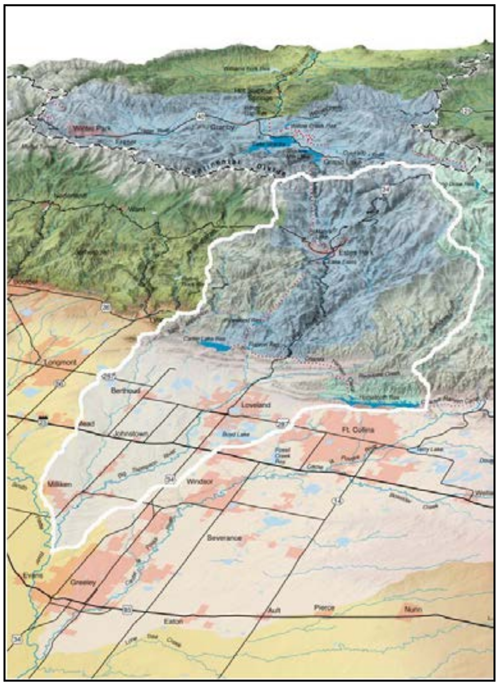
BIG THOMPSON STATE OF THE WATERSHED

2015 Report



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ACRONYMS AND ABBREVIATIONS

AF/yr	Acre-feet per year
ATSDR	Agency for Toxic Substances and Disease Registry
C-BT	Colorado-Big Thompson
CDOT	Colorado Department of Transportation
COOP	Cooperative Sampling Program
CWCB	Colorado Water Conservation Board
DBP	Disinfection By-products
E. Coli	Escherichia Coliform
EPA	U.S. Environmental Protection Agency
IQR	Inter-quartile range
JFA	Joint Funding Agreement
mg/L	Milligrams per liter
ND	Non-detect
NH_3	Ammonia
NO_3	Nitrate
TKN	Total Kjeldahl Nitrogen
TMDL	Total Maximum Daily Load
TOC	Total Organic Carbon
TSS	Total Suspended Solids
ug/L	Micrograms per liter
USGS	U.S. Geological Survey
WQCD	Water Quality Control Division
WWTP	Wastewater Treatment Plant
WY	Water Year

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Cover Photographs:

Top Right: Trees Torching - High Park Wildfire; June, 2012

- Photo from U.S. Department of Agriculture - Flickr: 20120620-FS-UNK- 0009. Licensed under Public Domain via Wikimedia Commons - https://commons.wikimedia.org/wiki/File:Trees_torching_-_High_Park_Wildfire.jpg#/media/File:Trees_torching_-_High_Park_Wildfire.jpg

Bottom Right: September, 2013 Flooding on the Big Thompson River at 1st Street and Taft Avenue in Loveland, CO.

- Photo courtesy of City of Loveland.

EXECUTIVE SUMMARY

This report presents the current State of the Watershed for rivers, streams, and canals in the Big Thompson watershed. The assessment was sponsored by the Big Thompson Watershed Forum (the Forum), a nonprofit stakeholder organization founded in 1997 and dedicated to protecting and improving water quality in the Big Thompson watershed. This report meets the Forum's mission and program goals by summarizing current water-quality conditions, evaluating trends and changes in water quality, comparing Forum data to applicable Colorado water-quality standards, and identifying water-quality impacts from adverse events and watershed perturbations such as wildfires, floods, and the mountain pine beetle epidemic. Findings documented in the report support broader efforts to identify and evaluate strategies for watershed management and water-quality protection in the context of a comprehensive watershed management plan.

ES-1. SITE DESCRIPTION

Colorado's Big Thompson watershed, located approximately 50 miles northwest of Denver, is a large, complex hydrologic system covering more than 900 square miles east of the Continental Divide. The ecosystems, subsurface geology, water uses and routing, population density, and water quality vary widely across the watershed. The watershed also serves as a conduit for Colorado's largest trans-basin water diversion, the Colorado-Big Thompson (C-BT) Project. The C-BT project brings water from the Three Lakes System (Granby Reservoir, Shadow Mountain Reservoir and Grand Lake) to the eastern slope through the Adams Tunnel to provide for evolving municipal and agricultural needs of Colorado's Front Range. Figure ES-1 shows the Big Thompson River watershed (white outline) as well as the Three Lakes System watershed on the west side of the continental divide (dashed blue outline).

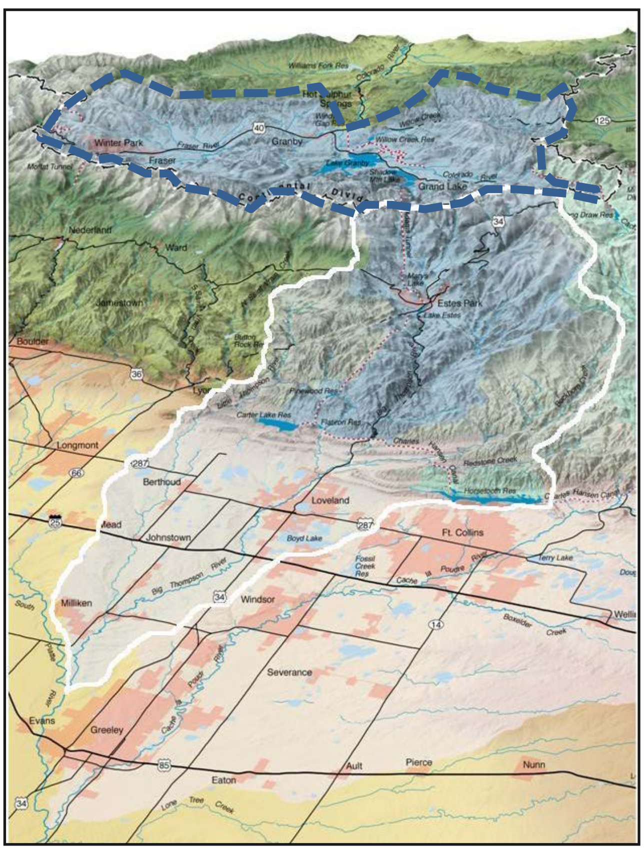

Figure ES 1. Big Thompson Watershed

Flow in much of the Big Thompson River is highly regulated and managed through numerous diversions, returns, and reservoirs. Water quality in the watershed is potentially affected by the spatially-variable subsurface geology, the C-BT project, discharge from wastewater treatment plants (WWTPs), power plants, agriculture activities and diversions, livestock and ranching activities, septic systems, trans-basin exchanges, urban and suburban stormwater runoff, wildfires, the mountain pine beetle epidemic, floods, and droughts. Previous studies identified nutrients (phosphorus and nitrogen) as constituents of concern for the watershed (Buirgy, 2007 and Hydros, 2011). In addition, various segments of the Big Thompson River and its tributaries are on Colorado's 2012 (most recent) 303(d) List[1] of impaired waters. The listed parameters are copper, cadmium, selenium, zinc, dissolved oxygen, Escherichia Coli (*E. Coli*), pH, sulfate, and temperature (WQCD, 2012a). Note that proposed revisions to the 303(d) List are scheduled for consideration by the Colorado Water Quality Control Commission in the upcoming December 2015 rulemaking hearing.

ES-2. DESCRIPTION OF THE ASSESSMENT

This assessment builds on three previous State of the Watershed reports evaluating data from the flowing water sites: Jassby and Goldman (2003), Haby and Loftis (2007), and Hydros (2011). Insights developed in those reports are reevaluated in this assessment, with a larger (greater spatial coverage and longer duration) dataset. Specifically, this report attempts to define the current state of water quality in the Big Thompson River by answering the following questions:

1. **Patterns**: What seasonal and spatial patterns are apparent in the concentrations and loads of water-quality parameters?
2. **Long-Term Trends:** What are the statistically-significant long-term trends in concentrations across the watershed?
3. **Compliance:** How do concentrations compare to applicable Colorado water-quality standards and interim nutrient values (Regulation 38, Water Quality Control Division [WQCD], 2015b).
4. **2013 Flood Effects:** What do the data tell us about short-term and lingering impacts from the September 2013 flood?
5. **Wildfire Effects:** What do the data tell us about short-term and lingering impacts of wildfire, including the 2012 Fern Lake Fire?

[1] The 303(d) List identifies those water bodies where there are exceedances of water-quality standards or non-attainment of uses. This list of impaired waters is generally updated every two years (although the last update in Colorado was in 2012). The list is submitted to EPA by the states under the auspices of the Clean Water Act. The intent is to identify water-quality concerns triggering development of Total Maximum Daily Loads (TMDLs). At this point, TMDLs have not been developed for any segments of the Big Thompson Watershed, and the timing of TMDL development remains uncertain.

Additionally, program recommendations were generated, suggesting minor refinements to data collection to better support the Forum's mission.

The Forum's database for rivers and streams in the Big Thompson watershed from water year (WY)[2] 2000 through WY 2014 provided the water-quality data for this 15-year assessment. The assessment focused on flow rates, select metals, general parameters, nutrients, and microbiological parameters. In total, 27 water-quality parameters were assessed at 31 sampling stations across the watershed. The five canal sites are sampled by Northern Water and the USGS. The remaining stations are currently sampled as part of the Forum's two major water-quality monitoring and assessment programs: (1) the Cooperative Monitoring (COOP) Program and the Volunteer Monitoring (Volunteer) Program (Figure ES-2).

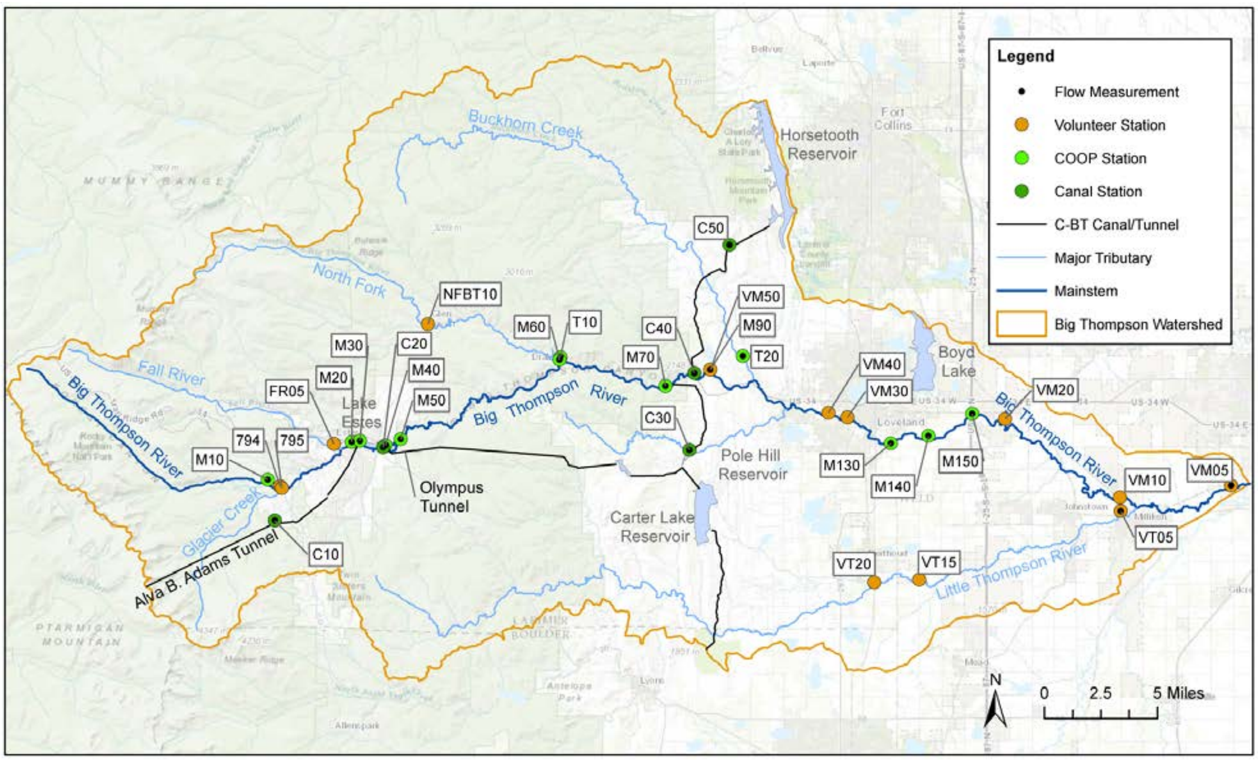

Figure ES 2. Sampling Station Locations

[2] A water year, as defined here, begins in October of the previous calendar year and extends through September (e.g., WY 2000 covers the period from October 1, 1999 through September 30, 2000).

ES-3 SUMMARY OF FINDINGS

Overall, the state of the watershed varies from good in the upper watershed to fair in the lower watershed. Key findings are summarized for each of the major assessment objectives. Patterns, long-term trends, compliance issues and observed fire and flood effects are summarized in the following subsections, followed by program recommendations.

