2015 Big Thompson River Water Quality Summary Report

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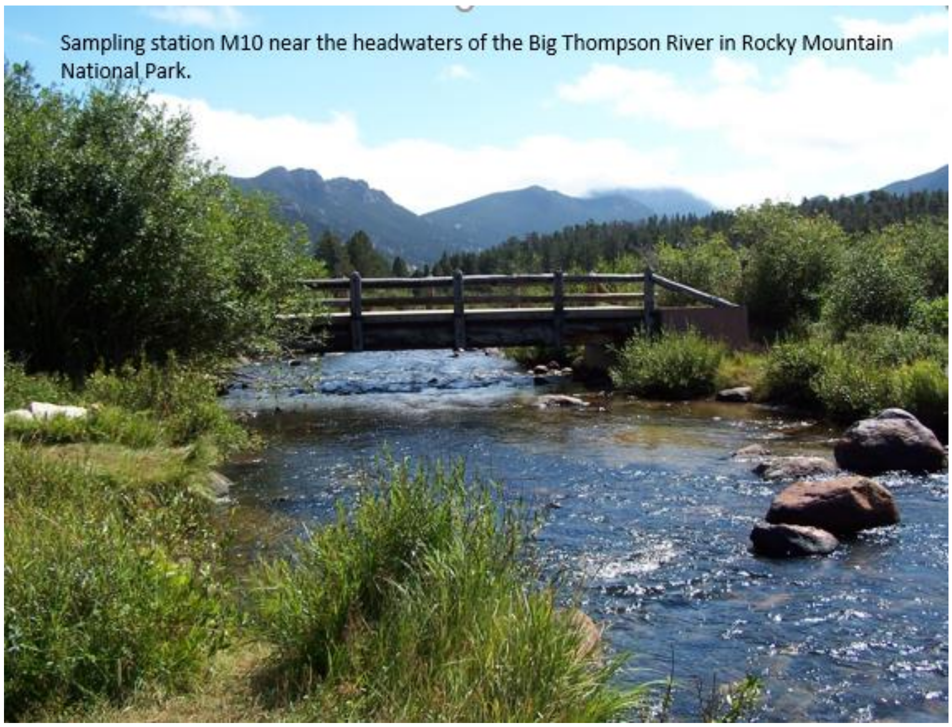
Executive Summary

Based on an overall evaluation of water quality parameters collected in 2015, water quality in the Big Thompson River was generally good. This conclusion was based on an examination of data that came from water samples collected at 27 sites throughout 2015 by the United States Geological Survey and volunteers as part of the USEPA8 Volunteer Monitoring Program. Meteorological conditions caused relatively warm water temperatures and slightly elevated flow in 2015. Although some parameters of interest occasionally exceeded levels thought to indicate good water quality, as adopted by the Colorado Water Quality Control Commission Regulations 31 and 38, most parameters were at levels that suggested good water quality in 2015 when compared to the reference time period of 2010-2014. Copper levels occasionally exceeded water quality standards but median values were relatively low in 2015 compared to the reference period of 2010-2014. Similarly, virtually all parameters considered to reflect nutrient availability conducive to the growth of algae were relatively low in 2015 when compared to the reference period of 2010-2014. Hopefully, the relatively low level of nutrients is indicative of a trend that will continue into the future. Selenium levels continued to exceed water quality standard levels, particularly in the lower river. These exceedances are likely the result of the bedrock geology of this portion of the river (Pierre shale) which is rich in selenium. It is unclear 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. *E. coli* levels were also relatively high in 2015, particularly in the lower portion of the mainstem and in the Little Thompson River. Continued monitoring and vigilance of *E. coli* levels will aid in documenting this potential issue as well as suggesting potential causes and solutions.



Sampling station M10 near the headwaters of the Big Thompson River in Rocky Mountain National Park.

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Introduction

Big Thompson Watershed Forum

The Big Thompson Watershed Forum (BTWF) is a collaborative non-profit organization headquartered in Loveland, Colorado and founded in 1997. The BTWF represents the interests of private citizens, corporations, non-governmental organizations, and government agencies with respect to water quality in the Big Thompson River. The Forum's major funders include the City of Loveland, the City of Fort Collins, the City of Greeley, the Soldier Canyon Filter Plant, and the Northern Colorado Water Conservancy District (Northern Water).

The mission of the BTWF is to support the protection and improvement of water quality in the Big Thompson River Watershed through educational and outreach programs, collaborative monitoring, and assessment. The Forum created a Cooperative Monitoring Program (COOP) and an Environmental Protection Agency Volunteer Monitoring Program (Volunteer) 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.

The Forum's program goals include: 1) increasing community awareness, understanding, and consideration of water quality issues and watershed stewardship, 2) comparing and analyzing sampling data with existing water quality standards, and 3) identifying and quantifying spatial and/or temporal water quality trends on a watershed scale.

Report Objectives

Summary data provided in this report are meant to provide an overall picture of the status of water quality in the Big Thompson River. Context for data collected in 2015 are provided by the previous five years (2010-2014) as well as water quality standards adopted by the Colorado Water Quality Control Commission (Regulations 31 and 38), and the Clean Water Act Section 303(d) water quality impairments as adopted by the Colorado Water Quality Control Commission and contained in Colorado's 2016 303(d) List (Regulation 93).

Two primary monitoring efforts and analytical laboratories were utilized between 2010 and 2015. The USGS water quality laboratory processed all samples collected by USGS personnel and not measured in the field with the exceptions of *Escherichia coli* (analyzed by the City of Loveland) and total organic carbon (analyzed by the City of Fort Collins). The EPA Water Quality Laboratory analyzed samples collected as part of the Volunteer Monitoring Program.

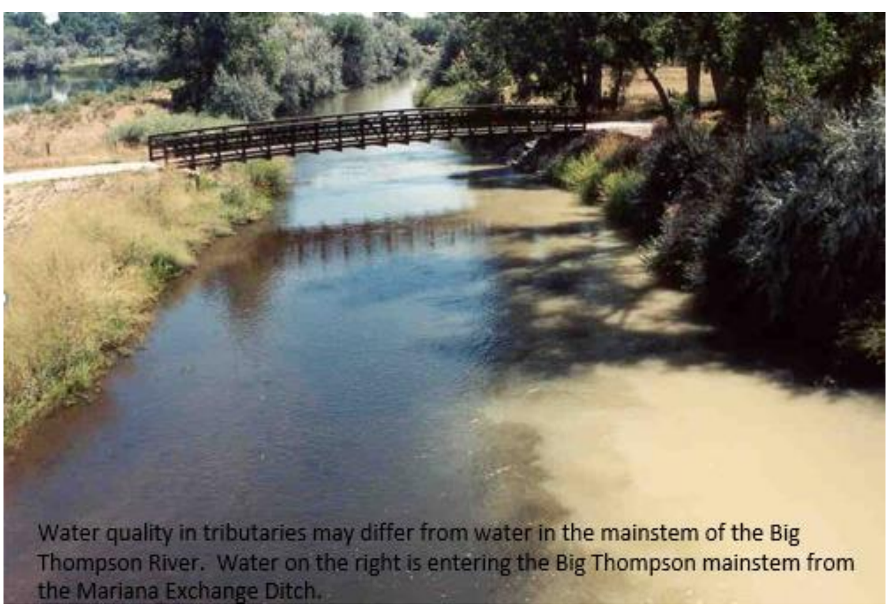
Data Collection

Data were collected on 38 water quality parameters in 2015. This annual report focuses on 14 parameters that were determined to be of the greatest interest to the BTWF as they either represent core indicators of water quality or are of potential concern regarding water quality standards. The focus metrics include: flow, dissolved oxygen, specific conductance, water temperature, total organic carbon, copper, mercury, selenium, total nitrogen, nitrate + nitrite, total phosphorus, orthophosphate, sulfate, and *E. coli*.

