2017 Big Thompson River
Water Quality Summary Report

Andrew H. Fayram
Big Thompson Watershed Forum
Monitoring Program Manager
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Big Thompson Watershed Forum

Executive Summary

Water quality parameters collected in 2017 were evaluated and indicate that water quality in the Big Thompson River continues to be relatively good. While it is likely that some aspects of water quality were negatively impacted in 2017 by the massive construction effort associated with Highway 34 rebuilding, our 2017 data suggest that these effects were minor, at least during the time period included in this report. This conclusion was based on an examination of data that came from water samples collected at 17 sites in 2017 by the United States Geological Survey (USGS) and by USGS and volunteers as part of the USEPA8 Volunteer Monitoring Program between 2011 and 2015. Where applicable, values were compared to water quality standards as adopted by the Colorado Water Quality Control Commission Regulations 31 and 38.

Although water quality was generally good in 2017, some measured parameters differed from levels that would be considered acceptable. Water temperatures were near the 5-year median value in 2017. The previous five years included some of the hottest years on record and, therefore, temperature continues to be of concern. Copper levels occasionally exceeded water quality standards (particularly in the upper river) but median values were relatively low in 2017. Similarly, total organic carbon (TOC) levels were near 5-year median values. However, it is worth noting that our monitoring in 2017 did not include samples during the most intense in-river construction activity that occurred during the winter months, which may have affected water quality parameters such as copper and TOC.

Selenium levels continued to be higher than water quality standard levels on a sporadic basis and were higher than the median of the reference period in the lower river. Sulfate levels were also higher than water quality standards in the lower river in 2017, with many more samples exceeding standards than in 2016. The elevated selenium and sulfate levels are likely caused in part by the bedrock geology of this portion of the river (Pierre Shale), but it is unclear why they were particularly elevated in 2017. It is also not clear the degree to which elevated levels of selenium affect the aquatic communities of the lower river. Developing a deeper understanding of the relationship between the aquatic communities in the lower portion of the river and selenium levels would clarify the need to meet or adjust selenium water quality standards in this portion of the river. In addition, the BTWF is in the process of applying for grant funds to further characterize the contribution of the Mariana Exchange Ditch to mainstem selenium levels. Unfortunately, after several years of apparent decline, nutrient levels seem to have increased somewhat in 2017 when compared to the reference time period. Similarly, *Escherichia coli* (*E. coli*) levels in the lower river continue to be somewhat above levels that would reflect good water quality.

Conversely, other water quality parameters, such as dissolved oxygen and mercury, were near optimal or appeared to be improving. Dissolved oxygen levels were very good throughout the river, as evidenced by the fact that no samples anywhere in the river measured dissolved oxygen levels below recommended levels. Mercury levels continued to be relatively low, and none of the samples were above the associated water quality standard.

In 2017, BTWF participated in monthly water quality monitoring stakeholder meetings associated with Highway 34 construction. Generally, water quality was minimally impacted by construction activities, based on data collected by the USGS between February and November 2017. However, noticeable increases in turbidity did occasionally occur and forced the City of Loveland to alter its use of Big Thompson River water. During the winter of 2017-2018, turbidity levels were very high and almost continually above levels expected during the winter. The BTWF partnered with Kiewit, Colorado Department of Transportation, Colorado Parks and Wildlife, USGS, and the Federal Highway Administration to conduct real-time monitoring at one station during the winter months. Fayram (2018) outlines a separate summary of these results.

List of Figures and Tables

Big Thompson Watershed Forum

Founded in 1997, the Big Thompson Watershed Forum (BTWF) is a collaborative non-profit organization located in Loveland, Colorado. The BTWF represents a wide range of interests, including private citizens, businesses, non-governmental organizations, and government agencies (http://btwatershed.org/about-btwf/). The BTWF's major funders include the City of Loveland, the City of Fort Collins, the City of Greeley, and Northern Water. The BTWF is also supported by a number of minor funders. The mission of the BTWF is to support the protection and improvement of water quality in the Big Thompson River Watershed through collaborative monitoring, assessment, and education/outreach projects. BTWF's objectives include: 1) analyzing relevant water quality data to detect temporal and spatial trends and identify potential issues and improvements; 2) identifying priority protection measures and educating affected parties; and 3) developing and promoting voluntary practices that protect the Big Thompson Watershed and the quality of its waters.

The BTWF created a Cooperative Monitoring Program (COOP) (http://btwatershed.org/cooperative-monitoring-program) and an Environmental Protection Agency Volunteer Monitoring Program (Volunteer) (http://btwatershed.org/usepa-volunteer-monitoring-program/) to assess water quality and related ecological concerns throughout the Big Thompson 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 Monitoring Program, which 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 2017. Water quality data collected in 2017 are compared to those collected during the previous five years (2012-2016). Data collected for the COOP in 2017 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 67 water quality parameters in 2017, 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 included: 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 2017 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 2017 (M10, M20, M30, M40, M50, M60, M70, M90, M130, M140, M150, T10, T20, VT05, VM05, C10, and C20) (Figure 1). All sites were sampled by the USGS as part of the COOP Program. The two tunnel sites, C10 and C20, are part of the Colorado-Big Thompson (C-BT) 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.