ES-3.1 PATTERNS

Detailed review and analysis of flow and water-quality data from canals, rivers, and tributaries in the Big Thompson watershed reveal some consistent patterns for the upper watershed, lower watershed, C-BT canals, major tributaries, and below WWTPs:

Upper Watershed: The upper watershed is generally characterized by good water quality. This reflects the igneous and metamorphic rock of the subsurface geology, low populations, and natural runoff patterns (dominated by the annual snowmelt runoff hydrograph). Concentrations of dissolved solids (as represented by specific conductivity; Figure ES-3), metals, nutrients, chlorophyll *a*, total organic carbon (TOC), total suspended solids (TSS), and coliforms all tend to be low, especially relative to the lower watershed.

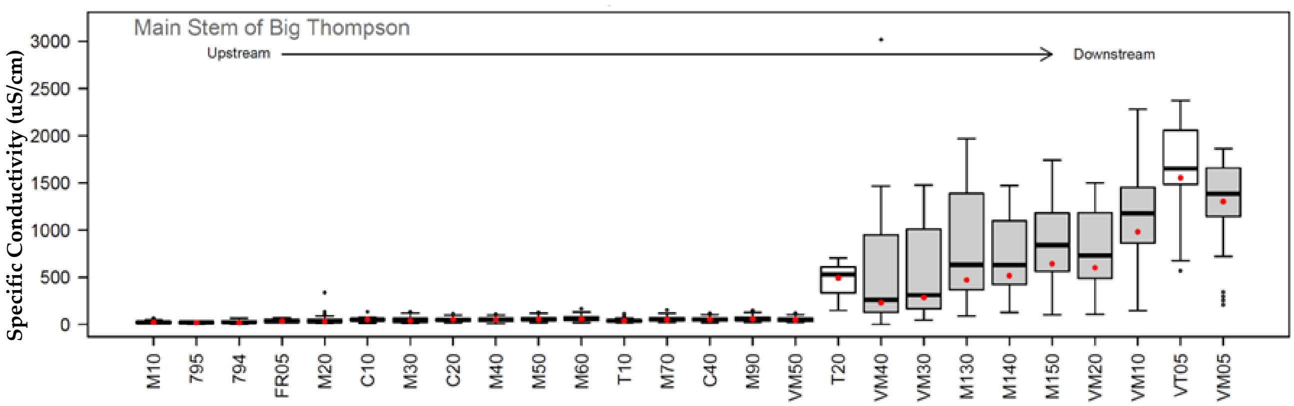

Figure ES-3. Box Plot of Specific Conductivity (uS/cm) in the Big Thompson River, WY2000-WY2014

Grey-shaded boxes indicate mainstem locations. Unshaded boxes indicate inflows. Red dots indicate the median for the recent 5 years of record (WY2010-WY2014).

Lower Watershed: The water quality in the lower watershed is generally fair. It is characterized by higher populations, urban development, agriculture and livestock, more WWTP effluent, more alluvial groundwater, and sedimentary subsurface geology, including Pierre shale. The lower watershed exhibits lower annual flow rates, with a sharp decrease between M90 and M130 due to the City of Loveland drinking water treatment plant intake and numerous ditch diversions. Snowmelt runoff signals are minimized in the lower watershed, and the greater percent of impervious surface area is apparent in the somewhat "flashy" response of flow rates to precipitation. Relative to the upper watershed, the lower watershed exhibits notably higher concentrations of dissolved solids, nutrients, chlorophyll *a*, TOC, suspended solids, and coliforms. Selenium is also consistently higher in the lower watershed due to the underlying Pierre shale (Figure ES-4).

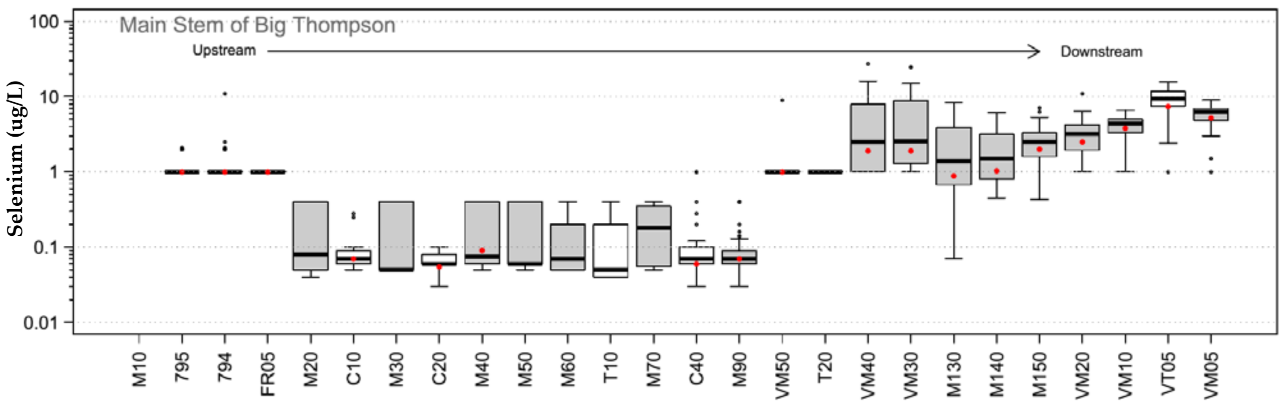

Figure ES-4. Box Plot of Dissolved Selenium (μg/L) in the Big Thompson River, WY2000-WY2014

Grey-shaded boxes indicate mainstem locations. Unshaded boxes indicate inflows. Red dots indicate median for recent 5 years of record (WY2010-WY2014).

<u>C-BT Canals:</u> Water quality in the C-BT canals is good and reflects the conditions in Grand Lake on the west side of the continental divide. Average annual volumes of water delivered from the Adams Tunnel into the Big Thompson watershed are much greater than natural runoff volumes (Figure ES-5). These flows do not follow consistent seasonal patterns. Water quality in the canals is comparable to that of the upper-most Big Thompson watershed, with low nutrients, metals, suspended solids. Differences include lower coliforms, orthophosphate and nitrate and slightly higher chlorophyll *a,* TOC, and dissolved solids (specific conductivity, alkalinity, and hardness) from the Adams Tunnel.

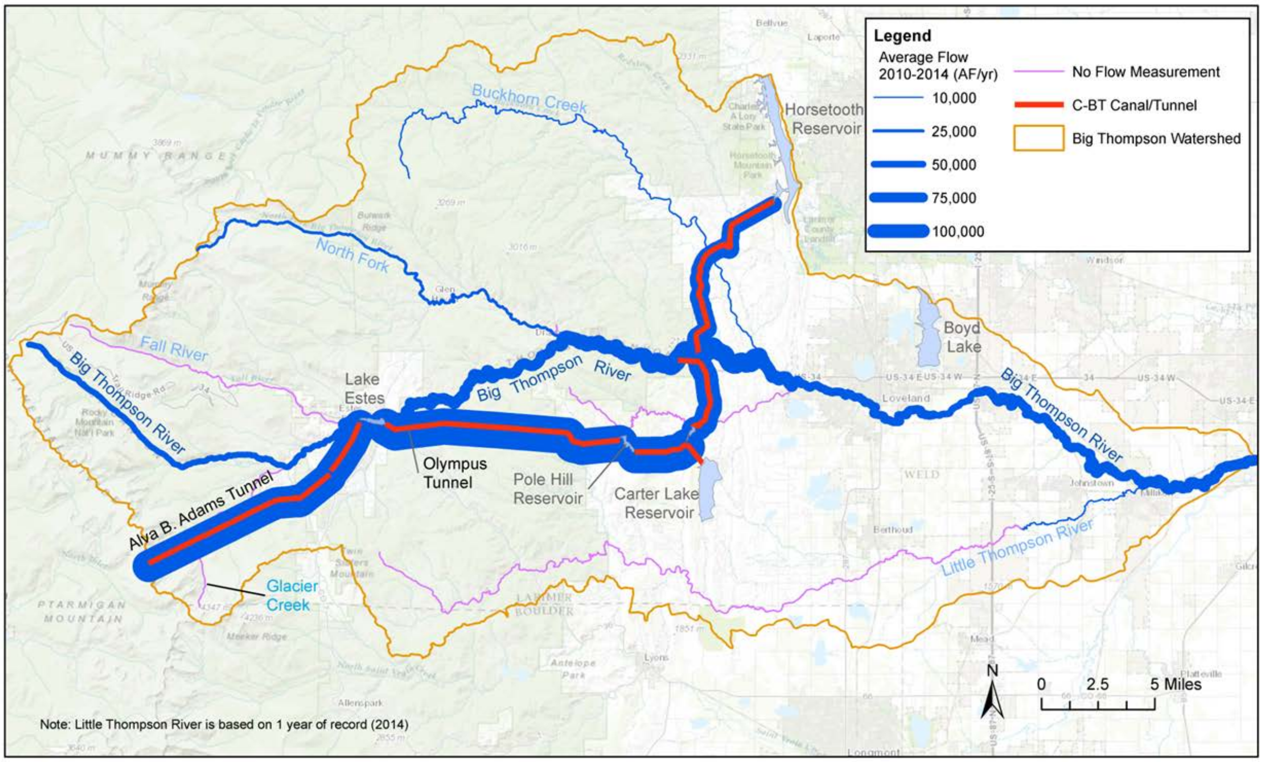

Figure ES-5. Diagram of Average Annual Flows in the Big Thompson Watershed, WY2010-WY2014

Major Tributaries: Major tributaries with sampling data in the Big Thompson watershed include Glacier Creek, Fall River, the North Fork, Buckhorn Creek, and the Little Thompson River (Figure ES-2).

- ***Glacier Creek, Fall River, and the North Fork*** drain fairly pristine high-mountain granitic watershed. As such, the water quality from these tributaries tends to be good and similar to that of the upper watershed on the mainstem of the Big Thompson River.
- ***Buckhorn Creek*** also exhibits low nutrients, TOC, and chlorophyll *a*; however, measures of dissolved solids are more similar to lower watershed conditions. Specifically, Buckhorn Creek has high alkalinity, hardness, specific conductivity and sulfate. This is indicative of the change in subsurface geology from the granitic rock of the upper watershed to sedimentary rock. Additionally, there are several quarries in the Buckhorn Creek watershed.
- ***The Little Thompson River*** exhibits water quality similar to that observed on the mainstem of the Big Thompson in the lower watershed. This includes elevated concentrations of TOC, chlorophyll *a*, sulfate, and coliforms. Ammonia, nitrate, dissolved solids, and selenium concentrations are also elevated in the Little Thompson River and tend to be greater than those in the lower Big Thompson. Phosphorus

concentrations tend to be lower in the lower Big Thompson as compared to the Lower Big Thompson River.

Below WWTPs: WWTPs serve an important function in the watershed, treating wastewater and returning it to the river. For many rivers, including the Big Thompson, WWTPs represent major point sources for loading of nutrients, organic matter, and sometimes metals. In the Big Thompson watershed, total nitrogen and total phosphorus concentrations increase at stations below each of the major WWTP in the watershed: M30 (below the Estes Park Sanitation District effluent), M50 (below the Upper Thompson Sanitation District effluent), significantly at M140 (below the Loveland WWTP effluent), and at VT15 (below the Berthoud WWTP). These increases below WWTPs largely reflect loading of nitrate and orthophosphate, which are forms of nutrients that are readily available for algae and plant growth. Loadings for nitrogen and phosphorus are anticipated to decrease as wastewater treatment plants comply with Colorado Regulation 85 and 38 state standards. In addition, WWTPs in the South Platte Basin received compliance schedules for implementation over the next five years. Improvements are expected to be completed by the spring of 2020.

ES-3.2 LONG-TERM TRENDS

Testing of the 15-year record for statistically-significant trends revealed two key findings:

Increasing TOC in canals and the upper watershed: Statistically-significant trends of increasing TOC concentrations were found in the C-BT canal system (C10, as shown in Figure ES-6 , C20, C30, C40 and C50) as well as in much of the Big Thompson upper watershed mainstem (M20 to M130). This finding is in agreement with findings from previous State of the Watershed reports (Hydros, 2011), but it includes more stations. The magnitude of this increasing trend ranges from 0.02 to 0.09 mg/L of TOC per year. This finding of increasing TOC is important because it can directly affect drinking water treatment costs, operations, and regulatory compliance. These increasing trends include the reach from which the City of Loveland diverts water for drinking water treatment, as wells as inflows to major C-BT reservoirs including Horsetooth. Further trend testing suggests that the increasing trend may have recently begun to plateau. The cause of this increasing trend in TOC concentrations in water from the west and east slopes is hypothesized to be the large-scale tree death from the ongoing mountain pine beetle epidemic. This finding agrees with recently published research from Colorado (Mikkelson et al., 2013).

