2018 Big Thompson River
Water Quality Summary Report

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Big Thompson Watershed Forum

Executive Summary

We evaluated water quality parameters collected in 2018 from flowing waters in the Big Thompson River watershed and generally conclude that water quality in the Big Thompson River continues to be relatively good. This conclusion was based on an examination of data that came from water samples collected at 17 sites in 2013-2018 by the United States Geological Survey (USGS) and volunteers as part of the USEPA8 Volunteer Monitoring Program between 2011 and 2015. Where applicable, we compared measured values to water quality standards as adopted by the Colorado Water Quality Control Commission Regulations 31 and 38.

Although water quality was generally good in 2018, some measured parameters differed from levels that would be considered acceptable with regard to water quality standards and operational standards used by water utilities. Elevated water temperatures have continued to be of concern, as climate change and other factors have resulted in broadly increasing temperatures in recent decades, but the temperatures were fairly average in 2018. The water temperatures in 2018 were near the five-year median although the last five years have had some of the hottest temperatures on record. Copper levels occasionally exceeded water quality standards (particularly in the upper river) but median values were relatively low in 2018 when compared to the median value from 2013-2017. Similarly, total organic carbon (TOC) levels were very close to the five-year median values.

Selenium levels in 2018 were generally lower than seen in 2017 but near the five-year median values (2013-2017). An important note is that levels of selenium were lower below the City of Loveland wastewater discharge (site M140) than above the discharge point (site M130), which suggests that the City of Loveland may generally dilute levels of dissolved selenium in the Big Thompson River. However, all sites in in the lower portion of the river have higher levels of dissolved selenium than sites located in the upper portion of the river. likely caused by the fact that the bedrock geology of this portion of the river (Pierre shale) is rich in selenium.

E. coli levels in 2018 were slightly lower than the five-year median values and the number of samples that exceeded water quality standards was lower than in 2017. Elevated *E. coli* samples continue to occur exclusively in the lower portion of the river.

Conversely, some water quality parameters were consistently better than accepted water quality standards. Dissolved oxygen (DO) levels decrease downstream, but overall, tended to be good throughout the river and none of the measured values were below accepted water quality standards. Orthophosphate levels in 2018 were also generally good as median values were lower than the five-year median values in all portions of the river.

List of Figures and Tables

Big Thompson Watershed Forum

Founded in 1997, the Big Thompson Watershed Forum (Forum) is a collaborative non-profit organization located in Loveland, Colorado. The Forum represents a wide range of interests, including private citizens, businesses, non-governmental organizations, and government agencies (https://btwatershed.org/about-btwf/). The Forum's major funders include the City of Loveland, the City of Fort Collins, the City of Greeley, and Northern Water. The Forum is also supported by a number of minor funders including Larimer County, the City of Fort Morgan, the North Weld County Water District, the Town of Estes Park, the Town of Milliken, and several individual donors. The mission of the Forum is to support the protection and improvement of water quality in the Big Thompson River Watershed through collaborative monitoring, assessment, and education/outreach projects. The Forum's goals are to foster stakeholder teamwork in conducting watershed assessment, identify priority protection measures, educate affected interests, and promote voluntary practices that protect the Big Thompson Watershed and the quality of its waters.

The Forum created a Cooperative Monitoring Program (COOP) (http://btwatershed.org/cooperative-monitoring-program) and an Environmental Protection Agency Volunteer Monitoring Program (Volunteer) (https://btwatershed.org/history/) to assess water quality and related ecological concerns throughout the Big Thompson River Watershed. The COOP program involves collection and analysis of samples by the United States Geological Survey (USGS) and is ongoing. An additional group of sites were sampled by the Volunteer program. The Volunteer program began in August 2001 and ended in November 2015.

Report Objectives

This report is intended to summarize water quality in the Big Thompson River in 2018. Water quality data collected in 2018 are compared to those collected during the previous five years (2013-2017). Data collected for the COOP in 2018 were also compared to water quality standards adopted by the Colorado Water Quality Control Commission (Regulations 31 and 38; WQCC 2018a, WQCC 2018b).

Data Collection

While water quality sampling for the COOP included 72 water quality parameters in 2018, this report focuses on a subset of 14 parameters commonly used to characterize water quality and those of potential concern regarding water quality standards. These parameters include flow, dissolved oxygen, specific conductance, water temperature, total organic carbon (TOC), copper, mercury, selenium, total nitrogen, nitrate + nitrite, total phosphorus, orthophosphate, sulfate, and *Escherichia coli* (*E. coli*).

Most samples collected during COOP monitoring in 2018 were analyzed at the USGS' National Water Quality Laboratory in Denver; however, *E. coli* and TOC were analyzed by the Cities of Loveland and Fort Collins, respectively.

Study Sites

A total of 17 sites were sampled on the mainstem and tributaries of the Big Thompson River in 2018 (M10, M20, M30, M40, M50, M60, M70, M90, M130, M140, M150, T10, T20, VT05, VM05, C10, and C20) (Figure 1, Table 1).The sites ranged from areas with essentially pristine water quality conditions, such as M10 which is located in Rocky Mountain National park, to sites where water quality is more heavily dependent on direct management by water utilities and other users. The total distance between the uppermost site (M10) and the site just above the confluence of the Big Thompson River and the South Platte River (VM05) is approximately 75 miles. All sites were sampled by the USGS as part of the COOP Program. The use of "M" in a site name indicates that the site is located in the mainstem of the Big Thompson River and the use of a "T" indicates that the site is located in a tributary to the Big Thompson River. The tributary sites sampled in 2018 included: the North Fork Big Thompson River (T10), Buckhorn Creek (T20), and the Little Thompson River (VT05). The two tunnel sites, C10 and C20, are part of the Colorado-Big Thompson Project conveyance system, where C10 monitors the quality of water originating from the Upper Colorado River watershed as it enters the East Slope from the Adams Tunnel and C20 monitors water quality after water has exited Lake Estes and as entered the Olympus Tunnel.

