2016 Big Thompson River Water Quality Summary Report

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Big Thompson Watershed Forum

Executive Summary

An evaluation of water quality parameters collected in 2016 was conducted and indicates that water quality in the Big Thompson River continues to be generally good. This conclusion was based on an examination of data that came from water samples collected at 18 sites in 2016 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.

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

Although water quality was generally good in 2016, some measured parameters differed from levels that would be considered optimal. Meteorological conditions caused relatively warm water temperatures in the lower river which was approximately 1° C warmer than the 2011-2015 median value. Copper levels occasionally exceeded water quality standards (particularly in the upper river) but median values were relatively low in 2016. 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. These elevated levels are likely caused in part by the fact that the bedrock geology of this portion of the river (Pierre shale) is rich in selenium. It is 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.

Conversely, several water quality parameters, particularly nutrients, dissolved oxygen, and mercury were near optimal or appeared to be improving. Parameters considered to reflect nutrient availability conducive to the growth of algae were relatively low or average in 2016 when compared to the reference period of 2011-2015. Hopefully, the relatively low level of nutrients is indicative of a trend that will continue. 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. Finally, mercury levels continued to be relatively low and none of the samples were above the associated water quality standard.

Despite the generally good water quality in the Big Thompson River in 2016, a relatively large fish kill occurred on 3/7/16 which resulted from a spike in pH according to Colorado Parks and Wildlife staff. Many construction projects on Highway 34 occurred in 2016 to repair damage done by the 2013 flood. These projects will continue through at least 2018. Approximately, 5,600 fish were killed in the 3/7/16 event. American Civil Constructors, the contractor whose activities caused the release of concrete and grout through an earthen berm, paid over $200,000 in fines. The City of Loveland was unable to utilize water from the Big Thompson River for drinking water for an extended period due to concern and uncertainty regarding the cause of the fish kill.

The BTWF contracted with the USGS to conduct additional water quality sampling in areas associated with the fish kill. Although pH was slightly elevated near the source of the fish kill on 3/9/16, two days after the fish kill, the large spike measured on the day of the fish kill had dissipated. However, aluminum and iron concentrations that were measured in the samples collected on 3/9/16 were elevated to a level that could have resulted in continued impacts to the fish population.

List of Figures & Tables

Introduction

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, 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 collaborative monitoring, assessment, and education/outreach projects. BTWF's objectives include: 1) developing and promoting voluntary practices that protect the Big Thompson Watershed and the quality of its waters, 2) analyzing relevant water quality data to detect temporal and spatial trends and identify potential issues and improvements, 3) identifying priority protection measures and educating affected parties.

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 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 2016. Water quality data collected in 2016 are compared to those collected during the previous five years (2011-2015). Data collected for the COOP in 2016 were also compared to water quality standards adopted by the Colorado Water Quality Control Commission (Regulations 31 and 38; WQCC 2016a, WQCC 2016b).

Data Collection

While water quality sampling for the COOP included 53 water quality parameters in 2016, 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: discharge, 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)*. Additional metrics associated with the fish kill event included aluminum, iron, chromium, and pH.

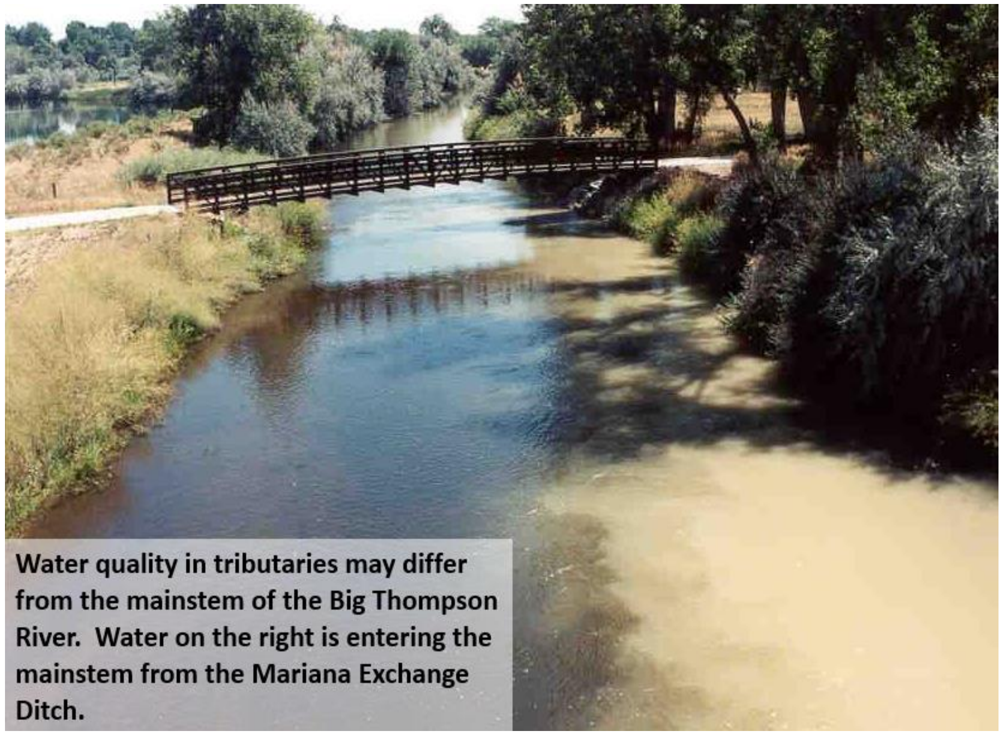
Most samples collected during COOP monitoring in 2016 were analyzed at the USGS' National Water Quality Laboratory in Denver; however, *E. coli* and TOC were analyzed by the Cities of Loveland and Fort Collins, respectively.

Study Sites

A total of 18 sites were sampled on the mainstem and tributaries of the Big Thompson River in 2016 (M10, M20, M30, M40, M50, M60, M70, M90, M130, M140, M150, T10, T20, NFBT05, 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 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.

Tributary samples were collected from the North Fork of the Big Thompson (NFBT05 and T10), Buckhorn Creek (T20), and the Little Thompson River (VT05).