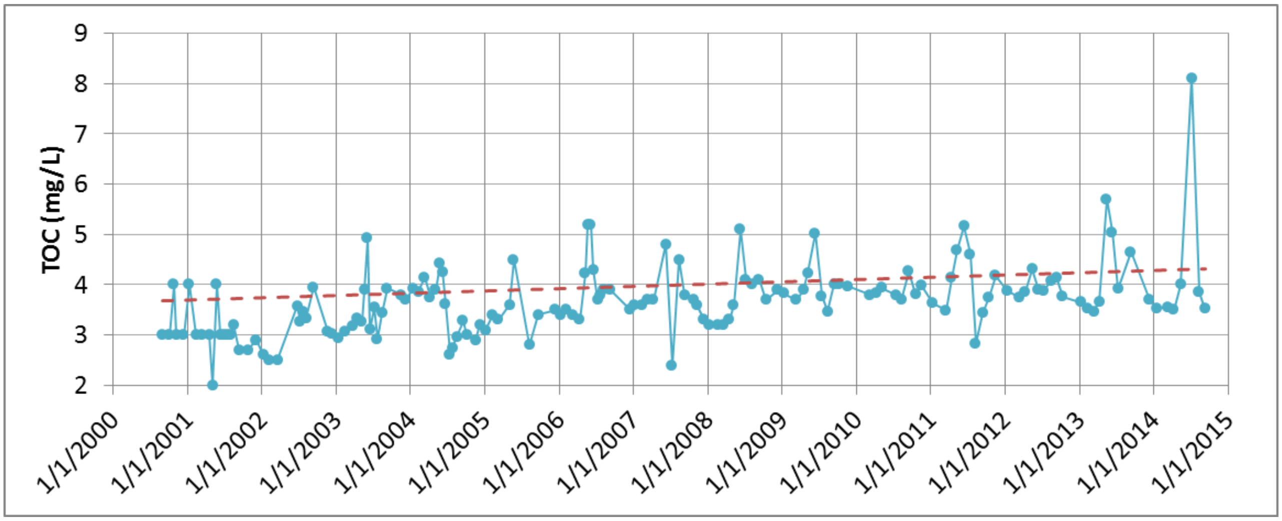

Figure ES-6. TOC Concentrations (mg/L) at C10 (Trend slope shown as red dotted line.)

Decreasing nitrate in the upper watershed: In the upper-most portions of the watershed (M10, 794, M20, and M30), statistically-significant long-term trends of decreasing nitrate concentrations were found. Over the 15-year period, the trend corresponds to a decrease of 25 to 55% of the median concentration. This finding agrees with recently published findings of a long-term study in the Colorado Front Range (Mast et al., 2014). That study found that nitrate concentrations in streams in Rocky Mountain National Park increased in the 1990's but have been decreasing since the early 2000s, coincident with a decline in atmospheric concentrations of nitrogen oxides. The decrease is attributed to U.S. Environmental Protection Agency (EPA)-mandated regulatory limits placed on emissions. Interestingly, there is also a statistically-significant long-term trend of decreasing lead concentrations across the watershed that may relate to long-term reductions in atmospheric emissions and subsequent deposition.

ES-3.3 COMPLIANCE

Comparison of the Forum's water-quality dataset to relevant standards produced a few noteworthy findings:

Acute and chronic copper exceedances at the top of the watershed and at M90: There is a high frequency of copper standard exceedances (61% for chronic and 41% for acute) in the most upstream station in the watershed (M10). The low hardness values at this station results in very low copper water-quality standards. However, moving downstream the increase in hardness rapidly decreases the fraction of samples above the standards, reaching 11% chronic and 6% acute exceedances by station M20. There is also a relatively high frequency of chronic copper standard exceedances (22%) at M90. The City of Loveland occasionally uses copper sulfate for algal biomass control in Green Ridge Glade Reservoir (near site M90), which can discharge augmentation water back to the Big Thompson River.

<u>Lower watershed exceeds chronic standard for selenium:</u> The lower watershed, including the Little Thompson River, exhibits relatively high frequencies of exceedance of the chronic selenium standard. This reflects the effects of the selenium-rich Pierre shale in this area.

<u>Frequent exceedances of *E. Coli* in the lower watershed and Little Thompson River:</u> *E. Coli* exceedances are infrequent in the upper reaches and in the central mainstem of the Big Thompson River. In the lower watershed, however, beginning with T20 (Buckhorn Creek), the frequency of exceedances generally increases downstream (Figure ES-7). The most frequent exceedances (>60%) are observed on the Little Thompson River (VT20, VT15, and VT05). This may reflect livestock sources of bacteria in this reach.

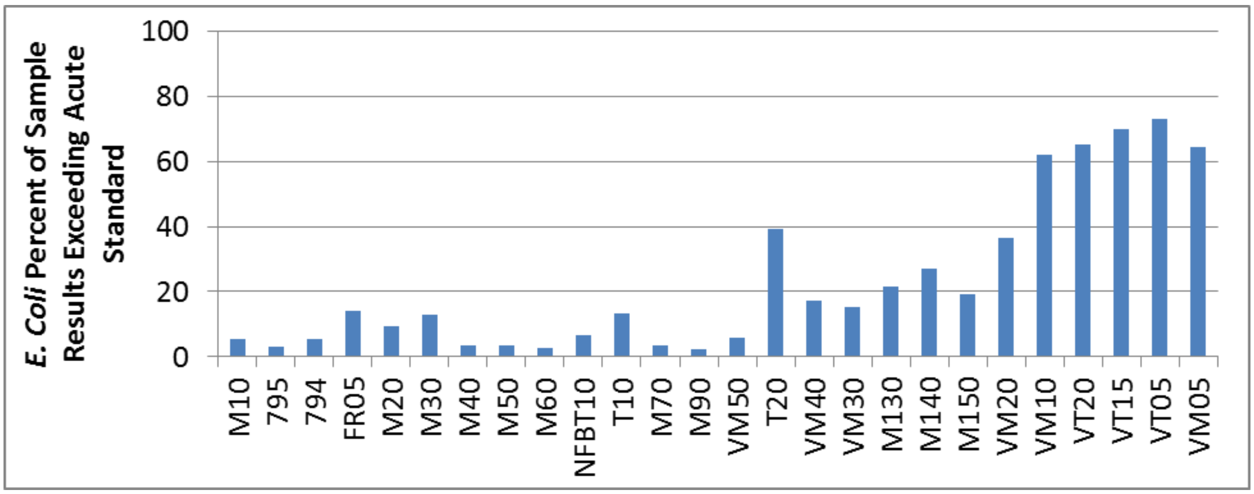

Figure ES-7. Summary of Data Comparison to *E. Coli* Standards, 2000-2014

<u>Recently-updated sulfate standards indicate issues at M130 and on the lower Little Thompson River:</u> Recently adopted standards, effective December 31, 2015 (WQCD, 2015c), apply water supply standards to segments 4b and 9. As a result, exceedance of sulfate standards are anticipated in these reaches most years, based on existing data.

<u>The Forum's dataset does not support 2012 303(d) listings of cadmium, copper, and zinc:</u> Based on review of the Forum's dataset, the basis for 303(d)-listing of copper for the lower Little Thompson River is uncertain. Likewise, the Forum's dataset does not support 303(d)-listing of cadmium and zinc in much of the upper watershed. This agrees with the currently-proposed changes to the 303(d) listings for cadmium and zinc, as of August 2015. It is also expected that the lower Little Thompson River will be de-listed for copper for the 2016 303(d) List, again consistent with the findings of this review (Billica, 2015, personal communication). The final revised listings, however, will not be set until after the December, 2015 hearing (WQCD, 2015c).

<u>Interim Nutrient Criteria review suggests possible future challenges:</u> The interim numeric criteria for total nitrogen and total phosphorus indicate potential future areas of concern at the downstream end of the watershed. High frequencies of years exceeding the nutrient criteria (>50%) begin at M140 below the Loveland WWTP outfall on the Big Thompson River and VT15 below the Berthoud WWTP on the Little Thompson River (Figure ES-8). The data used in this comparison (WT2000-WY2014) were not collected at a time when nutrient standards were effective for the Big Thompson. Total phosphorus standards were adopted for some stream segments within the Big Thompson River watershed (1, 2, 6, 7, 8, 9, and 10) on August 10, 2015 (effective December 31, 2015), but total nitrogen standards have not yet been adopted for any segment (WQCD, 2015b). Based on the Forum database, total phosphorus is expected to be a concern on the Little Thompson River and at the downstream end of the Big Thompson when these standards become effective in 2016. However, implementation of Regulation 85 should result in future phosphorus and nitrogen reductions in effluent from WWTPs within the watershed.

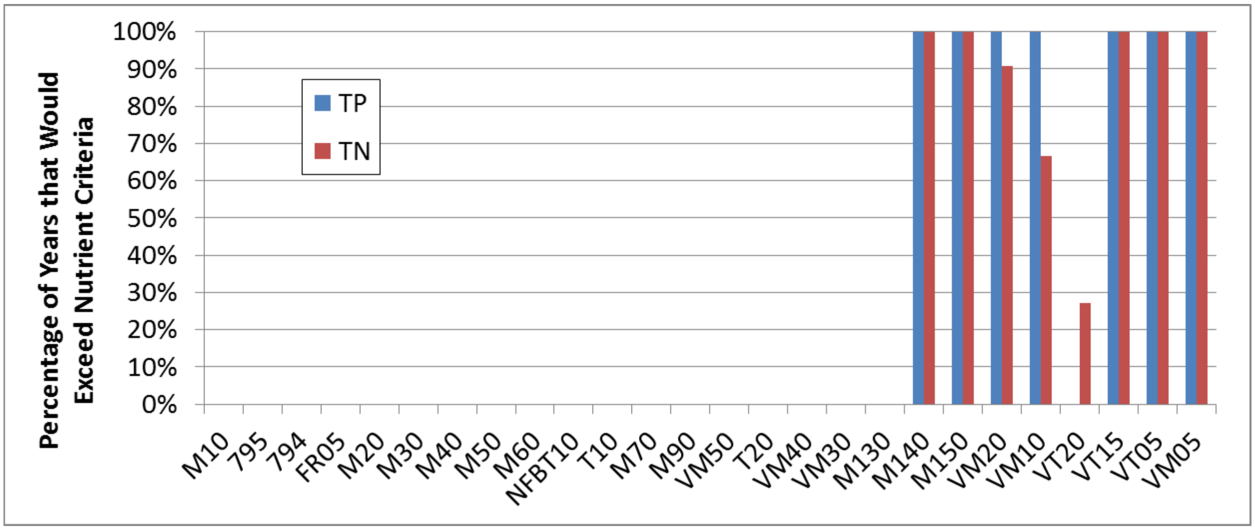

Figure ES-8. Summary of Data Comparison to Interim Nutrient Criteria, 2000-2014

ES-3.4 Fire Effects

There were four major wildfires entirely or partially within the Big Thompson watershed in recent years (Figure ES-9):

- **Cow Creek Fire:** June 2010,
- **Crystal Fire:** April 2011,
- **High Park Fire:** June 2012, and
- **Fern Lake Fire:** October 2012.

Water-quality data collected downstream of these locations indicate some water-quality effects for some of the fires (High Park and Fern Lake), including increased specific conductivity, nitrate, TOC, TKN, total phosphorus, and sulfate (varying for the different fires). However, the measured effects were generally short-lived and not significant enough to impact aquatic life and drinking water supplies (Billica, 2014). Data also indicate that the spatial extent of downstream water-quality effects was limited. Fires in the future, however, could have greater adverse water-quality impacts, depending on their location, extent, and severity.

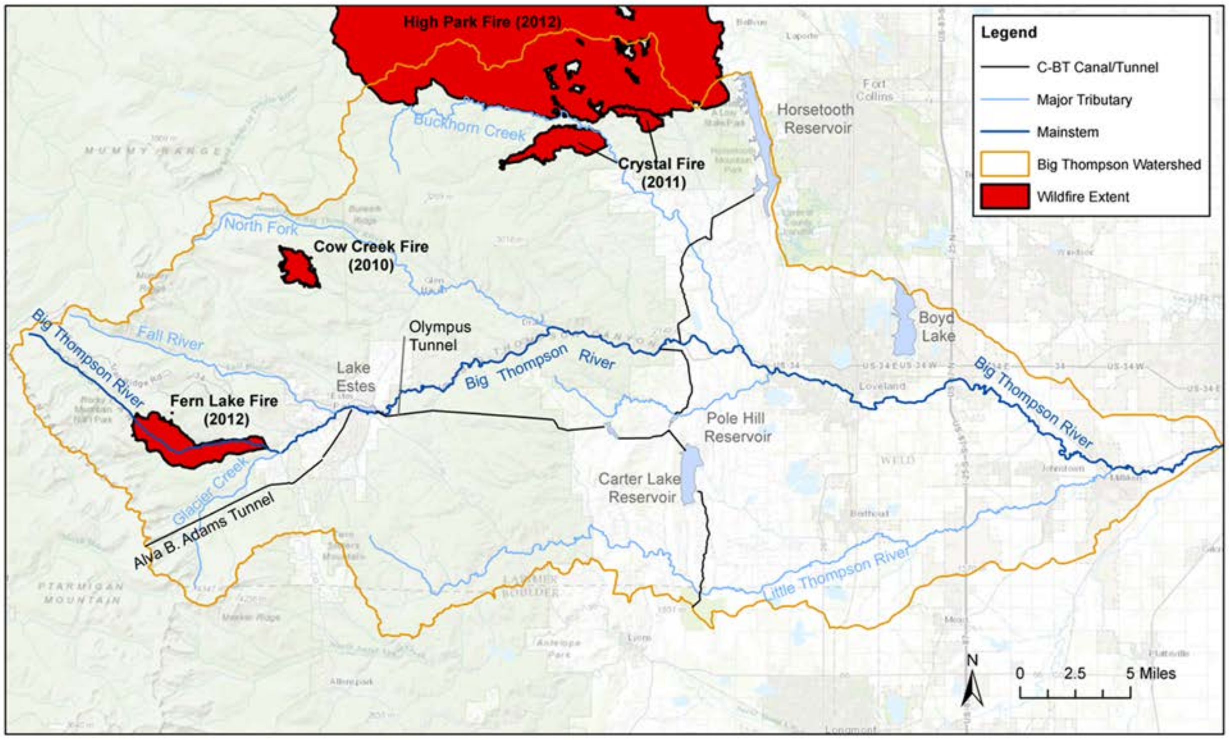

Figure ES-9. Location and Burn Extent of Recent Fires in the Big Thompson Watershed

ES-3.5 Flood Effects

In September 2013, a week of record-breaking rainfall resulted in extensive flooding along the Front Range. Rainfall amounts over a seven-day period exceeded 15 inches near Estes Park. The Colorado Water Conservation Board [CWCB] estimated the flood to have been a 100- to more than 500-year flood in the Big Thompson and Little Thompson Rivers (CH2MHill, 2014, Jacobs, 2014, and Jacobs, 2015). Damage from flash flooding and debris flows was extensive (Figure ES-10).

