usually from eroding soils where bacteria and plants have captured it from precipitation and the atmosphere. There are uncommon nitrogen enriched minerals that can also contribute a portion through erosion. Nitrogen increases in aquatic environments are usually linked to anthropogenic influence such as agricultural runoff or sewage. In the instance of this system, there is increased use of nitrogen containing explosives within the drainage along with wildfires, but it is unclear what influence these may have on the concentrations observed. The largest input to the system for nitrogen is during freshet after which the levels stabilize at much lower concentrations (Figure 44 - Figure 48). This lends support to the input being erosion of soils, potentially soils in a burnt area or mineralized geology.

There is no CCME Aquatic Life Guideline for total or dissolved nitrogen.

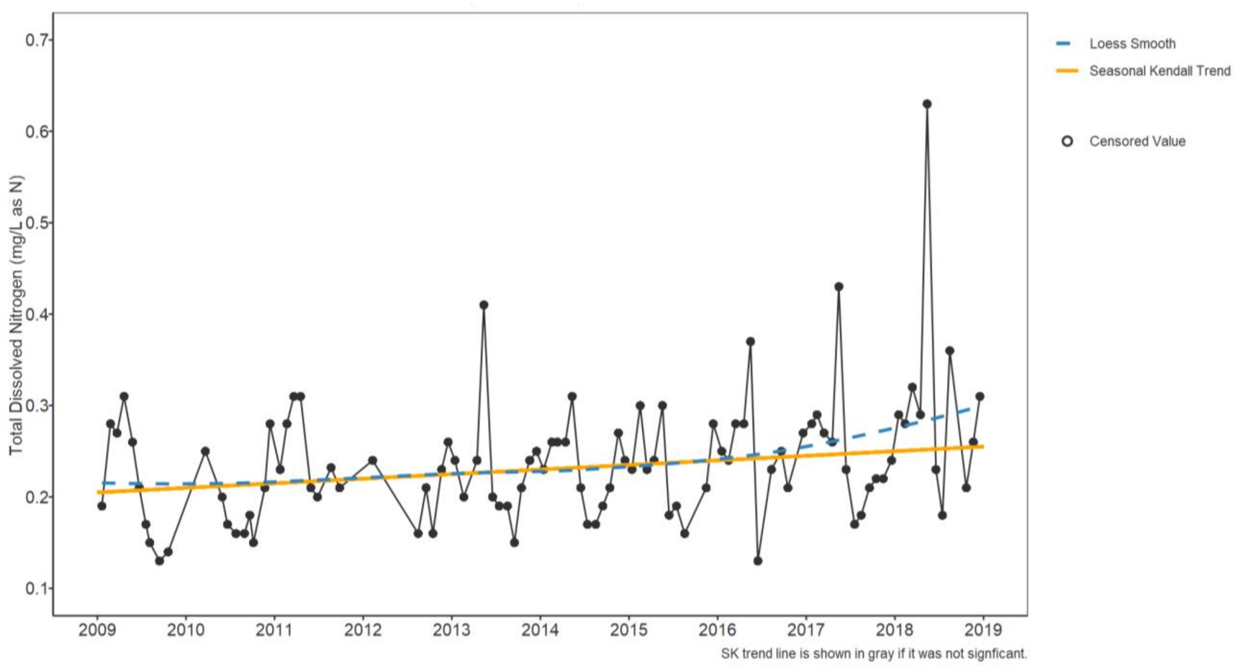


Figure 44. Distribution of dissolved nitrogen concentrations between 2009-2018 using Seasonal Kendall Trend analysis

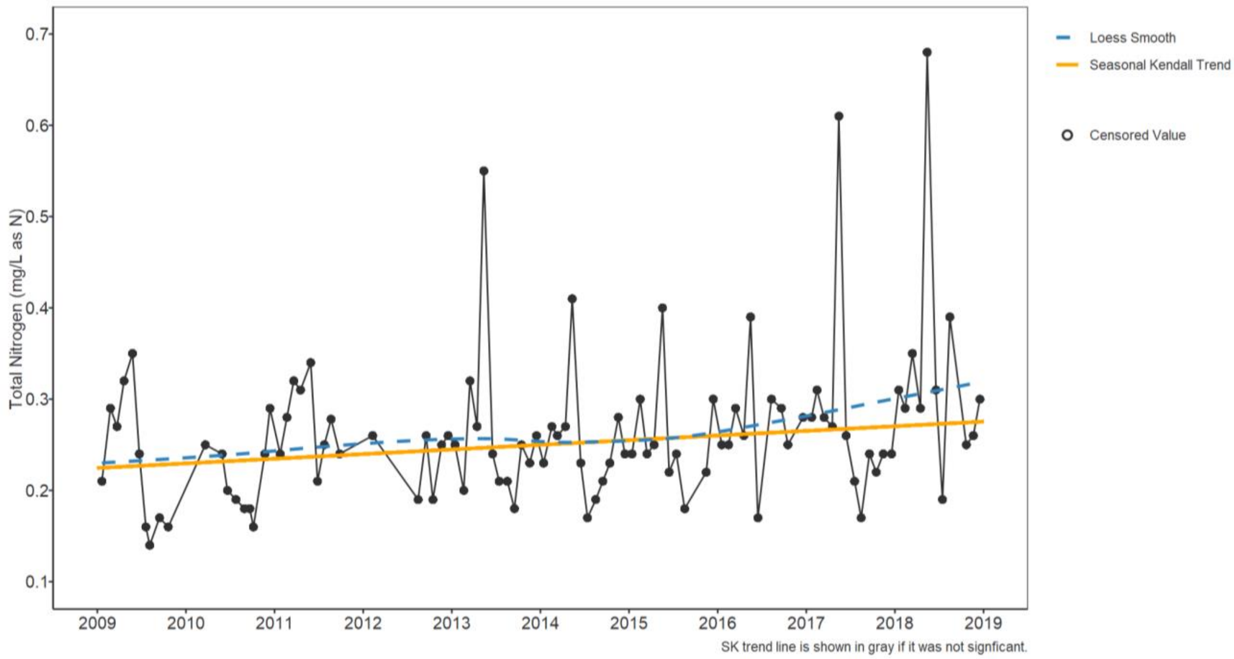


Figure 45. Distribution of total nitrogen between 2009-2018 using Seasonal Kendall Trend analysis

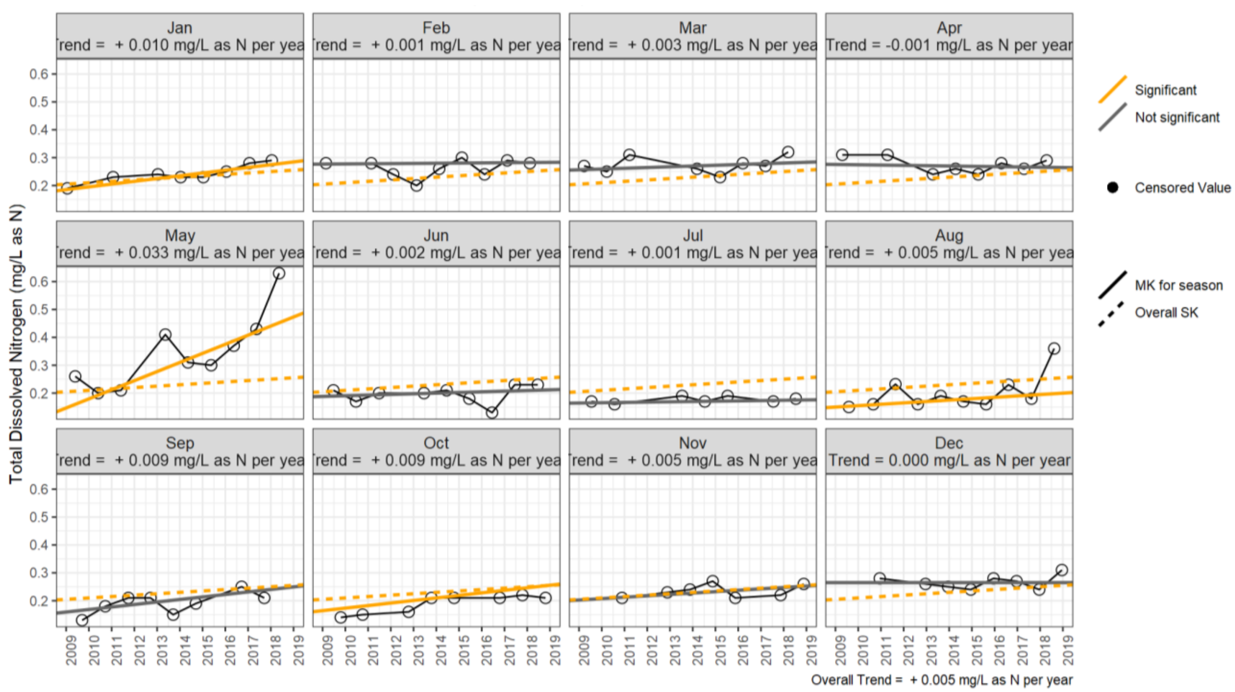


Figure 46. Monthly distribution of dissolved nitrogen from 2009-2018 using Mann-Kendall