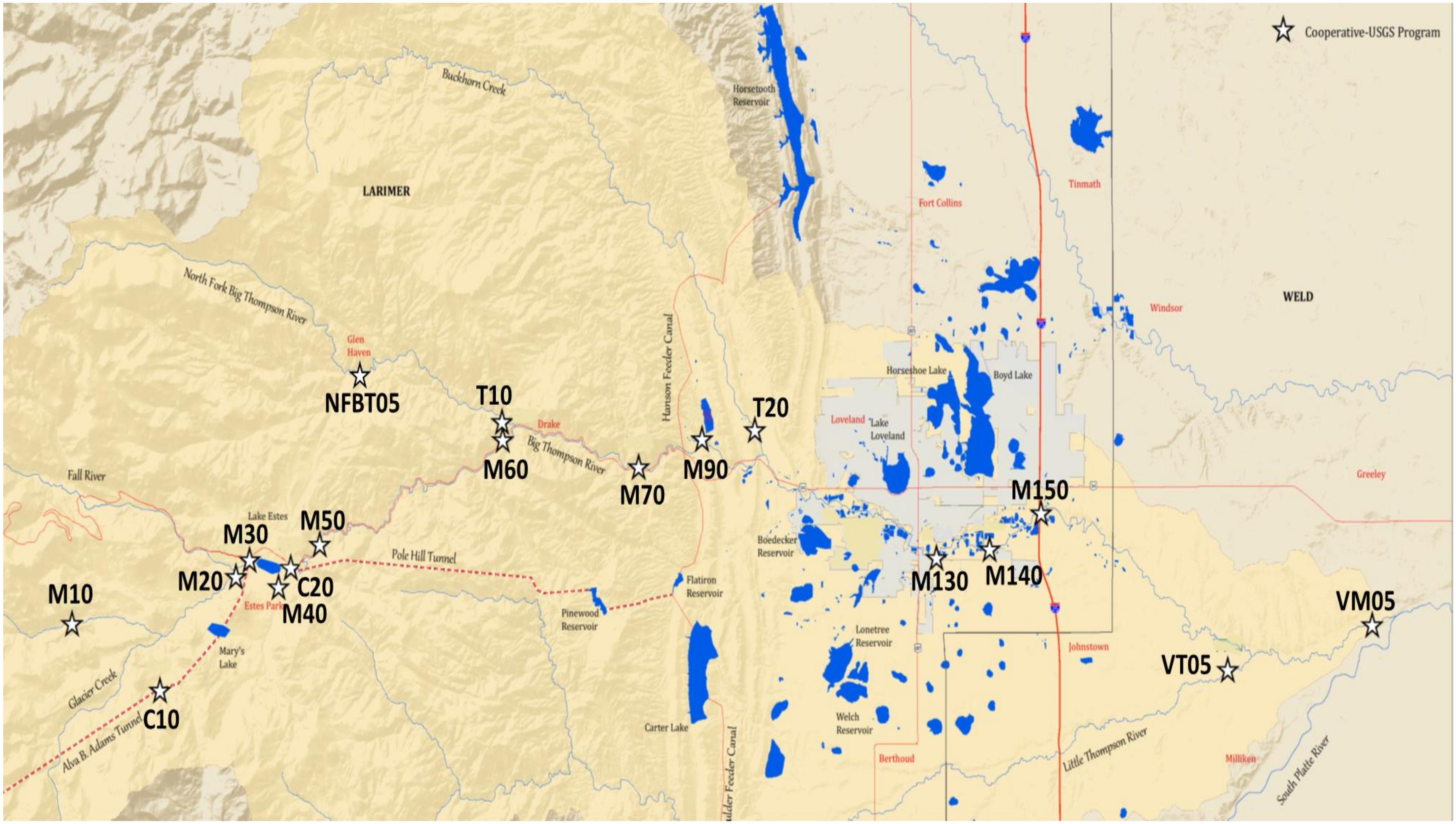
Water quality in tributaries may differ from the mainstem of the Big Thompson River. Water on the right is entering the mainstem from the Mariana Exchange Ditch.

2016 Fish Kill

Many construction projects on Highway 34 occurred in 2016 to repair damage done by the 2013 flood. These projects will continue through at least 2018. Generally, the construction projects have proceeded with relatively few water quality impacts. However, a relatively large fish kill occurred on 3/7/16 which resulted from a spike in pH according to Colorado Parks and Wildlife staff. Approximately, 5,600 fish were killed in the 3/7/16 event which occurred along county Road 43 adjacent to the North Fork Big Thompson River, approximately 0.4 miles above the confluence with the Big Thompson River. American Civil Constructors, the contractor whose activities caused the release of concrete and grout through an earthen berm, paid over $200,000 in fines. The earthen berm, used to separate the river from an area where 290,000 lbs. of concrete and grout were being mixed failed in some regard and resulted in the release of concrete byproducts into the river. Fish mortality extended 8 miles downstream. Water quality was not being actively monitored at the mixing site. The City of Loveland was unable to utilize water from the Big Thompson River for drinking water for an extended period due to concern and uncertainty regarding the cause of the fish kill.

In response to the fish kill, the BTWF contracted with the USGS to conduct additional water quality sampling in an area associated with the fish kill (NFBT05) and to conduct analyses for additional water quality analytes along with the standard suite of analytes from March through November 2016 at sites downstream from the fish kill site (T10, M50, M60, M70, and M90). The additional analytes included silica, aluminum, calcium, iron, magnesium, chromium, and nickel.

Figure 1. Locations of sites on the Big Thompson River, canals, and associated tributaries in 2016.



Parameter Descriptions

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 was measured at fifteen stations. Thirteen of these stations are COOP monitoring stations and two are canal stations. These 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 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. 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 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. 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 2016b).

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 background sulfate, 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 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 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.

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 River 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 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.

Data Analysis

All data with sample dates from January 1, 2010-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. 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 2016 median values for each analyte by river section to all data collected for the same river section during the 2011-2015 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 2016 in each river section are represented by a red circle in the figures. All data collected between 2011 and 2015 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 2016. 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 2016 were also compared to CDPHE water quality standards from Colorado Regulations 31 (WQCD 2016a) and 38 (WQCD 2016b), 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.

Fish Kill

Measurements of focus metrics available for the fish kill event (3/7/16) and additional metrics of interest were examined in a spatial and temporal context by examining data collected from the downstream site

(T10) before (February), two days after (3/9/16), and one month after (April) the fish kill event and comparing these values to the upstream reference site (NFBT05) which was sampled two days after the event (3/9/16).

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.

		Nutrients			Microbiological		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]
	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]
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]
7	NFBT05	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]

1 June-September
2 October-May
3 April-October
4 November-March
5 March-November
6 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	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
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
7	NFBT05	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

Results

General Parameters

Flow

A total of 161 flow measurements were collected in 2016 between February and November. The flow in the mainstem of the Big Thompson ranged from a high of 848 cfs at site M20 on 6/7/16 to a low of 3.6 cfs at site M10 on 2/9/16.

Dissolved oxygen (D.O.)

Dissolved oxygen levels were generally good at all sites in 2016 with 0 of 175 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 6.52 mg/L at site VT05 on 8/11/16 to a high of 13.1 mg/L at site M140 on 1/12/16.

Specific conductance

Specific conductance was measured 186 times at various locations throughout 2016. Specific conductance ranged from 15 uS/cm in the headwaters at site M10 on 6/8/16 to 2,261 uS/cm at site VT05 on 6/8/16. 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 1/13/16 to 23.2°C on 8/6/16 at site M130. Of the total of 187 water temperature records, 16 were above the site associated chronic standard (9%), most of which occurred in October during the low flow period.

Total organic carbon (TOC)

Of the 153 samples taken, total organic carbon levels ranged from a low of 1.61 mg/L in the headwaters at site M10 on 9/12/16 to a high of 9.39 mg/L at site T10 on 5/11/16. 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 1.17 mg/L at site M10 on 6/28/16 to 629 mg/L at site M130 on 4/10/16. Sulfate levels were above the domestic water supply standard of 250 mg/L in 4 of 131 samples (3%). 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.