Figure ES-10. September, 2013 Flooding on the Big Thompson River
(Left: Fun City in Estes Park [Photo from Twitter by @TWCBreaking]; Right: 1st Street and Taft Avenue in Loveland, CO [Photo Courtesy of the City of Loveland])

There was no in-river sampling during the 2013 flooding event due to safety and access issues. However, some samples were collected in the C-BT canals during the flood event. Overall, there were no major or persistent adverse water-quality effects of the flood observed in the Forum dataset, though there have been reports of periodic high turbidity continuing into 2015 (Shelley, 2015b, personal communication). Such high turbidity may reflect resuspension of material moved into riverbeds during the flooding or resuspension during in-river, post-flood repair activities with heavy machinery. Such events could easily be missed by the pre-scheduled Forum data collection.

Observed effects differed in the lower watershed compared to the upper watershed:

- C-BT canal locations downstream of Lake Estes exhibited short-lived increases in nutrients, TSS, TOC, sulfate, and possibly some metals, during and immediately following the flood. This largely reflected east-slope watershed runoff into Lake Estes, as opposed to west-slope water quality from the Adams Tunnel. Pumping of west slope water through the Adams Tunnel was stopped on September 11, 20113 and restarted in late November 2013.
- In the upper watershed, where concentrations tend to be low, increased TSS, turbidity, dissolved solids, and in some cases total phosphorus, total nitrogen, and nitrate were observed after the flood. These increases in the upper watershed reflect leaching from shallow soils and mobilization of solids available for transport following the high flood flows. In the upper watershed, Forum data suggest that concentrations had largely returned to typical levels by the end of WY2014. However, periodic elevated turbidity has been reported outside of this dataset into 2015, particularly during storm events and in response to post-flood recovery work in the river (Shelley, 2015b, personal communication).

- In the lower watershed, downstream of M130/M140, increased baseflow appears to have resulted in decreased concentrations of hardness, specific conductivity, nitrate, orthophosphate, and sulfate. These decreases were particularly evident in winter months. The decreased concentrations reflect dilution from greater groundwater inflow (and groundwater from different areas) in these reaches where typical concentrations tend to be relatively high. These effects have persisted into 2014 but are expected to diminish as groundwater levels return to normal. Elevated suspended solids and turbidity have also been reported outside of this dataset into 2015, particularly during storm events or in response to post-flood recovery work in the river (Shelley, 2015b, personal communication).

ES-4. PROGRAM RECOMMENDATIONS

Overall, the Forum monitoring program is well-conceived and well-managed, generating a very useful dataset to support evaluation of water quality across the watershed. Through the process of developing this report, recommendations for program improvements were generated for consideration by the Forum:

- Lower the Volunteer program detection limits for metals to match those of the COOP program. The most critical parameters and locations for this proposed change are copper at VM50, NFBT10, FR05, and 794, and cadmium at 794.
- Reduce frequency of Volunteer sampling at nearly-collocated COOP stations (VM50 and 795).
- Add TSS sampling back to Volunteer and COOP programs, at least for a subset of locations.
- Develop an event-response sampling plan to increase chances of safely capturing some samples during or shortly after major events like fires or floods.
- Add continuous temperature monitoring or locate other sources of continuous stream temperature data. Note: The City of Loveland is installing continuous temperature monitoring upstream of its WWTP to meet compliance requirements by September 30, 2016. All major WWTPs have this monitoring requirement in most recent permits.
- Add a sampling station upstream of the Culver Ditch Diversion on the Little Thompson River to evaluate the upper Little Thompson River.

1 INTRODUCTION

This report, sponsored and supported by the Big Thompson Watershed Forum (the Forum), presents and assesses water-quality data collected at flowing water sites in the Big Thompson watershed. The report considers data from the 15 year period between water year (WY)[3] 2000 and WY 2014. The flowing water sites comprise rivers, streams, and canals. Water-quality data from the lakes and reservoirs within the Big Thompson watershed are not evaluated in this report.

The Forum is a nonprofit stakeholder organization founded in 1997 with an ongoing collaboration of participants from the community, the private sector, non-governmental groups, and government agencies. The mission of the Forum is to protect and improve water quality in the Big Thompson River Watershed through collaborative monitoring, assessment, education, and restoration projects. The work presented in this report was developed under the guidance and review of the Forum's Science and Monitoring Committee. The assessment and analyses presented here directly support the mission and program goals of the Forum as well as broader efforts to identify and evaluate strategies for watershed management and water-quality protection.

The following subsections provide a description of the watershed, notes of major recent events that could affect water quality, and the objectives and organization of the report.

1.1 WATERSHED DESCRIPTION

1.1.1 Setting

Colorado's Big Thompson watershed, located approximately 50 miles northwest of Denver, Colorado, is a large, complex hydrologic system covering more than 900 square miles east of the Continental Divide (Figure 1). Water that flows through the watershed serves more than 800,000 people, providing residential, industrial, commercial, agricultural, recreational, and wildlife habitat benefits. The ecosystems, water uses, population density, and water quality vary widely across the watershed.

The natural headwaters for the Big Thompson River originate in Rocky Mountain National Park, with a maximum elevation of 14,259 ft. The river empties into the South Platte River

[3] A water year begins in October of the previous calendar year and extends through September (e.g., WY 2000 covers the period from October 1, 1999 through September 30, 2000).

on the eastern plains at an elevation of 4,670 ft. The watershed can be broadly divided into of upper and lower sub-watersheds (Figure 2). The upper watershed includes the upper Big Thompson, Fall River, upper Little Thompson River, and the North Fork sub-watersheds. The upper Big Thompson sub-watershed contains the Adam's Tunnel outfall, the Town of Estes Park, Lake Estes, and the upper end of the Olympus Tunnel. The lower Big Thompson sub-watershed includes the cities of Loveland, Berthoud, Johnstown, and Milliken and is comprised of the lower Big Thompson, lower Little Thompson, Buckhorn Creek, and Horsetooth Reservoir watersheds.