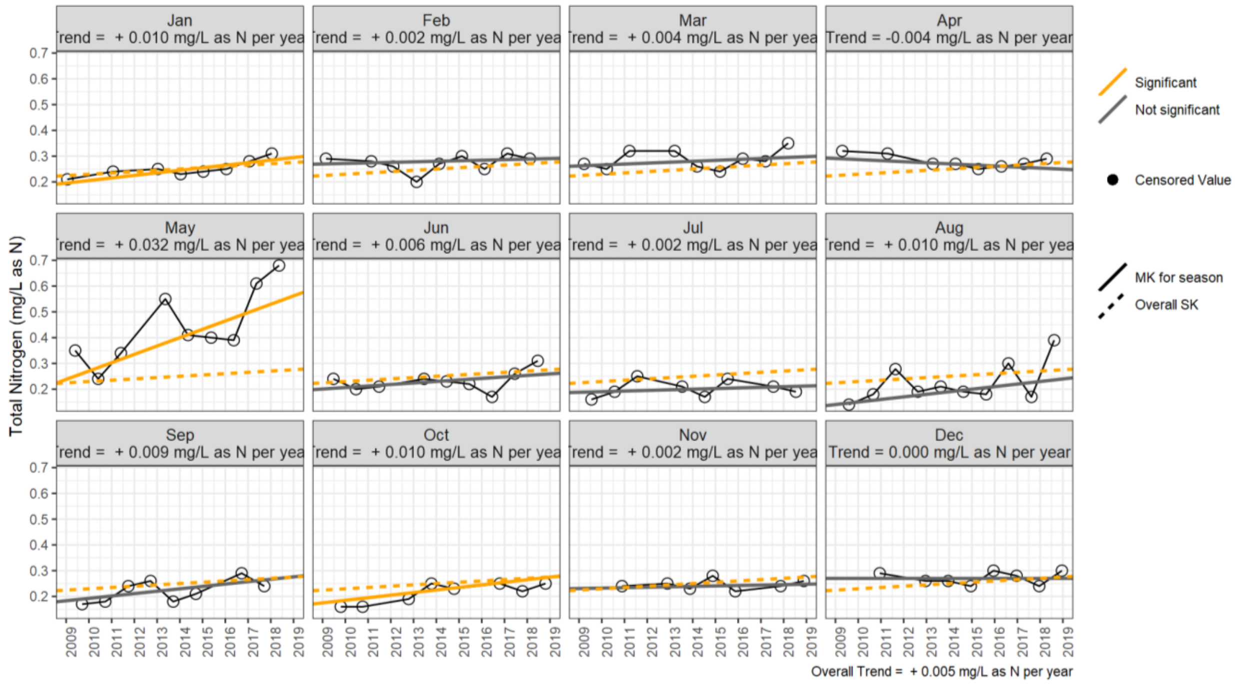
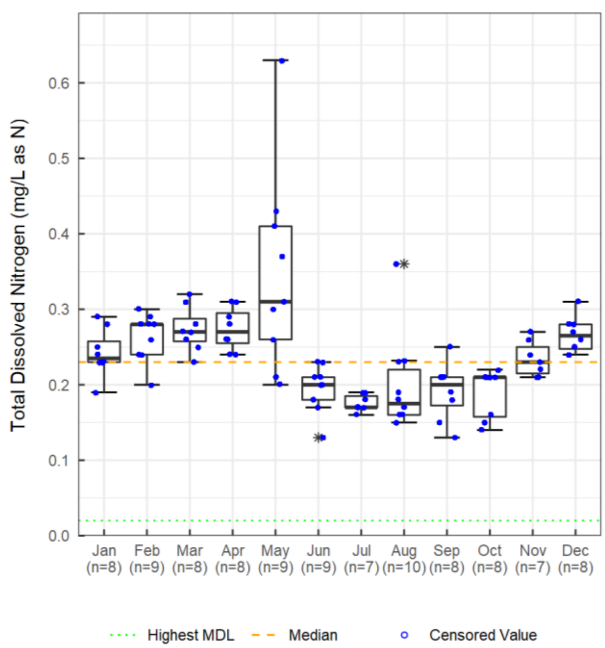


Figure 47. Monthly distribution of total nitrogen from 2009-2018 using Mann-Kendall



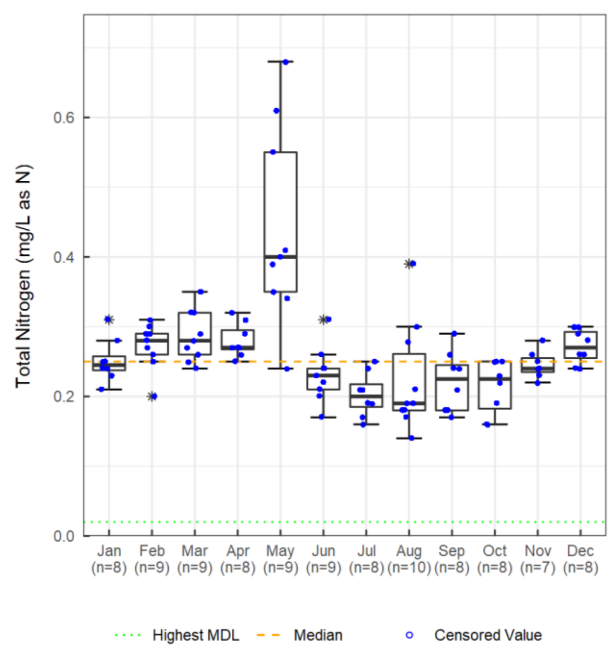


Figure 48. Monthly range of dissolved nitrogen and total nitrogen from 2009-2018

5.5.2.3 Beryllium

There is a slight upward trend for total beryllium within the system at a rate of 0.0002 µg/L per year (Figure 49). As the primary source of beryllium in an aquatic system is the weathering of silicate minerals, there may be an increase in such erosion within the system. The combustion of hydrocarbons can also emit trace amounts of beryllium so there may be an association with the increased development of the watershed for both sources (Figure 50 - Figure 51).

There is no CCME guideline for the protection of aquatic life for beryllium.

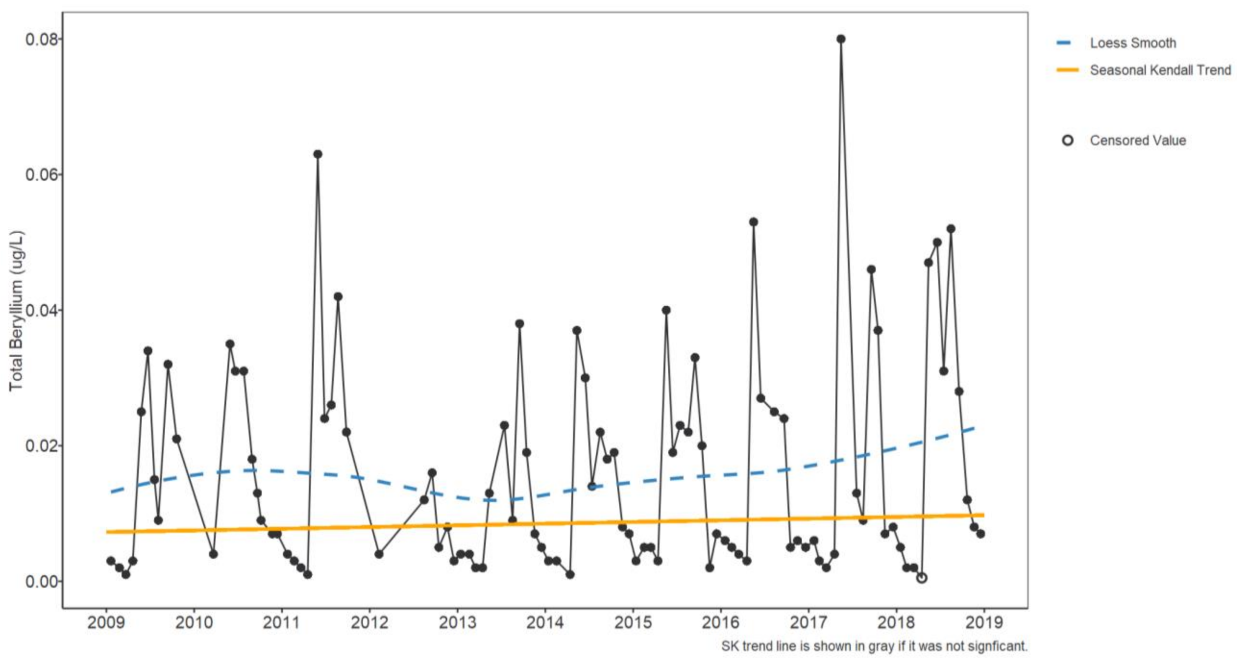


Figure 49. Distribution of total beryllium between 2009-2018 using Seasonal Kendall Trend analysis

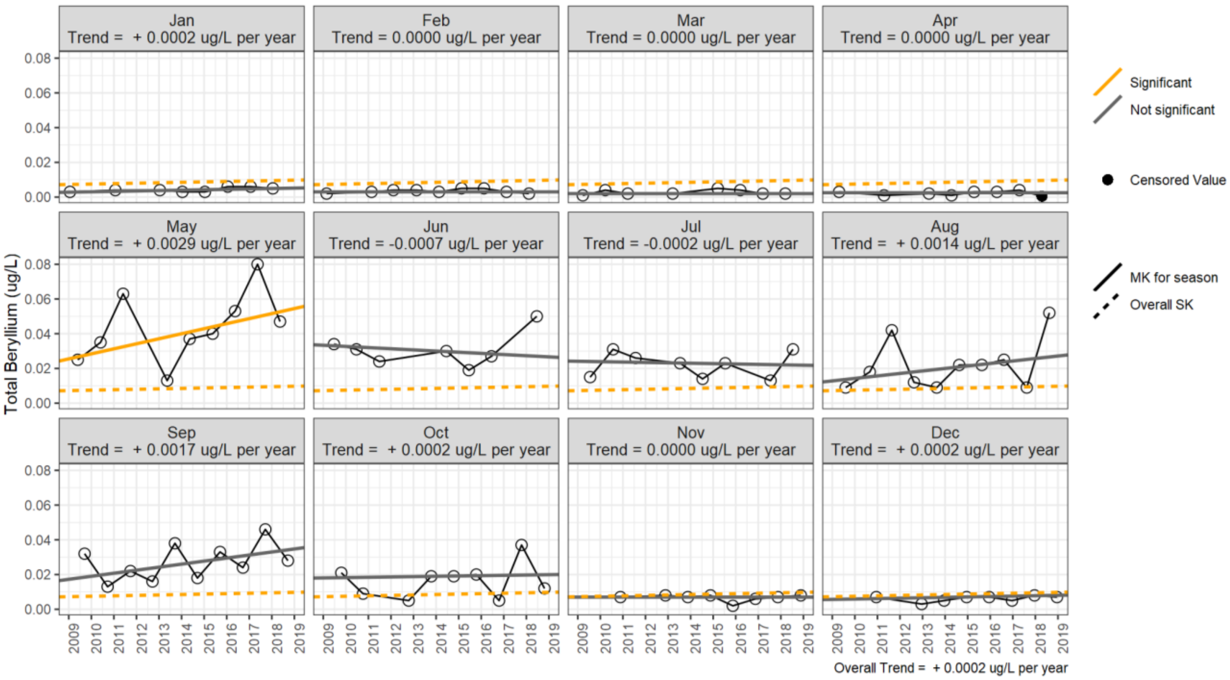


Figure 50. Monthly distribution of total beryllium from 2009-2018 using Mann-Kendall