A total of 27 sites were sampled in 2015. Twelve of these sites were sampled as part of the USEPA8 Volunteer Monitoring Program (794, FR05, NFBT10, VM05, VM10, VM20, VM30, VM40, VT05, VT05, VT15, and VT05) (Figure 1). Fifteen sites were sampled by the USGS as part of the Cooperative USGS Monitoring program (M10, M20, M30, M40, M50, M60, M70, M90, M130, M140, M150, T10, T20, C10, and C20) (Figure 1).

Staff from the USGS, the BTWF, and generous volunteers collected data from 27 sites throughout the year on the Big Thompson River in 2015.

Tributary samples were collected from the North Fork of the Big Thompson (NFBT10 and T10), Buckhorn Creek (T20), and the Little Thompson River (VT05, VT15, and VT20). These samples were collected to characterize water entering the mainstem of the river from tributaries as they may differ considerably from the river in the Big Thompson itself.



Water quality in tributaries may differ from water in the mainstem of the Big Thompson River. Water on the right is entering the Big Thompson mainstem from the Mariana Exchange Ditch.

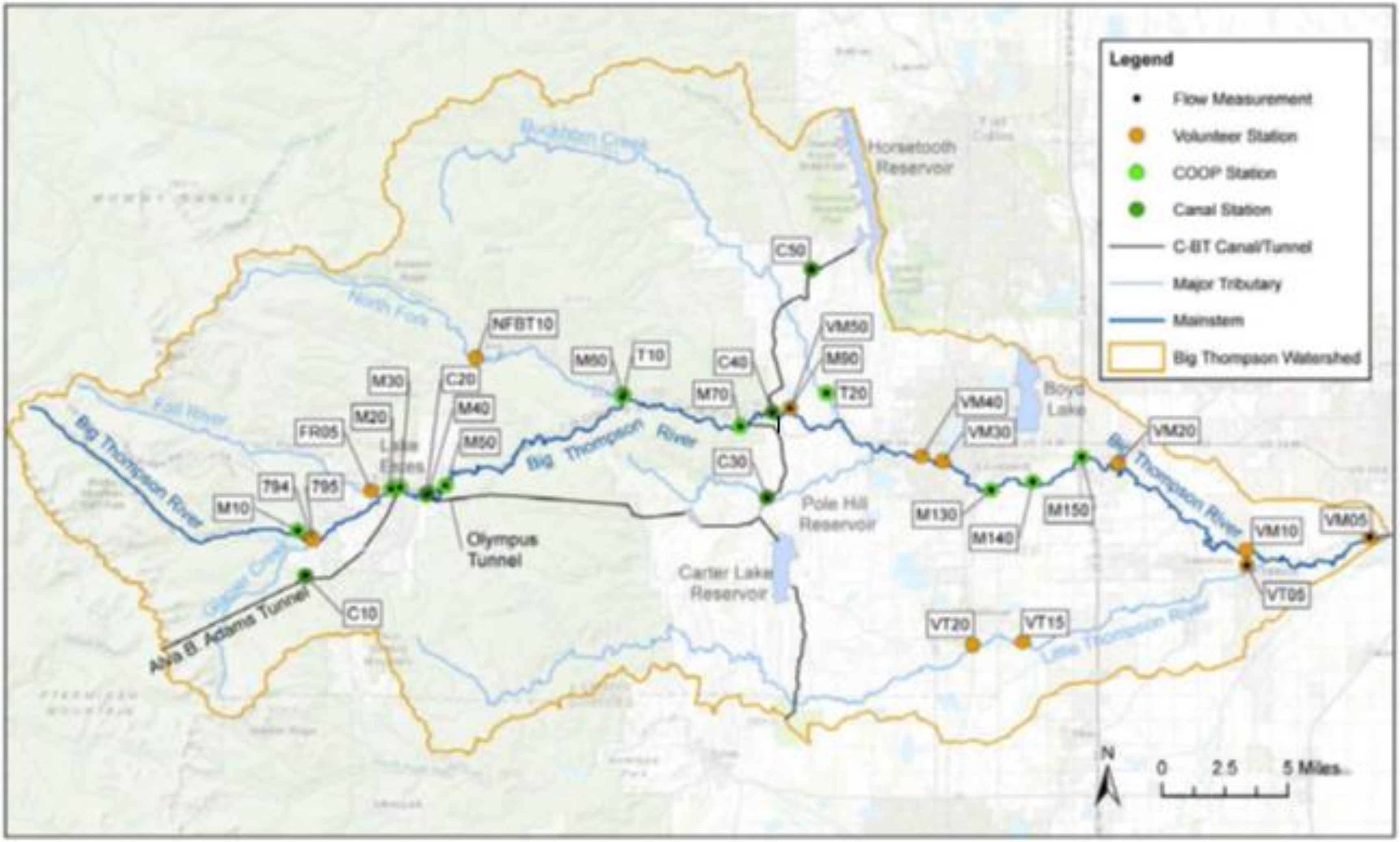


Figure 1. Locations of sites on the Big Thompson River, canals, and associated tributaries in 2015 (Hydros 2015). This figure represents all sites that have been sampled historically. Some sites may not have been sampled between 2010 and 2015.

Parameter Descriptions

<u>General</u>

Flow
Flow represents the volume of water passing by a given site in one second measured in cubic feet per second (cfs). Flow was measured at fifteen stations. Thirteen of these stations are COOP monitoring stations and two are canal stations. These flow rate data are presented site and river section specific medians and as such do not address important components of flow such as seasonal dynamics. Averages 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
Most aquatic organisms require dissolved oxygen of a particular concentration to survive. The necessary concentration differs by species. Many species in the upper portion of the Big Thompson River have evolved to live in coldwater streams requiring 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 events if the dissolved oxygen levels drop below a given level for even a short time.

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 itself does not directly impact water quality, it is easily measured and indicates general seasonal and spatial differences in water quality. Specific conductance may also indicate whether an issue may exist that merits more detailed investigation.

Water temperature
Aquatic organisms have preferred and lethal temperatures. These temperatures 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 other stressful time periods. 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.

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, and is the primary form that sulfur takes in oxygenated waters such as the Big Thompson River. Sulfate 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 sulfate.