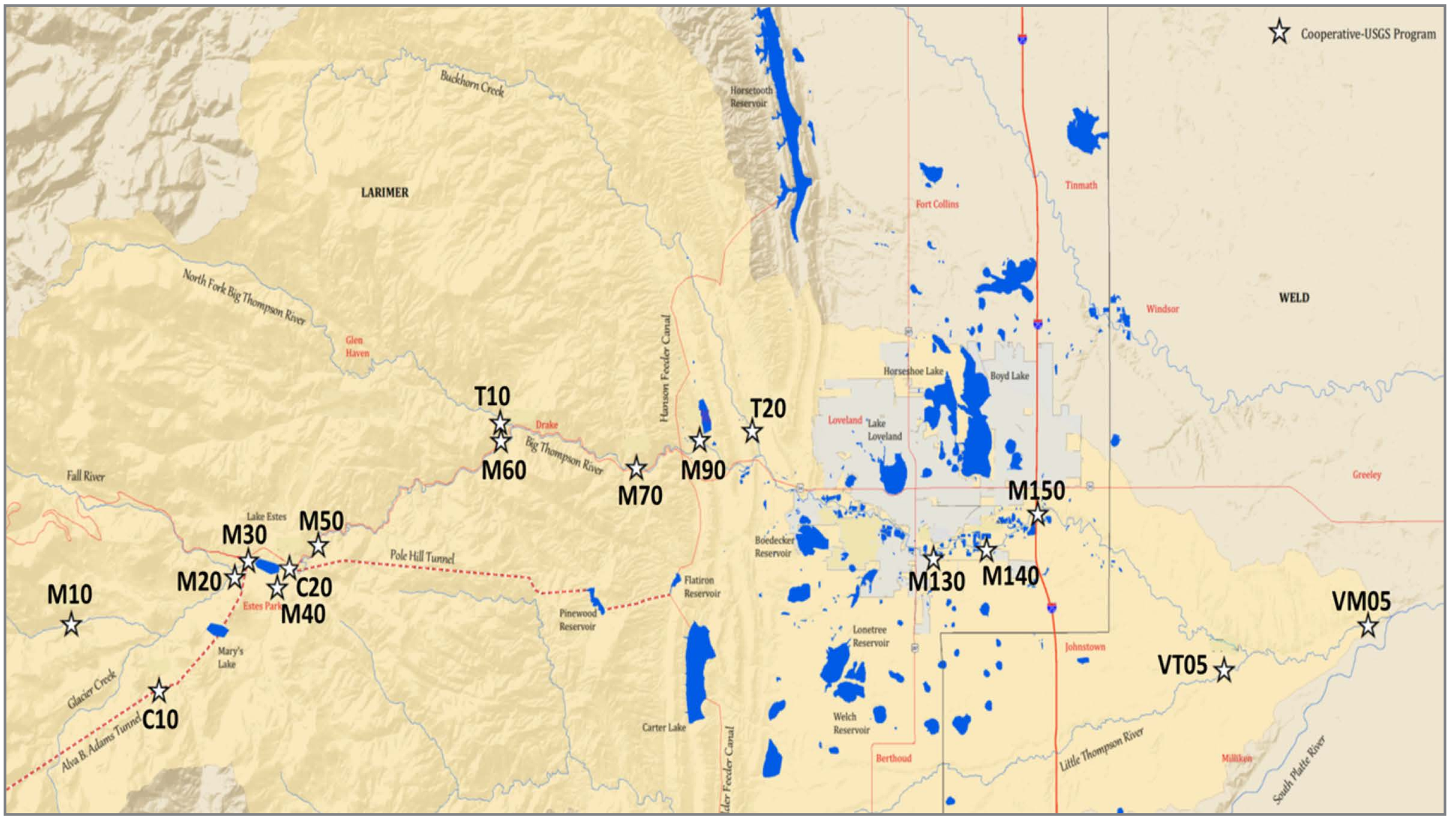

Figure 1. Locations of sites on the Big Thompson River, canals, and associated tributaries in 2017.

General

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

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 cold-water 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., plains killifish *Fundulus zebinus*). Aquatic organisms can experience mortality if the dissolved oxygen levels drop below their threshold level for even a short time.

Specific conductance

Specific conductance is a measure of how well water conducts electricity. Specific conductance increases with higher 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. As such, temperature standards are based on species groups with similar thermal tolerances. Segments of the Big Thompson River are classified as Coldwater I, Coldwater II, or Warmwater II (WQCC 2018b).

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 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 gastro-intestinal 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.

Metals

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, and chronic effects include reduced survival, growth, and reproduction. Copper sulfate was historically used in the C-BT Project canals to control periphyton (attached algae) and aquatic plants, with Northern Water's use dating back to as early as 1964. Elevated concentrations of copper in stream segments downstream of the C-BT Project canal releases have resulted in identified impairments and placements on the Colorado 303(d) List or the Monitoring and Evaluation (M&E) List. However, Northern Water discontinued the use of copper sulfate in 2008, while the Bureau of Reclamation discontinued its use in 2012, resulting in a decrease in copper concentrations in these areas.

Mercury

Mercury is toxic to humans at relatively low levels. Mercury in water bioaccumulates in fish, which can result in mercury toxicity in humans if fish are consumed frequently. Currently, there are fish consumption advisories in Horsetooth Reservoir and Carter Lake due to the occurrence of high mercury concentrations in fish tissue. Both water bodies receive water from the Big Thompson River. Boyd Lake also receives water from the Big Thompson River and, until recently, also had a fish consumption advisory due to mercury levels in fish tissue.

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 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).

Nutrients

Eutrophic water bodies have high levels of nutrients and high algal productivity. High levels of nutrients can lead to algal blooms, low dissolved oxygen levels at reservoir bottoms, and reduced clarity. Algal blooms can also be problematic for drinking water treatment because geosmin (and other taste and odor compounds) and TOC can become elevated. Nitrogen and phosphorus are the major nutrients that support algal growth in aquatic systems. To prevent nutrient enrichment of water bodies and to protect their designated beneficial uses, the Colorado Water Quality Control Commission adopted interim total phosphorus and total nitrogen numeric values in 2012 for streams, rivers, lakes, and reservoirs. However, total phosphorus standards have not yet been adopted for steam segments below wastewater treatment plants (monitoring sites M30, M50, and M140). Total nitrogen standards have not yet been adopted for any segment in the Big Thompson Watershed. Interim standards are used for contextual purposes in this report. A final decision regarding the adoption of these interim standards is expected in 2022.

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.

Microbiological

Escherichia coli (E. coli)

E. 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, 2012-December 31, 2016 were exported from the BTWF's NPStoret database and transferred to an Excel file to assemble a final dataset of comparable sites and metrics. 2017 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 2017 median values for each analyte by river section to all data collected for the same river section during the 2012-2016 time period. To maximize the degree of comparability between years, only mainstem sites sampled in all six 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 C-BT 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 Wastewater Treatment Plant (WWTP) 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 2017 in each river section are represented by a red circle in the figures. All data collected between 2012 and 2016 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 farther from the interquartile range from the median.