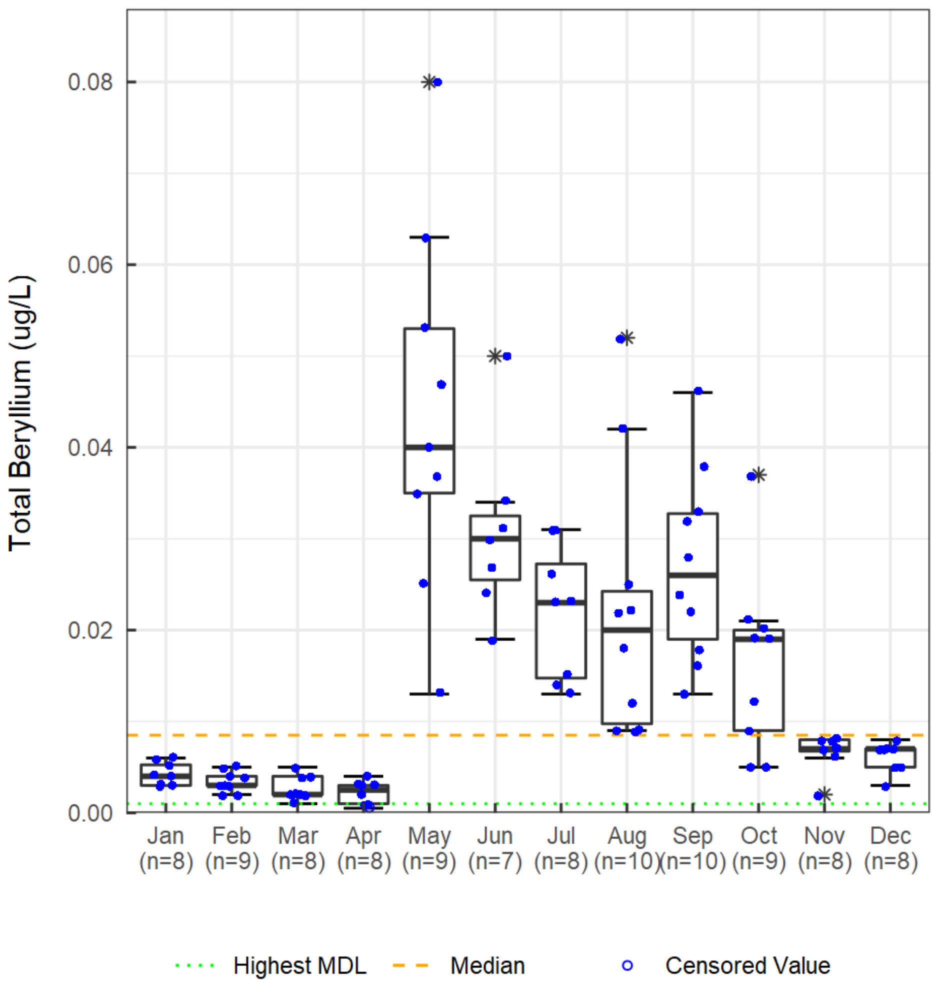


Figure 51. Monthly range of total beryllium from 2009-2018

5.5.2.4 Cerium

Cerium is the most abundant of the rare earths and the system analysis shows an increasing trend for total cerium of 0.0148µg/L per year (Figure 52). Rare earths in the aquatic environment are related to erosion of the local geology in areas lacking industrial inputs. The major inputs of cerium to the system occur during freshet and the open water months of the year suggesting a suspended particulate relationship (Figure 53 - Figure 54). Recent research seems to indicate that rare earth elements may be increasingly released in water due to climate change (Rue and McKnight 2021).

There is no CCME aquatic life guideline for cerium.

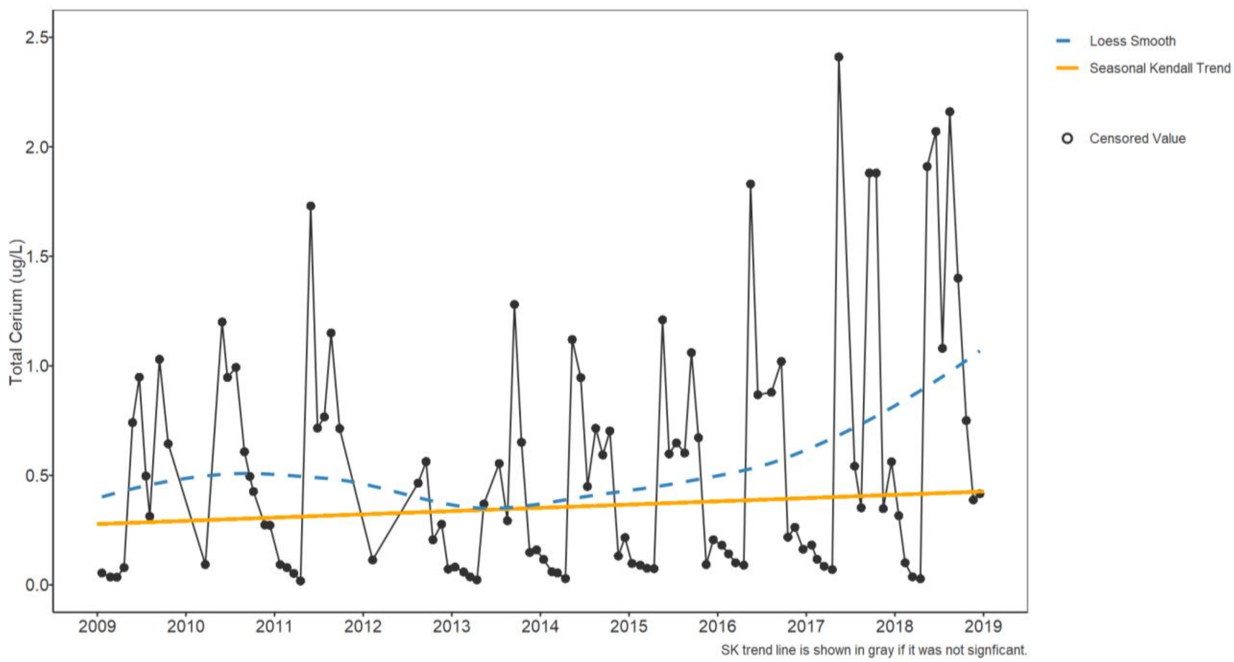


Figure 52. Distribution of total cerium concentrations between 2009-2018 using Seasonal Kendall Trend analysis

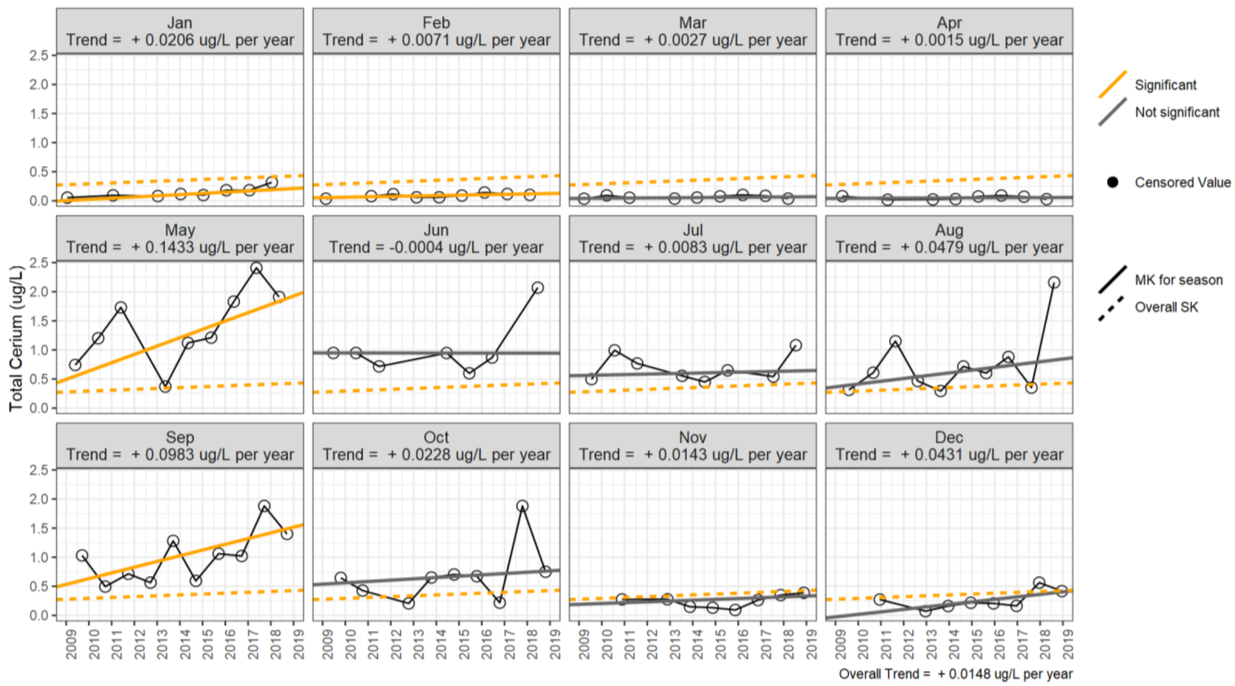


Figure 53. Monthly distribution of total cerium from 2009-2018 using Mann-Kendall