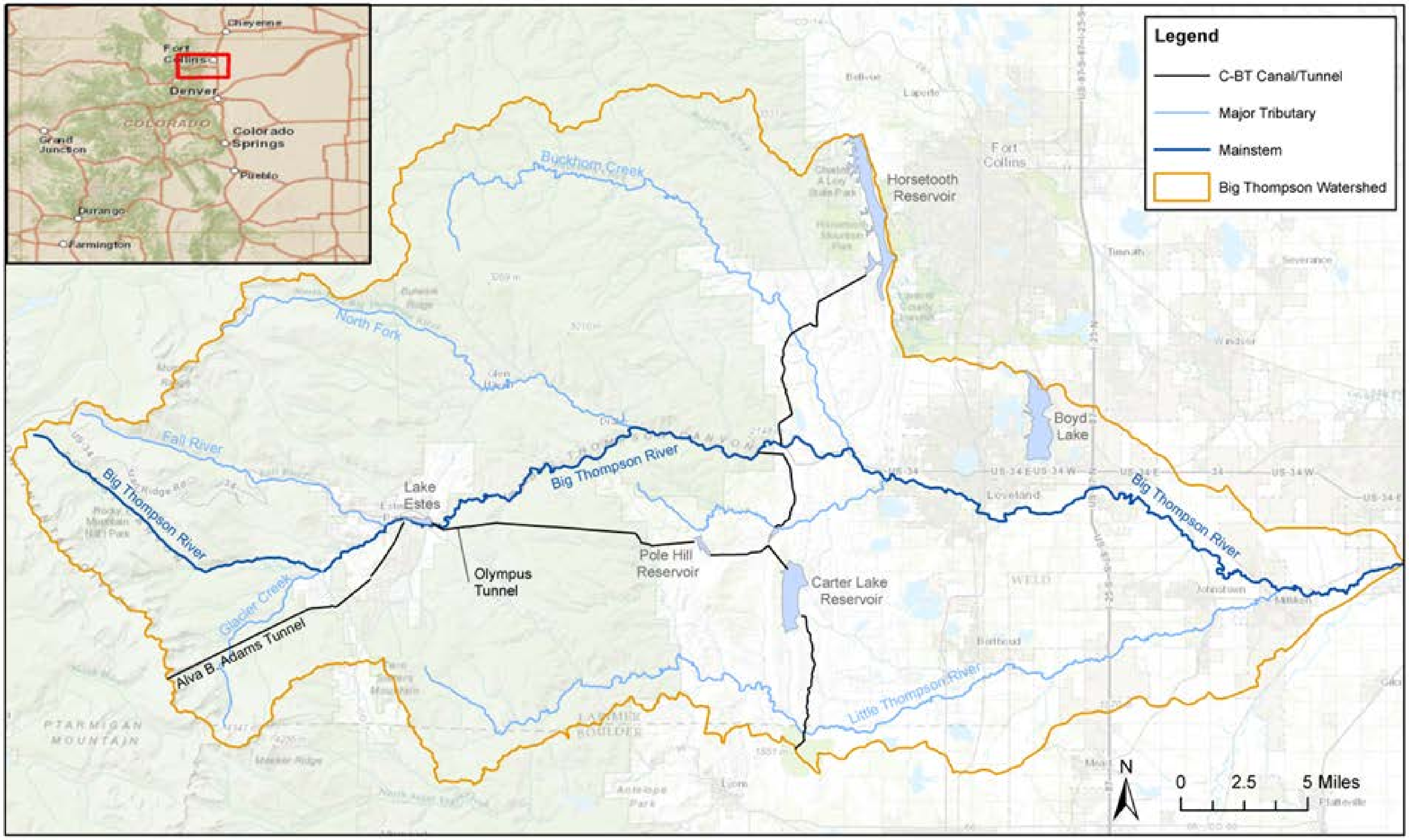

Figure 1. Location of the Big Thompson Watershed

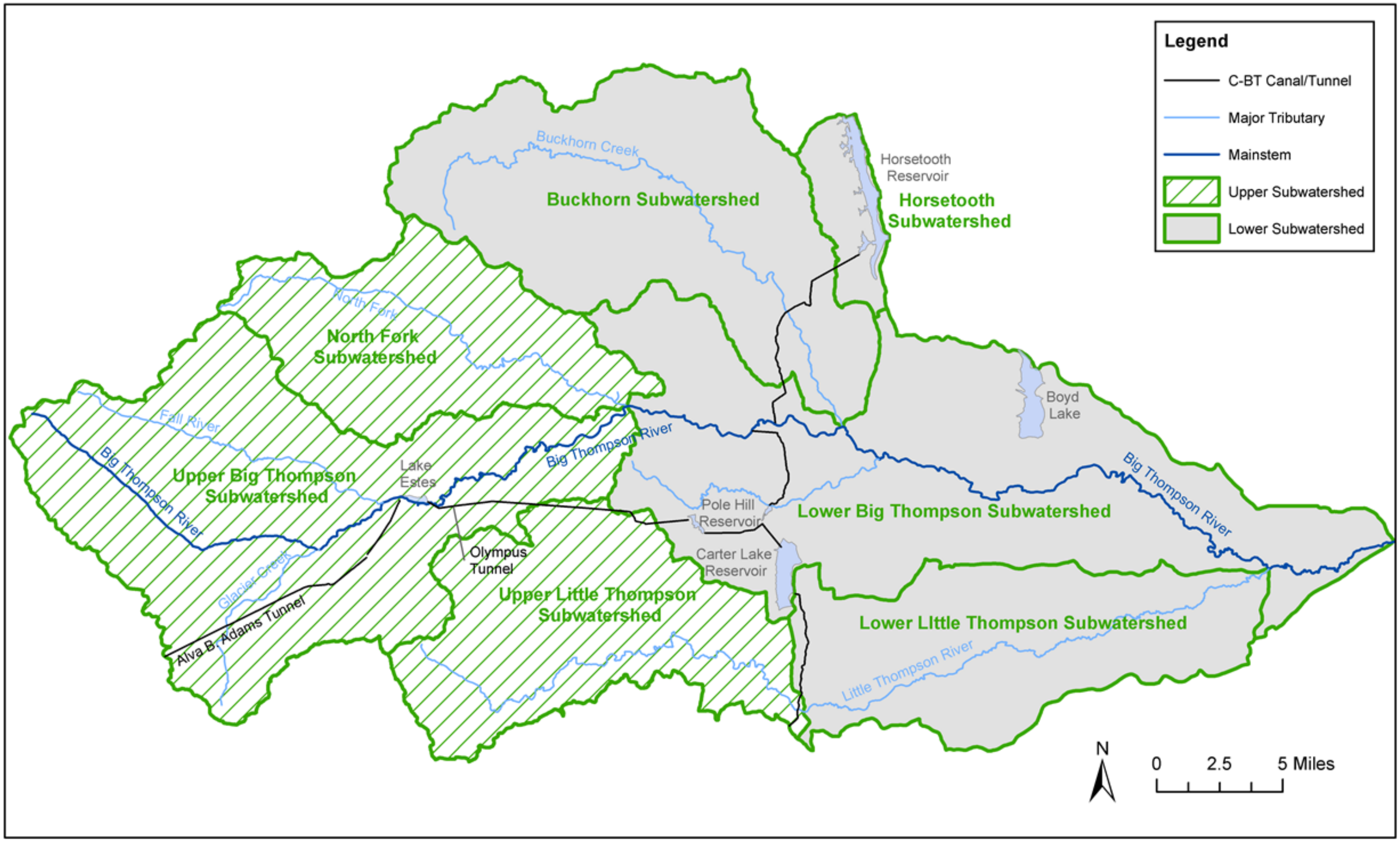

Figure 2. Big Thompson River Sub-Watersheds

1.1.2 Colorado Big Thompson Project

The Big Thompson Watershed serves as a conduit for Colorado's largest trans-basin water diversion, the Colorado-Big Thompson (C-BT) Project. The C-BT system brings water from the headwaters of the upper Colorado River on the western slope of the continental divide to the eastern slope via the Adam's Tunnel (Figure 1). C-BT water enters the Big Thompson mainstem at Lake Estes. At this location, C-BT water contributes more than twice as much water on an annual average basis as the natural watershed above Lake Estes. The largest average annual flow volumes in the Big Thompson Watershed are in the canal and tunnel structures of the C-BT Project (Figure 3).

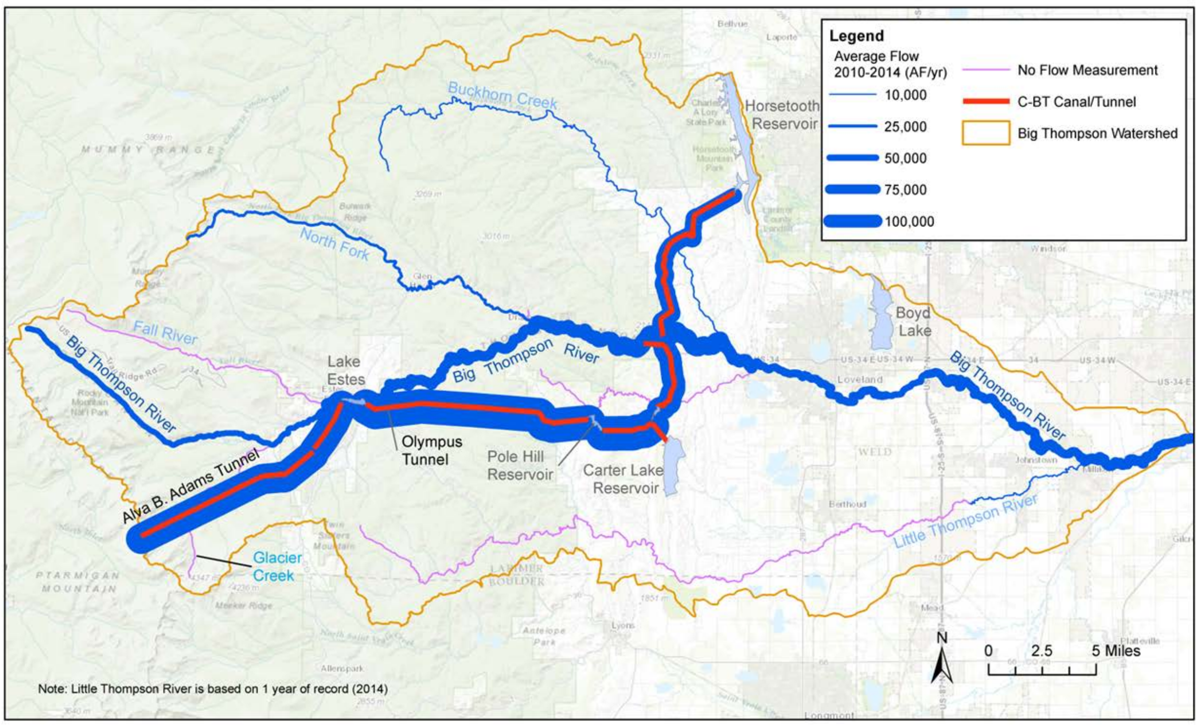

Figure 3. Aortic Diagram of Flows in the Big Thompson Watershed (Annual Average 2010-2014)

From Lake Estes, a portion of the mixed C-BT and upper Big Thompson watershed waters are diverted into a system of tunnels and canals for delivery to downstream, off-channel reservoirs. Below Lake Estes, the Big Thompson River steadily gains flow from tributaries until the canyon mouth. Near the canyon mouth, water can again be diverted from the Big Thompson River into the C-BT system. Below the canyon mouth, populations increase and flows are diminished by diversions. Continuing downstream, as the Big Thompson traverses the plains to the confluence with the South Platte River, flows are highly variable due to numerous irrigation and municipal diversions and returns.

The complexity of water management on the Big Thompson is exemplified by the "trifurcation" structure (Figure 4), located near the canyon mouth. Water diverted through the Dille Tunnel serves three purposes:

1) Supply the City of Loveland with their decree water from the Big Thompson River, which they then take out of the Loveland Turnout further down on the Hansen Feeder Canal;
2) "Skim" water and pass it through the Big Thompson Power Plant to generate electricity; and,
3) Divert water associated with C-BT water rights in the Big Thompson River during wetter years when the water right comes in priority.

Skim water is returned to the river at the trifurcation structure at the junction of the Charles Hansen Feeder Canal and Big Thompson Canyon. Figure 4 presents a simplified diagram of the trifurcation structure (for clarity, numerous unrelated diversions are not shown).

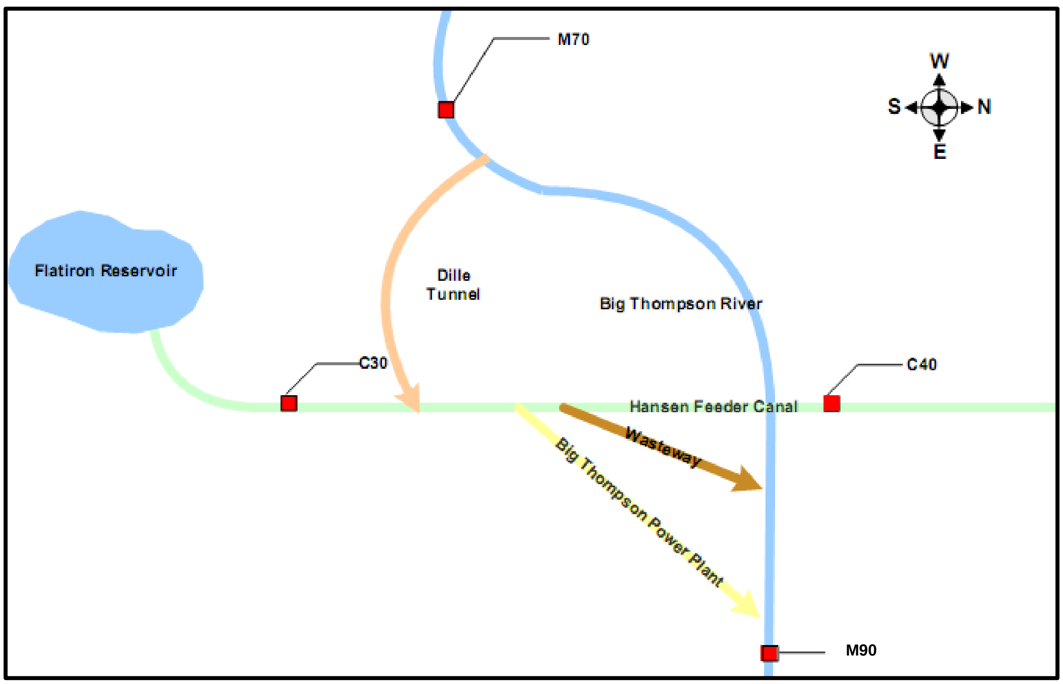

Figure 4. Simplified Depiction of the Trifurcation Structure

1.1.3 Water Quality

There are many stresses on water quality in the Big Thompson River and its tributaries. Anthropogenic stresses include population growth, discharge from wastewater treatment plants (WWTPs; Figure 6), atmospheric deposition, diversions and return flows, ranching and agriculture, septic systems, transbasin imports, impoundments, and stormwater runoff. A land-use map of the watershed, developed from the USGS Groundwater Toolbox (Barlow et al., 2014), is presented in Figure 5.

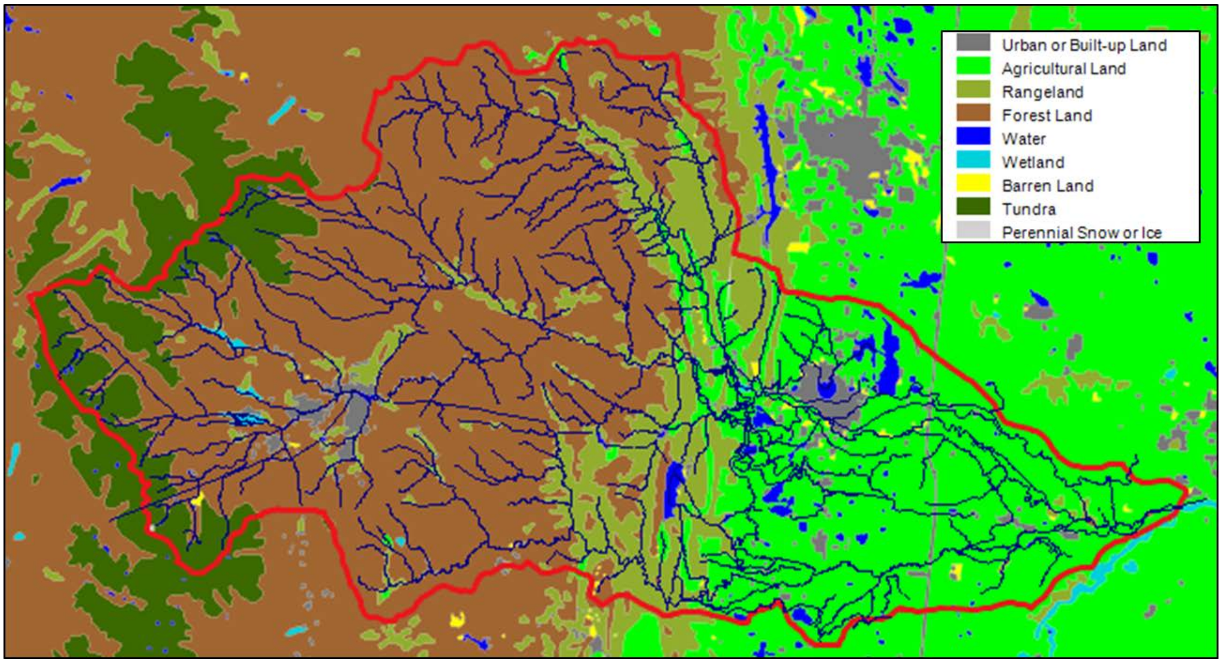

Figure 5. Current Land Use Map for the Big Thompson Watershed (Barlow et al., 2014)