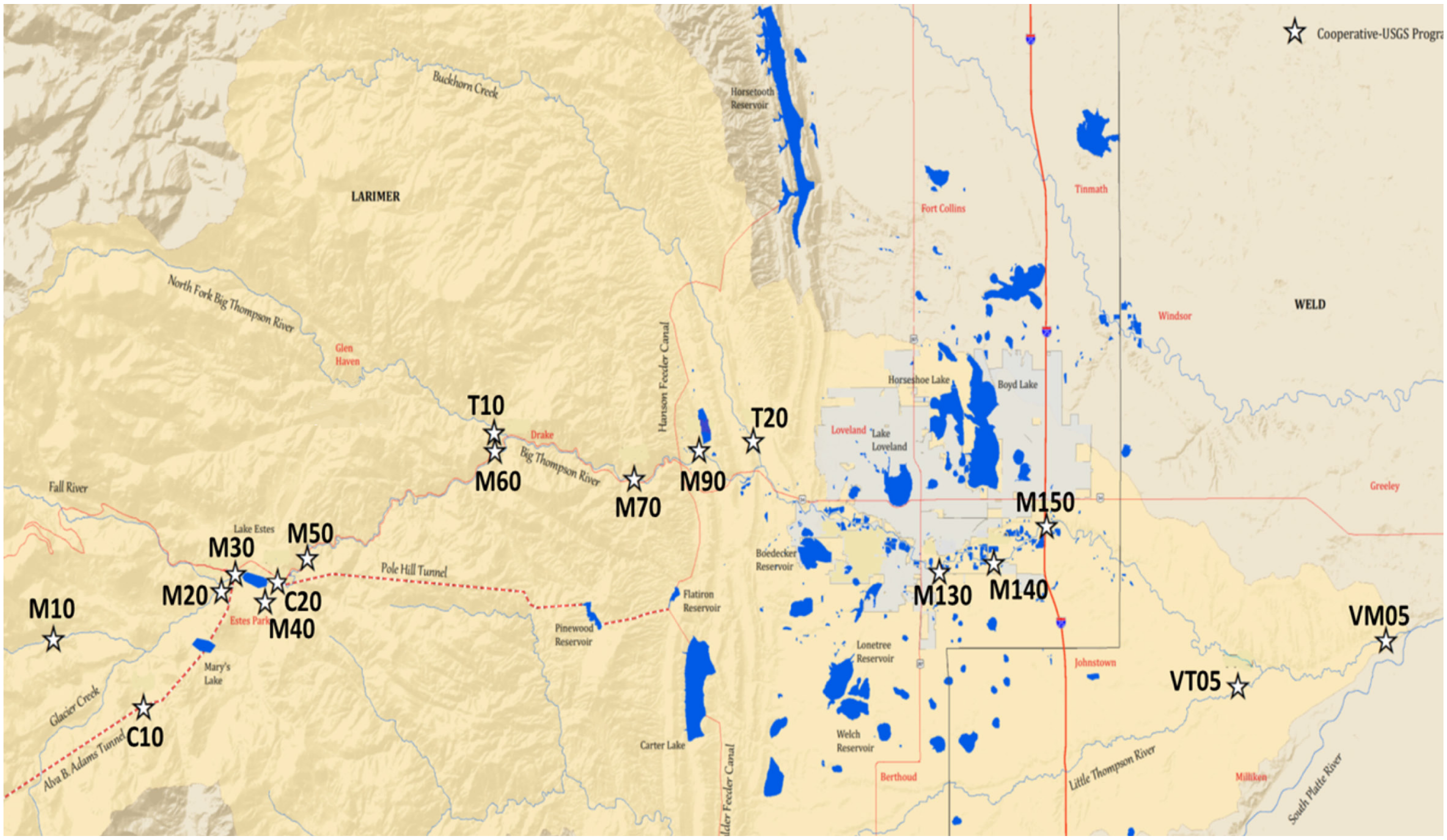

Figure 1. Locations of sites on the Big Thompson River, canals, and associated tributaries in 2018.

Site	Water Body	Description	Lat.	Long.
T10	North Fork of Big Thompson	Upstream of confluence with Big Thompson River	40 26' 00"	105 20' 18"
T20	Buckhorn Creek	Upstream of confluence with Big Thompson River	40 26' 04"	105 11' 06"
M10	Big Thompson	Downstream of Moraine Park – USGS Benchmark Site	40 21' 14"	105 35' 01"
M20	Big Thompson	Upstream of Estes Park Sanitation District Outlet	40 22' 42"	105 30' 48"
M30	Big Thompson	Downstream of Estes Park Sanitation District Outlet	40 22' 45"	105 30' 23"
M40	Big Thompson	Downstream of Olympus Dam/Upstream of Upper Thompson Sanitation District Outlet	40 22' 35"	105 29' 06"
M50	Big Thompson	Downstream of Upper Thompson Sanitation District Outlet	40 22' 49"	105 28' 20"
M60	Big Thompson	Drake, upstream of confluence with North Fork	40 25' 54"	105 20' 21"
M70	Big Thompson	Upstream of Dille Tunnel Diversion	40 24' 54"	105 15' 00"
M90	Big Thompson	Upstream of Loveland Drinking Water Plant Intake	40 25' 33"	105 12' 43"
M130	Big Thompson	Upstream of Loveland Wastewater Outlet (St. Louis St.)	40 22' 43"	105 03' 38"
M140	Big Thompson	Downstream of Loveland Wastewater Outlet (Co. Rd. 9E)	40 23' 00"	105 01' 45"
M150	Big Thompson	At Interstate 25	40 23' 51"	104 59' 32"
VM05	Big Thompson	County Road 396	40 21' 5"	104 46' 30"
VT05	Little Thompson	Highway 257; Little Thompson River	40 17' 29"	105 2' 12"
C10	Adams Tunnel	East Portal	40 19' 40"	105 34' 39"
C20	Olympus Tunnel	Tunnel Outlet of Lake Estes	40 22' 30"	105 29' 13"

Table 1. 2018 sample site locations and descriptions.

Flow

Flow represents the volume of water passing through a specific location in given unit of time, generally expressed as cubic feet per second (cfs). Flow rate data are presented as site and river section specific medians and as such do not reflect important components of flow such as seasonal dynamics. Medians presented here suggest relative flow differences between sites and can be used to determine whether a given year is relatively wet or dry.

Dissolved oxygen

Dissolved oxygen levels are important to aquatic life and drinking water facilities. Virtually all aquatic organisms require dissolved oxygen to survive, with the necessary concentration differing by species. For example, many fish species in the upper portion of the Big Thompson River have evolved to live in coldwater streams and require higher concentrations of dissolved oxygen (e.g. cutthroat trout *Oncorhynchus clarki*) than those who have evolved to persist in the lower warmwater portion of the river (e.g. johnny darter *Etheostoma nigrum*). Aquatic organisms can experience mortality if the dissolved oxygen levels drop below their threshold level for even a short time. Some life stages of aquatic organisms are more sensitive to low dissolved oxygen levels and therefore the standards vary based on the type of organisms that are expected to be found in a particular reach as well as the time of year (Table 1). In addition, dissolved oxygen levels regulate the degree to which some elements (like manganese and sulfur) remain in solution. Relatively high dissolved oxygen levels allow these elements to precipitate out of the water column and make drinking water treatment easier.

Specific conductance

Specific conductance is a measure of how well water conducts electricity. Specific conductance increases with increasing concentrations of ions that are dissolved in water such as chloride, sulfate, nitrate, phosphate, sodium, magnesium, calcium, potassium and iron. Although specific conductance does not directly impact water quality, it is commonly used to characterize water quality within and between sites both spatially and temporally. Specific conductance may also indicate whether an issue may exist that merits more detailed investigation.

Water temperature

Aquatic organisms have preferred temperature ranges. These ranges can vary widely and species with similar temperature tolerances are often associated with one another. Some organisms require relatively cold water to survive, particularly during spawning and egg and larval growth and development. Consequently, elevated water temperatures can cause reduced reproduction, growth, or mortality. Conversely, water temperatures can be too low for optimal growth and survival of some species, particularly those found in the lower reaches of the Big Thompson River.

Turbidity

Turbidity is essentially a measure of how transparent water is. Water with higher turbidity levels has a greater number of suspended particles in it and is less clear. Elevated turbidity has negative impacts on municipal water treatment plants and aquatic communities. For example, the City of Loveland alters the location of their water collection when turbidity levels rise above 100 NTU. High turbidity generally means there is an increased sediment present in the water. Accommodating sediment is a challenge to drinking water utilities. Turbidity levels are also positively associated with total organic carbon (TOC) levels which in turn require additional water treatment efforts. Elevated turbidity can have direct negative effects on aquatic organisms in addition to indirect effects such as increasing the levels of some dissolved metals. Elevated turbidity and suspended sediment can have negative effects on density and species richness of macroinvertebrates. Growth of trout species such as rainbow trout (*Oncorhynchus mykiss*) is negatively associated with increased turbidity and increased turbidity can lead to increased mortality as well. Effects of elevated turbidity become more severe with longer exposure.

Total organic carbon

Total organic carbon (TOC) is a measure of the amount of dissolved and particulate organic matter in a water sample. Dissolved organic carbon compounds are the result of the decomposition of organic matter such as algae, terrestrial plants, animal waste, detritus, and organic soils. The higher the carbon or organic content of a water body, the more oxygen is consumed as microorganisms break down the organic matter.

Although TOC is not a direct human health hazard, the dissolved portion of the TOC can react with chemicals (chlorine and others) used for drinking water disinfection to form disinfection byproducts that are regulated as potential carcinogens (e.g. chloroform $CHCl_3$). As such, TOC levels are of concern to drinking water treatment facilities.

Sulfate

Sulfate is a naturally occurring, major ion in surface and ground waters. Sulfate is the primary form that sulfur takes in highly oxygenated waters such as the Big Thompson River and is of interest due to taste and gastrointestinal issues that elevated levels may cause in drinking water. A domestic water supply stream standard of 250 mg/L and a treated drinking water secondary maximum contaminant level of 250 mg/L (non-enforceable guidance level for aesthetic quality) have been adopted for sulfate. Sources of sulfate include the decay of organic matter, acid mine drainage, industrial effluent, runoff from fertilized agricultural lands, atmospheric deposition, and wastewater treatment plant effluent. Sulfate can be present in surface and ground waters at elevated concentrations due to interactions with soluble evaporite minerals such as gypsum in sedimentary bedrock. Pierre Shale, a source of selenium within the lower portion of the watershed, is also a source of background sulfate (Tourtelot 1961), particularly when it is disturbed in events such as floods or land development projects.