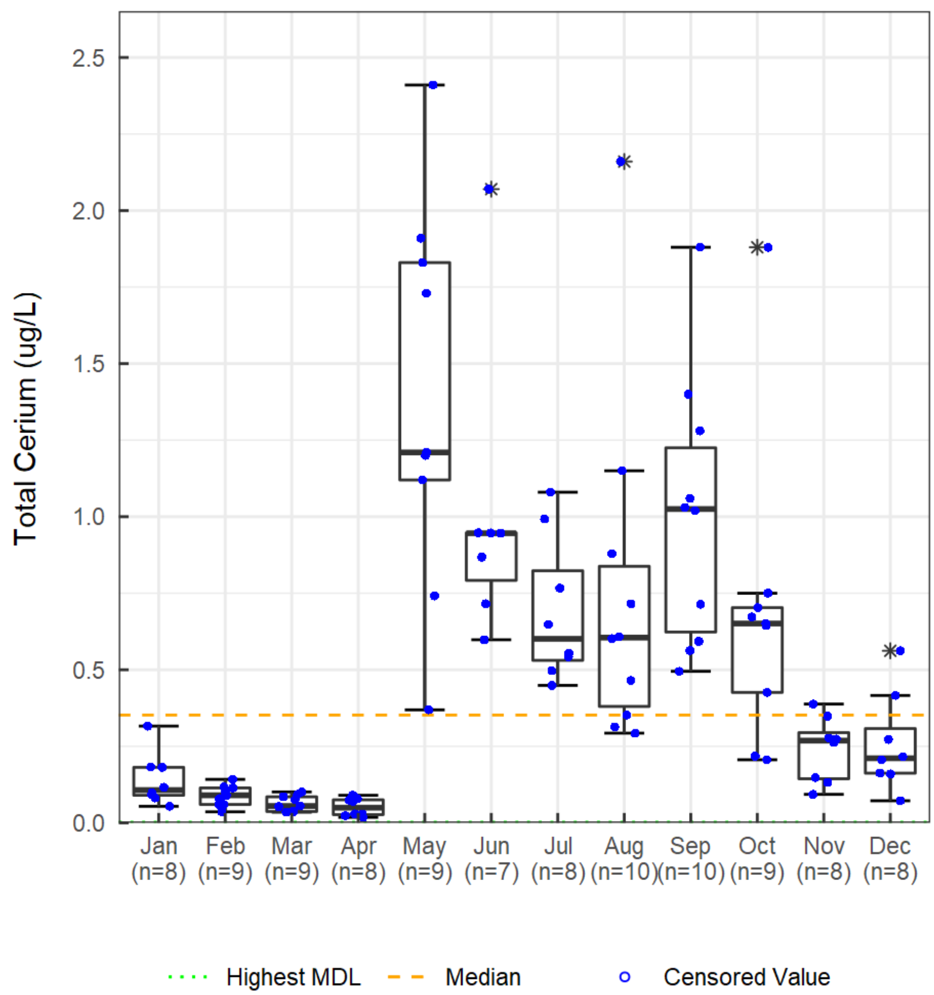


Figure 54. Monthly range of total cerium from 2009-2018

5.5.2.5 Chromium

The trend for total Chromium in the system is increasing at the rate of 0.0025µg/L per year (Figure 55). Chromium in the natural environment is from the erosion of mineralized geology particularly serpentine ores. The predominant input of chromium to the system is at freshet, which suggests a direct correlation to particulate inputs to the system at that time (Figure 56 - Figure 57). The levels seen in the system for Total Chromium are well below the CCME criteria of 8.9µg/L for trivalent Chromium.

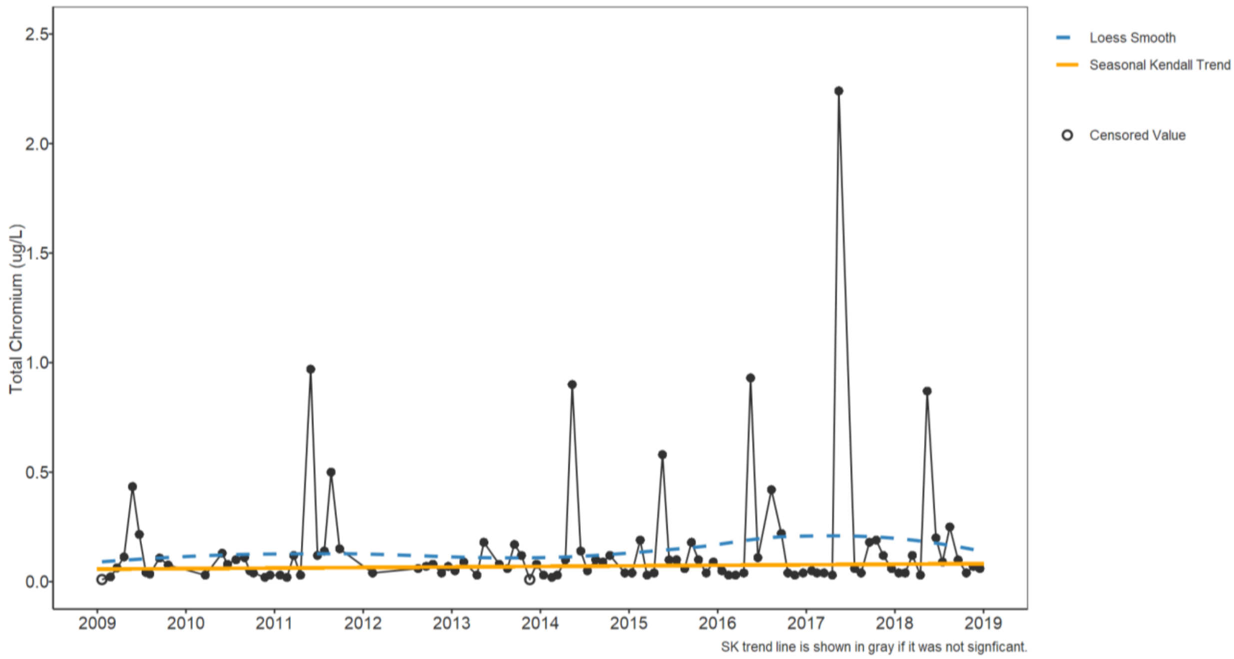


Figure 55. Distribution of total chromium concentrations between 2009-2018 using Seasonal Kendall Trend analysis

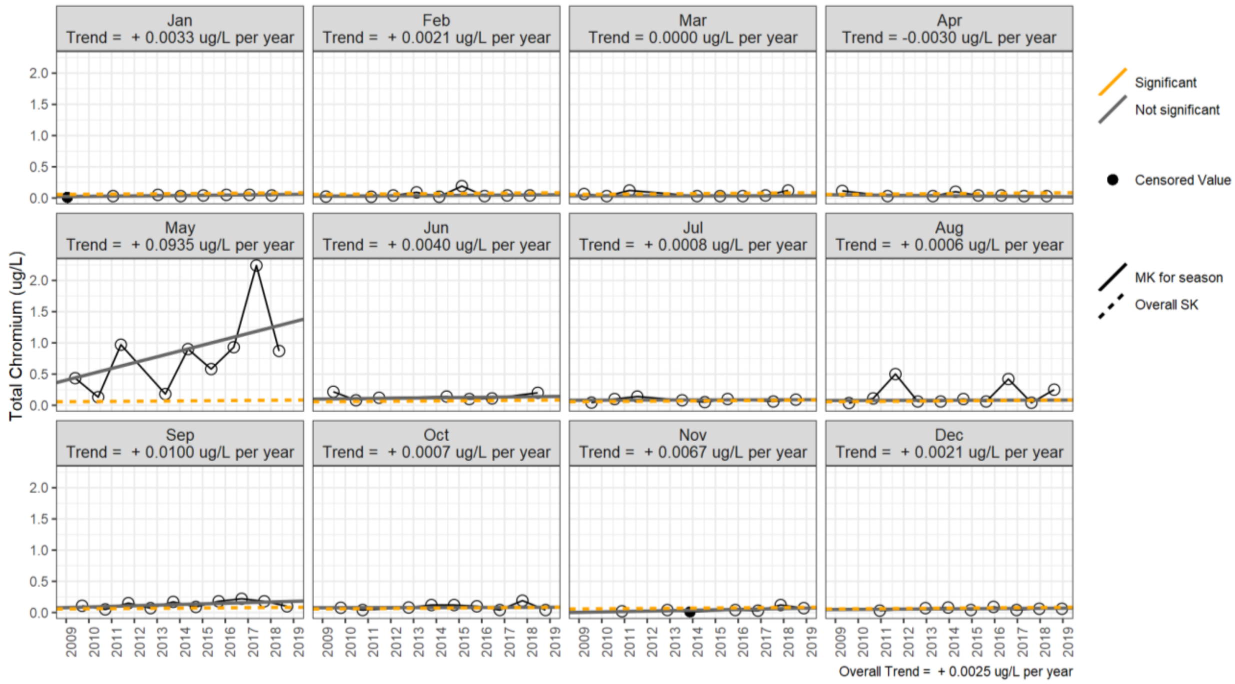


Figure 56. Monthly distribution of total chromium from 2009-2018 using Mann-Kendall