Metals

Copper

Dissolved copper is of interest primarily due to its potential effects on aquatic life. While copper is an essential nutrient at low concentrations, it can be toxic at higher levels. Acute effects include mortality and chronic effects can lead to reduced survival, growth, and reproduction of aquatic organisms.   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 around 1964. Elevated concentrations of copper in stream segments downstream of C-BT Project canal releases have resulted in identified impairments and placements on the Colorado 303(d) List or the 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 based on mercury concentrations in fish tissue from Horsetooth Reservoir and Carter Lake, both of which receive water from the Big Thompson River. In addition, Boyd Lake 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 levels in water can negatively affect aquatic organisms and is therefore included in this report. Acute and chronic aquatic life standards of 18.4 µg/L 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 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.

<u>Nutrients</u>

Nitrogen and phosphorus are the major nutrients that support algal growth in aquatic systems. High levels of these nutrients can lead to increased algae productivity and associated issues including algal blooms, low dissolved oxygen levels at reservoir bottoms, low clarity, and drinking water treatment issues such as the presence of taste and odor compounds and increased levels of TOC. Eutrophic water bodies have high levels of nutrients and high algal productivity.

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 while total nitrogen standards have not yet been adopted for any segment in the Big Thompson River watershed. Monitoring sites M30, M50, M140, VT05, and VT15 are all immediately downstream of wastewater treatment plants and are impacted by phosphorus and nitrogen in the discharged effluent.

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, rainfall, 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 (Total P) 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.

<u>Microbiological</u>

Escherichia coli (E. coli)
E. coli is a species of bacteria that occurs in the intestines of animals and aids in the digestion of food. *E. coli* is usually not pathogenic but it can be measured in a relatively straightforward manner and is used as an indicator of the potential presence of disease causing bacteria. Water with elevated levels of *E. coli* may indicate a potential water consumption or contact risk for humans.

Data Analysis

All data with sample dates from January 1, 2010-December 31, 2015 were exported from the Big Thompson Watershed Forum NPStoret database and transferred to an Excel file to assemble a final dataset of comparable sites and metrics. 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 2015 median values for each analyte by river section to all data collected for the same river section during the 2010-2014 time period. To maximize the degree of comparability between years, only mainstem sites sampled in all 6 years were included in summary data (M10, M20, M30, M40, M50, M60, M70, M90, M130, M140, M150, and VM05). The river sections were defined as follows:

- “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 2015 in each river section are represented by a red circle in the figures. All data collected between 2010 and 2014 in each river section are represented as the maximum, minimum, 25th quartile, 50th quartile, and 75th quartile for the constructed "boxes". 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 2015. 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.

Individual data points were examined with regard to water quality standards as appropriate (Table 1). The water-quality standards utilized here are from Colorado Regulation 31 (WQCD 2016a), which specifies water-quality standards and methodology for various stream and river types, and Colorado Regulation 38 (WQCD 2016b), which specifies standards from Regulation 31 that have been adopted for the various segments of the Big Thompson River. Although comparisons are made in this report to applicable standards, this does not constitute a formal regulatory standards compliance assessment. The comparisons of individual data points to the applicable standards are made only to provide context for the data.

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), and temperature (°C) and pH.

		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	794	1.25*	0.11	10	126	126	250	6	7	6.5	9	21.7[1]	17[1]	13[2]	9[2]
	FR05	1.25*	0.11	10	126	126	250	6	7	6.5	9	21.7[1]	17[1]	13[2]	9[2]
	M20	1.25*	0.11	10	126	126	250	6	7	6.5	9	21.7[1]	17[1]	13[2]	9[2]
	M30	1.25*	0.11*	10	126	126	250	6	7	6.5	9	21.7[1]	17[1]	13[2]	9[2]
	M40	1.25*	0.11*	10	126	126	250	6	7	6.5	9	21.7[1]	17[1]	13[2]	9[2]
	M50	1.25*	0.11*	10	126	126	250	6	7	6.5	9	21.7[1]	17[1]	13[2]	9[2]
	M60	1.25*	0.11*	10	126	126	250	6	7	6.5	9	21.7[1]	17[1]	13[2]	9[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]
	VM50	1.25*	0.11*	10	126	126	250	6	7	6.5	9	23.9[3]	18.3[3]	13[4]	9[4]
4a	VM30	1.25*	0.11*	10	126	630	250	6	7	6.5	9	23.9[3]	18.3[3]	13[4]	9[4]
	VM40	1.25*	0.11*	10	126	630	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]
	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]
	VM10	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]
	VM20	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	NFBT10	1.25*	0.11	10	126	126	250	6	7	6.5	9	21.7[1]	17[1]	13[2]	9[2]
	T10	1.25*	0.11	10	126	126	250	6	7	6.5	9	21.7[1]	17[1]	13[2]	9[2]
	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]
	VT15	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]
	VT20	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 metals 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) and 2016 303(d) impairments and relative priority. Units for all standards are in ug/L.

		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
2	794	0.01	$e^{(0.9422(Ln(Hardness))-1.7408)}$	$e^{(0.8545(Ln(Hardness))-1.7428)}$	18.4	4.6	Temp, Cu, As	H, M, L
	FR05	0.01	$e^{(0.9422(Ln(Hardness))-1.7408)}$	$e^{(0.8545(Ln(Hardness))-1.7428)}$	18.4	4.6	Temp, Cu, As	H, M, L
	M20	0.01	$e^{(0.9422(Ln(Hardness))-1.7408)}$	$e^{(0.8545(Ln(Hardness))-1.7428)}$	18.4	4.6	Temp, Cu, As	H, M, L
	M30	0.01	$e^{(0.9422(Ln(Hardness))-1.7408)}$	$e^{(0.8545(Ln(Hardness))-1.7428)}$	18.4	4.6	Temp, Cu, As	H, M, L
	M40	0.01	11	7.5	18.4	4.6	Temp, Cu, As	H, M, L
	M50	0.01	11	7.5	18.4	4.6	Temp, As	H, L
	M60	0.01	11	7.5	18.4	4.6	Temp, As	H, L
	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
	VM50	0.01	$e^{(0.9422(Ln(Hardness))-1.7408)}$	$e^{(0.8545(Ln(Hardness))-1.7428)}$	18.4	4.6	Cu,As	M,L
4a	VM30	0.01	$e^{(0.9422(Ln(Hardness))-1.7408)}$	$e^{(0.8545(Ln(Hardness))-1.7428)}$	18.4	4.6	Se	M
	VM40	0.01	$e^{(0.9422(Ln(Hardness))-1.7408)}$	$e^{(0.8545(Ln(Hardness))-1.7428)}$	18.4	4.6	Se	M
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
	VM05	0.01	$e^{(0.9422(Ln(Hardness))-1.7408)}$	$e^{(0.8545(Ln(Hardness))-1.7428)}$	18.4	4.6	Se	L
	VM10	0.01	$e^{(0.9422(Ln(Hardness))-1.7408)}$	$e^{(0.8545(Ln(Hardness))-1.7428)}$	18.4	4.6	Se	L
	VM20	0.01	$e^{(0.9422(Ln(Hardness))-1.7408)}$	$e^{(0.8545(Ln(Hardness))-1.7428)}$	18.4	4.6	Se	L
7	NFBT10	0.01	$e^{(0.9422(Ln(Hardness))-1.7408)}$	$e^{(0.8545(Ln(Hardness))-1.7428)}$	18.4	4.6	Cu, As	H, L
	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
	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
	VT15	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
	VT20	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

Results

<u>General parameters</u>

Flow
A total of 160 flow measurements were collected in 2015 between February and November. The flow in the mainstem of the Big Thompson ranged from a high of 1,460 cfs at site M130 on 6/9/15 to a low of 6.2 cfs at site M10 on 2/9/15.