Copper

Dissolved copper is of interest primarily due to its potential effects on aquatic life. While copper is an essential nutrient, it can cause chronic and acute effects to aquatic life at higher concentrations. Acute effects include mortality; chronic effects include reduced survival, growth, and reproduction. Copper toxicity is determined in part by the hardness of the water. Copper toxicity to aquatic organisms is lower when hardness is higher because dissolved copper is less bioavailable when hardness is high.

Selenium

Elevated selenium concentrations can negatively affect aquatic organisms. Acute and chronic aquatic life standards of 18.4 and 4.6 µg/L respectively, have been adopted for all stream segments in the Big Thompson River Watershed. Several segments of the Big Thompson River are listed as impaired for selenium on Colorado's 303(d) List. However, selenium occurs at elevated levels in part due to the bedrock geology of the watershed. The lower portion of the watershed, below the canyon mouth, includes a type of bedrock called Pierre shale (Hart 1974) which is enriched in selenium. Selenium levels can be further elevated by surface disturbance caused by activities such as land development projects and events such as floods (Ackerman and Schiff 2003).

Manganese

Manganese is an element that is considered beneficial to human health at low levels and is one of the least toxic elements, but elevated levels can cause taste and staining issues and issues for water distribution systems. Specifically, manganese can cause a brownish color to water and may cause buildup in water distribution pipes. The relative toxicity of manganese to aquatic life is based on the hardness of the water, but manganese levels of concern to aquatic life are much higher than those present in the Big Thompson River. The drinking water standard for manganese is 50 ug/L which is much lower than levels that might be of concern to aquatic life.

Total nitrogen

Total nitrogen is the sum of total Kjeldahl nitrogen (i.e. ammonia + organic nitrogen), nitrate, and nitrite concentrations. Sources of nitrogen in surface waters include the decay of plant and animal matter, fecal matter, atmospheric deposition, wastewater treatment plant effluent, failing individual sewage disposal systems (i.e. septic systems), and runoff from fertilized agricultural lands, golf courses, and lawns.

Nitrate + nitrite

Nitrate and nitrite are of interest due to the role they play in aquatic plant growth and their potential effects on human health. Nitrate, along with ammonia, is a form of nitrogen that is available for immediate uptake by algae and is therefore of interest due to its role in determining the productivity of a given waterbody. At higher concentrations (e.g. >10 mg/L), nitrate can be of concern in drinking water because it can reduce the oxygen-carrying capacity of hemoglobin in humans and create a condition known as "methemoglobinemia" particularly in those under two years of age. Nitrite is also available for uptake by algae but is rarely present at significant concentrations.

Total phosphorus (Total P) and Orthophosphate (Ortho-P)

Total phosphorus is the sum of the inorganic, organic, dissolved, and particulate forms of phosphorus. Orthophosphate is a dissolved form of phosphorus and is the only form that is immediately available for uptake by algae. Total P represents the total amount of phosphorus that could potentially be transformed to Ortho-P and thereby become available for uptake by algae. Sources of Total P include the decay of plant debris and other organic matter, the minerals that make up rocks, soils, and sediments in the watershed, wastewater treatment plant effluent, failing individual sewage disposal systems, runoff from fertilized agricultural lands and urban areas, and erosion of stream channels, dirt roads, construction sites, and other land surfaces.

Escherichia coli

Escherichia coli is a species of bacteria that occurs in the intestines of warm-blooded animals and aids in the digestion of food. *E coli* is usually not pathogenic but is used as an indicator of the potential presence of disease-causing bacteria, protozoa and viruses. Water with elevated levels of *E. coli* may indicate a potential water consumption or contact risk for humans.

All data with sample dates from January 1, 2013-December 31, 2018 were exported from the Forum's database and transferred to an Excel file to assemble a final dataset of comparable sites and metrics. 2018 data were manipulated and managed directly in a Microsoft Excel environment. Records that were recorded as a "non-detect" (i.e. the value was lower than the detection limit for the methodology being used) were treated as values equivalent to one-half of the indicated detection limit. All figures were generated using the functions "boxplot" and "ggplot2" in the R programming environment (R Core Development Team 2016).

Box plot figures were constructed to allow for the comparison of the 2018 median values for each analyte by river section to all data collected for the same river section during the 2013-2017 time period. To maximize the degree of comparability between years, only mainstem sites sampled in all 6 years were included in summary data (C10, C20, M10, M20, M30, M40, M50, M60, M70, M90, M130, M140, M150, and VM05). The river sections were defined as follows:

- **"Tunnel" sites**: C10 and C20 are part of the Colorado-Big Thompson Project conveyance system. C10 monitors the quality of water from the Upper Colorado River watershed as it exits the east portal of the Adams Tunnel. Water at C20 is a mixture of Upper Big Thompson River water and Upper Colorado River water and is the outflow from Lake Estes and the inflow to the Olympus Tunnel.
- **"Upper" river section**: from Moraine Park in Rocky Mountain National Park to downstream of Lake Estes and Upper Thompson Sanitation District WWTP effluent discharge; sites M10, M20, M30, M40, and M50.
- **"Middle" river section**: from upstream of confluence with the North Fork to upstream of the City of Loveland water Treatment Plant intake; sites M60, M70, and M90.
- **"Lower" river section**: from upstream of City of Loveland WWTP effluent discharge to confluence with South Platte River; sites M130, M140, M150, and VM05.

Median values of all sites sampled in 2018 in each river section are represented by a red circle in the figures. All data collected between 2013 and 2017 in each river section are summarized by the constructed "boxes" to show the maximum, minimum, 25th percentile, 50th percentile (median), and 75th percentile. Blue dots represent either maximum or minimum values that are greater than 1.5 times further from the interquartile range from the median.

The spatial boxplots were constructed for each parameter using all data collected at each site in 2018. The sites are arranged (approximately) in upstream to downstream order (left to right on each figure) from the headwaters of the Big Thompson River in the west to the confluence with the South Platte River in the east.

Data collected in 2018 were also compared to CDPHE water quality standards from Colorado Regulations 31 (WQCD 2018a) and 38 (WQCD 2018b), shown in Tables 2 and 3. Water quality standards are used in this report to provide context for the data and to establish relative expectations for the purpose of evaluating water quality trends within and/or between sites. Please note that these analyses do not constitute a formal surface water quality regulatory assessment under the federal Clean Water Act.

		Nutrients (mg/L)			Microbiological (cfu/100 mL)		General								
Segment	Station	Total nitrogen*	Total phosphorus*	Nitrate (water supply)	*E. Coli* 5/1-10/15	*E. Coli* 10/16-4/30	Sulfate (domestic water supply)	Oxygen (non-spawning)	Oxygen (spawning)	pH (lower limit)	pH (upper limit)	Temperature (acute)	Temperature (chronic)	Temperature (acute)	Temperature (chronic)
1	M10	1.25*	0.11	10	126	126	250	6	7	6.5	9	21.7[1]	17[1]	13[2]	9[2]
2	M20	1.25*	0.11	10	126	126	250	6	7	6.5	9	21.7[1]	17[1]	13[2]	9[2]
2	M30	1.25*	0.11*	10	126	126	250	6	7	6.5	9	21.7[1]	17[1]	13[2]	9[2]
2	M40	1.25*	0.11*	10	126	126	250	6	7	6.5	9	21.7[1]	17[1]	13[2]	9[2]
2	M50	1.25*	0.11*	10	126	126	250	6	7	6.5	9	21.7[1]	17[1]	13[2]	9[2]
2	M60	1.25*	0.11*	10	126	126	250	6	7	6.5	9	21.7[1]	17[1]	13[2]	9[2]
2	M70	1.25*	0.11*	10	126	126	250	6	7	6.5	9	21.7[1]	17[1]	13[2]	9[2]
3	M90	1.25*	0.11*	10	126	126	250	6	7	6.5	9	23.9[3]	18.3[3]	13[4]	9[2]
4b	M130	2.01*	0.17*	10	126	630	250	5	5	6.5	9	28.6[5]	27.5	14.3[6]	13.8[6]
4c	M140	2.01*	0.17*	100[a]	126	630	-	5	5	6.5	9	28.6[5]	27.5[5]	14.3[6]	13.8[6]
5	M150	2.01*	0.17*	100[a]	205	630	-	5	5	6.5	9	28.6[5]	27.5[5]	14.3[6]	13.8[6]
5	VM05	2.01*	0.17*	100[a]	205	630	-	5	5	6.5	9	28.6[5]	27.5[5]	14.3[6]	13.8[6]
7	T10	1.25*	0.11	10	126	126	250	6	7	6.5	9	21.7[1]	17[1]	13[2]	9[2]
7	T20	1.25*	0.11	10	126	126	250	6	7	6.5	9	21.7[1]	17[1]	13[2]	9[2]
9	VT05	2.01*	0.17*	10	126	126	250	5	5	6.5	9	28.6[5]	27.5[5]	14.3[6]	13.8[6]