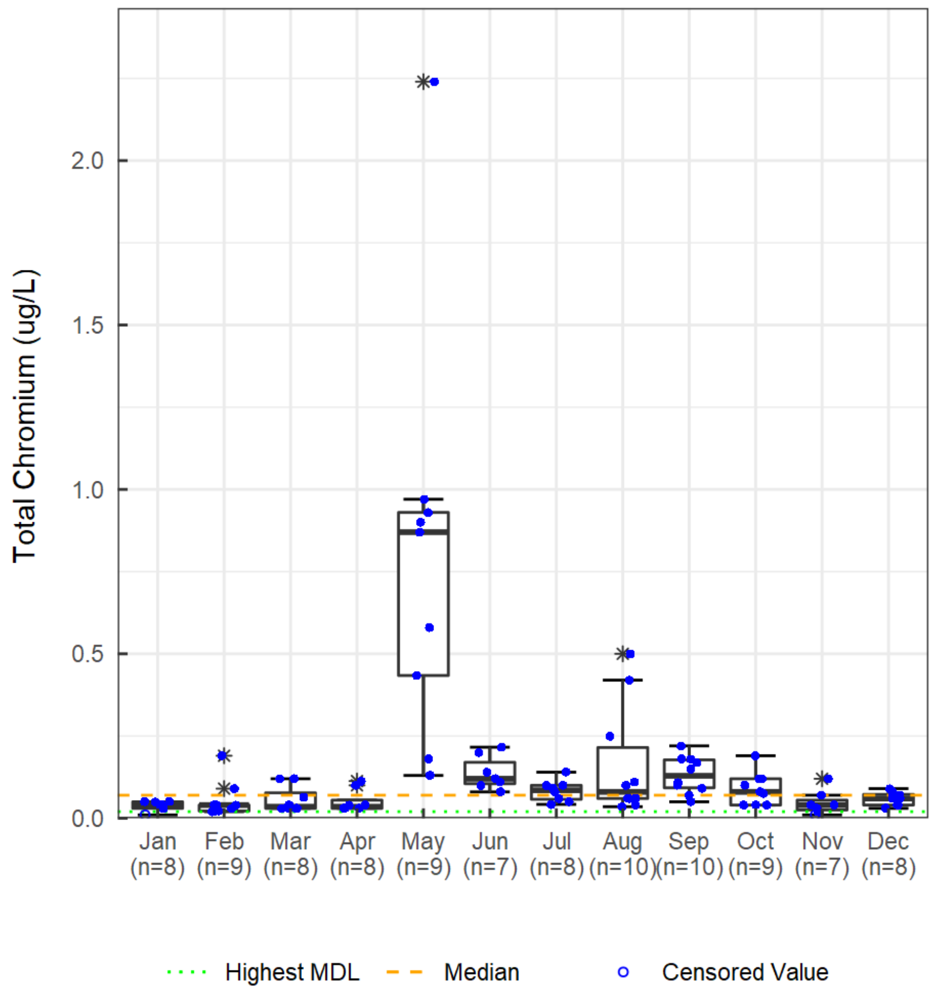


Figure 57. Monthly range of total chromium from 2009-2018

5.5.2.6 Copper

The level of total copper within the system is trending upward at a rate of 0.052µg/L per year (Figure 58). The highest levels of total copper in the system occur during freshet and then the open water months (Figure 59 - Figure 60). The input to the system during groundwater recharge is negligible. This suggests that the input of copper is in particle form. The toxicity of dissolved copper varies with hardness and the CCME guidelines suggest that in waters above 180 mg/L hardness, 4µg Cu/L is the upper limit, while in waters below 82 mg/L hardness, the upper limit for copper is 2µg/L. In medium hardness conditions, the copper CCME guideline is hardness-dependent. The Government of Canada released a copper guideline that is based on the Biotic Ligand Model, and this one depends on water temperature, pH, DOC and hardness (Government of Canada 2021). The system is hardest during the groundwater input in winter months and lowest during freshet. Conversely, copper levels in the system are highest during freshet and the open water months which can exceed the recommended threshold of 4µg/L. If the total copper levels being reported are tied to particulates then the copper is of limited bio-availability and the potential toxicity is greatly reduced.

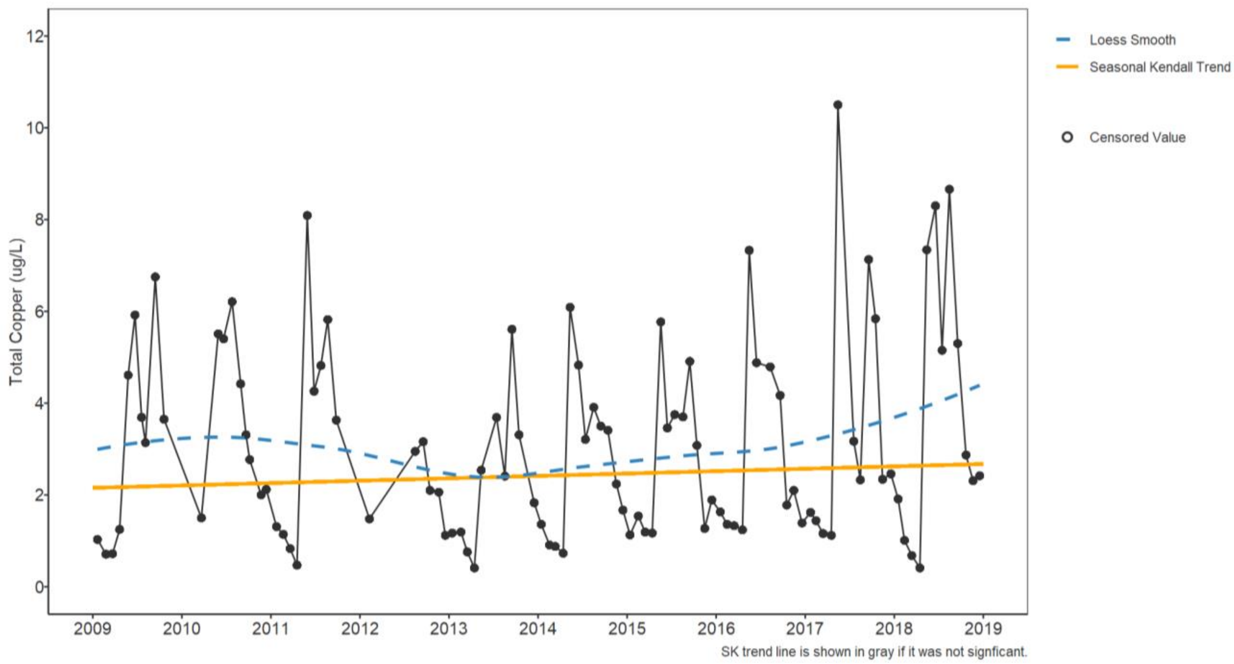


Figure 58. Distribution of total copper concentrations between 2009-2018 using Seasonal Kendall Trend analysis

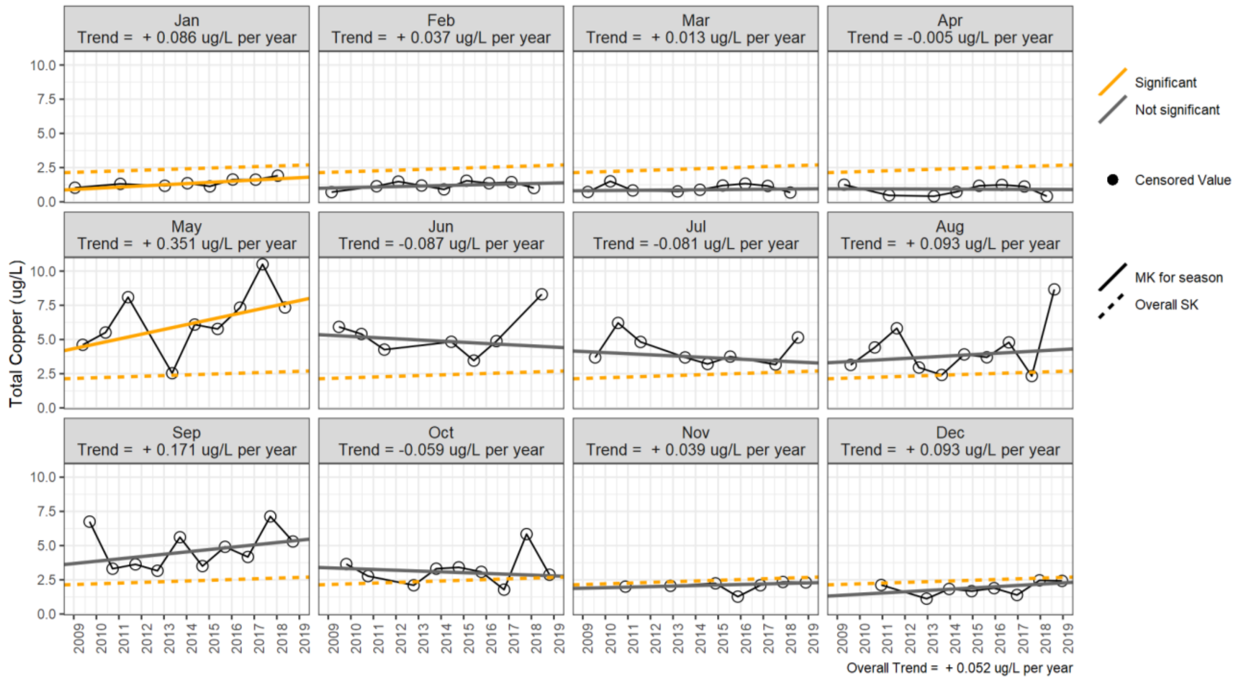


Figure 59. Monthly distribution of total copper from 2009-2018 using Mann-Kendall

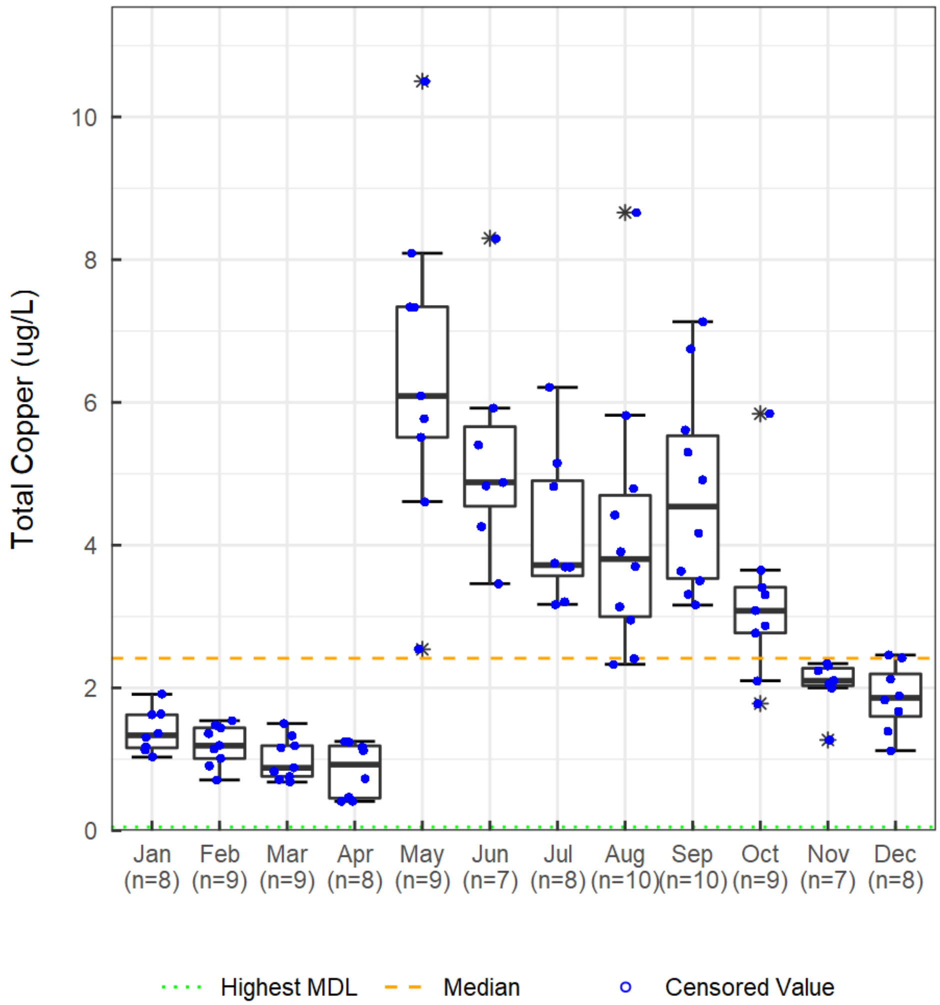


Figure 60. Monthly range of total copper from 2009-2018

5.5.2.7 Lanthanum

Lanthanum is another rare earth of relative abundance and in natural environments it is associated with geological erosion. Although it has low solubility in water, the system is trending upward for total lanthanum at the rate of 0.0085µg/L per year (Figure 61). Levels in the system are highest during freshet and the open water season (Figure 62 - Figure 63). The groundwater inputs to the system for lanthanum are negligible. It has an affinity for phosphate and may be one of the causes of the declining trend for that nutrient.