The spatial boxplots were constructed for each parameter using all data collected at each site in 2017. 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 2017 were also compared to CDPHE water quality standards from Colorado Regulations 31 (WQCD 2018a) and 38 (WQCD 2018b), shown in Tables 1 and 2. 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[4]
4b	M130	2.01*	0.17*	10	126	630	250	5	5	6.5	9	28.6[5]	27.5[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 1. 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 2. 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.

General Parameters

Flow

A total of 196 flow measurements were collected in 2017 between January and December. The flow in the mainstem of the Big Thompson ranged from a high of 824 cfs at site M20 on 6/7/17 to a low of 2.6 cfs at site M130 on 12/5/17.

Dissolved oxygen (D.O.)

Dissolved oxygen levels were generally good at all sites in 2017, with 0 of 201 samples dropping below the site and temporally associated aquatic life standard of 5, 6, or 7 mg/L. Dissolved oxygen levels ranged from a low of 5.7 mg/L at site VT05 on 3/8/17 to a high of 14.3 mg/L at site VM05 on 6/20/17.

Specific conductance

Specific conductance was measured 210 times throughout 2017. Specific conductance ranged from 13 uS/cm in the headwaters at site M10 on 7/12/17 to 2,390 uS/cm at site VT05 on 2/6/17. The higher specific conductance levels at the downstream sites reflect the higher concentrations of dissolved solids such as calcium and sulfate.

Water temperature

Water temperatures ranged from 0.0°C at site M10 on 11/30/17 to 22.0°C at site M130 on 6/7/17. Of the total 211 water temperature records, 15 were above the site-associated chronic standard (9%), and three were above the acute standard (1.5%). Most of the temperatures recorded above a standard occurred in spring (March, April, and May). Historically, most temperatures above standards have occurred in October during the low flow period.

Total organic carbon (TOC)

Of the 218 samples taken, total organic carbon levels ranged from a low of 1.55 mg/L in the headwaters at site M10 on 8/7/17 to a high of 16.2 mg/L at site VT05 on 5/23/17. These values are typical for the upper watershed, where TOC concentrations peak during the spring snowmelt runoff period as organic matter is mobilized from the watershed, with concentrations returning to much lower baseline concentrations after the spring runoff.

Sulfate

Sulfate levels ranged from 1.03 mg/L at site M10 on 6/21/17 to 629 mg/L at site VT05 on 2/6/17. Sulfate levels were above the domestic water supply standard of 250 mg/L in 30 of 165 samples (18%). Relatively high levels of sulfate primarily occurred in the lower river (M130, M140, and M150) and in the Little Thompson River (VT05), reflecting the influence of the sedimentary bedrock geology in the lower portion of the watershed.

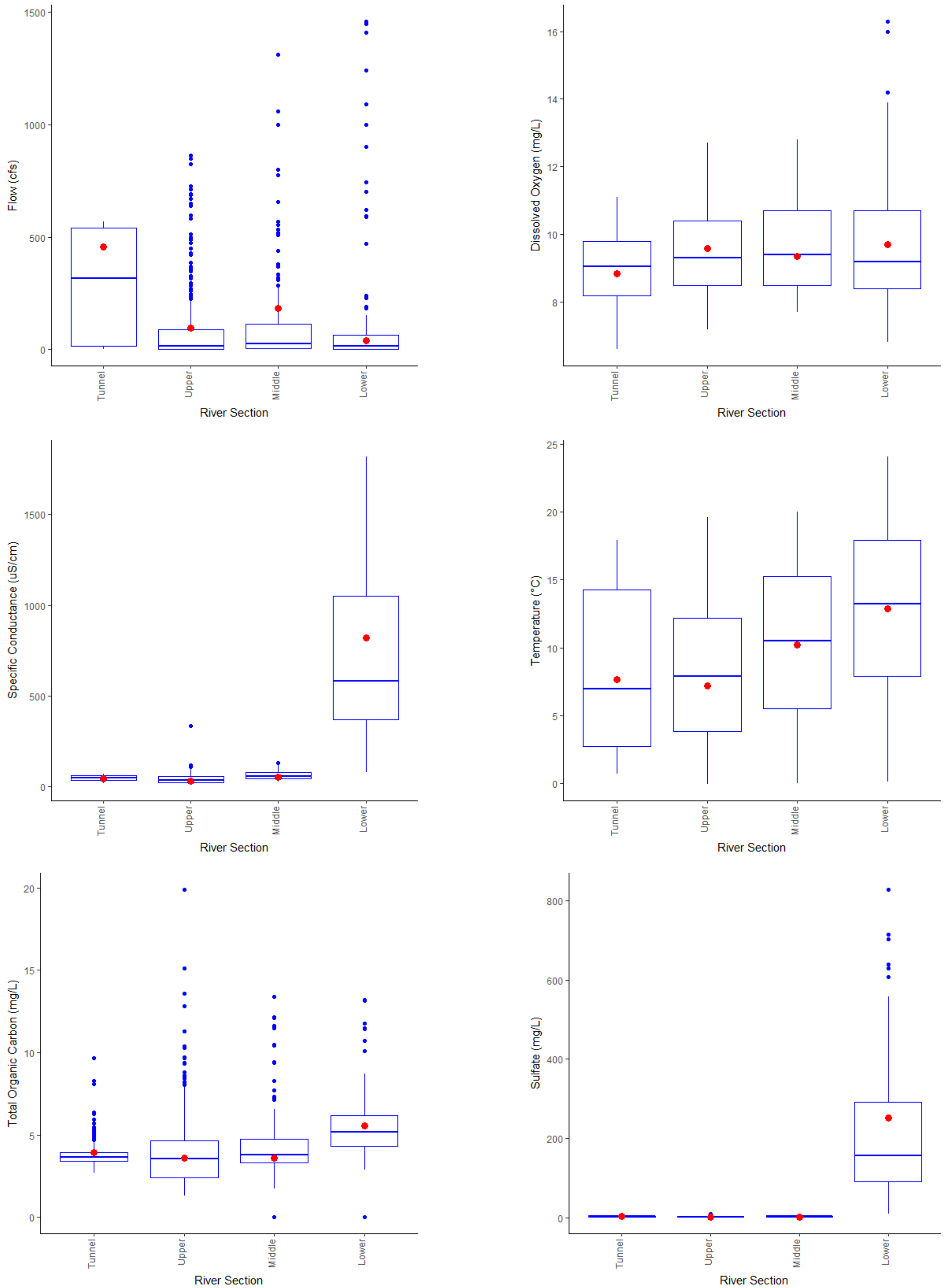

Figure 2. Box plots of general parameters representing the 2012-2017 time period. "Box-and-whiskers" constructed using all available data 2012-2016. Red circle represents 2017 median value.