1 June-September
2 October-May
3 April-October
4 November-March
5 March-November
7 December-February

*These nutrient criteria values are not currently applicable standards for the noted segments, but are used here for informational comparisons to observations.
In August 2015, in-stream interim nutrient criteria for total phosphorus were adopted for some segments where the BTWF has sampling sites (segments 1,2,7, and 9).
Total nitrogen standards have not yet been adopted for any stream segment in the Big Thompson watershed.
a:Agricultural use standard

Table 2. Segment specific water quality standards for nutrients, *E. coli*, and general parameters as adopted by Colorado Regulations 31 and 38, and Clean Water Act Section 303(d) Impairments as adopted by Colorado Regulation 93 (2016 303(d) List). Units for all standards are in mg/L except *E. coli* (cfu/100 mL), temperature (°C) and pH.

		Metals					Clean Water Act 303(d)	
Segment	Station	Mercury (Total)	Copper (Acute)	Copper (Chronic)	Selenium (Acute)	Selenium (Chronic)	Impairment	Priority
1	M10	0.01	$e^{(0.9422(Ln(Hardness))-1.7408)}$	$e^{(0.8545(Ln(Hardness))-1.7428)}$	18.4	4.6	Cu, As	H, H
2	M20	0.01	$e^{(0.9422(Ln(Hardness))-1.7408)}$	$e^{(0.8545(Ln(Hardness))-1.7428)}$	18.4	4.6	Cu, As	M, L
2	M30	0.01	$e^{(0.9422(Ln(Hardness))-1.7408)}$	$e^{(0.8545(Ln(Hardness))-1.7428)}$	18.4	4.6	Cu, As	M, L
2	M40	0.01	11	7.5	18.4	4.6	Cu, As	M, L
2	M50	0.01	11	7.5	18.4	4.6	Temp, As	H, L
2	M60	0.01	11	7.5	18.4	4.6	Temp, As	H, L
2	M70	0.01	11	7.5	18.4	4.6	Temp, As	H, L
3	M90	0.01	$e^{(0.9422(Ln(Hardness))-1.7408)}$	$e^{(0.8545(Ln(Hardness))-1.7428)}$	18.4	4.6	Cu, As	M, L
4b	M130	0.01	$e^{(0.9422(Ln(Hardness))-1.7408)}$	$e^{(0.8545(Ln(Hardness))-1.7428)}$	18.4	4.6	Se	L
4c	M140	0.01	$e^{(0.9422(Ln(Hardness))-1.7408)}$	$e^{(0.8545(Ln(Hardness))-1.7428)}$	18.4	4.6	-	-
5	M150	0.01	$e^{(0.9422(Ln(Hardness))-1.7408)}$	$e^{(0.8545(Ln(Hardness))-1.7428)}$	18.4	4.6	Se	L
5	VM05	0.01	$e^{(0.9422(Ln(Hardness))-1.7408)}$	$e^{(0.8545(Ln(Hardness))-1.7428)}$	18.4	4.6	Se	L
7	T10	0.01	$e^{(0.9422(Ln(Hardness))-1.7408)}$	$e^{(0.8545(Ln(Hardness))-1.7428)}$	18.4	4.6	Cu, As	H, L
7	T20	0.01	$e^{(0.9422(Ln(Hardness))-1.7408)}$	$e^{(0.8545(Ln(Hardness))-1.7428)}$	18.4	4.6	As	L
9	VT05	0.01	$e^{(0.9422(Ln(Hardness))-1.7408)}$	$e^{(0.8545(Ln(Hardness))-1.7428)}$	18.4	4.6	Se, *E. coli* (May-October)	L, H

Table 3. Segment specific water quality standards for metals as adopted by Colorado Regulations 31 and 38, and Clean Water Act Section 303(d) Impairments as adopted by Colorado Regulation 93 (2018 303(d) List) and 2016 303(d) impairments and relative priority. Units for all standards are in ug/L.

Flow

A total of 190 flow measurements were collected in 2018 between January and December. The flow in the mainstem of the Big Thompson ranged from a low of 0.99 cfs at site M150 on 6/4/18 to a high of 455 cfs at site M30 on 6/5/18 (Figure 6).

Dissolved oxygen

Dissolved oxygen levels generally decrease in a downstream direction, however, of the 194 samples taken, the lowest measured DO level was 6.6 mg/L which was measured in the Little Thompson River (VT05) on 7/23/18. The highest measured DO level in 2018 of 14 mg/L was found at site M150 on 2/7/18 (Figure 6). None of the measured DO values were below seasonal and site-specific water quality standards.

Specific conductance

The higher specific conductance levels at the downstream sites reflect the higher concentrations of dissolved solids such as calcium and sulfate. The lowest recorded value of 15 uS/cm occurred on 6/19/18 at site M10. The highest specific conductance in 2018 of 2460 uS/cm was recorded on 5/21/18 at site VT05 (Figure 6).

Water temperature

Temperatures were fairly average in 2018. However, of the 192 temperature values measured, 22 were above the recommended chronic standard and none were above the acute standard. The maximum temperature recorded during 2018 was 27.3°C at site M150 on 7/10/18 (Figure 6).

Turbidity

Of the 149 turbidity measurements in 2018, only 5 were above 100 NTU. The turbidity values ranged from a low of 2 NTU at site M10 on 2/7/18 and a high of 210 at site M70 on 3/8/2018 (Figure 6).

Total organic carbon

Although TOC values generally increase further down the watershed, 2018 was a bit unusual that both the highest and lowest TOC values were recorded at site M10 (Figure 6). The low value of 1.69 was recorded on 9/10/19 and the high value was recorded of 9.62 was recorded on 5/7/18.

Sulfate

Sulfate levels in 2018 ranged from a low of 1.2 mg/L at site M10 on 6/19/18 to a high of 1040 mg/L on 3/7/18 at site VT05 (Figure 6). Of the 162 recorded values, 10 were above the drinking water standard. All 10 were sampled at site VT05 in the Little Thompson River.

Copper

Dissolved copper levels ranged from 0.4 ug/L at site T20 on 11/7/18 to 5.8 ug/L at site M90 on 3/8/18 (Figure 7). The aquatic life standards for copper are generally dependent on the associated hardness level (up to a maximum hardness level of 400 mg/L) of the sample as the bioavailability of copper depends on hardness of the water. Copper toxicity is reduced in hard water because the cations bind with copper and other metals and make them less bioavailable (Niyogi and Wood, 2004). Although the aquatic life standards for dissolved copper depend on hardness, the bioavailability of copper also depends on other factors such as the amount of dissolved organic carbon and pH. The Biotic Ligand Model (Windward 2017) can be used to more accurately calculate the true bioavailability of metals such as copper by incorporating other important water quality parameters.

All sites except M40, M50, M60, and M70 have aquatic life standards calculated based on an equation that includes the associated hardness of the sample. The copper aquatic life standards for sites M40, M50, M60, and M70 are 11.0 ug/L (acute) and 7.5 ug/L (chronic).

The aquatic life standards for copper based on hardness are calculated as:

$$\text{Copper standard (acute)} = e^{(0.9422(\text{Ln(Hardness)})-1.7408)}$$

$$\text{Copper standard (chronic)} = e^{(0.8545(\text{Ln(Hardness)})-1.7428)}$$

Hardness values at Forum sites in 2018 ranged from 4.86 mg/L at site M10 on 7/9/2018 to 1110 mg/L at site VT05 on 3/7/2018. Calculated acute copper standards from ranged from 0.78 ug/L to 49.6 ug/L. Of the 158 samples collected, 6 (4%) of the samples were above the acute standard and 16 (10 %) were above the chronic standard. Most of the cases where concentrations were above the standards occurred in the upper portion of the river where hardness values were generally very low, resulting in very low values for the calculated standards.