There is no CCME aquatic life guideline for lanthanum.

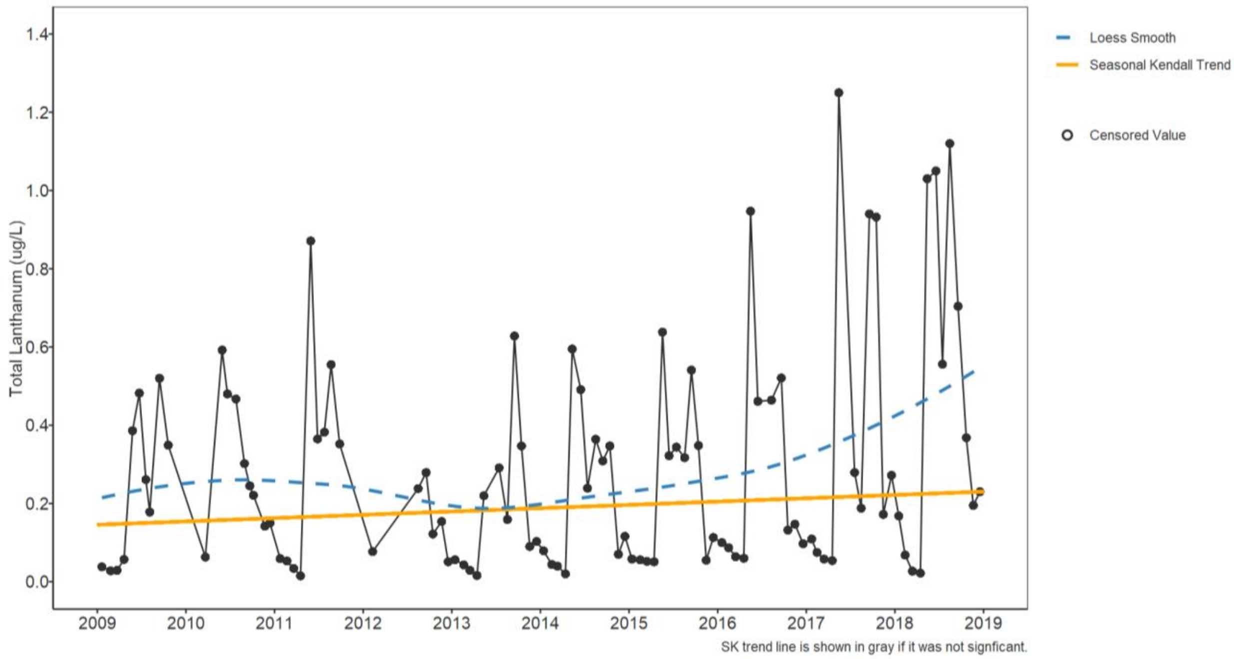


Figure 61. Distribution of total lanthanum concentrations between 2009-2018 using Seasonal Kendall Trend analysis

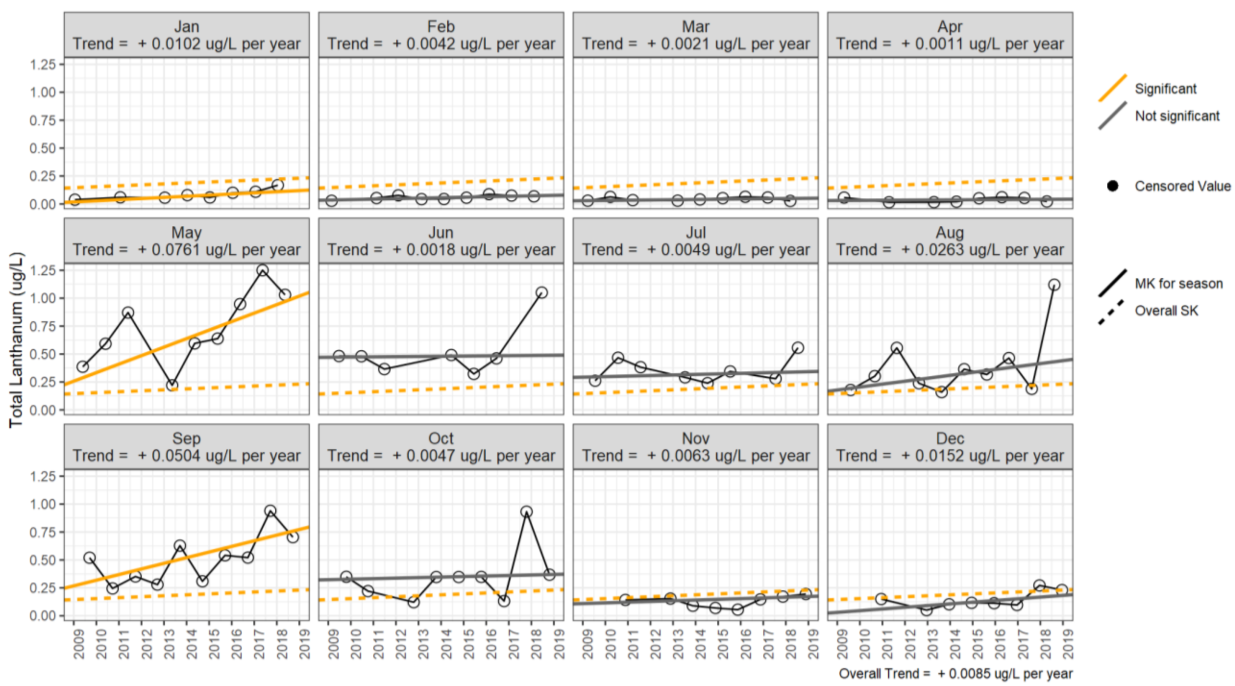


Figure 62. Monthly distribution of total lanthanum from 2009-2018 using Mann-Kendall

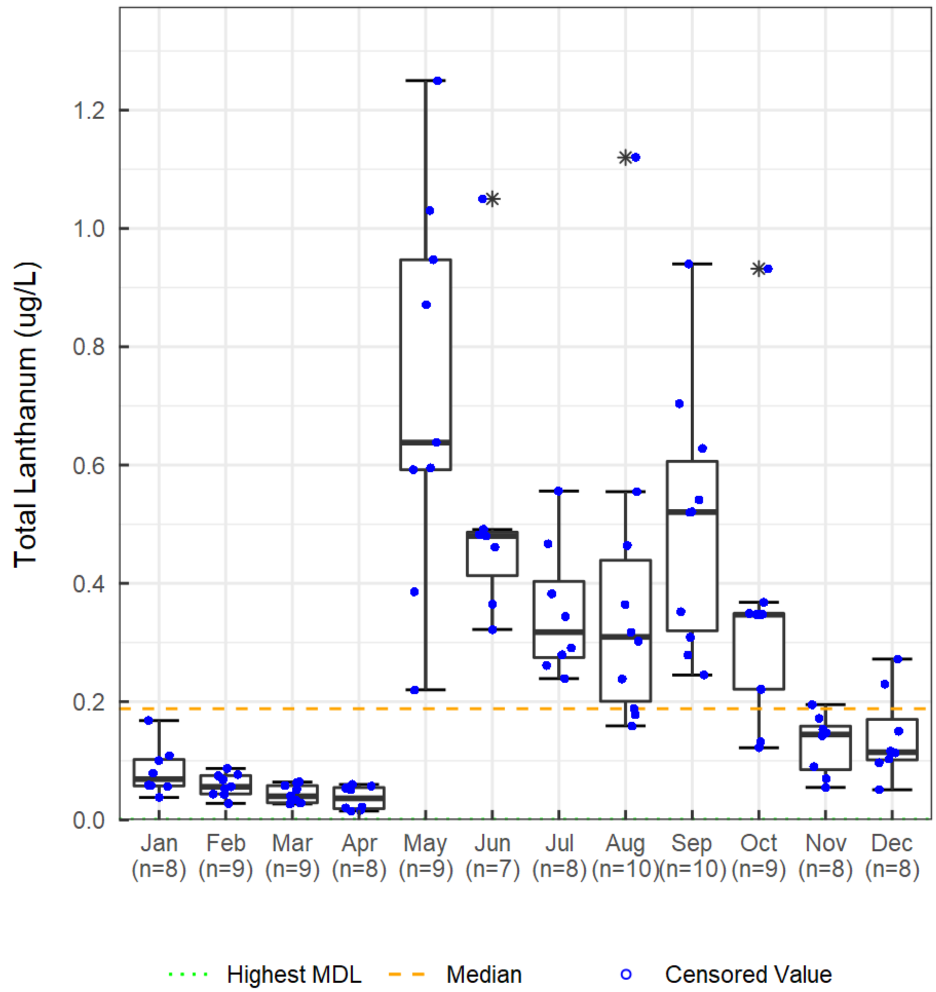


Figure 63. Monthly range of total lanthanum from 2009-2018

5.5.2.8 Yttrium

Second only to cerium as the most common of the rare earth metals, total yttrium is increasing in the system at a rate of 0.0085µg/L per year (Figure 64). In conjunction with cerium and lanthanum, the inputs for yttrium are highest at freshet and then the open water months, after which they drop to trace levels in the months of groundwater influence (Figure 65 -Figure 66). It is likely the total metals for all three are tied to particles of the same eroding geology entering the system during open water.

There is no CCME aquatic life guideline for yttrium.