Dissolved oxygen (D.O.)
Dissolved oxygen levels were generally good at all sites in 2015 with 0 of 244 samples dropping below the site associated aquatic life standard of 5, 6, or 7 mg/L. Dissolved oxygen levels ranged from a low of 6.2 mg/L at site VT05 on 8/12/15 to a high of 11.7 mg/L at site M30 on 3/9/15.

Specific conductance
Specific conductance ranged from 13 uS/cm in the headwaters at site 794 on 6/10/15 to 2,609 uS/cm at site VT20 on 9/9/15. 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 0.1° C at site M10 on 2/9/15 to 22.4° C on 8/12/15 at site MED01. Of the total of 255 water temperature records, there were 4 exceedances of the site associated acute standard (2%), most of which occurred in October during the low flow period.

Total organic carbon (TOC)
Total organic carbon levels ranged from 1.4 mg/L in the headwaters at site 794 on 9/9/15 to 13.4 mg/L at site M70 on 5/26/15. 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 7/8/15 to 1570 mg/L at site VT20 on 9/9/15. Sulfate levels exceeded the domestic water supply standard of 250 mg/L in 12 of 182 samples (7%). Relatively high levels of sulfate primarily occurred in the lower river (M150, VM20, VM10, and VM05) and in the Little Thompson River (VT20, VT15, and VT05), reflecting the influence of the sedimentary bedrock geology in the lower portion of the watershed.

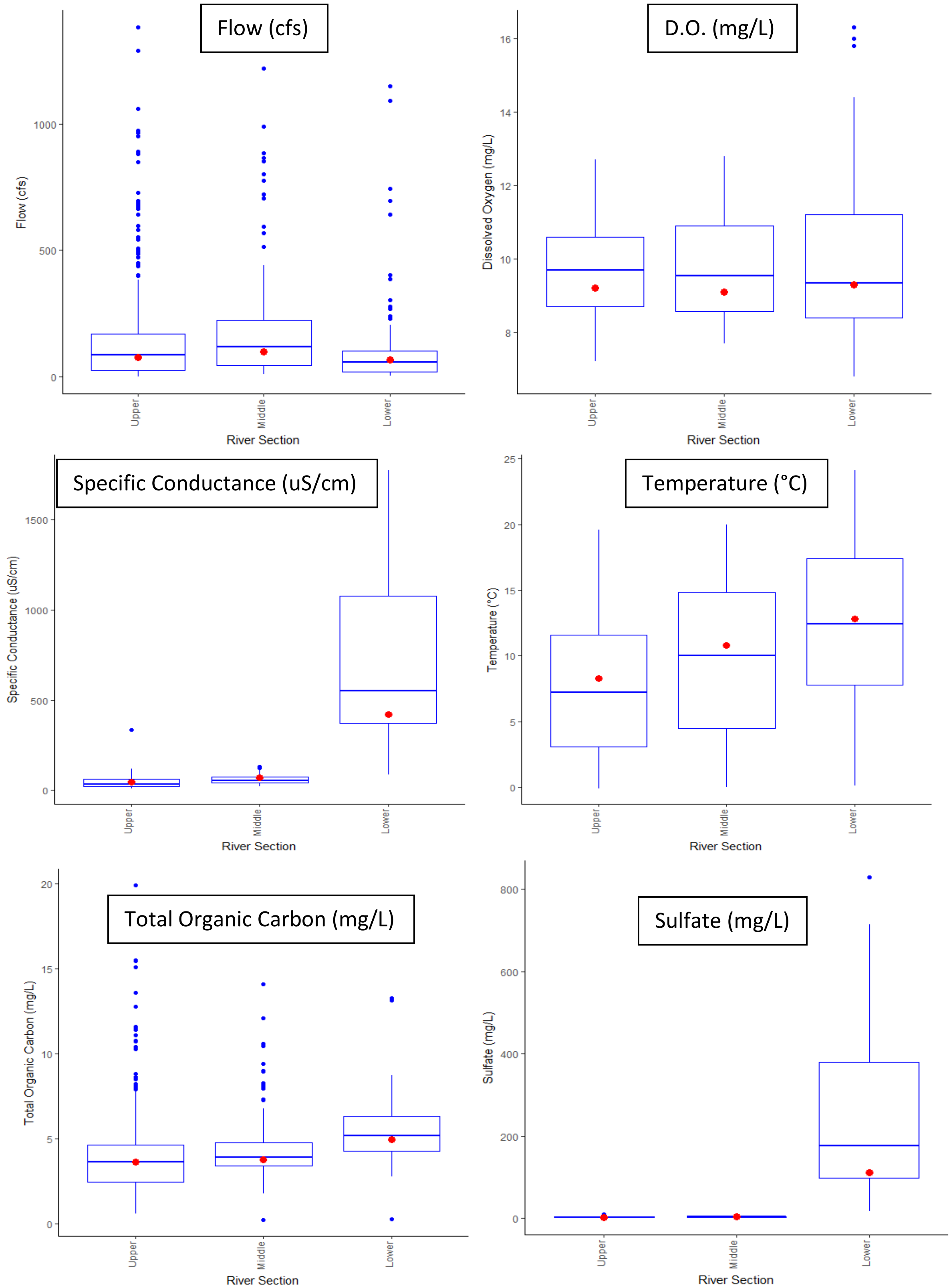


Figure 2. Box plots of general parameters representing the 2010-2015 time period. "Box-and-whiskers" constructed using all available data 2010-2014. Red circle represents 2015 median value.