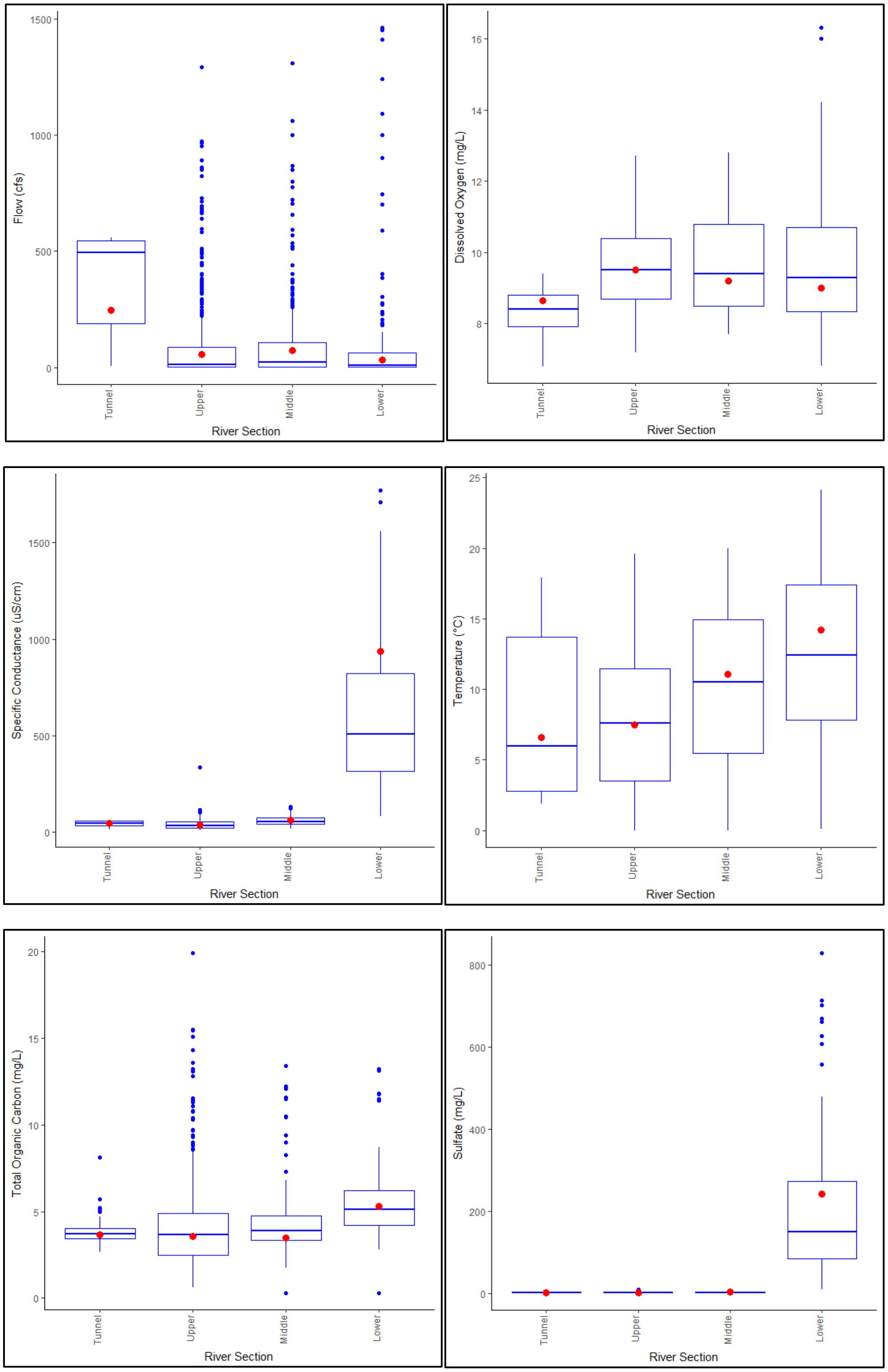


Figure 2. Box plots of general parameters representing the 2011-2016 time period. "Box-and-whiskers" constructed using all available data 2011-2015. Red circle represents 2016 median value.

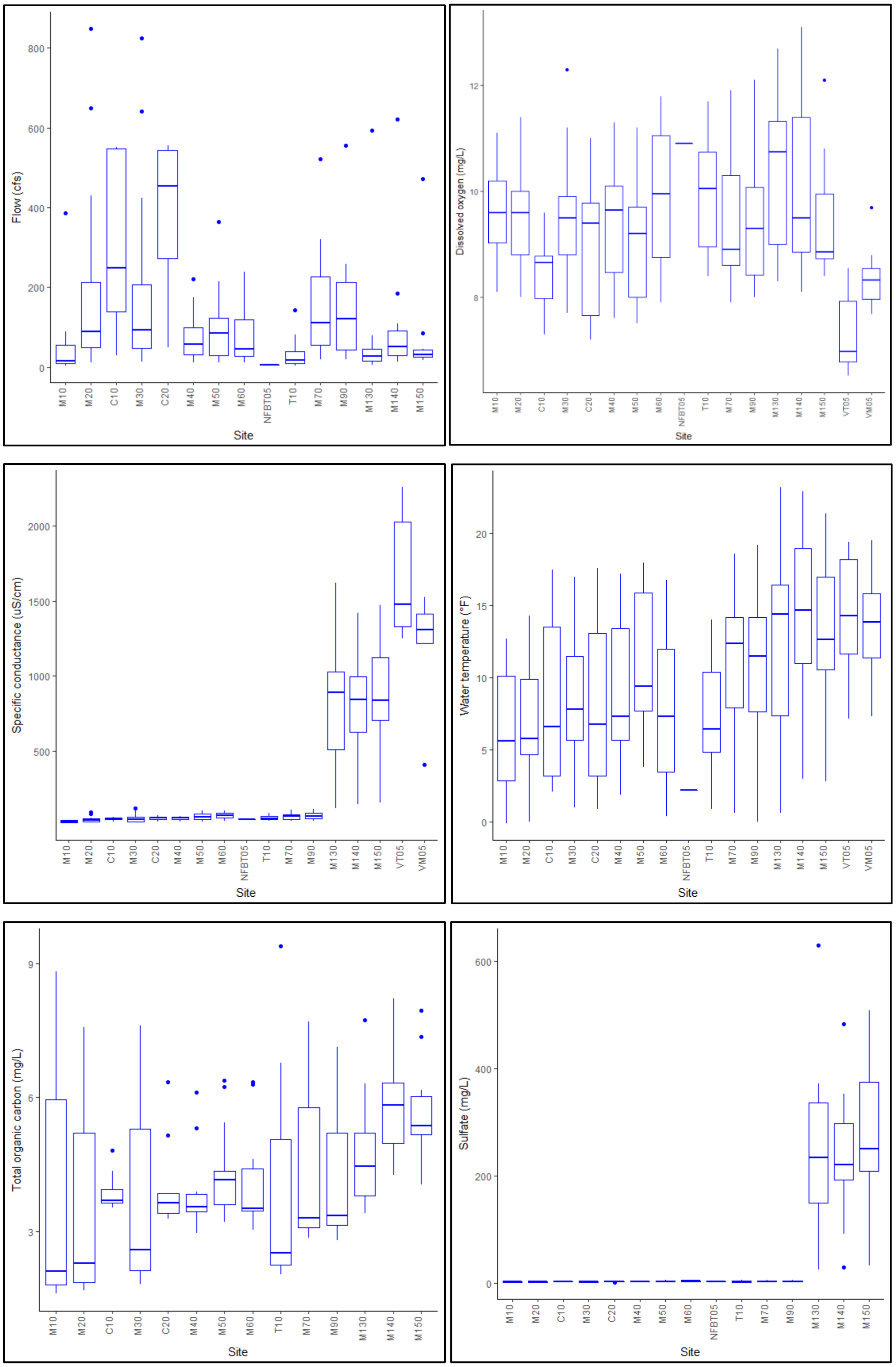


Figure 3. Spatial box plots for general parameters by site in 2016.

Metals

Copper

Dissolved copper levels ranged from 0.53 ug/L at site T10 on 11/8/16 to 9.3 ug/L at site M70 on 9/13/16. 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:

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

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

Hardness values at BTWF sites in 2016 ranged from 4.78 mg/L at site M10 on 4/11/16 to 768 mg/L at site M130 on 4/12/16. Calculated acute copper standards from ranged from 0.77 ug/L to 49.61 ug/L. Of the 119 samples collected, thirteen (11%) of the samples were above the acute standard and 6 (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 0.00033 µg/L at site M130 on 11/8/16 to 0.00988 µg/L at site T10 on 5/11/15. The water quality standard for chronic exposure is 0.01 µg/L and there were 0 exceedances from a total of 58 samples in 2016. 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 on 9/12/16 at site C10 to 14.8 ug/L on 4/12/16 at site M130. 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 45 samples analyzed for selenium, none were above the acute standard, but seven were above the chronic standard (16%). Note, again, that this is not a regulatory assessment but simply a comparison of individual data points to the standard.