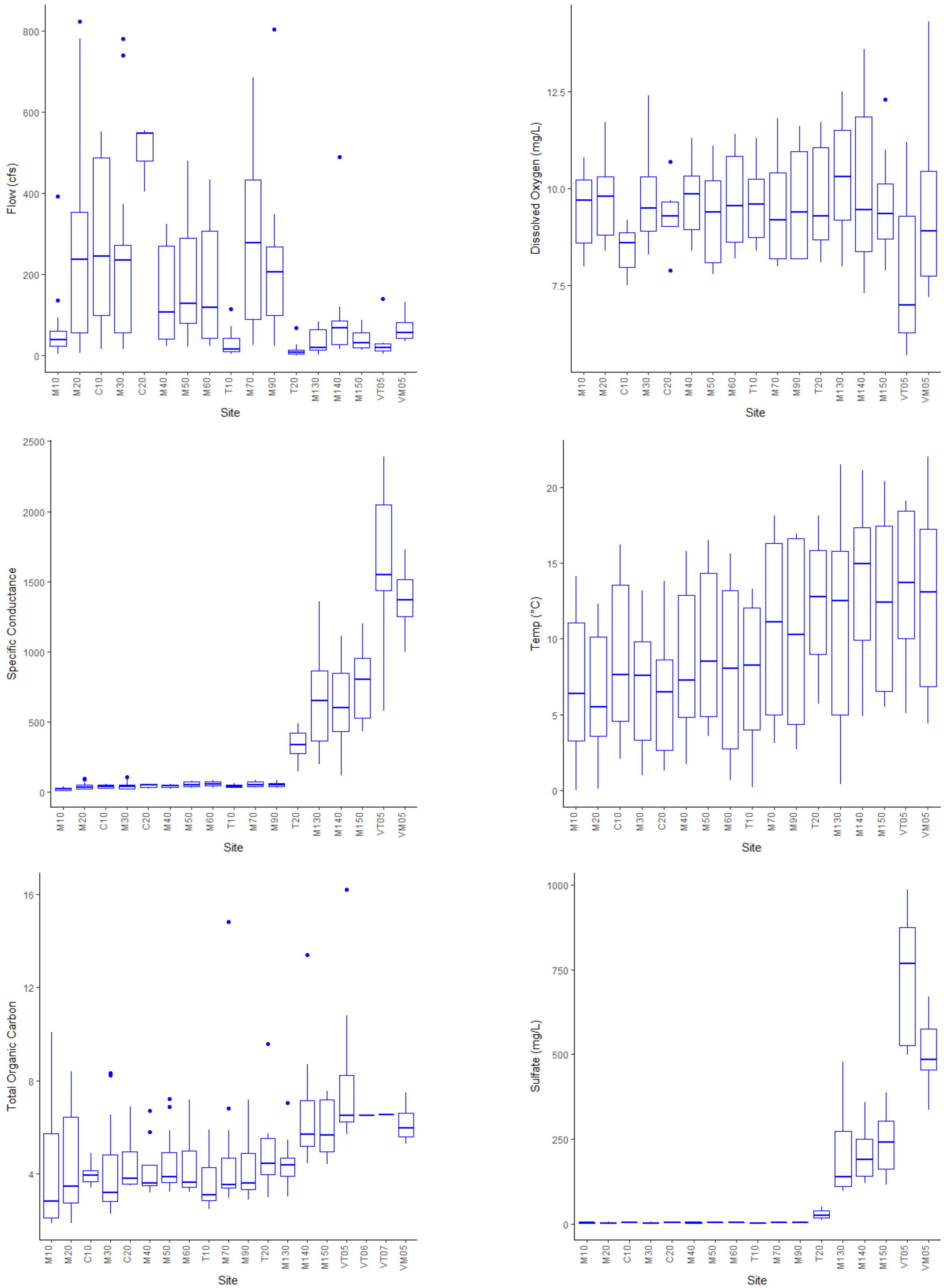

Figure 3. Spatial box plots for general parameters by site in 2017.

Metals

Copper

Dissolved copper levels ranged from 0.34 ug/L at site T20 on 2/8/17 to 2.8 ug/L at site VM05 on 10/11/17. 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:

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

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

Hardness values at BTWF sites in 2017 ranged from 4.73 mg/L at site M10 on 7/10/17 to 1060 mg/L at site VT05 on 3/8/17. Calculated acute copper standards ranged from 0.77 ug/L to 49.61 ug/L. Of the 157 samples collected, 13 (8%) of the samples were above the acute standard and 8 (5%) were above the chronic standard. The majority 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.

Mercury

Mercury levels ranged from 0.33 µg/L at site M130 on 3/7/17 to 7.4 µg/L at site M10 on 5/8/17. The water quality standard for chronic exposure is 10 µg/L, and there were 0 exceedances from a total of 44 samples in 2017. Note, however, that this is not a regulatory assessment but simply a comparison of individual data points to the standard.

Selenium

Dissolved selenium levels ranged from 0.04 ug/L at site C20 on 1/9/17 to 9.8 ug/L at site M130 on 3/7/17. 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 47 samples analyzed for selenium, none were above the acute standard, but eight were above the chronic standard (17%). Note, again, that this is not a regulatory assessment but simply a comparison of individual data points to the standard.