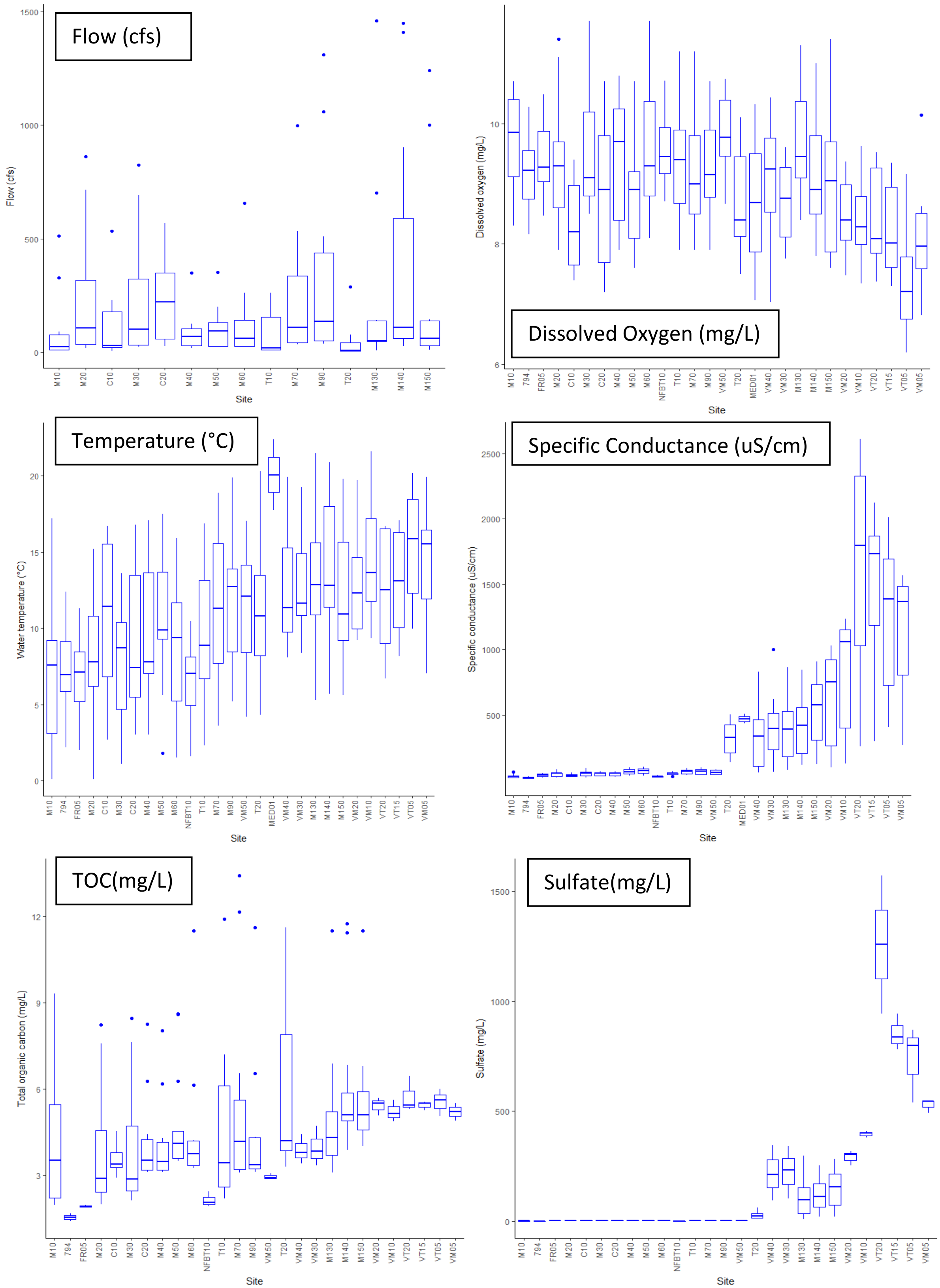


Figure 3. Spatial box plots for general parameters by site in 2015.

Metals

Copper

Among samples above the detection limit, the levels of copper ranged from 0.81 ug/L at site M40 on 8/11/15 to 5.5 ug/L at site T20 on 5/15/15. 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). 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:

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

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

Hardness values at BTWF sites in 2015 ranged from 5.5 mg/L to 1,440 mg/L with calculated copper standards from 0.88 ug/L to 49.61 ug/L. Excluding the copper values that were analyzed by a method with a high detection limit (i.e., 10 ug/L at sites 794, FR05, NFBT10, VM50, VM40, VM30, VM20, VM10, VM05, VT20, VT15, and VT05) there were 16 acute standard exceedances of 171 samples (9%) and 34 chronic standard exceedances of 171 samples (15%). The majority of the exceedances occurred in the upper portion of the river where hardness values were generally very low.

Mercury

Mercury levels ranged from 0.38 ng/L at site T20 on 11/10/15 to 13.0 ng/L at site T10 on 5/15/15. The water quality standard for chronic exposure is 10 ng/L and there were 6 exceedances from a total of 61 samples (10%) in 2015. Note however, that this is not a regulatory assessment but simply a comparison of individual data points to the standard.

Selenium

Of the samples above the analytical method detection limit, selenium levels ranged from 0.6 ug/L on 2/10/15 at site M90 to 10.9 ug/L on 11/4/15 at site VM30. 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 78 samples analyzed for selenium, none exceeded the acute standard and 13 exceeded the chronic standard (17%). Note, again, that this is not a regulatory assessment but simply a comparison of individual data points to the standard.