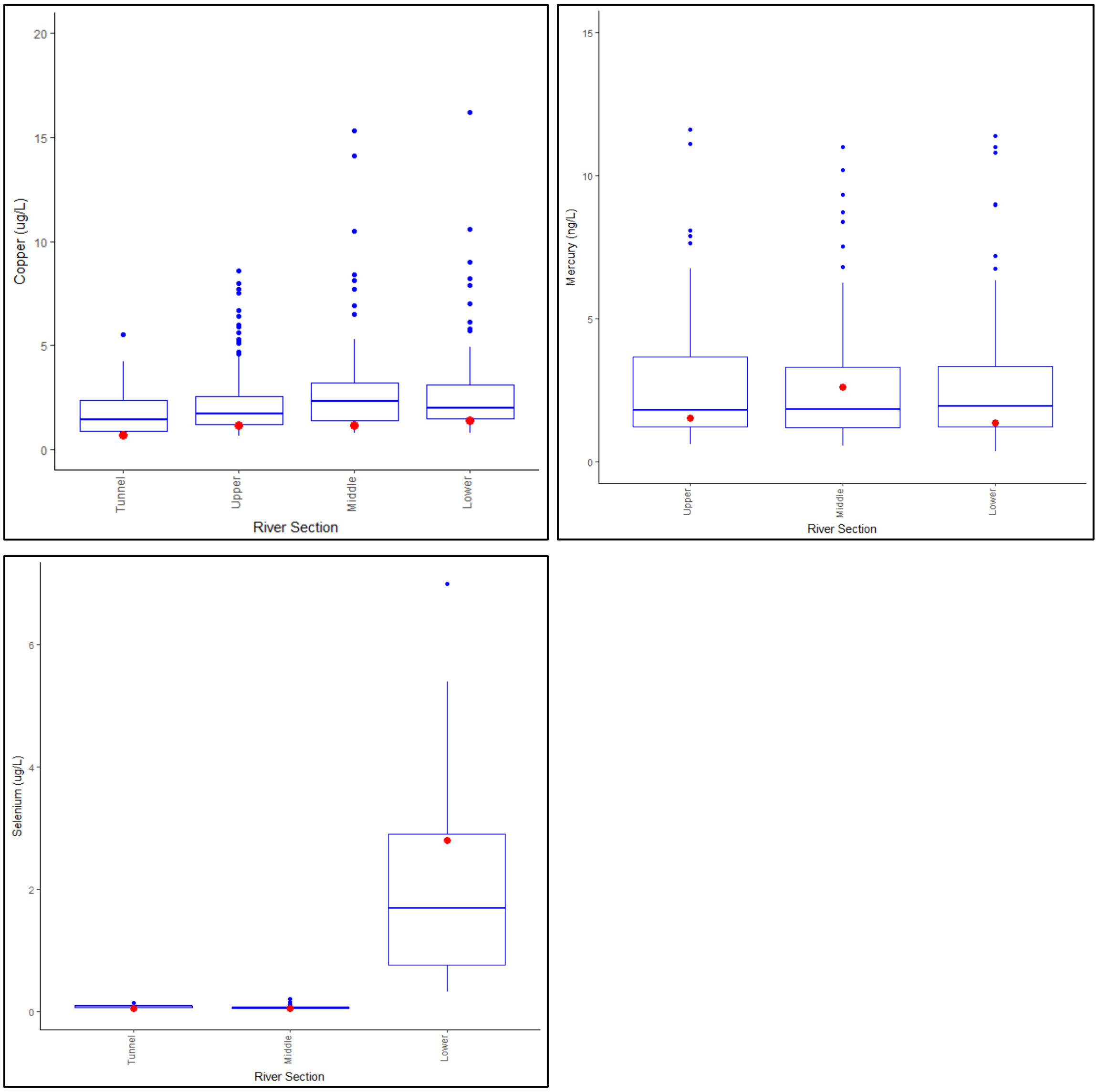


Figure 4. Box plots of metal parameters representing the 2011-2016 time period. "Box-and-whiskers" constructed using all available data 2011-2015. Red circle represents 2016 median value.