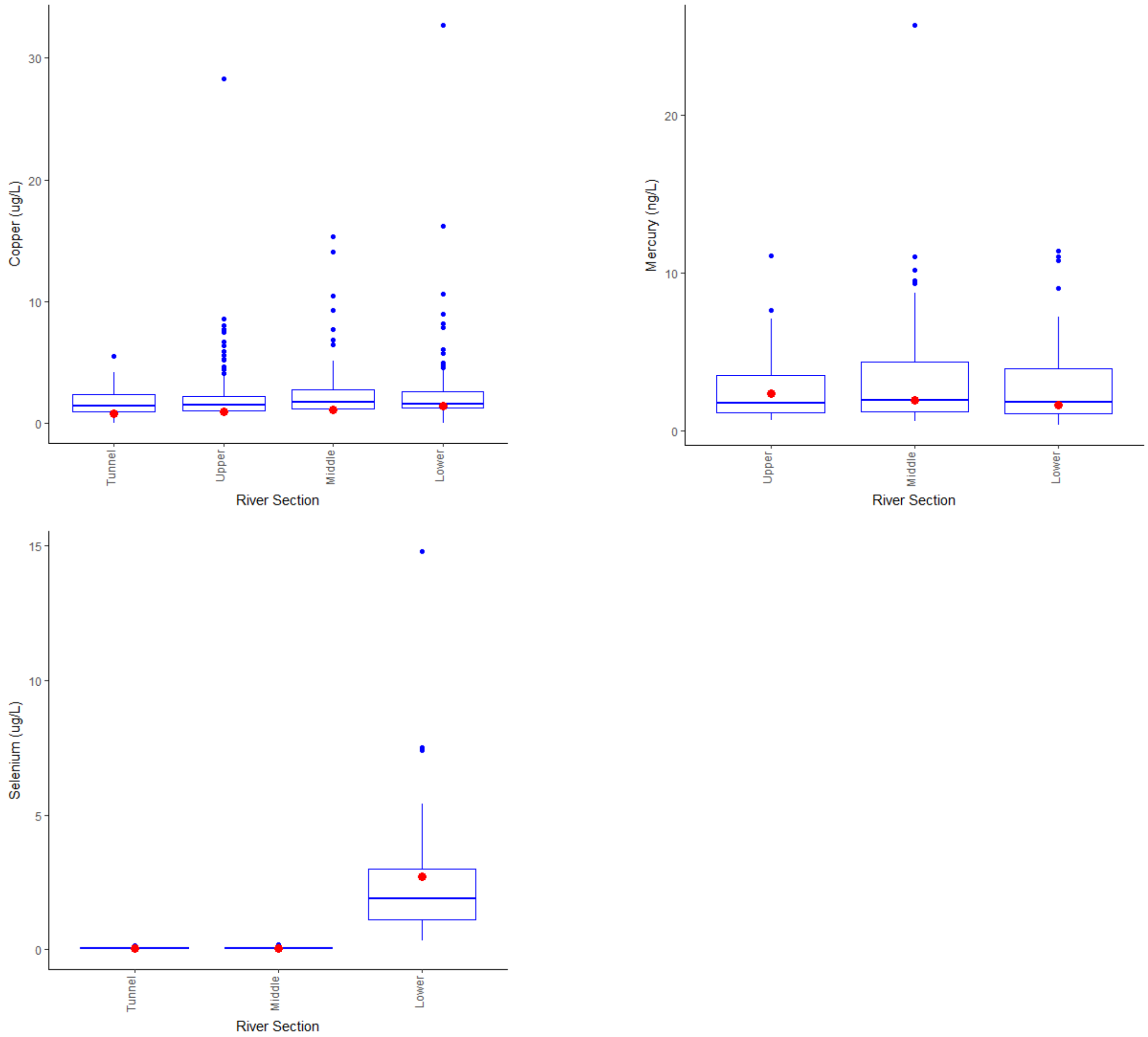

Figure 4. Box plots of metal parameters representing the 2012-2017 time period. "Box-and-whiskers" constructed using all available data 2012-2016. Red circle represents 2017 median value.