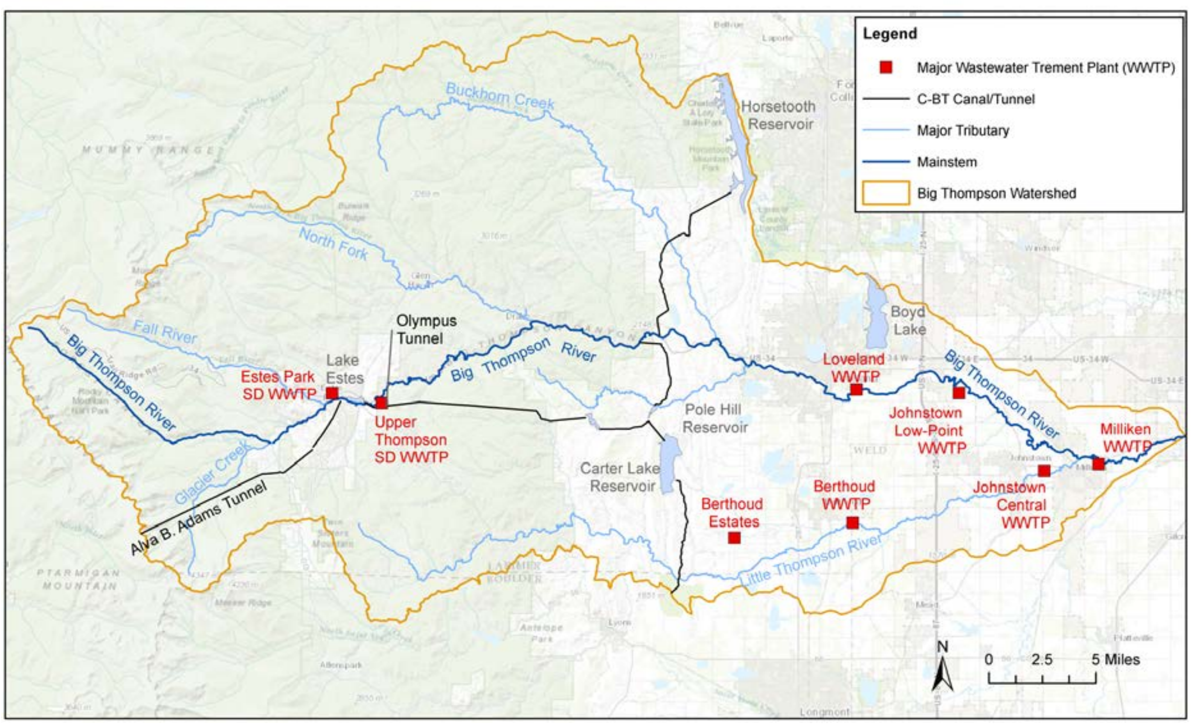

Figure 6. Wastewater Treatment Plants in the Big Thompson Watershed

Examples of natural stresses on water quality include wildfires, floods, drought, forest health including mountain pine beetle and other large-scale forest insect infestations, and groundwater loading of selenium to surface water from the selenium-rich Pierre shale geologic formations in the area (Figure 7). In some cases, such natural stresses can be exacerbated by anthropogenic activities. For example, diversions and irrigation can affect flow rates and dilution in the river as well as increase groundwater recharge to the river.

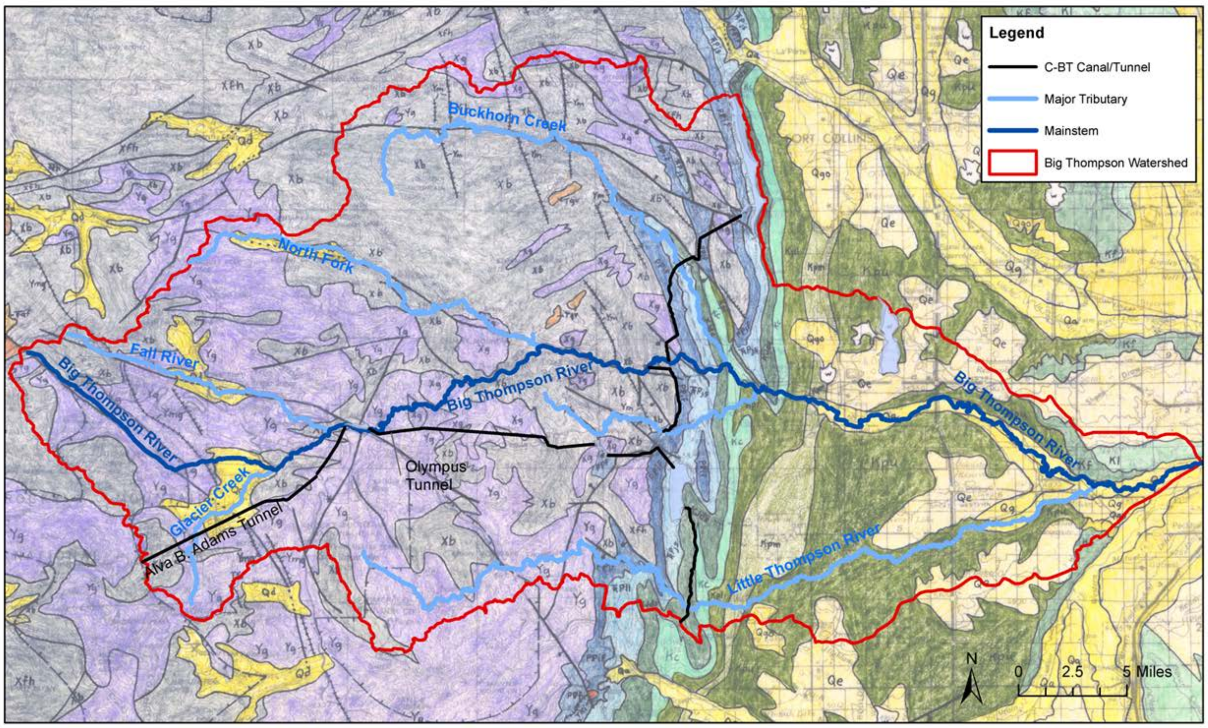

Figure 7. Geologic Map of Big Thompson Watershed; Overlay from Braddock and Cole (1978); Pierre Shale Indicted in Green

(Purple and grey indicate igneous and metamorphic rock; teal indicates sandstones and conglomerates; light blue indicates Foxhills / Laramie bedrock; beige and yellow indicate alluvial deposits.)

In 2007, the Forum identified phosphorus and nitrogen as constituents of concern for the watershed (Buirgy, 2007). Total organic carbon (TOC) is also recognized as a concern in the watershed due to the challenges it presents for drinking water treatment (Beggs et al., 2013). In addition, various segments of the Big Thompson River and its tributaries are on Colorado's 2012 (most recent) 303(d) List[4] of impaired waters. The listed parameters are

[4] The 303(d) List identifies those water bodies where there are exceedances of water-quality standards or non-attainment of uses. This list of impaired waters is generally updated every two years (although the last update

copper, cadmium, selenium, zinc, dissolved oxygen, Escherichia Coli (*E. Coli*), sulfate, pH, and temperature (Water Quality Control Division [WQCD], 2012a). Of these, the high priority listings are for segment 1 (copper), segment 2 (pH, copper, cadmium, and zinc), segment 7 (copper), segment 8 (sulfate, temperature, and dissolved oxygen), and segment 9 (*E. Coli* only). The only change in the 2012 listing from the previous listing in 2010 (WQCD, 2010) was the addition of sulfate for segment 8. A summary of the 303(d) listings is presented in Table 1. Figure 8a through 7c present these listings spatially.

Some changes to these listings are expected beginning in 2016. There are currently-proposed revisions to the 303(d) List. Final revisions will be adopted by the Colorado Water Quality Control Commission in the upcoming December 2015 rulemaking hearing and will become effective beginning in 2016. Because the proposed changes are not final, Table 1 presents the current (2012) 303(d) listings. Potential changes include removal of the cadmium and zinc listing for Segment 2 and the possible removal of the copper listing for Segment 9. These expected changes are noted, where relevant, in compliance discussions in Section 3.

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in Colorado was in 2012). The list is submitted to EPA by the states under the auspices of the Clean Water Act. The intent is to identify water-quality concerns triggering development of Total Maximum Daily Loads (TMDLs). At this point, TMDLs have not been developed for any segments of the Big Thompson Watershed, and the timing of TMDL development remains uncertain.

Table 1. 2012 303(d) Listings for Big Thompson Watershed Stream Segments.
See Colorado WQCC Regulation 93 at: http://www.cdphe.state.co.us/regulations/wqccregs

Big Thompson Segment Number	Segment ID	Segment Description	Relevant Portion	Clean Water Act Section 303(d) Impairment	303(d) Relative Priority
1	COSPBT01	Mainstem of the Big Thompson River including all tributaries and wetlands, which are within Rocky Mountain National Park, except for specific listings in Segment 2	all	Copper	High
2	COSPBT02	Big Thompson River and tribs, RMNP to Home Supply Canal diversion	Fish Creek below Marys Lake	pH	High
2	COSPBT02	Big Thompson River and tribs, RMNP to Home Supply Canal diversion	all	Copper, Cadmium, Zinc, Temperature	High
3	COSPBT03	Mainstem of the Big Thompson River from the Home Supply Canal diversion to the Big Barnes Ditch diversion.	all	Copper	Medium
4a	COSPBT04a	Mainstem of the Big Thompson from the Big Barnes Ditch diversion of the Greeley-Loveland Canal diversion.	all	Selenium	Medium
4b	COSPBT04b	Big Thompson River, Greeley-Loveland Canal diversion to CR11H	all	Selenium	Medium

Big Thompson Segment Number	Segment ID	Segment Description	Relevant Portion	Clean Water Act Section 303(d) Impairment	303(d) Relative Priority
5	COSPBT05	Big Thompson River, I-25 to S. Platte River	all	Selenium	Low
6	COSPBT06	All tributaries to the Big Thompson River, from Home Supply Canal to the confluence with the South Platte River.	all	Copper	Medium
7	COSPBT07	Mainstem of the North Fork of the Big Thompson from RMNP to confluence with Big Thompson	North Fork of Big Thompson	Copper	High
8	COSPBT08	Mainstem of the Little Thompson River, from source to the Culver Ditch diversion.	all	Temperature, Dissolved Oxygen	High
8	COSPBT08	Mainstem of the Little Thompson River, from source to the Culver Ditch diversion.	From source to St. Vrain Supply Canal	Sulfate	High
9	COSPBT09	Little Thompson River, Culver Ditch to Big Thompson River	all	Copper, Selenium, *E. Coli* (May-October), Aquatic Life Use	Medium/ Low/ High/ Medium
10	COSPBT10	Tributaries to the Little Thompson River	Big Hollow	Selenium	Low

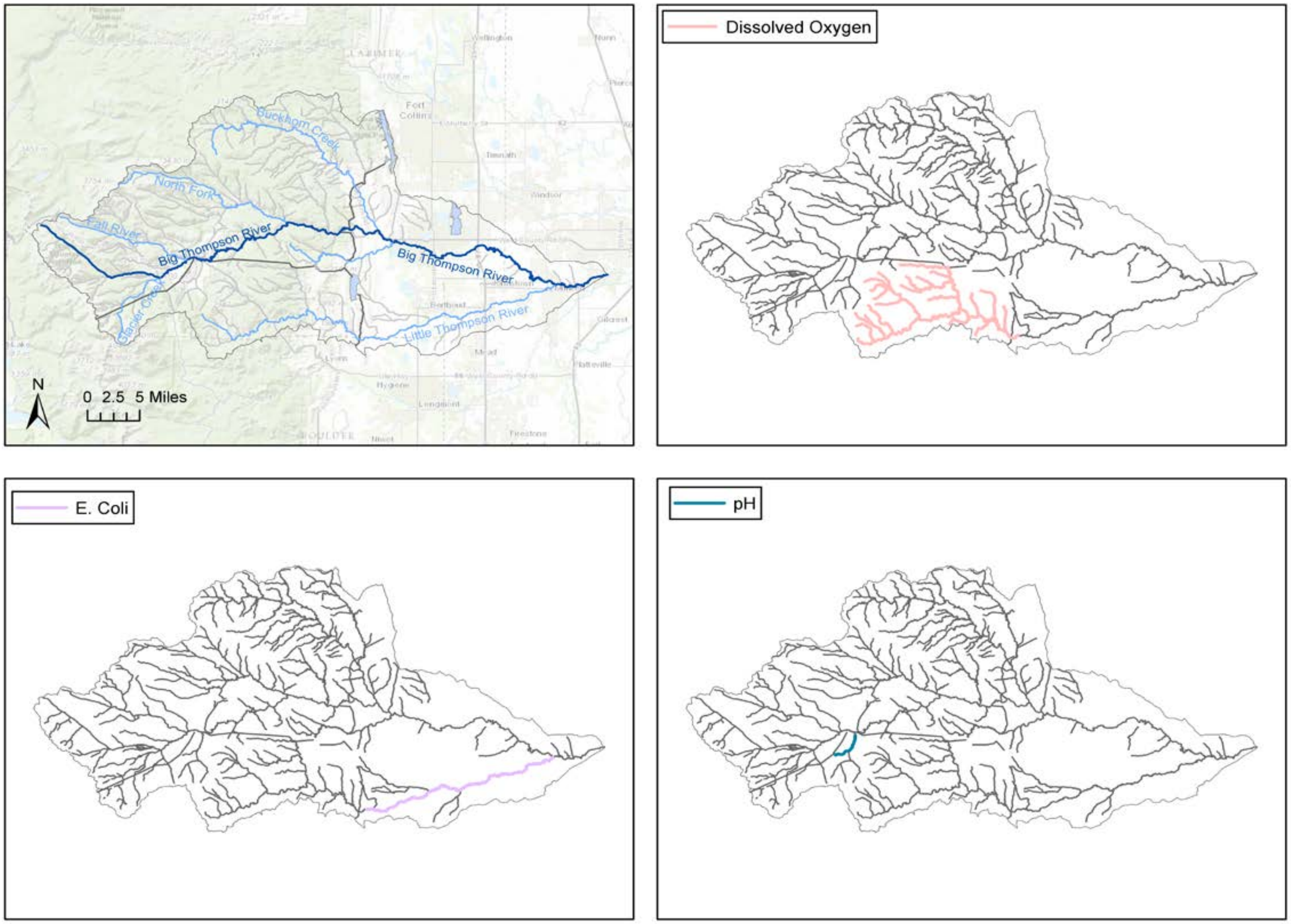

Figure 8a. 303(d)-Listed Stream Segments in the Big Thompson Watershed; Dissolved Oxygen, *E. Coli*, pH