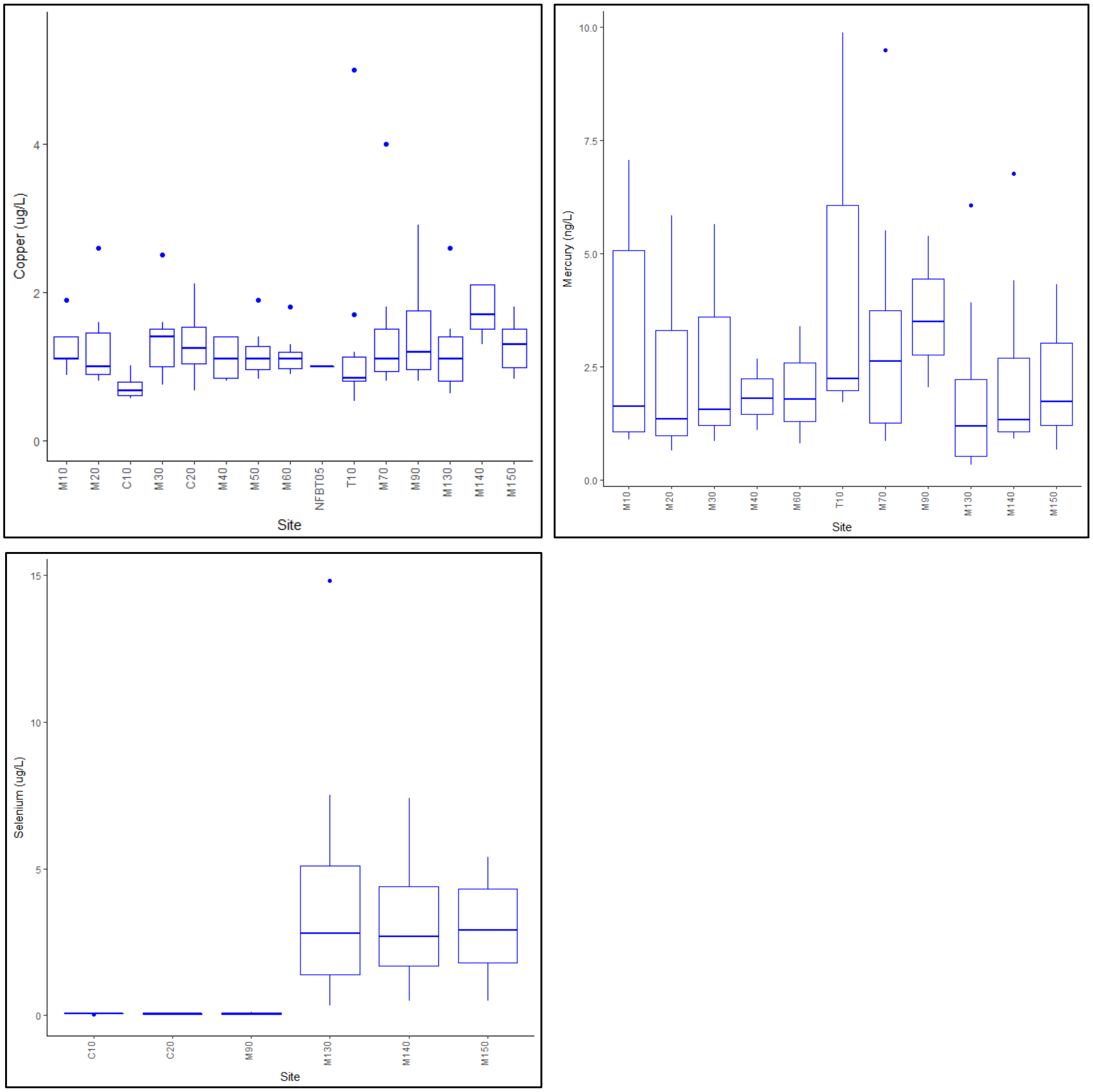


Figure 5. Spatial box plots for metal parameters by site in 2016. Solid lines represent the fact that all samples from that site were reported as "non-detect." One data point (25.7 ug/L, M90, 12 Nov 2013) was excluded from the mercury box plot to increase visual resolution. Similarly, two data points (32.7 ug/L, M150, 10 Feb 2014 and 28.3 ug/L, M50, 12 Nov 2013) were removed from the copper box plot.

Nutrients

Total nitrogen

Total nitrogen ranged from 0.12 mg/L at site MT10 on 10/12/16 to 8.0 mg/L at site M140 on 11/8/16. 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 16 of the 171 samples collected in 2016 (9%). However, total nitrogen standards have not yet been adopted for any stream segment in the Big Thompson watershed. Fifteen of the 16 potential exceedances were located at sites M140 and M150 in the lower portion of the Big Thompson River.

Nitrate + nitrite

Excluding tunnel sites C10 and C20, which generally had very low levels, nitrate + nitrite levels ranged from a low of 0.03 mg/L at site M40 on 3/8/16 to a high of 7.11 mg/L at site M140 on 9/12/16. Nitrite is typically a very small component of the nitrate + nitrite samples. None of the 168 nitrate + nitrite samples exceeded the 10 mg/L nitrate standard for drinking water in 2016.

Total phosphorus

Of the samples above detection limits, total phosphorus levels ranged from a low of 0.06 mg/L at site M10 on 2/9/16 to a high of 1.7 mg/L at site M140 on 11/8/16. Monitoring sites M30, M50, and M140 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 170 samples analyzed for total phosphorus, 43 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.

Orthophosphate

Orthophosphate levels ranged from a low of 0.001 mg/L at site C10 on 1/11/16 to a high of 1.45 mg/L at site M140 11/8/16. 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.

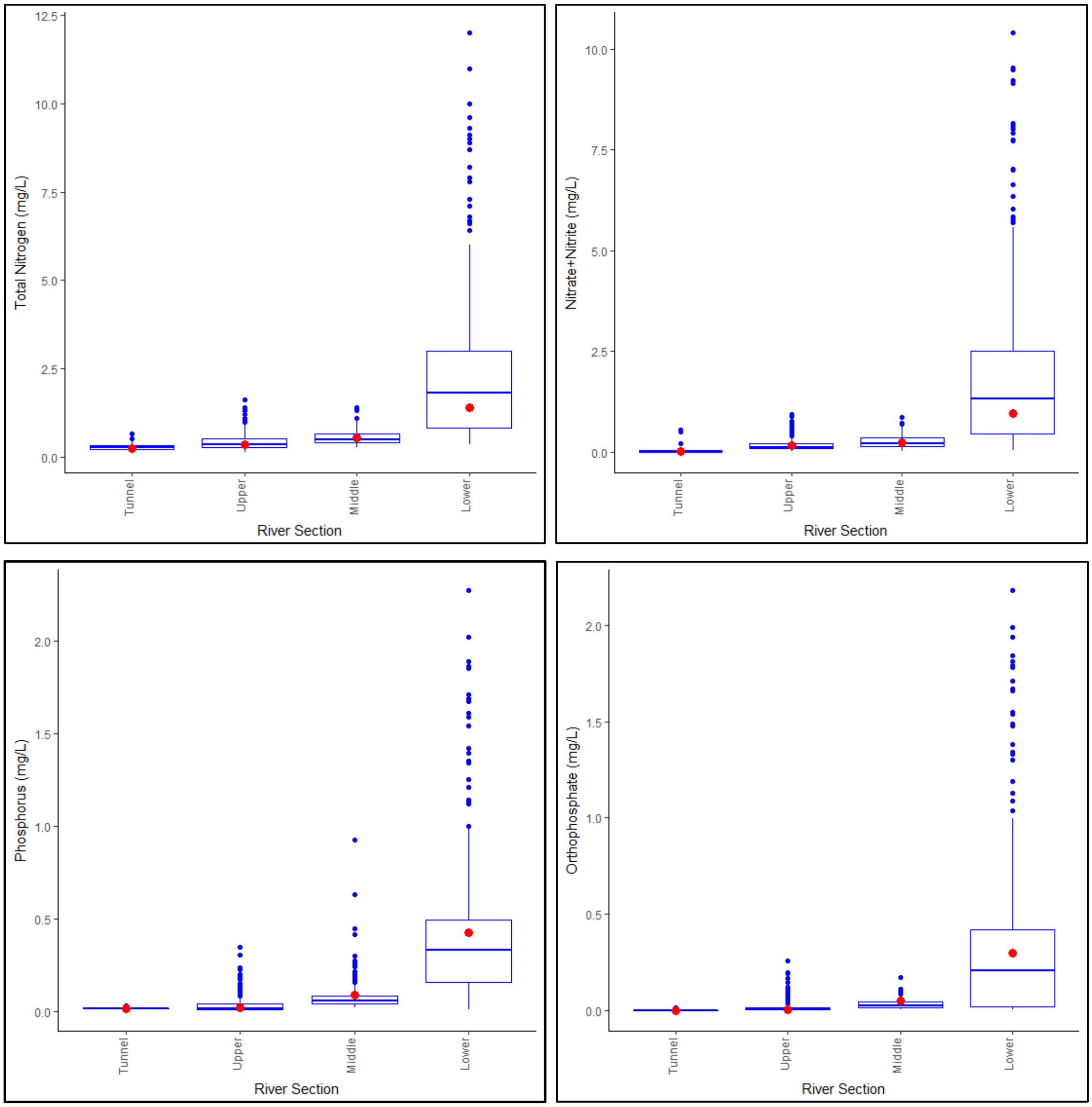


Figure 6. Box plots of nutrient parameters representing the 2011-2016 time period. "Box-and-whiskers" constructed using all available data 2011-2015. Red circle represents 2016 median value.