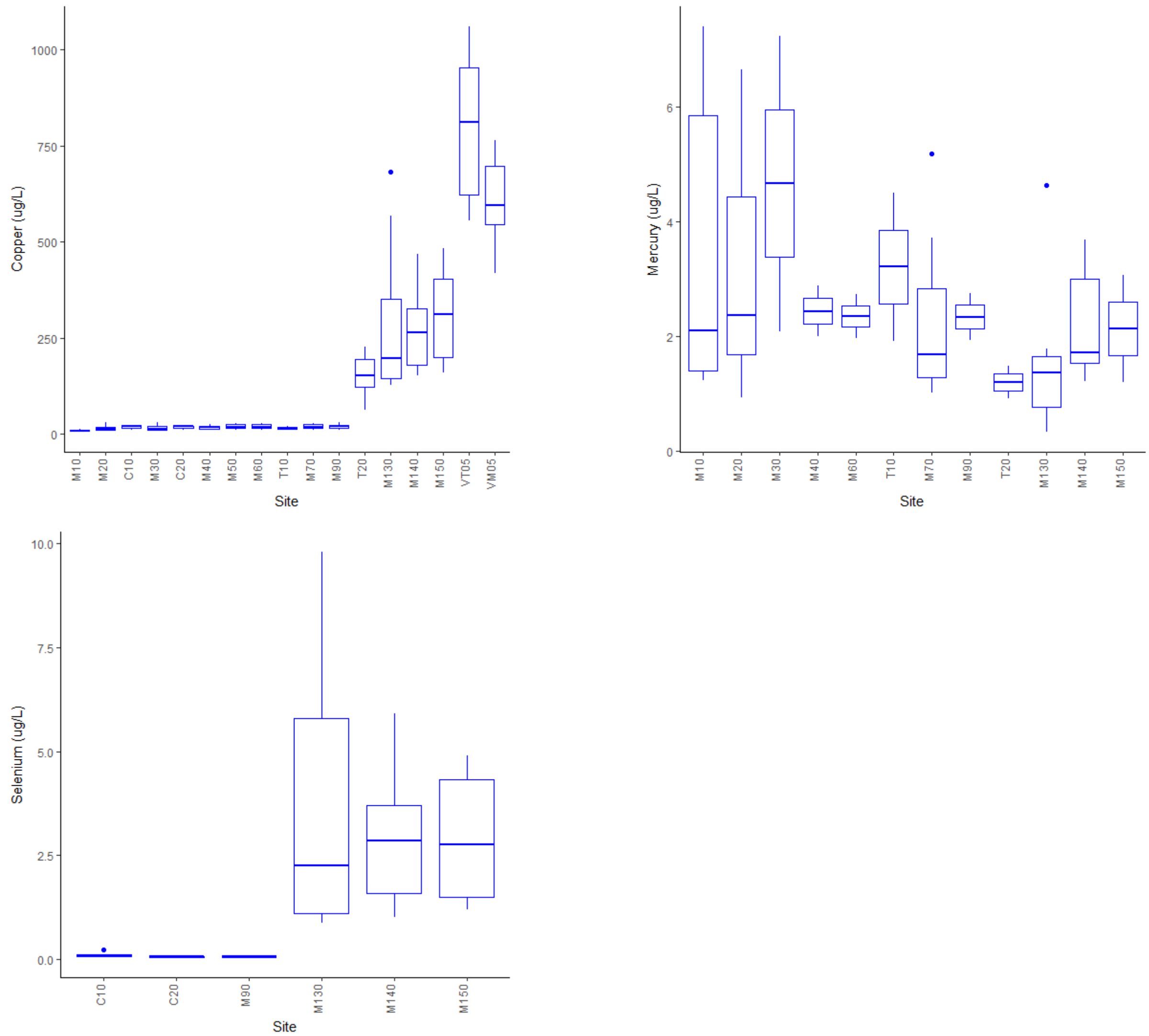

Figure 5. Spatial box plots for metal parameters by site in 2016. Solid lines represent the fact that all samples from that site were reported as “non-detect.”

Nutrients

Total nitrogen

Total nitrogen ranged from 0.13 mg/L at site M10 on 4/17/17 to 16.0 mg/L at site VT05 on 4/12/17. 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 43 of the 228 samples collected in 2016 (19%). There were twice as many measured values above interim numerical standards in 2017 when compared to 2016. However, total nitrogen standards have not yet been adopted for any stream segment in the Big Thompson Watershed. All of 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

Excluding tunnel sites C10 and C20, which generally had very low levels, nitrate + nitrite levels ranged from a low of 0.02 mg/L at site M40 on 9/12/17 to a high of 12.0 mg/L at site VT05 on 4/12/17. Nitrite is typically a very small component of the nitrate + nitrite samples. Of the 195 nitrate + nitrite samples, one exceeded the 10 mg/L nitrate standard for drinking water in 2017.

Total phosphorus

Of the samples above detection limits, total phosphorus levels ranged from a low of 0.003 mg/L at site M40 on 4/12/17 to a high of 2.26 mg/L at site M140 on 12/5/17. 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 203 samples analyzed for total phosphorus, 48 were above the total phosphorus interim numeric value of either 0.11 or 0.17 mg/L (25%). The vast majority of these elevated values occurred in lower portions of the river where the numeric value for comparison is 0.17 mg/L. However, four samples that were above interim numeric values occurred in the middle portion of the river (M50, M60, and M70).

Orthophosphate

Orthophosphate levels ranged from a low of 0.001 mg/L at site C10 on 1/9/17 to a high of 6.29 mg/L at site M140 12/5/17. The spatial pattern of ortho-P concentrations reflects the typically low levels in the upper watershed compared to elevated concentrations associated with segments that are impacted by wastewater treatment plant effluent.