Selenium

Dissolved selenium levels ranged from 0.04 ug/L on 5/7/18 at site C20 to 6.2 ug/L on 3/7/17 at site M130 (Figure 7). The highest concentrations occur in the lower watershed and reflect the influence of the Pierre Shale in this area. The aquatic life standard for selenium is 18.4 ug/L for acute exposure and 4.6 ug/L for chronic exposure. Of the 48 samples analyzed for selenium, none were above the acute standard, but two (both at site M130) were above the chronic standard (4%). These values were generally lower than values seen in 2017. In addition, the fact that the two highest selenium values were located at site M130, above the City of Loveland wastewater discharge, along with the fact that lower levels of selenium were seen at sit M140, below the City of Loveland wastewater discharge, continues to confirm the suggestion that the City of Loveland may act to dilute selenium levels in the Big Thompson River though their wastewater processing activities. Note, again, that this is not a regulatory assessment but simply a comparison of individual data points to the standard.

Manganese

Although manganese levels were generally similar to the median values in the previous five-year period, lower sites (M130, M150, and VM05) were somewhat elevated (Figure 7). The measured manganese values ranged from a low of 0.39 ug/L at site C10 on 1/9/28 to a high of 167 ug/L at site VT05 on 6/4/18. Of the total 157 samples analyzed for manganese, 32 (20%) were above the drinking water standard of 50 ug/L.

Total nitrogen

Total nitrogen ranged from 0.14 mg/L at site T10 on 11/05/18 to 8.3 mg/L at site VT05 on 4/12/17 (Figure 8). Monitoring sites M30, M50, M140, and VT05 are all downstream of wastewater treatment effluent discharge points and experience elevated nitrogen species concentrations as a result. Total nitrogen concentrations were above the interim numerical values adopted into Regulation 31 in 2012 (as shown in Table 1) in 38 of the 189 samples collected in 2017 (20%). This percentage was approximately the same as 2017. Total nitrogen standards have not yet been adopted for any stream segment in the Big Thompson watershed. All the potential exceedances were located in the lower portion of the river at sites M140, M150, VM05, and at site VT05 in the Little Thompson River.

Nitrate + nitrite

Nitrate+nitrite levels ranged from a low of 0.001 mg/L at site C10 on 5/17/18 and a high of 6.88 mg/L at site M150 on 3/7/18 (Figure 8). Nitrate+nitrite levels in the upper sites continue to be very low. Levels at sites in the lower river (M150 and VM05) while higher, were just above five-year median values and were far from levels to be of concern to drinking water.

Total phosphorus

Total phosphorus levels ranged from a low of 0.004 mg/L at site M10 on 2/7/18 to a high of 3.14 mg/L at site M140 on 3/7/18 (Figure 8). Monitoring sites M30, M50, M140, and VT05 are all downstream of wastewater treatment plant effluent discharge points and experience higher phosphorus concentrations compared to their associated upstream sites.

In August 2015, in-stream interim nutrient criteria for total phosphorus were adopted in Regulation 38 for steam segments in the Big Thompson watershed that are upstream of the most upstream wastewater treatment plant. However, for this report, all sites were compared to the interim numerical values adopted in Regulation 31 (see Table 1). Of the 191 samples analyzed for total phosphorus, 47 were above the total phosphorus interim numeric value of either 0.11 or 0.17 mg/L (25%). All these elevated values occurred in lower portions of the river where the numeric value for comparison is 0.17 mg/L.

Orthophosphate

Orthophosphate levels ranged from a low of 0.001 mg/L on 1/9/18 at site M10 to a high of 2.66 mg/L on 3/7/18 at site M140 (Figure 8). Orthophosphate levels in the upper sites continue to be extremely low. In addition, although 2018 orthophosphate levels at the downstream sites of M150 and VM05 are higher than the upstream sites, these levels are considerably lower than the five-year median values.

Escherichia coli

The levels of *E. coli* ranged from a low of 1 cfu/100 mL at site M10 on 2/7/18 to a high of >4840 cfu/100 mL at site M140 on 7/10/18. The site and season-specific water quality standard for *E. coli* is 126, 205, or 630 cfu/100 mL depending on time of year and location with higher standards generally applied to sites lower in the river and between October and April (Table 1). Of the 174 samples analyzed for *E. coli*, 25 were above the site associated standard (14%). The percentage of samples above the associated standard is less than in 2017 (25%) and similar to the percentage calculated in 2016. The elevated values are concentrated in the lower portion of the river.

Results

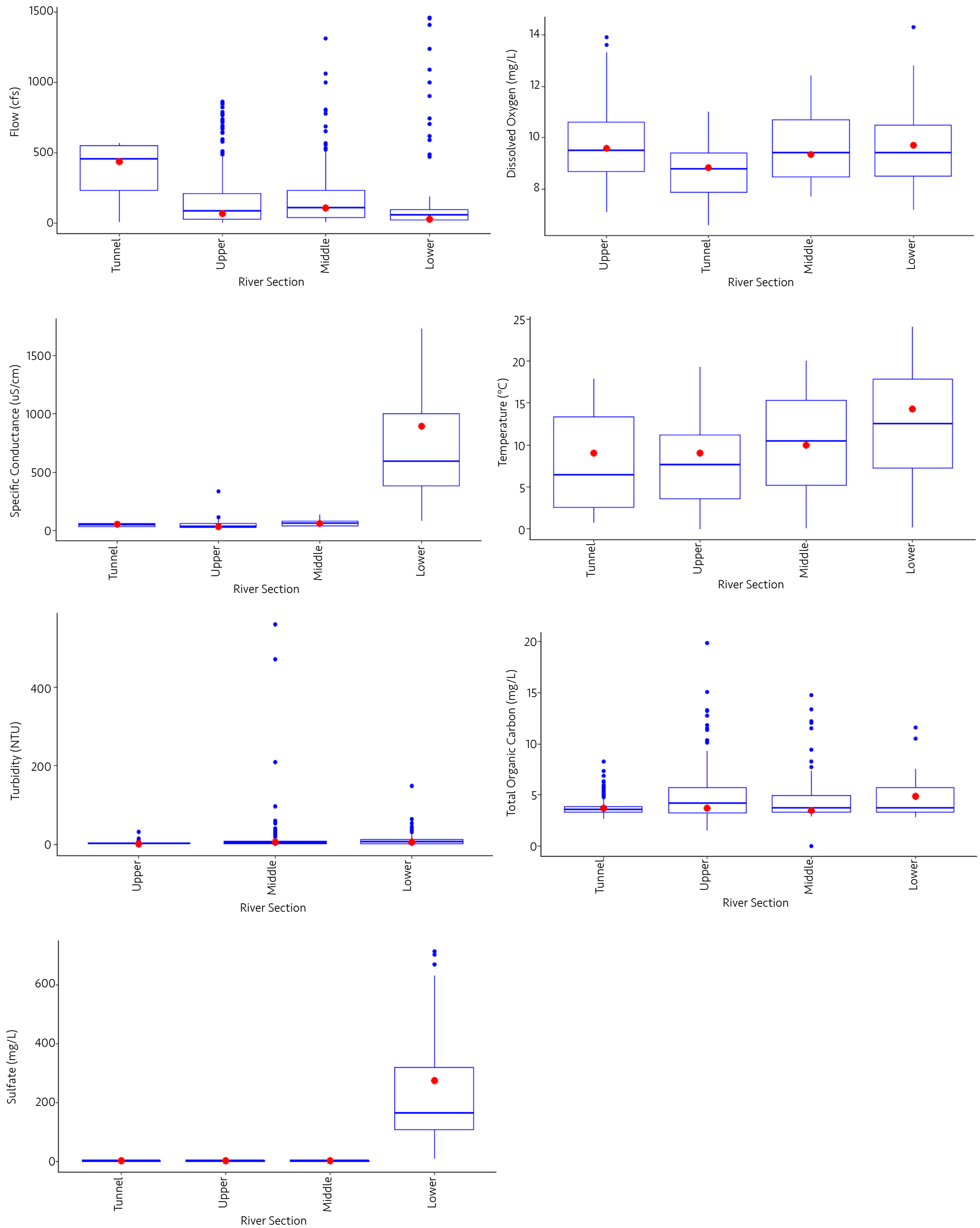

Figure 2. Box plots of general parameters representing the 2012-2018 time period. "Box-and-whiskers" constructed using all available data 2012-2016. Red circle represents 2018 median value.