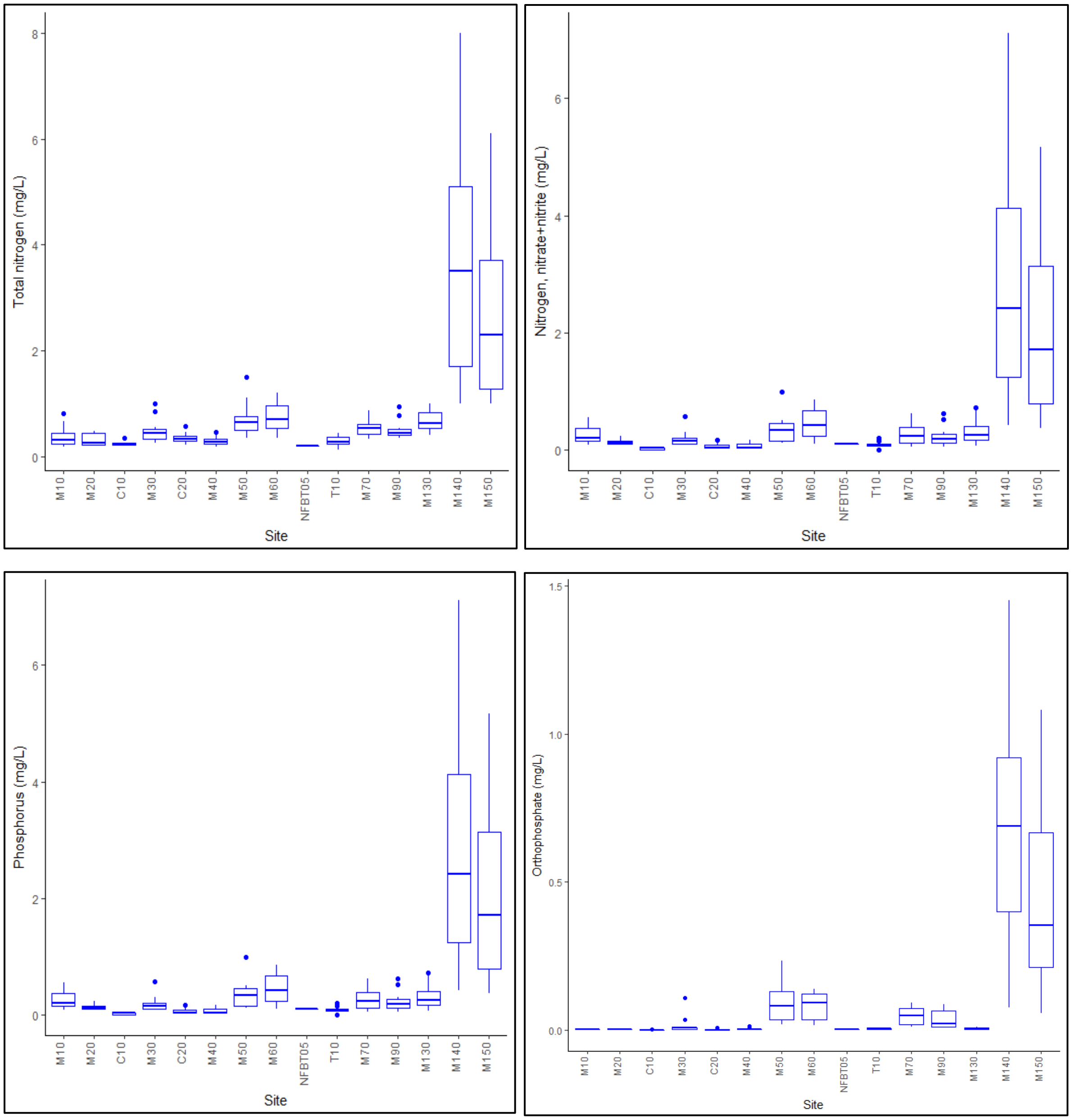


Figure 7. Spatial box plots for nutrient parameters by site in 2015.

Microbiological Parameters

Escherichia coli

The levels of *E. coli* ranged from a low of 0.5 cfu/100 mL at site C10 on 1/11/16 to a high of 488 cfu/100 mL at site M140 on 11/18/16. The site and season-specific water quality standard for *E. coli* is 126, 205, or 630 cfu/100 mL. Of the 128 samples analyzed for *E. coli*, 16 were above the site associated standard (13%).

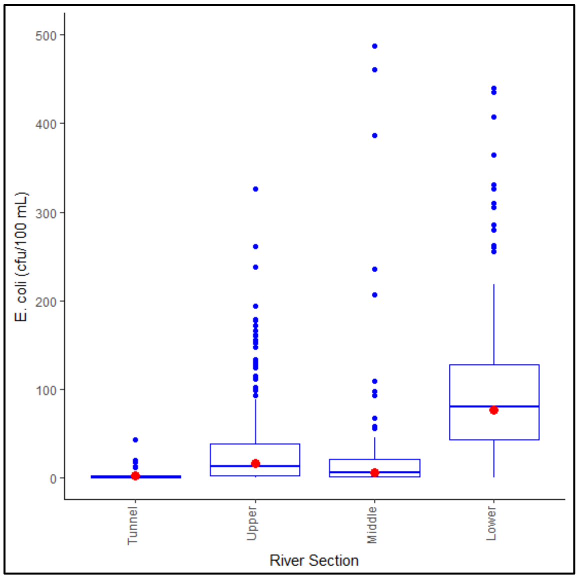


Figure 8. Box plot of *E. coli* levels representing the 2011-2016 time period. "Box-and-whiskers" constructed using all available data 2011-2015. Red circle represents 2016 median value.

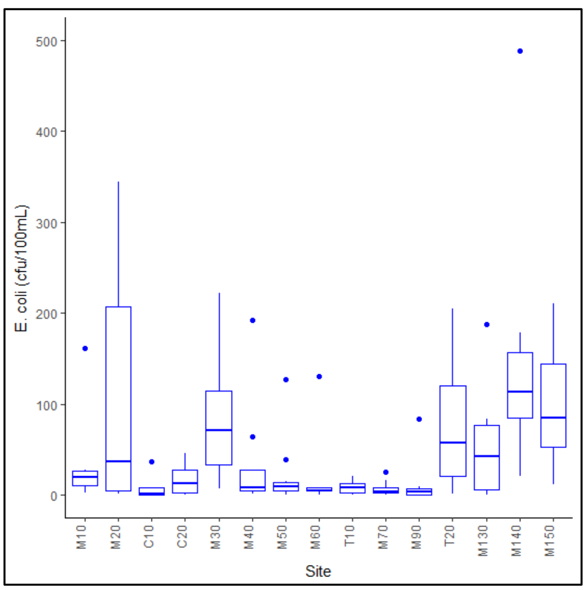


Figure 9. Spatial box plot of *E. coli* levels by site in 2016.

Fish Kill

Generally, parameters showed expected differences between samples taken at the North Fork site above the fish kill (NFBT05) and samples taken from the North Fork downstream site (T10) on 3/9/16. Parameters such as temperature, phosphorus, and nitrogen increased in an intuitive fashion (Figures 10 and 11). Other parameters of interest due to their ability to cause fish mortality such as dissolved copper and dissolved oxygen did not differ substantially between the upstream and downstream sites (Figures 10 and 12). Similarly, most parameters did not exhibit a dramatic temporal trend in the downstream site (T10) with comparable results observed before (February), shortly after (March T10), and a month after (April T10) the fish kill event.

Although pH was slightly elevated near the source of the fish kill when measured on 3/9/16, two days after the fish kill, the large spike in pH measured on the day of the fish kill had dissipated. Note that no increase in pH was reported downstream at the City of Loveland Water Treatment Plant intake during the fish kill.

However, elevated total recoverable aluminum and total recoverable iron concentrations were observed in the data (Figure 12). Although the Big Thompson River does not have a specified standard for aluminum (WQCC 2016b), the general aquatic life standard for aluminum based on hardness (WQCC 2016a) is calculated as:

$$\text{Aluminum standard (acute)} = e^{(1.3695(\text{Ln(Hardness)})+1.8308)}$$

The hardness at site T10 on 3/9/16 was 12.1 mg/L which results in an aquatic life acute standard for total recoverable aluminum of 190 ug/L. This acute standard was exceeded at T10 during the March sampling event.

Similarly, there is no specified aquatic life acute standard for total recoverable iron in the Big Thompson River. However, the chronic aquatic life standard for iron in the Big Thompson River is 1,000 ug/L. This value for the chronic standard was exceeded at T10 during the March sampling event.