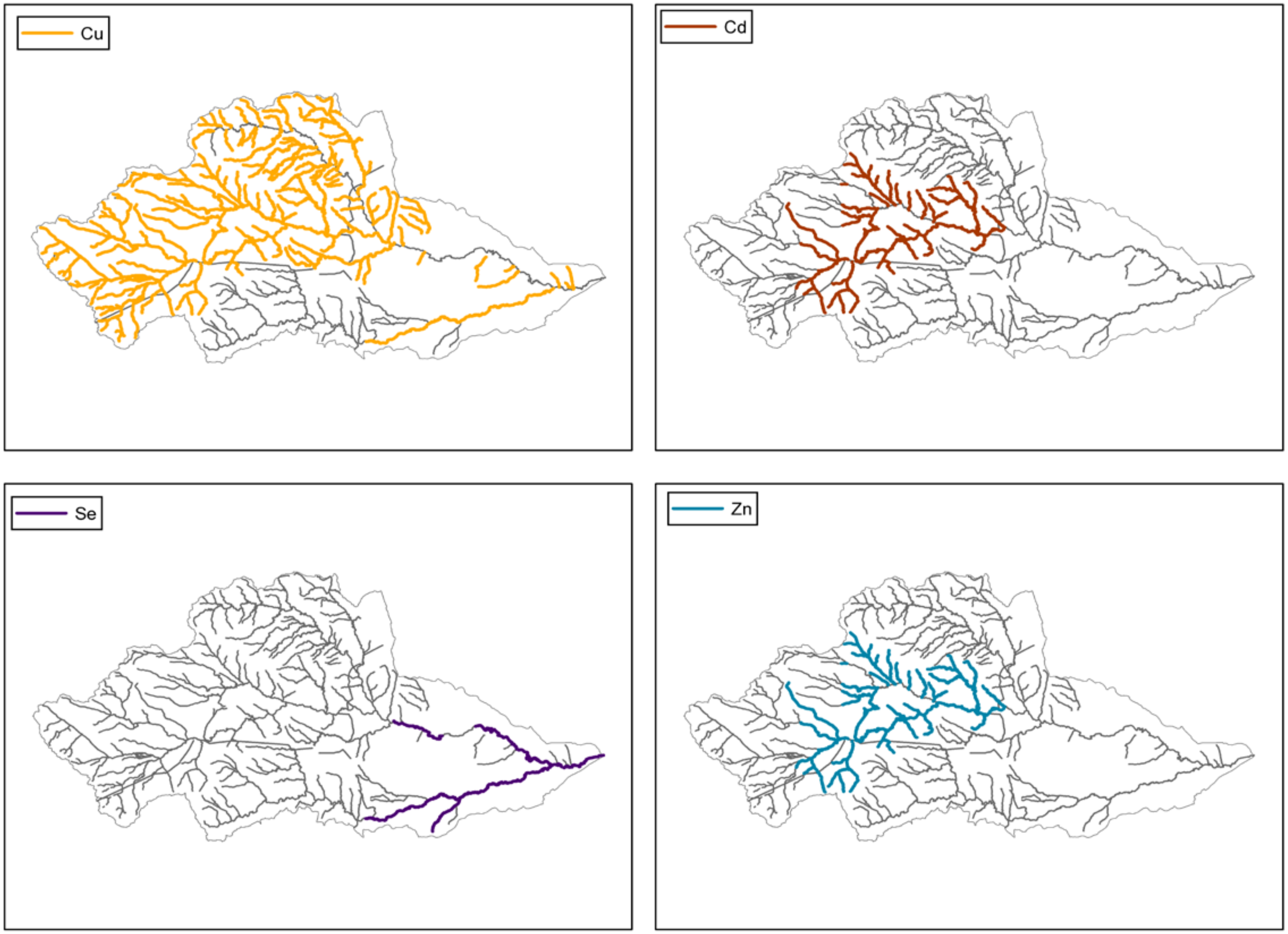

Figure 8b. 303(d)-Listed Stream Segments in the Big Thompson Watershed; Copper, Cadmium, Selenium and Zinc

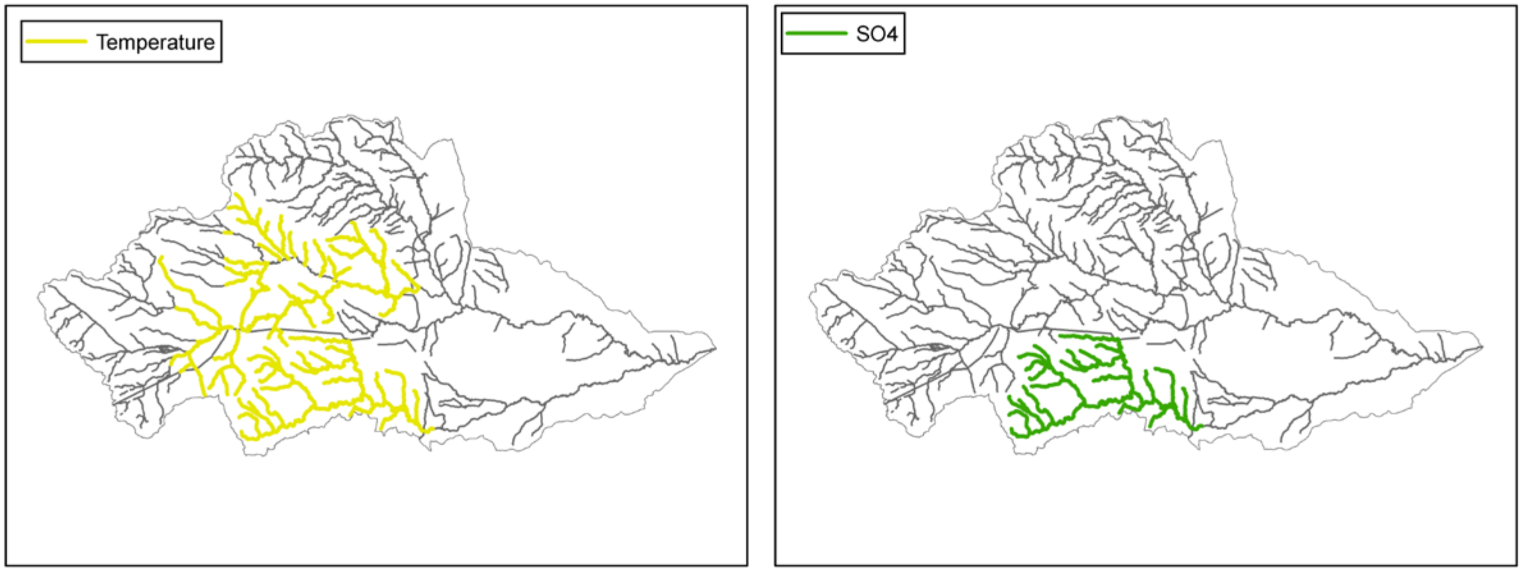

Figure 8c. 303(d)-Listed Stream Segments in the Big Thompson Watershed; Temperature and Sulfate

1.2 RECENT MAJOR WATERSHED EVENTS

The recent five years (2010-2014) were eventful in the Big Thompson watershed. Major wildfires and record flooding occurred during this period. These types of disturbances can have significant effects on water quality and were a focus of data analysis for this report.

1.2.1 Wildfires

Four major wildfires occurred within the watershed in the recent five years, all during the period of 2010 through 2012 (Figure 9):

- **Cow Creek Fire**: Started by lightening in June 2010 in the North Fork watershed within a remote area of Rocky Mountain National Park, this fire was eventually extinguished in November 2010 after burning 1,200 acres.

- **Crystal Fire**: Located west of Horsetooth Reservoir near Buckhorn Creek, this fire burned 3,000 acres in April 2011 after being started by an illegal open burn.

- **High Park Fire**: This fire was started on June 9, 2012 by a lightning strike in an area suffering from hot, dry conditions with an extreme fire danger. The fire burned over 87,000 acres, destroying 259 homes before being fully contained on June 30, 2012 (Figure 10). The majority of the burn area was located in the Cache la Poudre River watershed; however, the fire also affected upper Buckhorn Creek of the Big Thompson watershed.

- **Fern Lake Fire**: An illegal campfire started this high-elevation fire in October 2012 in Rocky Mountain National Park. This fire burned roughly 3,500 acres within the park before it was eventually extinguished by winter snows that began in December 2012.

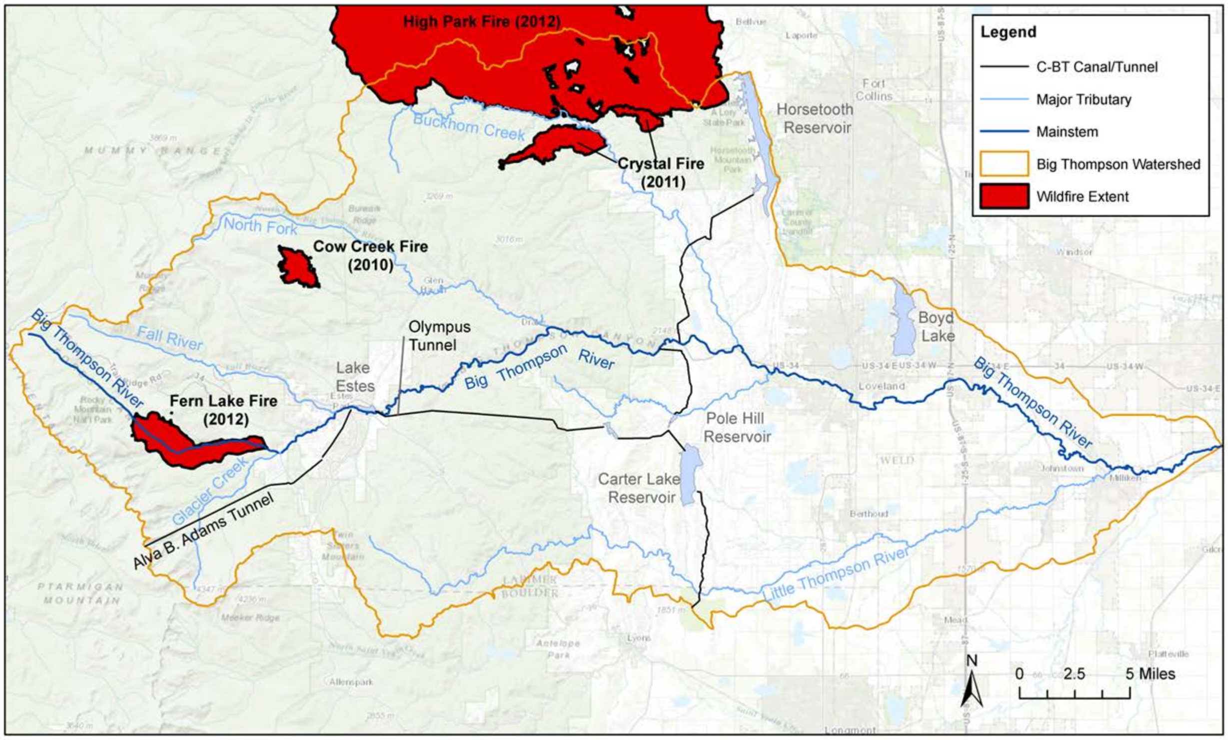

Figure 9. Location and Burn Extent of Recent Fires in the Big Thompson Watershed

Figure 10. Post-Fire Images: (Left) Fern Lake Fire Burn Scar in Forest Canyon (Photo: August, 2014 by J. Billica); (Right) High Park Burned Forest (CDOT et al., 2012)

Fires can have significant effects on surface water quality (Bitner et al., 2001, Ranalli, 2004, Neary et al., 2005). Effects may include increased sediment transport and delivery of ash to receiving waters. Increased suspended solids concentrations may bring increased metals concentrations. Due to ash loading, increased concentrations of organic carbon, calcium, magnesium, sodium, potassium, and chloride may be observed. Sulfate concentrations may also increase due to oxidation of sulfur present in soil organic matter. Increased nutrient concentrations (including nitrate, ammonia, organic nitrogen, orthophosphate, and total phosphorus) have also been observed in Colorado surface waters receiving runoff from areas affected by wildfire (e.g., Writer and Murphy, 2012, and Oropeza and Heath, 2013). Water-quality response in the year following the Fern Lake fire was evaluated by Northern Water (Billica, 2014). Water quality following the four wildfires noted above is discussed in greater detail in Section 3.6 of this report.