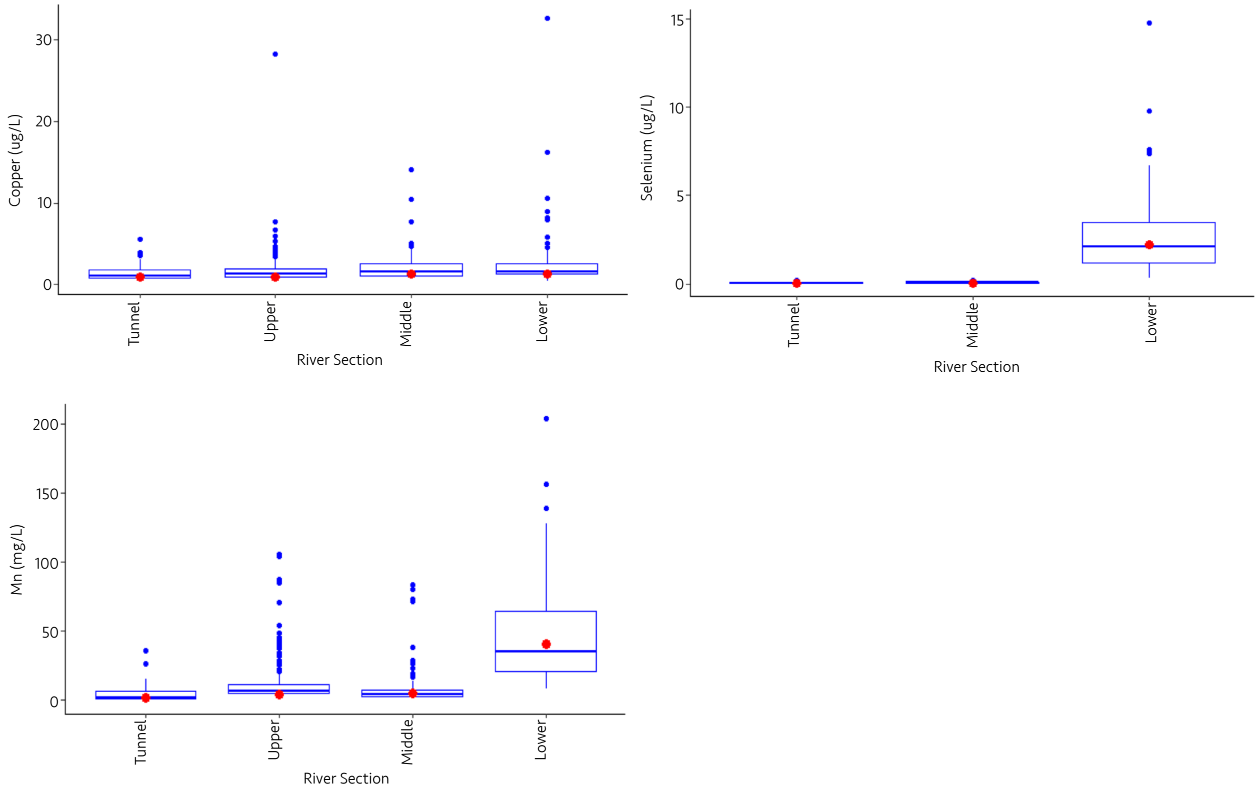

Figure 3. Box plots of metal parameters representing the 2013-2018 time period. "Box-and-whiskers" constructed using all available data 2013-2017. Red circle represents 2018 median value.

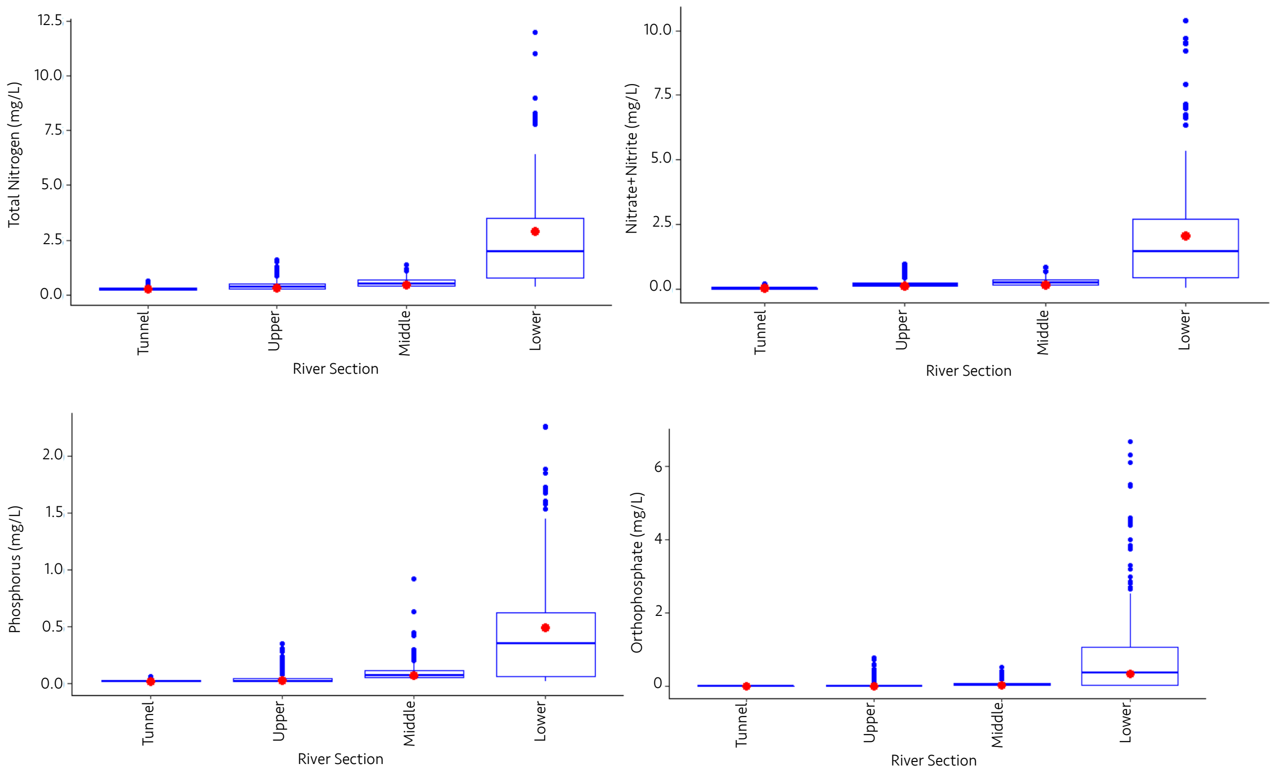

Figure 4. Box plots of nutrient parameters representing the 2013-2018 time period. “Box-and-whiskers” constructed using all available data 2013-2017. Red circle represents 2018 median value.

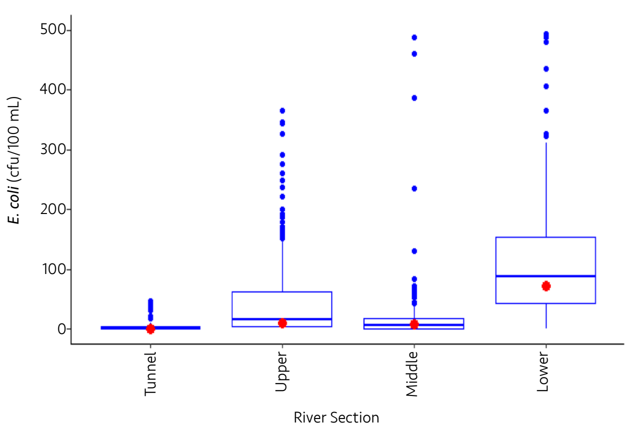

Figure 5. Box plot of *E. coli* levels representing the 2013-2018 time period. “Box-and-whiskers” constructed using all available data 2013-2017. Red circle represents 2018 median value.