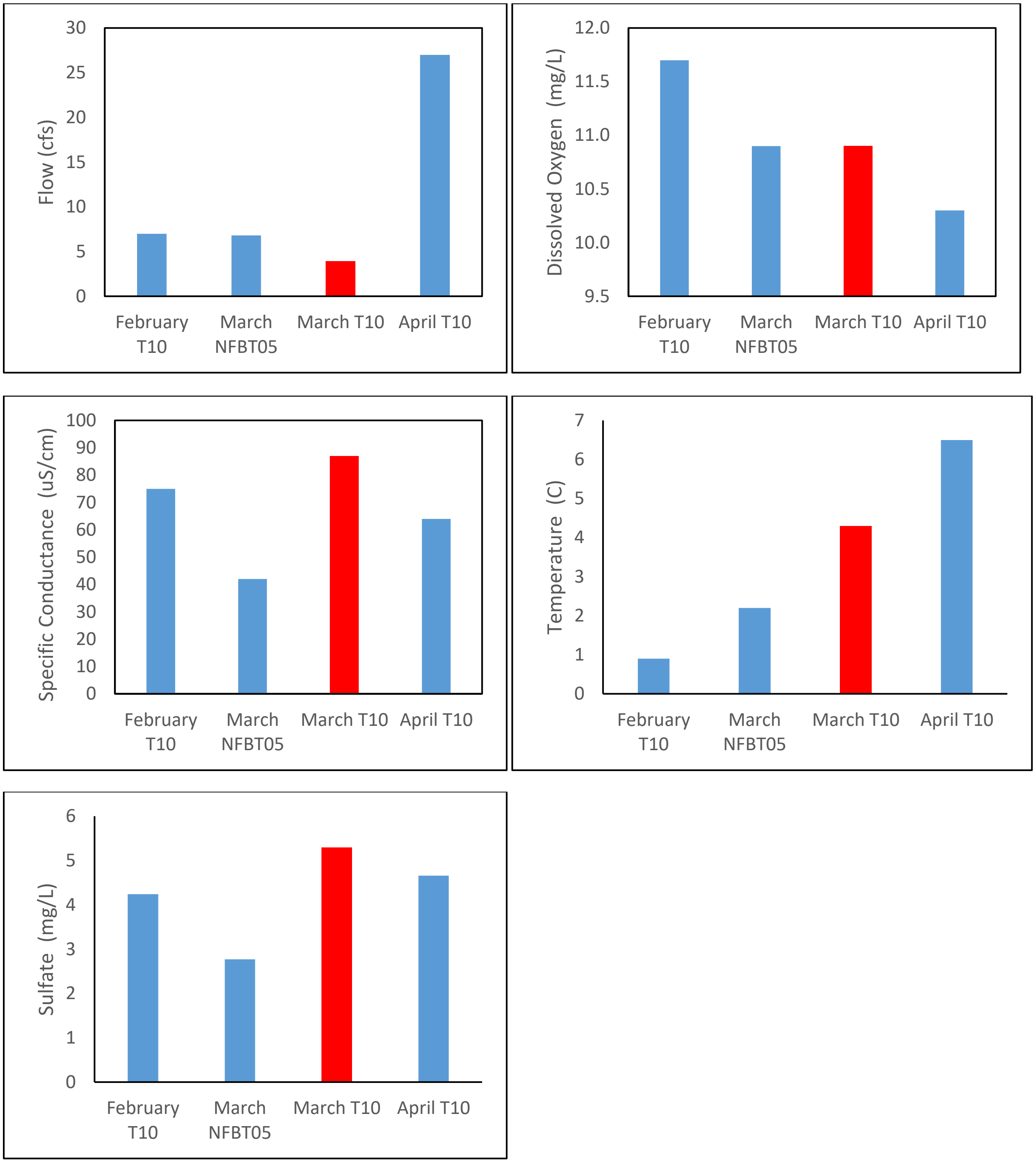


Figure 10. General parameter measurements associated with the Big Thompson River fish kill location. Measurements shown represent locations downstream and prior to the event ("February T10"), upstream and shortly after the event ("March NFBT05"), downstream and shortly after the event ("March T10"; bar shown in red) and downstream approximately one month after the event ("April T10").

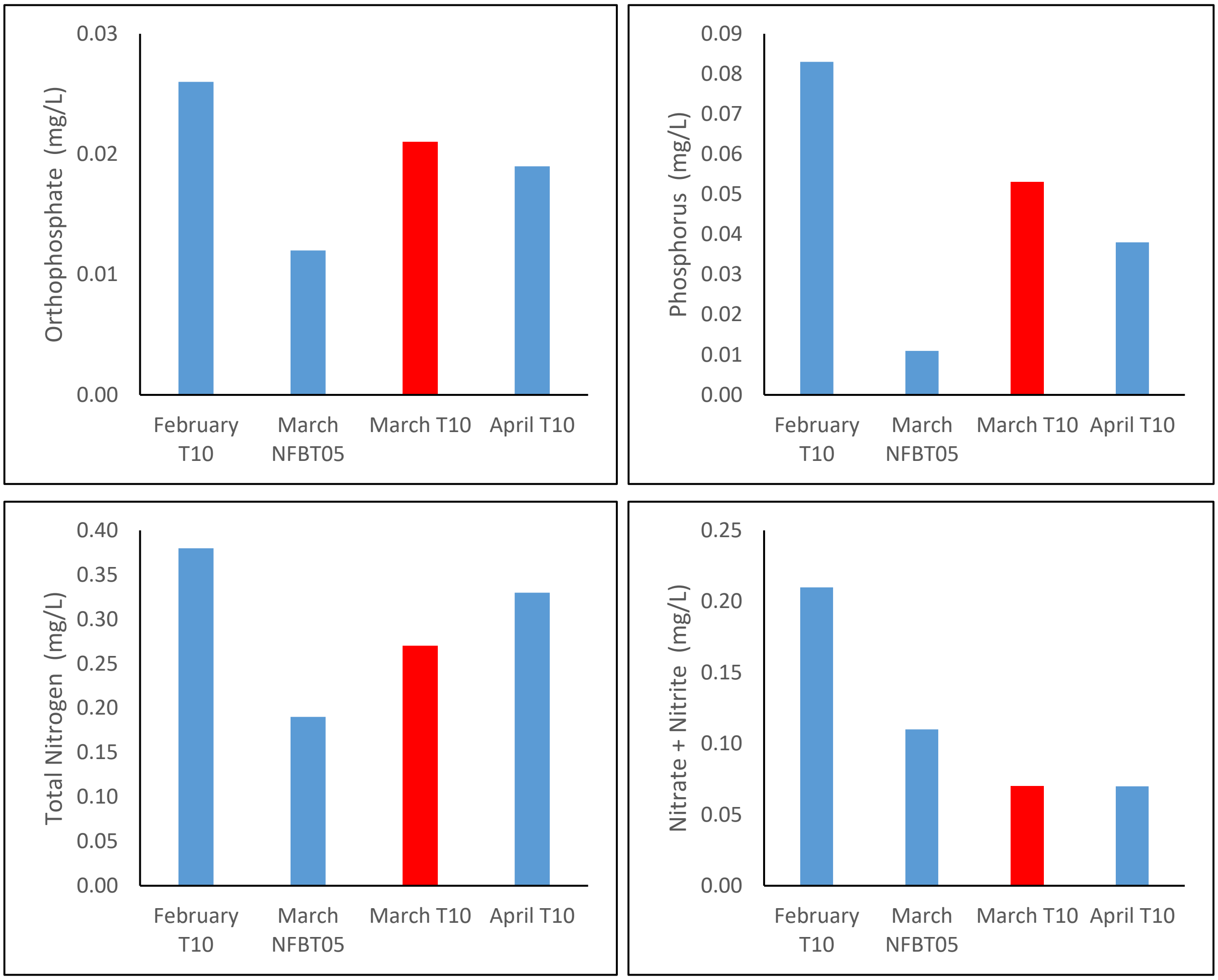


Figure 11. Nutrient parameter measurements associated with the Big Thompson River fish kill location. Measurements shown represent locations downstream and prior to the event ("February T10"), upstream and shortly after the event ("March NFBT05"), downstream and shortly after the event ("March T10"; bar shown in red) and downstream approximately one month after the event ("April T10").