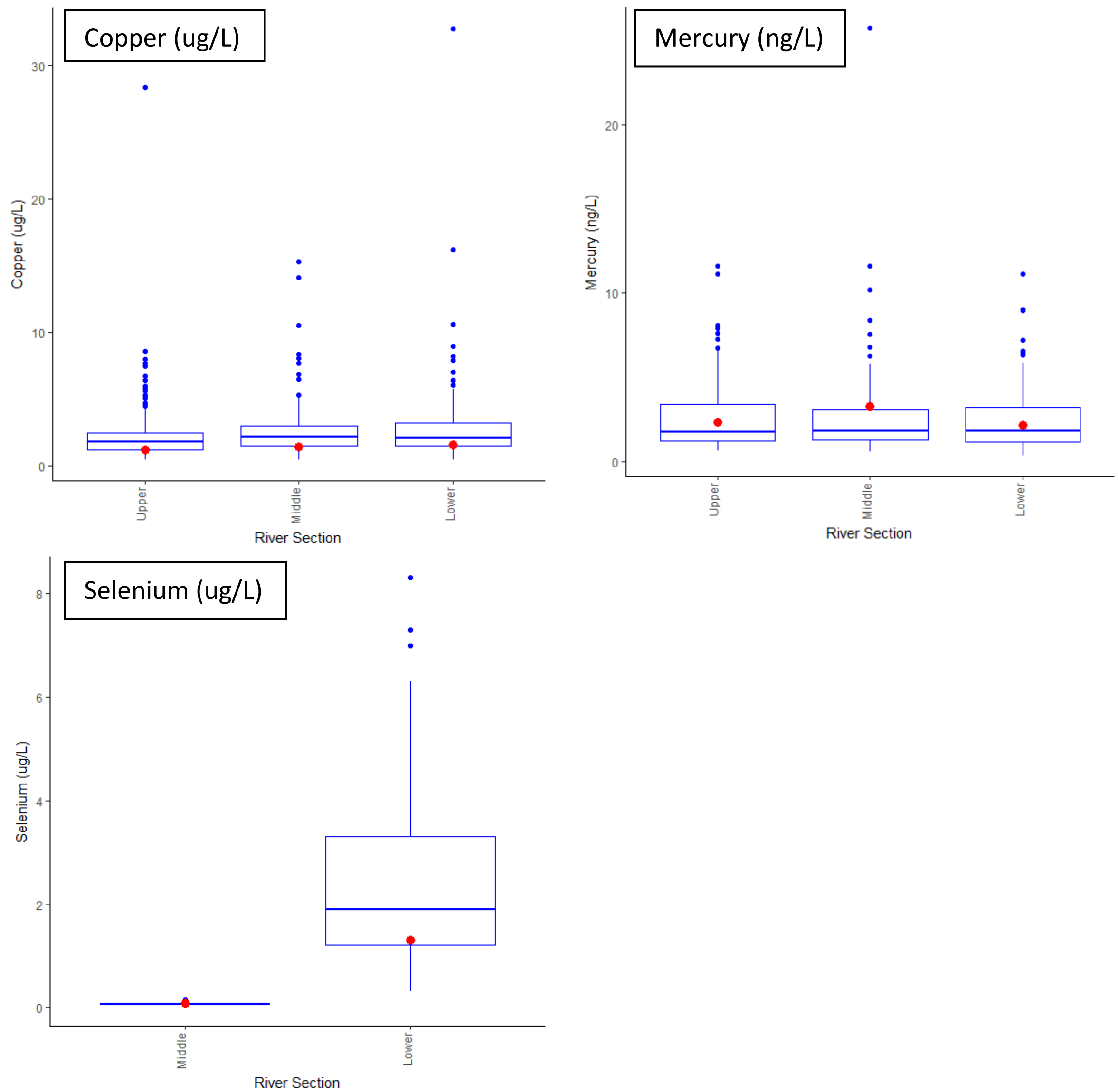


Figure 4. Box plots of metal parameters representing the 2010-2015 time period. "Box-and-whiskers" constructed using all available data 2010-2014. Red circle represents 2015 median value.

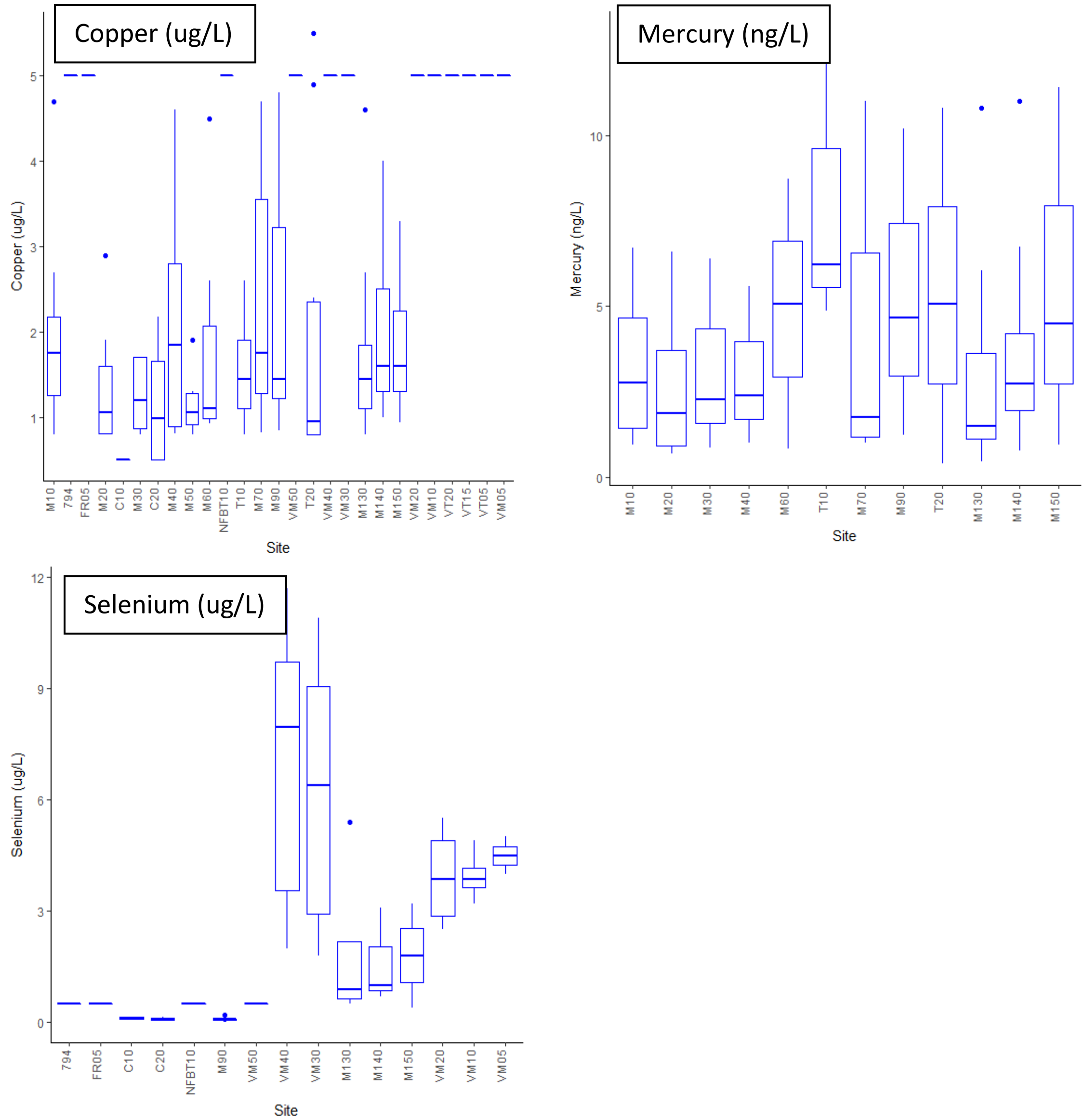


Figure 5. Spatial box plots for metal parameters by site in 2015. Dashes represent the fact that all samples from that site were reported as “non-detect.”

Nutrients

Total nitrogen

Total nitrogen ranged from 0.17 mg/L at site M20 8/10/15 to 5.4 mg/L at site M140 on 10/6/15. Monitoring sites M30, M50, M140, VT05, and VT15 are all downstream of wastewater treatment effluent discharge points and experience increases in nitrogen species concentrations compared to their associated upstream sites. Total nitrogen exceeded the interim numerical values adopted into Regulation 31 in 2012 (as shown in Table 1) in 12 of the 171 samples collected in 2015 (7%). 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 at sites M140 and M150 in the lower portion of the Big Thompson River.

Nitrate + nitrite
Excluding canal sites C10 and C20, which generally had very low levels, nitrate + nitrite levels ranged from a low of 0.03 mg/L at site M40 on 9/8/15 to a high of 4.824 mg/L at site VT05 on 8/12/15. Nitrite is a very small component of the nitrate plus nitrite result. Regardless of the contribution of nitrite, none of the 171 nitrate plus nitrate samples exceeded the 10 mg/L nitrate standard for drinking water in 2015.

Total phosphorus
Of the samples above detection limits, total phosphorus levels ranged from a low of 0.06 mg/L at site M10 on 2/9/15 to a high of 1.21 mg/L at site M140 on 10/6/15. Monitoring sites M30, M50, M140, VT05, and VT15 are all downstream of wastewater treatment plant effluent discharge points and experience increases in 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 255 samples analyzed for total phosphorus, 76 exceeded the total phosphorus numeric value of either 0.11 or 0.17 mg/L (30%). The vast majority of these exceedances occurred in lower portions of the river where the numeric value for comparison is 0.17 mg/L.