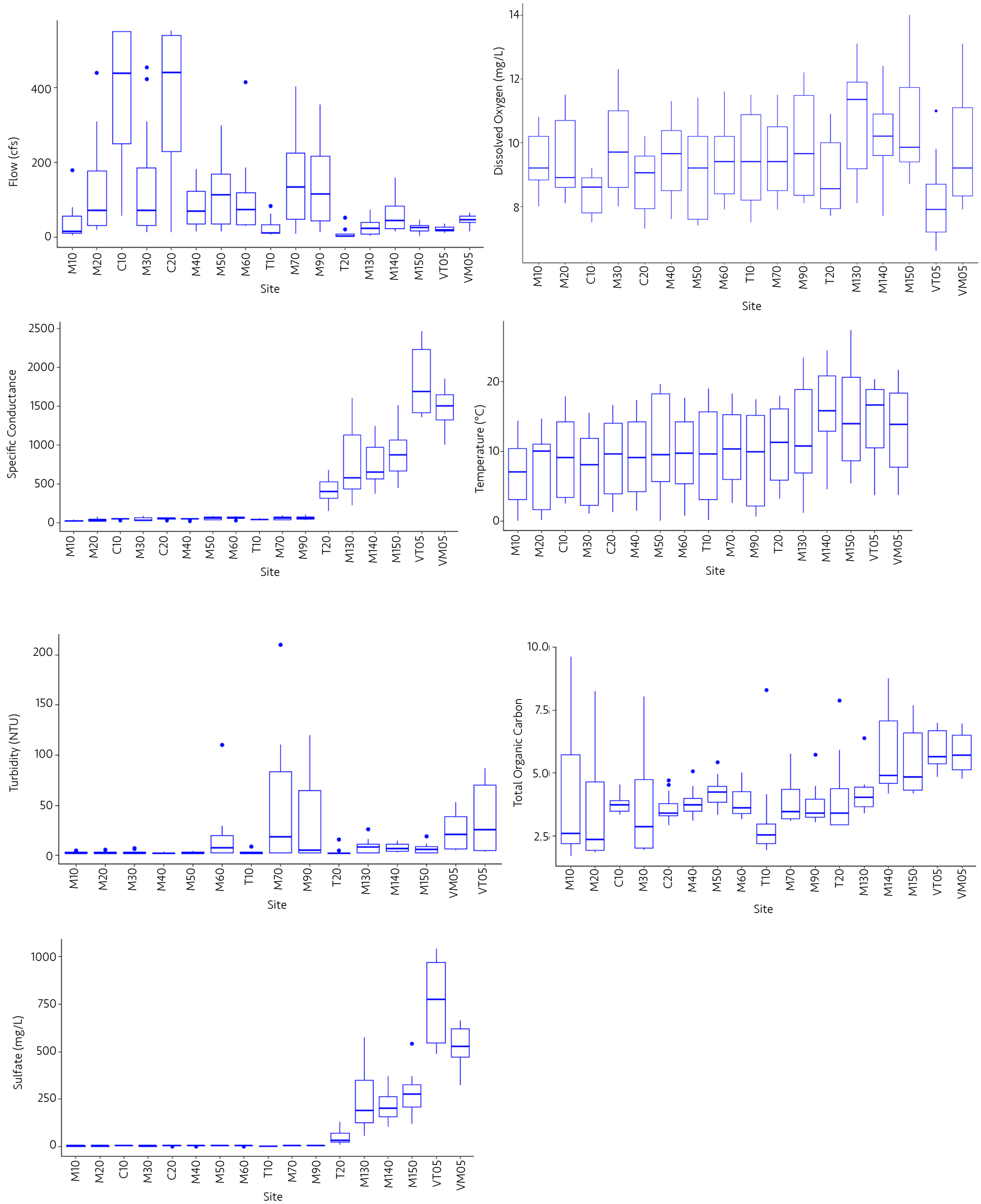

Figure 6. Spatial box plots for general parameters by site in 2018.

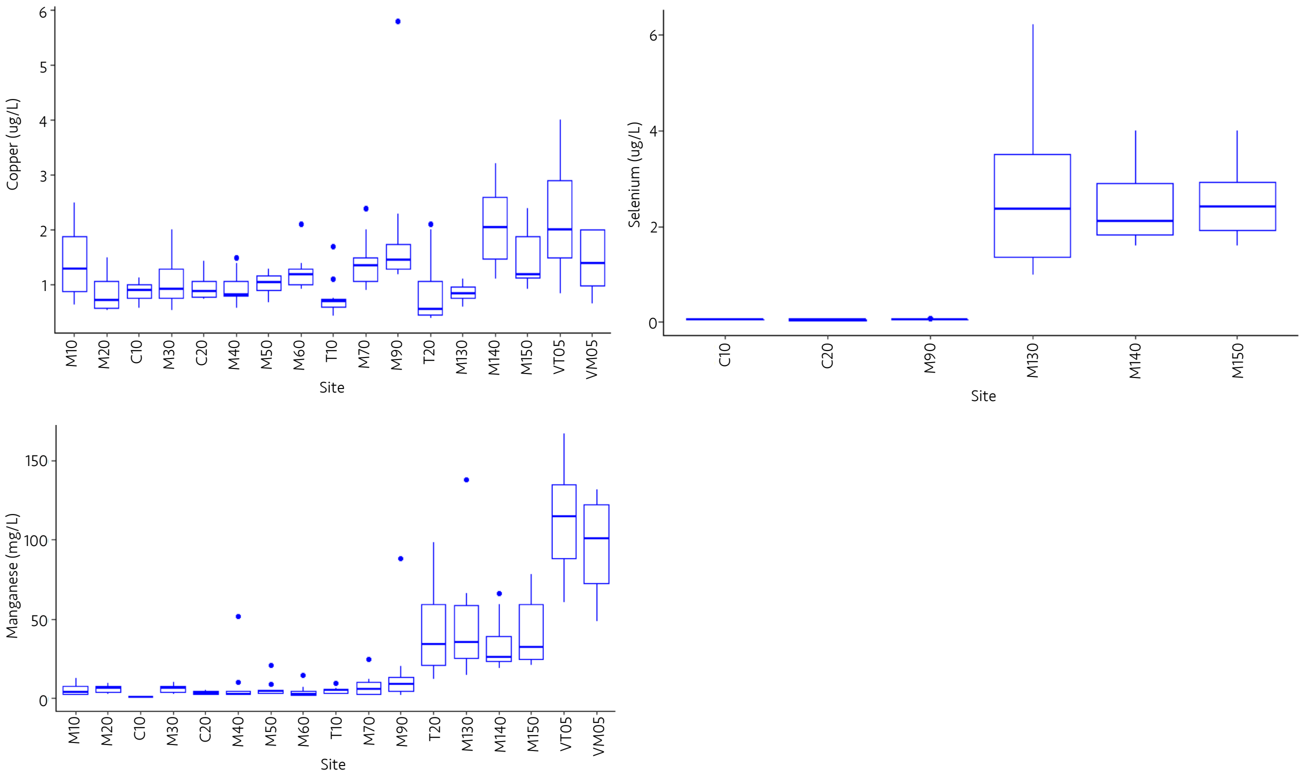

Figure 7. Spatial box plots for metal parameters by site in 2018. Solid lines represent the fact that all samples from that site were reported as "non-detect."