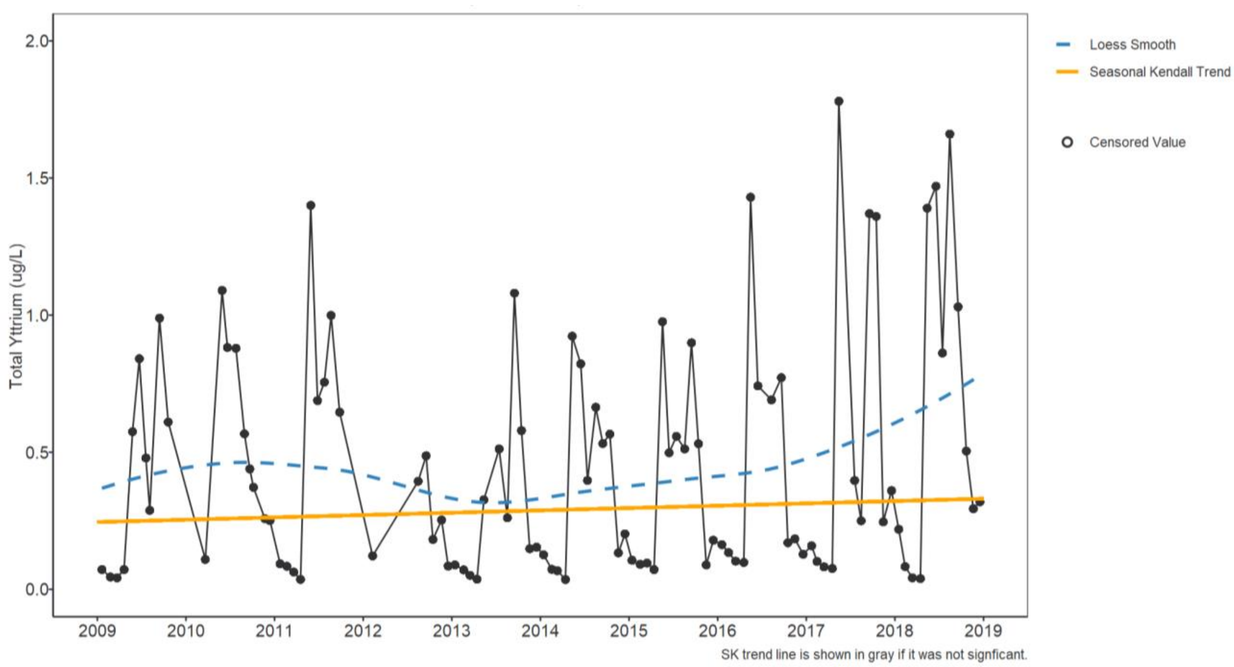


Figure 64. Distribution of total yttrium concentrations between 2009-2018 using Seasonal Kendall Trend analysis

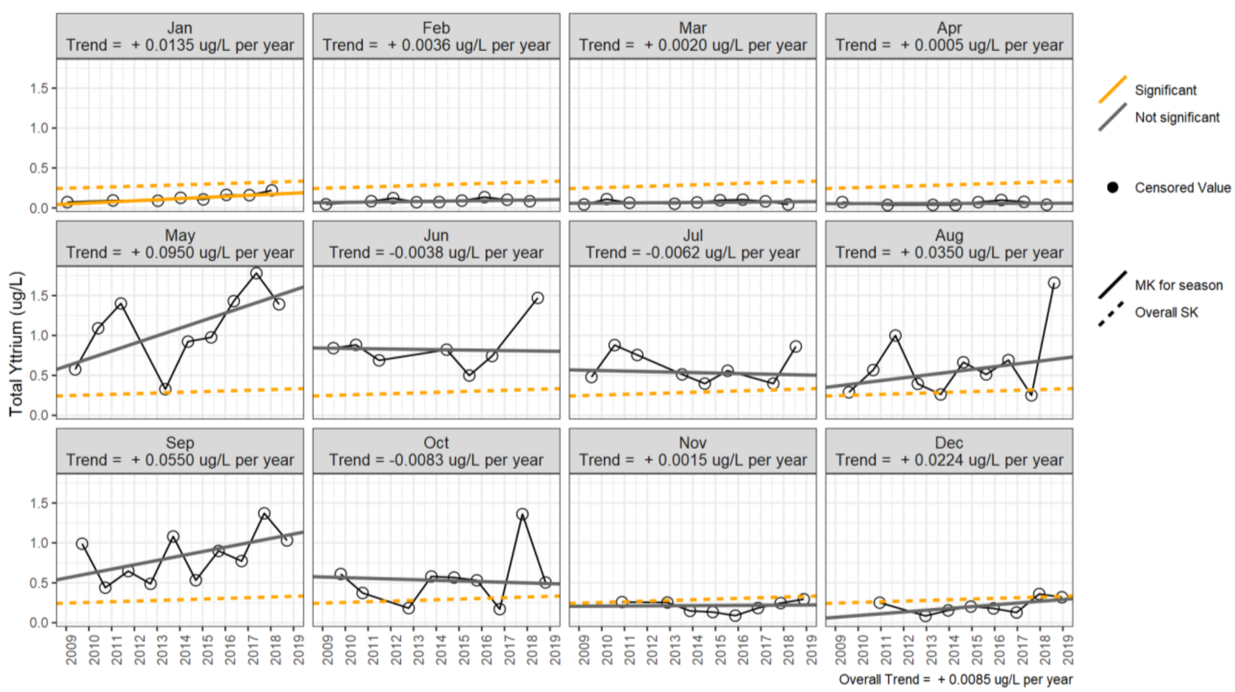


Figure 65. Monthly distribution of total yttrium from 2009-2018 using Mann-Kendall

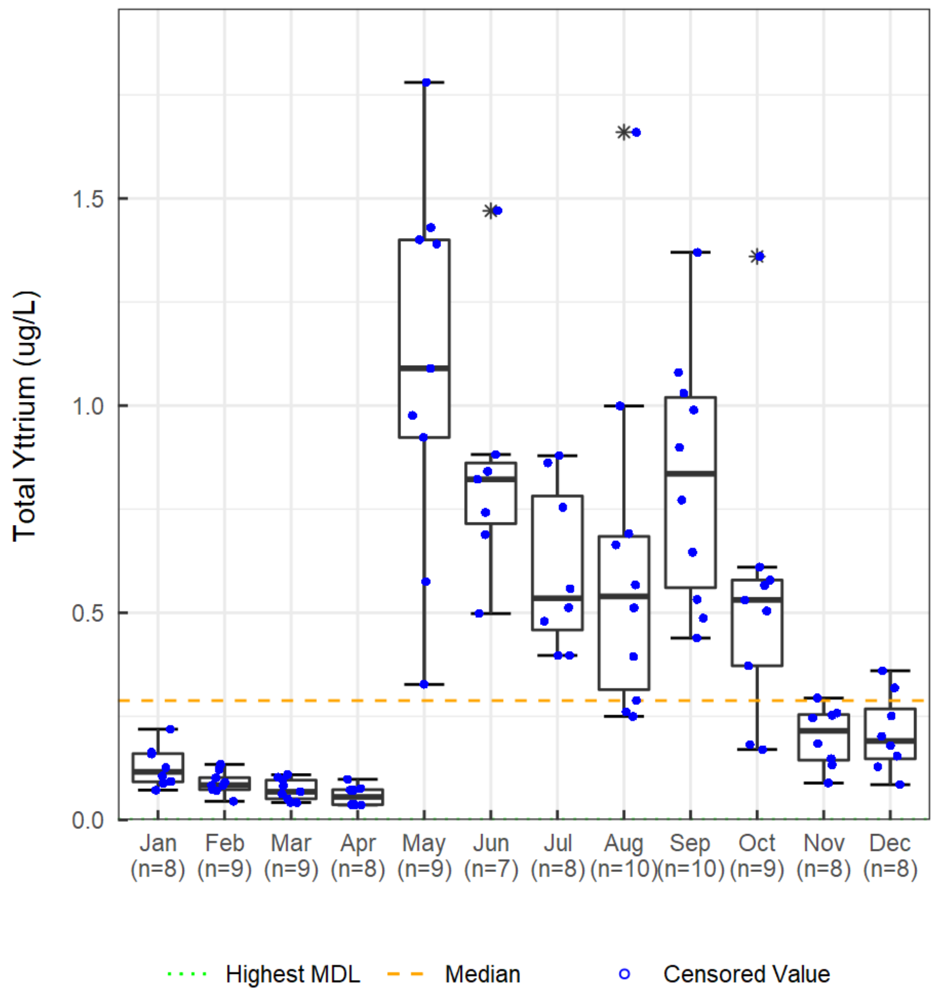


Figure 66. Monthly range of total yttrium from 2009-2018

6 Development of water quality objectives for the South McQuesten River

Water Quality Objectives (WQO) provide a means of guiding management of a healthy aquatic environment through establishing a numerical value for associated water quality parameters. These objectives are typically established for parameters of potential concern. The goal of developing WQOs is to support management of the watershed to protect the different users of the water body (e.g., aquatic life, wildlife and drinking water) and the aquatic habitat. WQOs are often developed in situations where the aquatic system is considered at risk of deterioration.

The development of WQOs was contracted out to Slater Environmental Consulting and Minnow Environmental Inc. The report in Appendix A describes the development process and the resulting WQOs. This report includes the information gathered during engagement meetings, how this information was used to define the narrative objectives, the station and parameters selected, and the preliminary average and maximum WQOs. In addition, this report makes recommendations, based on statistics, to validate the preliminary WQOs and to monitor for attainment of the objectives using four types of thresholds to compare with the observed water quality at the long-term monitoring station, YT09DD0008.

7 Recommendations

The work presented in this report has relied heavily on collaborations and inputs from other parties. This includes the water samples collection done by Bruce MacGregor and FNNND; the data that was collected and reported by the licensees; the trends analysis done by ECCC; and the definition of the water management approach that was based on the inputs collected from stakeholders and rights holders. WRB sees very high value in input and knowledge from other organizations and people. As such, WRB recognizes that achieving the sustainable management of the South McQuesten River for future generations cannot be done in isolation. Meaningful collaboration between governments is critical to uphold the mandates and values underlying the Yukon *Waters Act*, the *Canada Water Act*, the *Umbrella Final Agreement*, *Na-Cho Nyäk Dun Final Agreement* and *Tr'ondëk Hwëch'in Final Agreement*, especially Chapter 14 on water. However, governments alone cannot manage the land sustainably without participation from stakeholders and interested parties who want to see the area protected. Ongoing conversations among organizations, businesses and individuals living and working in the area is highly recommended.