Orthophosphate
Of the sample results above the detection limits, orthophosphate levels ranged from a low of 0.005 mg/L at site M40 on 2/9/15 to a high of 1.04 mg/L at site M140 10/6/15. 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.

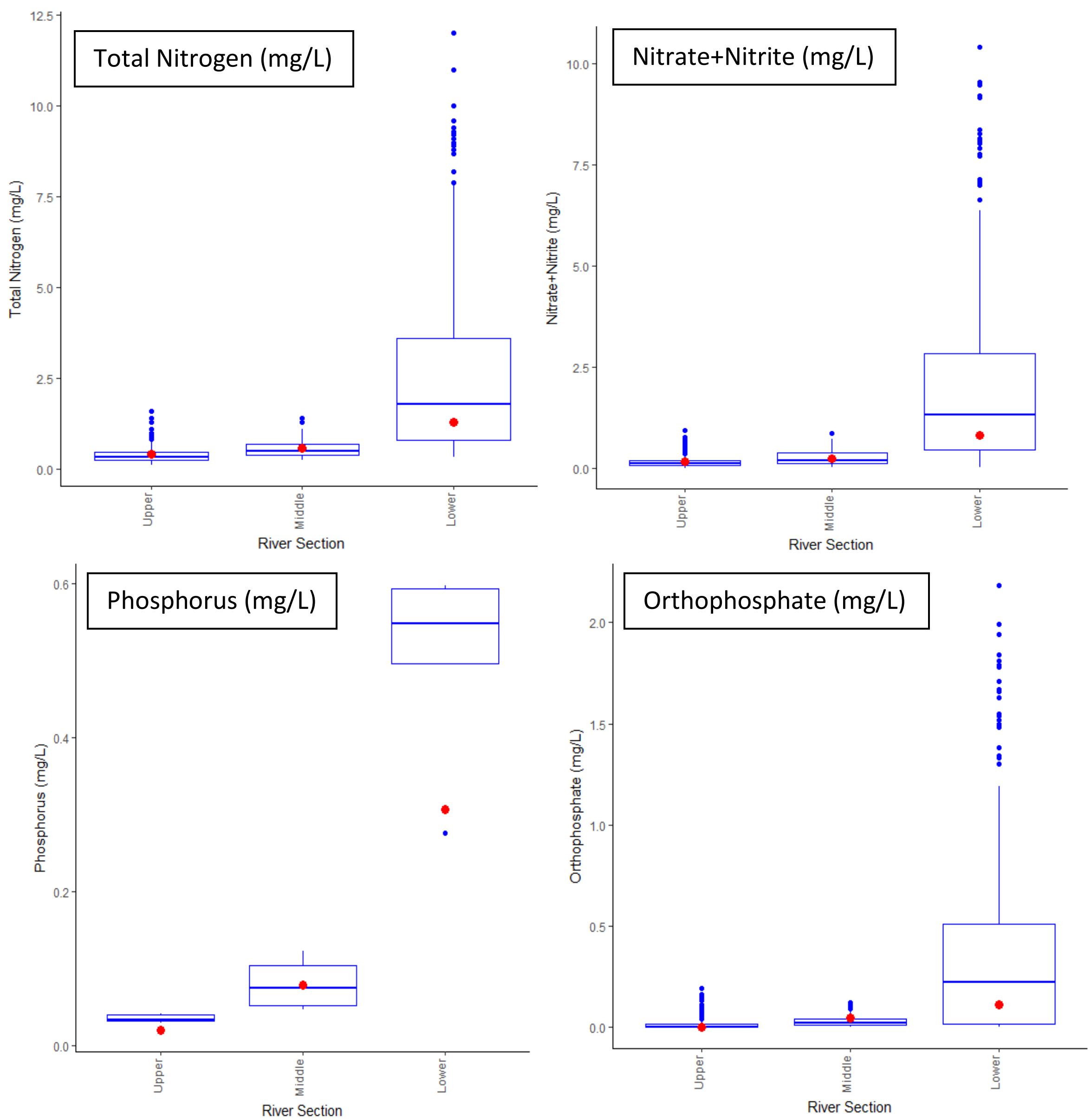


Figure 6. Box plots of nutrient parameters representing the 2010-2015 time period. “Box-and-whiskers” constructed using all available data 2010-2014. Red circle represents 2015 median value.