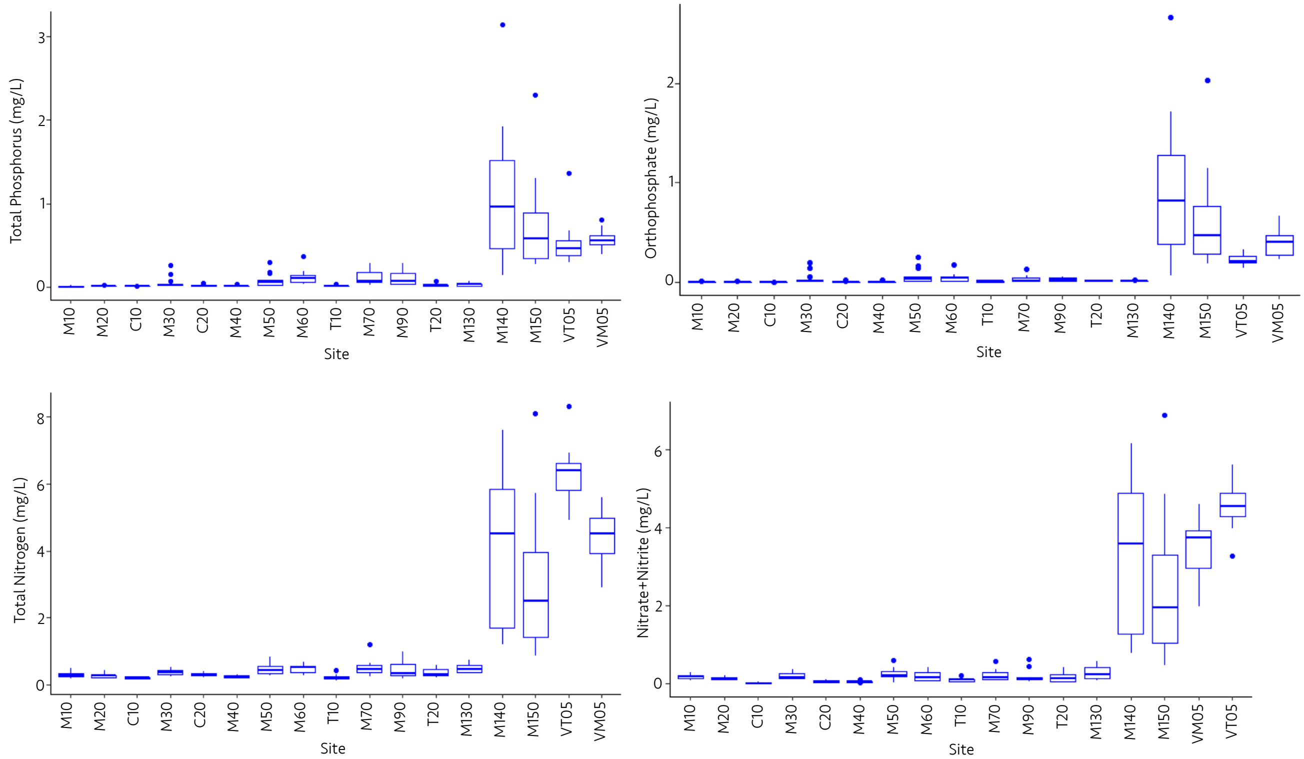

Figure 8. Spatial box plots for nutrient parameters by site in 2018.

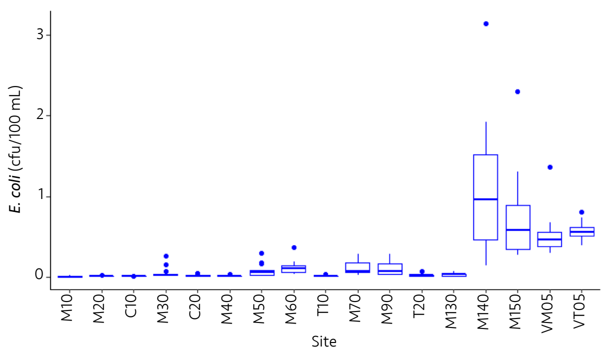

Figure 9. Spatial box plot of *E. coli* levels by site in 2018.

We believe that the number of number of samples collected in the Big Thompson River watershed in 2018 is sufficient to characterize the water quality within the watershed in both a temporal and spatial manner. Evaluations have been completed that characterize the uncertainty associated with spatial and temporal sampling efforts (Fayram et al. 2018, Giardullo 2006). A periodic review of a monitoring program is always a good idea to ensure that the effort provided to sampling matches with the expected resolution provided by the resulting data. We have conducted these analyses and while we deem the current program to be sufficient to meet our accepted level of understanding of the spatial and temporal dynamics of both individual parameters as well as the status of the watershed as a whole, any future reductions or additions should be evaluated in a similar manner.

Nutrient levels in 2018 are generally higher than five-year median values at the lower sites. These values were obtained prior to the completion of a City of Loveland biological nutrient removal upgrade to their wastewater facility. The completion of the facility is expected to reduce levels of various water quality components related to nutrient levels.

In general, the following water quality parameters can be characterized as a "good" (either above or below the five-year median depending on whether the parameter is considered to be beneficial or harmful to water quality) in 2018 when compared to the previous five years and to water quality standards.

- **Dissolved Oxygen**: Dissolved oxygen levels were very near the five-year median values for each section of river and were at levels sufficient to maintain aquatic life. Site VT-05 had substantially lower dissolved oxygen levels than other sites as has been the situation in the past but the median value in 2018 was approximately 7.75 mg/L which is far above the associated standard of 5 mg/L.
- **Orthophosphate**: Although orthophosphate increased in a downstream direction as expected, the 2018 median value was very near the five-year median value and differed from the other nutrient water quality parameters which were higher than the five-year median. The reason for this difference is unknown.
- ***E. coli***: *E. coli* levels increase in a downstream direction as expected given differential land use. In general, *E. coli* levels, while occasionally above the recommended standard, the frequency of occurrence of samples above the standard was lower than in 2017 and median levels in all sections of the river were similarly to or lower than the five-year medians.

In 2018, the following water quality parameters can be characterized as "average" with respect to the previous five-year period and water quality standards.

- **Flow**: The 2018 flow values were very similar to the five-year median values. Snowpack in the watershed was near median values for 2018 and flow values reflected this circumstance.
- **Specific Conductance**: Specific conductance in 2018 followed historic patterns with lower values in the headwaters of the Big Thompson River. Measures in the lower portion of the river were somewhat above the five-year median potentially due to the elevated sulfate concentrations in this portion of the river.
- **Turbidity**: In general, turbidity levels were near median values experienced in the previous five years. Turbidity levels at sites M70 and M90 were somewhat elevated in 2018 compared to other sites potentially due to final construction activities on Highway 34.
- **Total Organic Carbon**: Total organic carbon values were similar to those measured in the Big Thompson River in the previous 5 years except in the lower river where they were slightly elevated potentially due to final construction activities on Highway 34.
- **Copper**: Copper levels were generally low throughout the river in 2018 and were near the five-year median values. Although approximately 4% of the samples were higher than hardness-based acute water quality standards for copper, the value in 2018 was approximately a 5% (Fayram 2018). Many of the samples that were above applicable water quality standard levels occurred in the upper river. In general, the relatively low dissolved copper levels were in contrast to a Hydros (2015) report that noted a relatively high incidence of

copper being above the water quality standard. In addition, increases in dissolved copper are related to pine beetle tree mortality (Fayram et al. 2019). Tree mortality has abated somewhat in recent years and may result in continued decreases in dissolved copper levels in the upper Big Thompson River.

- **Total Organic Carbon**: Hydros (2015) suggested that TOC was increasing in the canals and upper watershed, potentially due to tree death caused by pine beetle population expansion (Mikkelson et al. 2013), but they also suggested that this trend may have been plateauing in recent years. The 2018 data suggest that the median TOC level was within the range of the previous five years (Figure 2) which supports the contention that the trend may be plateauing. This same conclusion was supported by 2015 and 2016 data (Fayram 2018).

- **Sulfate**: Sulfate levels were higher in the lower portion of the Big Thompson River and were somewhat above the five-year median value in the lower portion of the Big Thompson River. The elevated sulfate levels in the lower portion of the river can be attributed to the bedrock of Pierre Shale that is found in this portion of the river and is absent elsewhere (Tourtelot 1961). However, the percent of values in the lower portion of the river that were higher than water quality standards went from 18% in 2017 to 6% in 2018.

- **Manganese**: Although manganese levels increase in a downstream direction, levels in all sections of the river were very near the five-year median. However, of note is the fact that approximately 20% of the samples analyzed in 2018 were above the recommended drinking water standard of 50 ug/L.

- **Selenium**: Selenium levels were higher in the lower portion of the Big Thompson River compared to other sections of the river, but all sections of the river were near the five-year median value. The elevated selenium levels in the lower portion of the river can generally be attributed to the bedrock of Pierre Shale.

The following parameters can be characterized as of potential concern relative the previous five-year period and applicable water quality standards.

- **Temperature**: Temperature values in 2018 appear to be similar to those experienced by the Big Thompson River in the previous five years. However, the previous five years were also elevated when compared to long term average values (Fayram 2018). For example, 2015 was the third warmest year on record in Colorado (Doesken 2016) and 2016 air temperatures were the fifth highest year on record.

- **Total Nitrogen, Nitrate+Nitrite, and Total Phosphorus**: All of these water quality parameters showed similar patterns in 2018. All parameters increased in a downstream direction as expected. In addition, all three parameters were above the five-year median value in 2018.

Acknowledgements

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