Recommendation: Study the potential impact of placer mining in the watershed on the main stem of the McQuesten River

Rationale: Turbidity is showing an upward trend over the last ten years, especially in the month of May during freshet. The Water Quality Index is considered marginal, in part because of high turbidity. Placer mines are one source of particulates in the water and as such, settling ponds and other means are in place to reduce TSS discharges. All placer mines are located on tributaries to the McQuesten River and it is unknown how much particulates these placer mines contribute to the main stem of the river. The Water Quality Objectives defined under the Fish Habitat Management System differ between tributaries and the main stem of the McQuesten River (Fisheries and Ocean

Canada 2010). CMI conducts water quality monitoring in the South McQuesten River watershed on a regular basis and reports on compliance with the water quality objectives for the main stem of the river and its tributary. It is unclear however, if the measures in place to control the impact of placer mines, such as EQS for settleable solids, are effective in protecting the South McQuesten River by maintaining its natural turbidity regime. For this reason and because placer mining is generally considered a source of particulates, we recommend conducting a study to understand the correlation between Settleable Solids, TSS and turbidity and to characterize the impact of placer mining on fish habitat in the South McQuesten River.

Recommendation: Monitor turbidity, TSS and Settleable Solids on a monthly basis in the South McQuesten River downstream of all placer mining activities

Rationale: As discussed above, turbidity is significantly increasing in the month of May to levels above CCME guidelines at the long-term station, which is located upstream of Haggart Creek. A number of placer mines are located downstream of the long-term station; therefore, the long-term station is not able to monitor the impact of placer mining. We recommend that a water quality monitoring station is established downstream of placer mines to collect data that would enable a more thorough assessment of the health of the McQuesten River in the future.

Recommendation: Limit the release of nitrogen in the South McQuesten River by implementing relevant management actions

Rationale: Total Dissolved Nitrogen and Total Nitrogen are increasing in the South McQuesten River. The source may be runoff from forest fire soils, explosive by-products or other unknown sources. We encourage proponents, assessors and regulators to consider limiting the release of nitrogen species in the river by implementing relevant management actions. These can include establishing EQS for ammonia, nitrate or other nitrogen species, developing WQOs in tributaries to the South McQuesten River when relevant, consider adaptive management initiatives to monitor nitrogen species release and take action if an increase was observed.

Recommendation: Control the release of lead in Flat Creek and Christal Creek

Rationale: Flat Creek and Christal Creek contribute lead to the South McQuesten River. This area is rich with minerals, including lead, making mining extraction worthwhile. As a result, there is discharge of lead caused by the mining activities that adds to the natural release of lead. Water licences held by the Elsa Reclamation and Development Company Ltd. and by Alexco Keno Hill Mining Corp. both include an EQS for lead, of

0.20 mg/L in all cases, except for the new Birmingham operation, which as an EQS of 0,048 mg/L for lead. Special attention should be put on lead for any mine water management plans and reports from the area.

Recommendation: Monitor attainment of the WQOs at the long-term monitoring station in the South McQuesten River once established

Rationale: WQOs are a very useful tool to manage water and they should be used. In most cases in the Yukon, WQOs are developed by quartz mining licences and attainment of the WQOs is reported in the annual reports. Also adaptive management plans have response triggers and actions listed in case water quality in a particular waterway changes. Preliminary average and maximum WQO were developed at the long-term monitoring station along with a set of four thresholds to evaluate monitoring results and assess attainment of the WQOs. Attainment of the WQOs in the South McQuesten River should be assessed, reported and communicated moving forward.

Recommendation: Monitor dissolved metals at the long-term monitoring station and align with monitoring recommendations listed in the *Yukon Guide for Developing Water Quality Objectives and Effluent Quality Standards for Quartz Mining Projects*

Rationale: In response to the interim recommendations for this study, Government of Yukon and ECCC began analyzing dissolved, in addition to total, metal concentrations in water samples collected from YT09DD0008. Sampling and analyses should be completed at least monthly and more frequently during freshet, and other known periods of high variability, to align with the recommendations in the *Yukon Guide for Developing Water Quality Objectives and Effluent Quality Standards for Quartz Mining Projects* (Yukon Government 2021). This would allow Government of Yukon to revisit the data for this station after a few years' time and update the WQO. In addition, monitoring dissolved metals will allow for future assessment of the elements that are trending upward or downward over time and their associated potential effects on the McQuesten system.

Arsenic chromium and copper toxicity is greatly dependent on whether it is in a dissolved state or not. Arsenic bound to iron is not readily available and has low toxicity, such as in the arsenopyrite often encountered in mining. Chromium in mineral form is not toxic but dissolved chromium (VI) is. Copper can be found in native form but is most often found within a sulphide mineral complex where it has little toxicity.

Beryllium exhibits toxicity only if inhaled. Cerium, lanthanum and yttrium have no toxicity, often occur together and are usually in the same mineral complex. Molybdenum has no toxicity at normal levels and is an essential element for animals and plants. In this system it is likely in dissolved form, but it would be useful to know for certain to evaluate overall system health.

Consistent with the Guide, the study team recommends using dissolved concentration data (once available) to derive WQO for dissolved aluminum, cadmium, cobalt, copper, and iron and potentially lead and zinc because the dissolved forms of these metals are the forms most likely to be released by mining operations and are typically more representative of the bioavailable fraction.

Recommendation: Conduct physical evaluation of the watershed for potential permafrost degradation and slumping

Rationale: With turbidity on an increasing trend and likely producing the increasing trends for some elements and nitrogen, determining the sources for the turbidity is important. A visual examination of the watershed should be undertaken to see if climate and fire driven changes have induced permafrost degradation and slumping into the system. Remote sensing could be employed to define areas for later physical inspection.

Recommendation: Monitor mercury in the South McQuesten River

Rationale: Mercury is associated with increasing turbidity in riverine systems. It is contained in soils and usually in the more bioavailable methylated form. Studies have shown increasing levels of mercury in fish where river systems have increasing land erosion into the drainage. There has been no analysis to this point for mercury in the sampling regime and it should be added to further judge climate change impacts to the McQuesten system.

Recommendation: Assess trends in precipitation and consider monitoring flow at the long-term monitoring station

Rationale: Precipitation changes can drive erosion events and a larger freshet, which in turn can increase erosion. This leads to increased inputs of elements to the river drainage. Any data regarding precipitation over the period examined here for this drainage should be statistically evaluated for trend. This would particularly aid in determining a cause for increasing turbidity. It would also lend itself to evaluating future developments within the drainage system. Isotopic analysis of collected precipitation would aid in the development of a water isotopic map for the region. As well, flow data are valuable for understanding contaminant loading and seasonal fluctuations in parameter concentrations in the River. It is therefore recommended to coordinate flow monitoring with any future water quality monitoring at locations where there is an intention to derive WQO, including the long-term monitoring station (YT09DD0008).

Recommendation: Monitor water isotopes

Rationale: The use of water isotopes in river systems provides a better understanding of the regional water cycle. Over long periods of time they can track changes in source apportionment of recharge to the river system. Used within the drainage they can assess variations in production and respiration (P:R). This allows for better interpretation of the overall health of the river and can provide data on the sensitivity of the river to changes in inputs from either natural or anthropogenic sources. A water isotope monitoring program should be developed for the McQuesten to aid in further interpretation of trend data and in projecting the effects of future loading of those components to the river. Tritium analysis should also be added to determine the age of various water inputs to the system. This would promote a better overall understanding of the watershed and help to track shifts in water inputs to the river over time.

Recommendation: Monitor water quality in Cache Creek on a monthly basis all year round

Rationale: Assessment of water quality along the river and tributaries highlighted the fact that Cache Creek may be contributing significant loadings of cadmium, copper and zinc into the South McQuesten River. Regular monitoring of Cache Creek started in February 2020 by WRB. It is recommended that Cache Creek be monitored monthly over the long-term to understand if Cache Creek chemistry is fairly stable or if it keeps changing. In addition, it is recommended to better characterize Cache Creek and to investigate the sources of the high cadmium, copper and zinc concentrations and its potential impact on the South McQuesten River.

It should be noted that two reports were published by WRB in 2011 and 2015 with the data acquired to date. More recent data should be published and discussed as well.

Recommendation: Conduct trends analysis for arsenic in Haggart Creek

Rationale: Arsenic increases along the main stem of the South McQuesten River, likely from contributions from the tributaries. One of the large tributaries is Haggart Creek, which is known to have relatively high arsenic concentrations. A long-term water quality monitoring station was established in Haggart Creek in 2015. It is recommended to conduct a trend assessment at this station, in particular for arsenic to see if arsenic is stable or increasing in this tributary. Note that there is a quartz mining operation on Haggart Creek, with strict arsenic controls.

Recommendation: Conduct trends analysis for cerium across the Yukon

Rationale: Recent research by Rue and McKnight (2021) found indications that the leaching of rare earth element is accelerated by changes in climate in a mineralised area in Colorado. This study found that cerium, lanthanum and yttrium are showing an increasing trend over the last ten years based on monthly sampling. Cerium is considered the most abundant rare earth element on earth. Cerium is being monitored monthly at all 13 long-term water quality monitoring stations across the Yukon. Although the toxicology of cerium is not of concern right now it would be worth investigating the long-term trends in cerium across the Yukon, in various mineralized areas to see if cerium could be used as an indicator for changing water regimes and natural acid rock drainage.

Recommendation: Conduct a correlation analysis to determine the relationship between water quality and flow

Rationale: Flow dynamics within an aquatic system may contribute to the trends observed in the water quality concentrations. Higher water flow during the spring freshet can contribute to higher rates of erosion, re-suspension of precipitates or flushing material from terrestrial environment and transporting suspended material and chemicals in the receiving water column. These seasonal peaks in flow may contribute to increased concentrations of water quality parameters observed at monitoring stations downstream from the source. Further exploring the correlation of flow with increased trends observed in water quality data during the spring freshet will further provide understanding how sources of increased metals may impact the water quality of this watershed. This understanding of the correlation between flow and water quality may also contribute to understanding how changes in flow due to climate change may alter the impact of high metal concentrations have from tributaries into the main channel of the South McQuesten River.

8 Contact Information

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Appendix A: Water Quality Objective Memo