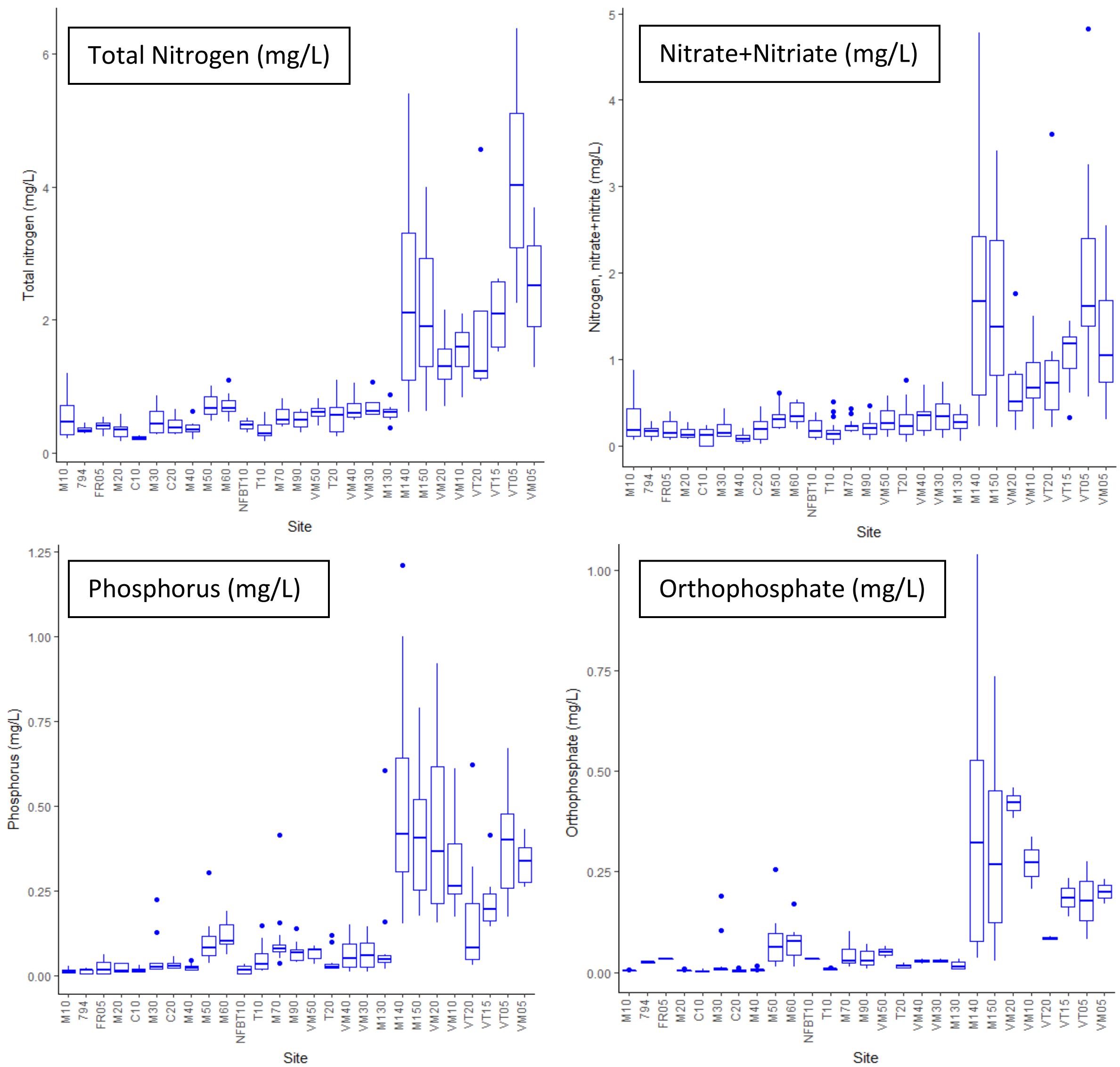


Figure 7. Spatial box plots for nutrient parameters by site in 2015.

Microbiological parameters

Escherichia coli

The levels of *E. coli* ranged from a low of 0.5 cfu/100 mL at site M10 on 3/11/15 to a high of 24,196 cfu/100 mL at site M140 on 8/11/15. The site-specific water quality standard for *E. coli* is 126, 205, or 630 cfu/100 mL. Of the 171 samples analyzed for *E. coli*, 39 exceeded the site associated standard (23%).

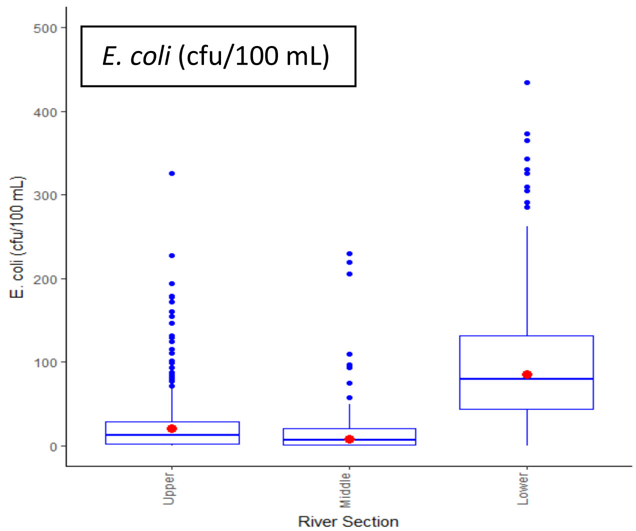


Figure 8. Box plot of *E. coli* levels representing the 2010-2015 time period. “Box-and-whiskers” constructed using all available data 2010-2014. Red circle represents 2015 median value. Values greater than 500 cfu/100 mL to increase visual resolution.

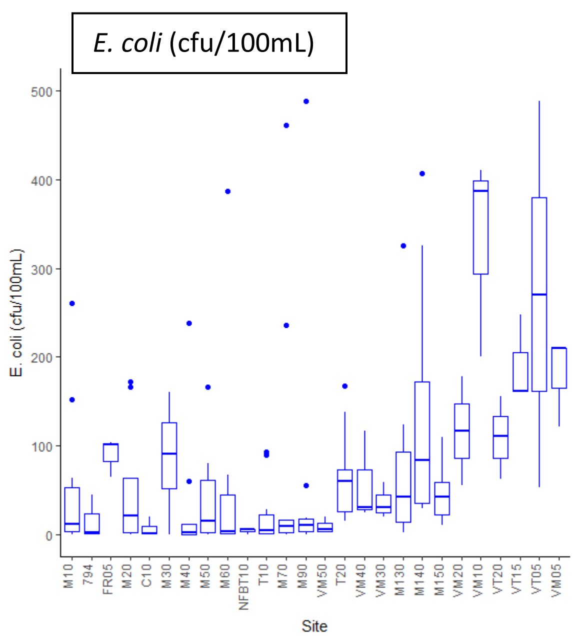


Figure 9. Spatial box plot of *E. coli* levels by site in 2015. Values greater than 500 cfu/100 mL not shown to increase visual resolution.

Conclusions

In general, 2015 can be characterized as an average year when compared to the previous five years for the following parameters:

- **Flow:** The median flow in the Big Thompson River was very close to the 5-year median value although numerous flow values throughout the river were greater than 1.5 times the interquartile range above the median (Figure 2). These elevated flow measurements are expected given the seasonality of runoff events in the Big Thompson River.

- **TOC:** 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 2015 data suggest that the median TOC level was average compared to the previous five years (Figure 2) which supports the contention that the trend may be plateauing.

- **Copper:** Hydros (2015) noted a relatively high incidence of water quality standard exceedances for copper. While there were certainly a number of exceedance events in 2015, the median copper concentrations for each river section were slightly lower than the median of the previous five years (Figure 4). Interestingly, many of the copper exceedances were in the upper section of the river and copper levels in this portion of the river have shown a small but significant increase over time (Billica 2017). The cause of this increase is unknown but may merit further investigation.

- **Selenium:** There were a number of exceedance events for selenium in 2015, primarily in the lower portion of the river, which runs through Pierre shale which is relatively high in selenium content. However, average selenium concentrations in 2015 were slightly below the five-year median (Figure 4).

Conversely, 2015 values differed considerably from the 5-year median value for a number of measured parameters including:

- **Water Temperature:** 2015 was the third warmest year on record in Colorado (Doesken 2016) and this was reflected by the relatively high water temperatures throughout the Big Thompson River (Figure 2). The median water temperatures in 2015 were approximately 1°C warmer than the median water temperature 2010-2014.

- **Nutrients:** Nutrient concentrations were generally relatively low. Median total nitrogen and nitrate + nitrite levels in 2015 were the generally at or below the median values 2010-2014 (Figure 6). Median levels of orthophosphate and total phosphorus were relatively low in 2015 as well. This finding supports a similar finding by Hydros (2015) and Mast et al. (2014) who suggest that nitrate + nitrite levels have demonstrated significant decreases over time.

- **Sulfate:** Although sulfate levels continued to be elevated in the lower portion of the river and the Little Thompson River, the 2015 median value for the lower river was lower than the median of the preceding 5-year period (Figure 2).

- ***E. coli*:** There were several exceedances of the *E. coli* standard in 2015 primarily in the lower river and the Little Thompson River (Figure 8). This finding is consistent with the findings presented in Hydros (2015) who also found exceedances in this portion of the river and suggested that the cause may be related to livestock concentrations. In addition, the fact that the median values of samples collected in 2015 were slightly higher than the median values 2010-2014 suggests that elevated levels of *E. coli* may be an appropriate topic for further investigation.

Acknowledgements

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