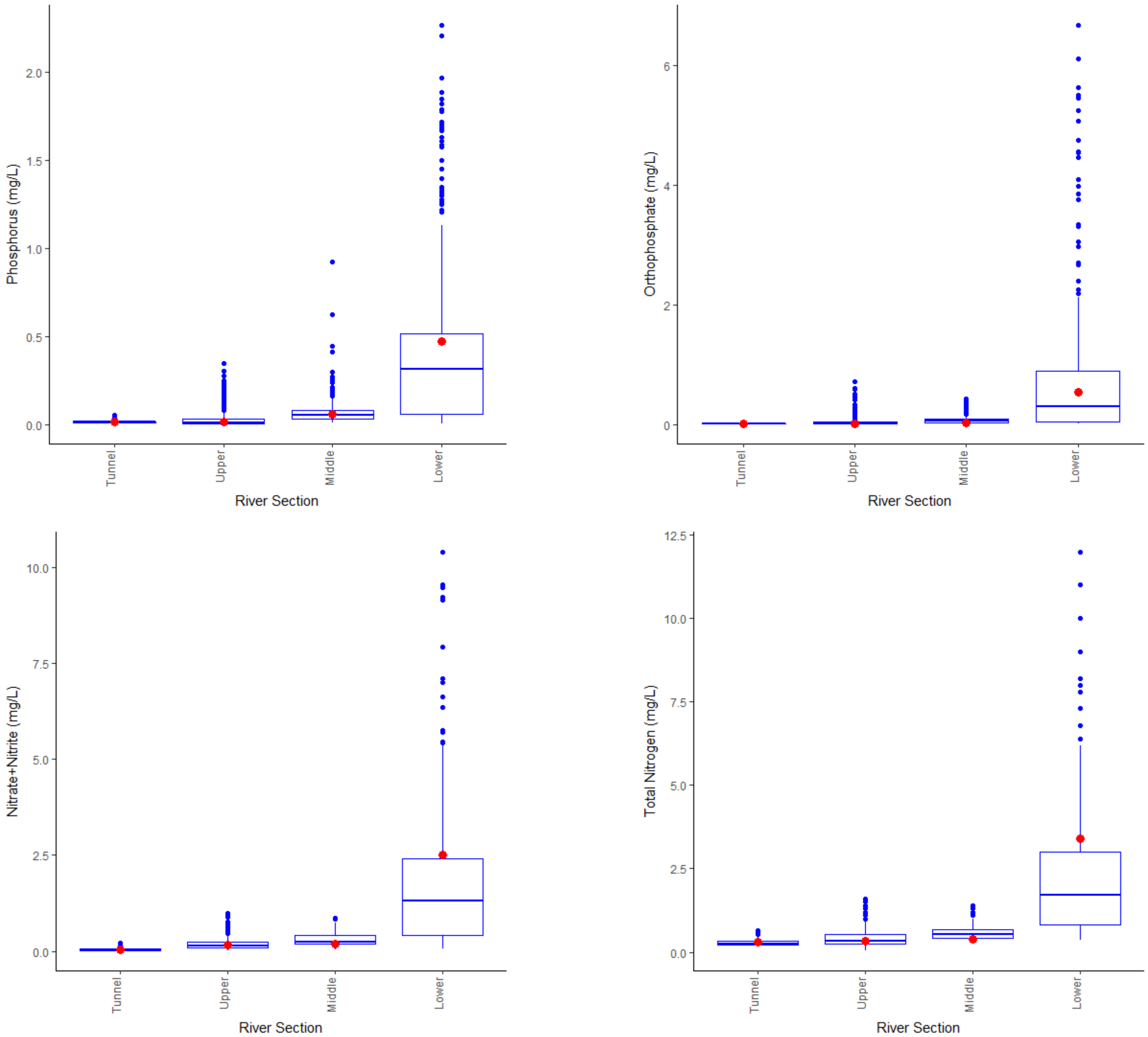

Figure 6. Box plots of nutrient parameters representing the 2012-2017 time period. “Box-and-whiskers” constructed using all available data 2012-2016. Red circle represents 2017 median value.

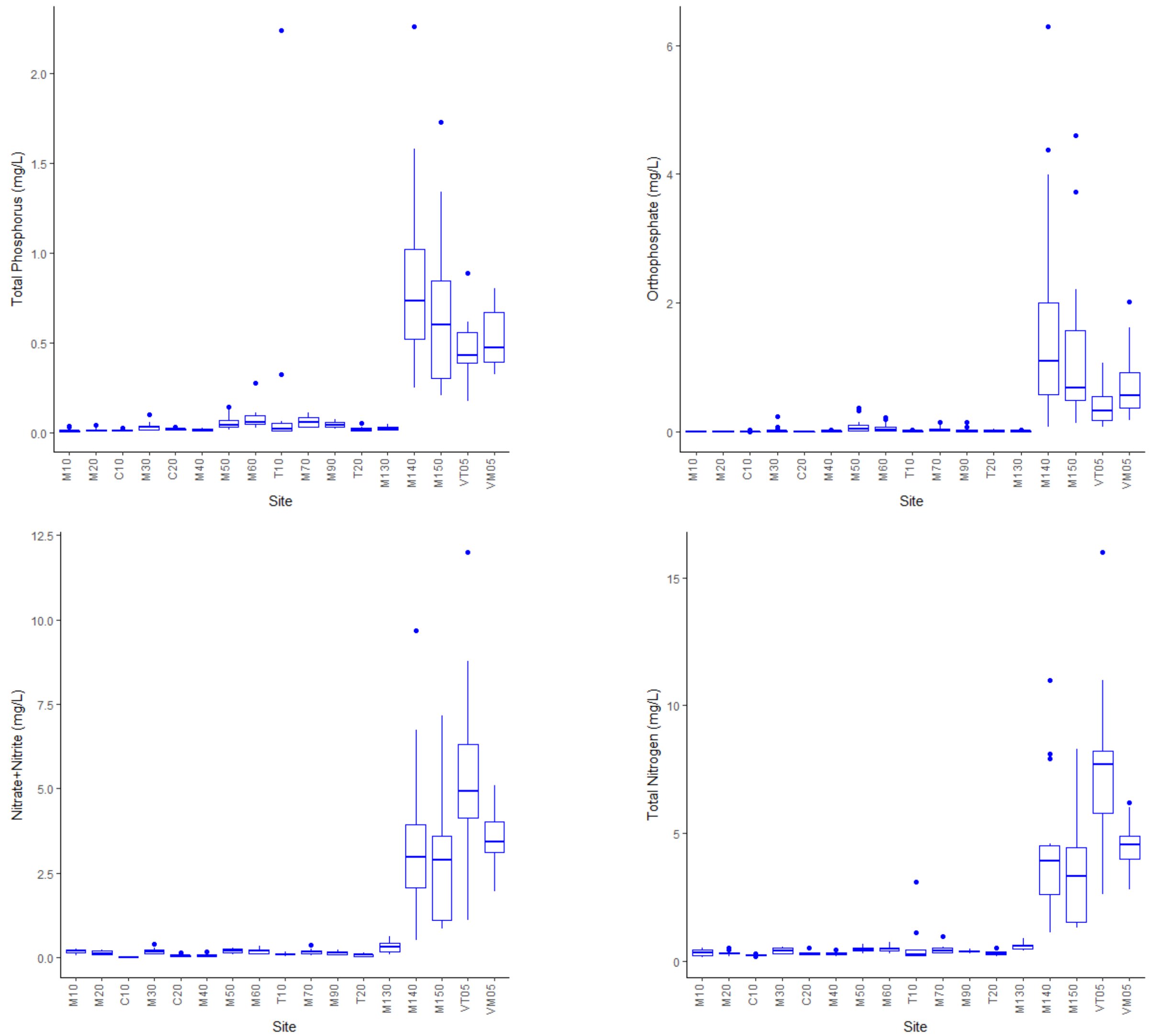

Figure 7. Spatial box plots for nutrient parameters by site in 2017.

Microbiological Parameters

Escherichia coli

The levels of *E. coli* ranged from a low of 0.5 cfu/100 mL at site C10 on 1/11/17 to a high of 2,420 cfu/100 mL at site M140 on 5/9/17. 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. Of the 166 samples analyzed for *E. coli*, 42 were above the site-associated standard (25%). The percentage of samples above the associated standard is approximately double the value calculated in 2016. While the elevated values are concentrated in the lower portion of the river, occasional samples that exceeded the site-associated standard occurred throughout the river.