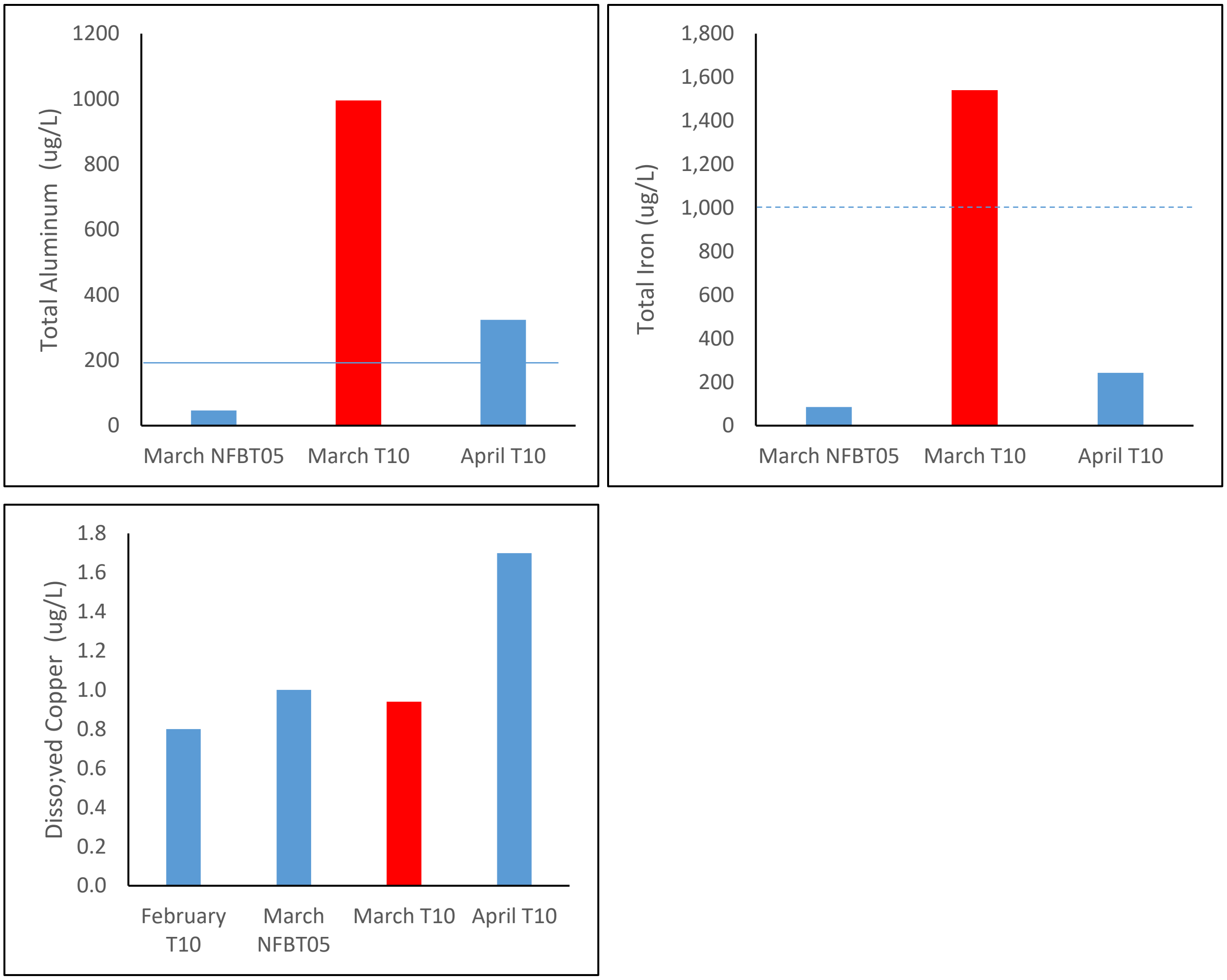


Figure 12. Metal parameter measurements associated with the Big Thompson River fish kill location. Measurements shown represent locations downstream and prior to the event ("February T10"), upstream and shortly after the event ("March NFBT05"), downstream and shortly after the event ("March T10"; bar shown in red) and downstream approximately one month after the event ("April T10"). Dashed line represents chronic water quality standard and solid line represents acute water quality standard where applicable.

Conclusions

In general, 2016 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.

- **Dissolved Oxygen:** Dissolved oxygen levels in 2016 were very close to 2011-2015 median values and there were no instances where measured DO was lower than associated standards (Figure 2).

- **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 2016 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 data (Fayram 2016).

- ***E. coli*:** There were several values above the *E. coli* standard in 2016, primarily in the lower river (Figure 8). However, median values in 2016 were very similar to the medians of the reference time period. Hydros (2015) found elevated levels in the lower portion of the river and suggested that the cause may be related to livestock concentrations. Although *E. coli* levels are still of concern, the relatively low values found in 2016, particularly when compared to higher levels found in 2015, suggest that concentrations are dynamic and caution should be used when evaluating one particular year in isolation.

Conversely, 2016 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 while 2016 air temperatures were somewhat lower, it was still the fifth highest year on record. The warm air temperatures were reflected by the relatively high water temperatures in the middle and lower river (Figure 2). The median water temperature in the lower river in 2016 was approximately 1°C warmer than the median water temperature for 2011-2015.

- **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 continued to be elevated in the lower portion of the river. The 2016 median value for the lower river was higher than the median of the preceding 5-year period (Figure 2).

- **Copper:** Hydros (2015) noted a relatively high incidence of copper being above the water quality standard. While there were certainly a number of elevated concentrations in 2016, the median copper concentration for each river section was 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 relate to pine beetle associated tree mortality and merits further investigation.

- **Selenium:** There were a number of sampling events with elevated selenium in 2016 in the lower portion of the river, which runs through selenium-rich Pierre shale. The median selenium concentration in 2016 was above the five-year median in the lower river (Figure 4). Elevated selenium levels in 2016 are a reversal from 2015 values and may be related to increased infiltration of groundwater, increased land disturbance from construction projects and development, or other factors.

- **Nutrients:** Nutrient concentrations were generally relatively low. Median total nitrogen and nitrate + nitrite levels in 2016 were below the median values 2011-2015 (Figure 6). This finding supports a similar finding by Hydros (2015) and Mast et al. (2014) who suggested that nitrate + nitrite levels have shown significant decreases over time. However, median levels of orthophosphate and total phosphorus were higher in 2016 in the lower river as compared to the 2011-2015 data.

- **Fish Kill**: The fish kill was reportedly caused by a large increase in pH associated with construction activities, specifically concrete and grout, in the North Fork Big Thompson River. However, while sampling two days after the event showed no residual pH issues, aluminum levels were at levels high enough to cause continued fish mortality (Gundersen et al. 2016).

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