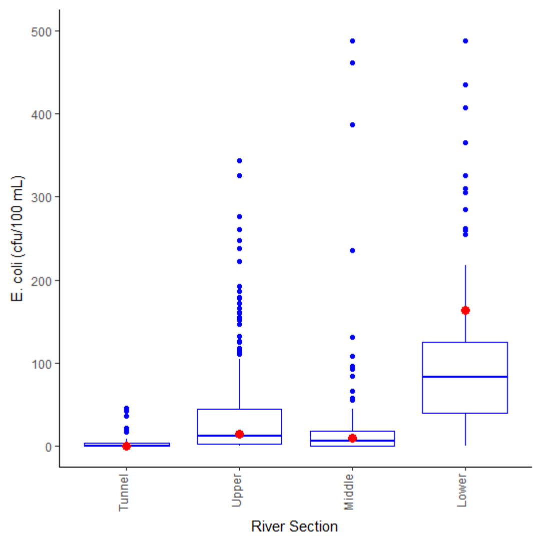

Figure 8. Box plot of *E. coli* levels representing the 2012-2017 time period. "Box-and-whiskers" constructed using all available data 2012-2016. Red circle represents 2017 median value.

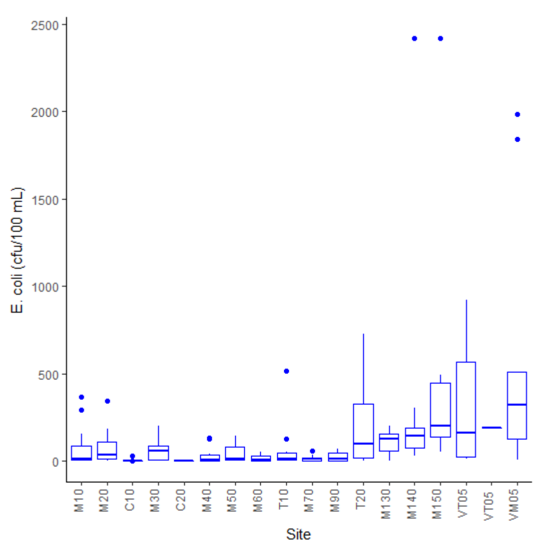

Figure 9. Spatial box plot of *E. coli* levels by site in 2017.

Conclusions

In general, 2017 can be characterized as an average year when compared to the previous five years for the following parameters:

- Dissolved Oxygen: Dissolved oxygen levels were very near the 5-year median values for each section of river (Figure 2) and were at levels sufficient to maintain aquatic life. Site VT-05 had substantially lower dissolved oxygen levels than other sites (Figure 3), but the median value was approximately 7.3 mg/L, which is far above the associated standard of 5 mg/L (Figure 2, Table 1).

- Temperature: Temperature values in 2017 appear to be similar to those in the Big Thompson River in the previous five years (Figure 2). However, the previous five years were also elevated when compared to long-term average values (Fayram 2017b). 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 Organic Carbon: Total organic carbon values were similar to those measured in the Big Thompson River in the previous five years (Figure 3). Although there was substantial construction work completed on Highway 34 during 2017, which increased turbidity, and therefore probably increased TOC levels at some sites, much of the intensive in-river work was completed during the winter after our standard sampling had been completed. Therefore, any increases in TOC that may have occurred in 2017 are not reflected in data presented here. 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 2017 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 2017a, Fayram 2017b).

- Specific Conductance: Specific conductance levels were generally similar to 5-year median values, with higher values in the lower river. However, the 2017 median value for the lower river section was slightly higher than the 5-year median value. Elevated sulfate and selenium levels found in the lower river in 2017 likely contributed to the slightly higher specific conductance values.

- Copper: Copper levels were generally low throughout the river in 2017 and were near the 5-year median values. Although approximately 5% of the samples were higher than hardness-based water quality standards for copper, there was also approximately a 5% exceedance rate in 2016 (Fayram 2016). 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. However, increased turbidity found in the winter 2017 (Fayram 2018), which was associated with construction activities, may have increased dissolved copper levels at this time as well because increased turbidity can be associated with increased levels of copper (Cauwet and Mackenzie 1993, Nason et al. 2012). However, samples in this report were collected only through November and, as such, may not have detected increased dissolved copper levels that may have been associated with construction activities. In addition, increases in dissolved copper are related to pine beetle tree mortality (Fayram et al. In Review)

- Mercury: Mercury values continued to be very low throughout the Big Thompson River in 2017. Similar to 2016, zero samples were above the water quality standard for mercury.

Conversely, 2017 values differed considerably from the 5-year median value for a number of measured parameters including:

- Flow: Flow values were somewhat elevated compared to the 5-year median value. These elevated flows were due in part to maintenance activities by the Bureau of Reclamation, which required additional water to be diverted to the mainstem of the Big Thompson River during spring and summer months.

- Specific Conductance: Specific conductance was quite high in the lower portion of the river in 2016. These elevated levels likely reflect the elevated sulfate levels also found in 2016 (Figure 2).

- Sulfate: Sulfate levels were higher in the lower portion of the Big Thompson River and were somewhat above the 5-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 3% in 2016 (Fayram 2017b) to 18% in 2017. The cause for this increase is unclear.

- Selenium: Selenium levels were higher in the lower portion of the Big Thompson River compared to other sections of the river and were also somewhat above the 5-year median value. Although the elevated selenium levels in the lower portion of the river can generally be attributed to the bedrock of Pierre Shale that is found in this portion of the river, the cause of the relatively elevated levels in 2017 is unclear.

- Nutrients (Phosphorus, Orthophosphate, Nitrogen, and Nitrate + Nitrite): Nutrient levels were generally higher in the lower river than the 5-year median values. Other portions of the river were near the 5-year median values. Nutrient levels have generally decreased in recent years (Fayram 2017b). This apparent increase in 2017 may be due to construction activities and increased sediment load.

- *E. coli*: There were several values above the *E. coli* standard in 2017, primarily in the lower river. *E. coli* levels were particularly high in the lower river section (Figure 8). Hydros (2015) found elevated levels in the lower portion of the river and suggested that the cause may be related to livestock concentrations.

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