1.2.2 September 2013 Flood

In September 2013, a week of record-breaking rainfall totals resulted in extensive flooding along the Front Range. Rainfall amounts over a seven-day period exceeded 18 inches near Boulder and exceeded 15 inches near Estes Park (Figure 11). Estimates developed for the CWCB indicate that this was a 100- to more than 500-year flood in the Big Thompson, and the Little Thompson Rivers (CH2MHill, 2014, Jacobs, 2014, and Jacobs, 2015).

Damage from flash flooding and debris flows was extensive. The flooding impacted 20 counties, resulting in 10 fatalities. Damages were reported to more than 16,000 homes, 750 businesses, and hundreds of miles of highway (CWCB, 2014). Examples of flood damage in the Big Thompson watershed are presented from upstream to downstream in Figure 12 through Figure 17.

Flooding can impact water quality during and after flood events. Flooding can produce large sediment loads, bringing increased metals concentrations and other associated contaminants. Major flooding can modify and reroute drainages and introduce new contaminants to rivers by mobilizing material previously isolated from the river. Due to safety concerns and access limitations, no water-quality data were collected in the Big Thompson watershed during the flood. Sampling, however, was resumed after waters receded and access could be gained to sampling sites. Observed effects on water-quality following the September 2013 flooding were considered throughout the data analysis and are discussed in Section 3.6.2.

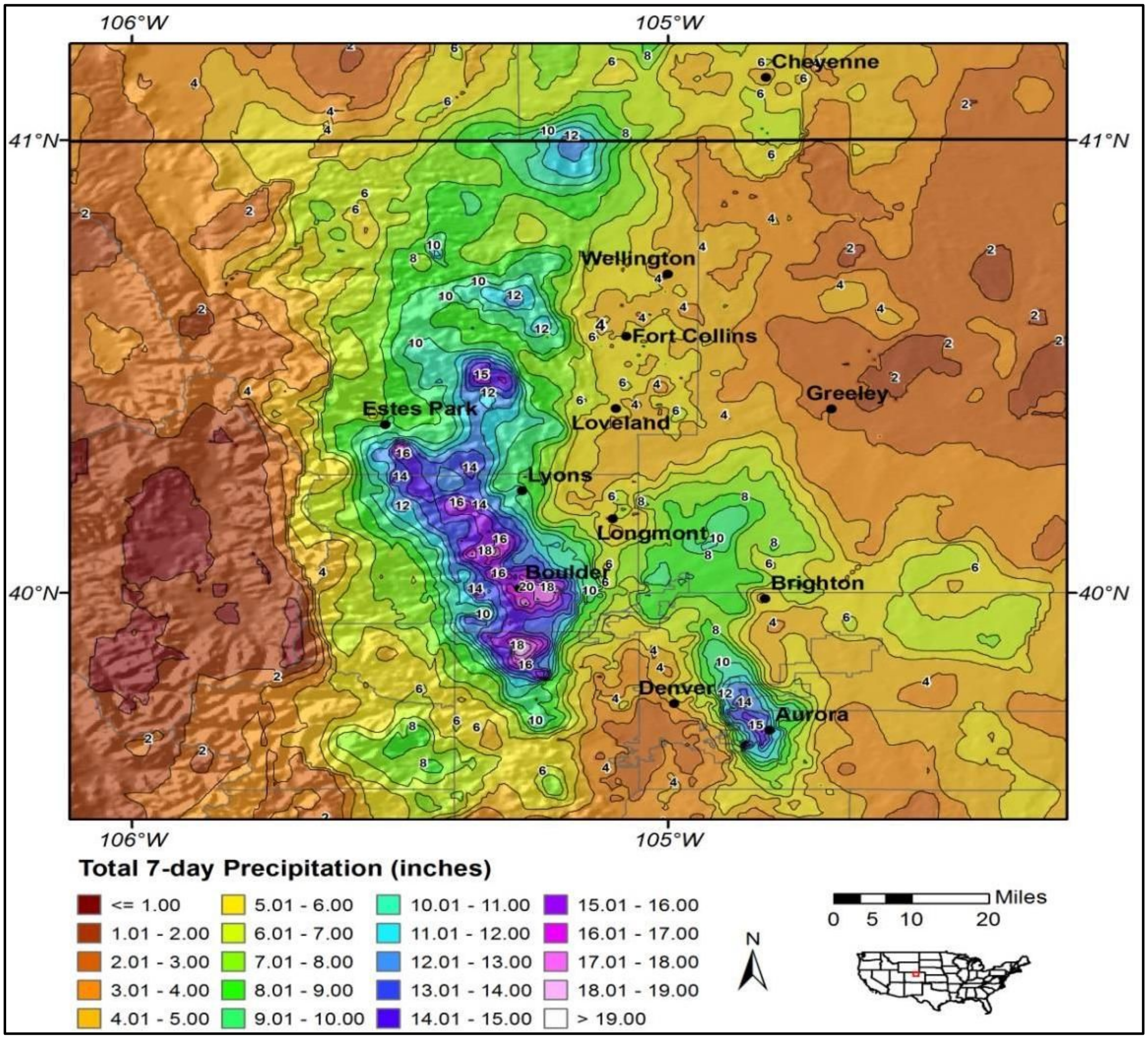

Figure 11. Total Seven Day Rainfall for September 11-17, 2013 Rainfall Event (NOAA, 2014)

Figure 12. September 2013 Flooding, Fun City in Estes Park (Photo from Twitter by @TWCBreaking)

Figure 13. September 2013 Flooding, Highway 34 Big Thompson Canyon, Highway Damage (Photo by Andy Cross, The Denver Post)

Figure 14. September 2013 Flooding, Sylvan Dale Guest Ranch, Located West of Loveland and Just Outside the big Thompson Canyon Narrows (Photo courtesy of Shelley, 2014)

Figure 15. September, 2013 Flooding on the Big Thompson River at 1st Street and Taft Avenue in Loveland, CO (Photo Courtesy of the City of Loveland)

Figure 16. September 2013 Flooding, Loveland Fairgrounds (Photo from Twitter by @CJose)

Figure 17. USGS Stream Gage on the Big Thompson River near Loveland on September 12, 2013 (Photo courtesy of Shelley, 2014)

1.3 REPORT OBJECTIVES

This report directly supports the Forum's mission and program goals through the review, analysis, assessment, and documentation of flow and water-quality data in the streams, rivers, and C-BT canals of the Big Thompson watershed. The assessment builds on three previous State of the Watershed reports that included analysis of data from the flowing water sites: Jassby and Goldman (2003), Haby and Loftis (2007), and Hydros (2011). Insights developed in those reports are reevaluated in this assessment with the context provided by the recent additional five years of data. This report attempts to answer the following questions based on review of monitoring data for the 15-year period of record (WY2000 – WY2014):

1. What is the current state of Big Thompson River water quality as revealed by the data collected for the Forum's monitoring programs?
2. What seasonal and spatial patterns are apparent in the water-quality parameter concentrations?
3. What are the statistically-significant temporal trends in water-quality concentrations across the watershed?
4. What are the estimated annual and seasonal loads of nutrients and total organic carbon, and the spatial patterns of these loads?
5. To what extent have water-quality concentrations been out of compliance with applicable Colorado water-quality standards, including acute and chronic aquatic life standards, water supply standards, and recreational use standards? How do the total phosphorus and total nitrogen concentrations compare to the Colorado interim nutrient values (not yet fully adopted as standards on the Big Thompson River)?
6. What do the data tell us about short-term (Fall 2013) and lingering (2014) impacts from the 2013 flood?
7. Are there any persistent water-quality changes at the downstream end of Moraine Park (M10) the second year after the 2012 Fern Lake Fire?

The findings of this analysis are summarized in the text of the main report and supported by detailed graphical and tabular presentations in appendices. Additionally, monitoring program recommendations generated through this analysis are provided. Finally, the results of this assessment are expected to directly support subsequent analysis of the data for the receiving reservoirs used for drinking water treatment plant inflows and to support regulatory permit renewal processes for wastewater treatment facility discharges to receiving streams.

1.4 REPORT ORGANIZATION

This report is organized into five main text sections, with five appendices presenting the extensive supporting figures and tables. The main report is organized as follows:

- **Section 1 - Introduction**

- **Section 2 - Dataset and Data Treatment** – This section presents the dataset, including description of the data treatment and handling. Section 2 also describes the calculations, statistical testing, and tabular and graphical products referenced throughout the remainder of the document.
- **Section 3 - Data Analysis** — This section presents the analysis of the data, organized by parameter group. Section 3.6 summarizes findings of observed flood and fire effects on water quality. The final discussion in Section 3 presents a brief cross-program comparison of sampling results.
- **Section 4 - Findings and Recommendations**
- **Section 5 - References**

The supporting appendices are organized as follows:

- **Appendix A** — Summary Statistics and Analytical Methods.
- **Appendix B** — Flow Rate Figures.
- **Appendix C** — Concentration Figures.
- **Appendix D** — Loading Calculation Results.
- **Appendix E** — Statistical Analysis of Long-Term Concentration Trends.
- **Appendix F** — Compliance Assessment Results.
- **Appendix G** — Comparison of COOP and Volunteer Monitoring Results.

2 DATASET AND DATA TREATMENT

This section presents the dataset analyzed in this report, as well as a description of the graphical and statistical methods applied to evaluate the data.

2.1 DATASET

This report reviews and evaluates the water-quality and flow-rate data from rivers, streams and C-BT canals in the Big Thompson watershed from WY2000 through WY2014. In total, the final dataset contains nearly 142,000 records for the focus parameters. These data were collected as part of the U.S. Geological Survey (USGS) Cooperative (COOP) Program (August 2000-present)[5] and the U.S. Environmental Protection Agency (EPA) Volunteer Program (August 2001-Present)[6]. In 2011, the five canal locations were removed from the COOP program to reduce financial burdens on the Forum. Since that time, sampling at three of these stations has been conducted by Northern Water, and sampling at the other two stations continued by the USGS under a Joint Funding Agreement with Northern Water, with laboratory analyses for all five canal sites conducted by laboratories used in Northern Water's monitoring program.

Water-quality data were compiled by the Forum into an NPSTORET Access relational database[7]. Water-quality and flow-rate summary statistics are presented in Appendix A1.

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[5] The Forum's Cooperative Monitoring (COOP) Program is a Joint Funding Agreement (JFA) with its major funders (City of Fort Collins, City of Greeley, City of Loveland, Northern Colorado Water Conservancy District and Tri-Districts-Soldier Canyon Filter Plant) and the U.S. Geological Survey (USGS). For this program, USGS personnel collected all samples at flowing water sites. Analyses were split between three labs. The USGS NWQL analyzed for metals, nutrients and physical parameters. The Fort Collins water quality lab analyzed for total organic carbon & chlorophyll *a*, and Loveland water quality lab analyzed for E. Coli and total coliforms. The COOP locations include 13 sites.

[6] The Forum's Volunteer Monitoring Program is a joint effort between the Forum and the U.S. Environmental Protection Agency Region VIII (USEPA8). In this program, Forum staff and watershed science volunteers collect water quality samples, and USEPA8 conducts all of the laboratory analyses. The volunteer monitoring program includes a total of 13 sites.

[7] NPSTORET v.1.85 is a complete water quality database management system based on STORET/WQX that allows users to enter information about their water quality monitoring Projects, Stations, Metadata, and Results in a Microsoft Access database. Users can generate reports, statistics, and graphics describing entered data. Data can be imported from a variety of data sources and formats, including the three major national water quality databases: EPA Legacy STORET, EPA Modern STORET, and USGS National Water Information System. NPSTORET can produce export files in WQX format, text format for import via WQX-Web or the STORET Import Module (SIM), and a variety of other formats. Tutorials, context-sensitive help, and demonstration videos are included. (http://www.epa.gov/storet/otherapps.html)

Appendix A2 presents a summary provided by the Forum of analytical methods used in development of the dataset. Summary statistics in Appendix A1 are organized by parameter group and present the following information for each parameter at each station:

- Location,
- Units,
- Number of samples/ measurements,
- Number detected[8],
- Percent detected,
- Sampling date range,
- Range of observed detection limits,
- Range of observed concentrations,
- Mean concentration,
- Median concentration, and
- Standard deviation.

The following sections describe the sampling locations and parameters included in the dataset, including data treatment.

2.1.1 Sampling Locations

In total, 31 sampling stations are included in this analysis, including 13 USGS COOP stations, 13 Volunteer Program stations, and the 5 canal stations currently sampled by Northern Water and the USGS[9]. Figure 18 presents the location of each station on the watershed map. Sampling stations that also have flow measurements are noted on Figure 18. Table 2 lists the stations roughly in order from upstream to downstream, including identification of the sampling program and a brief description of the primary sampling objective(s) for each location.

[8] Analytical equipment and procedures generally report a lower concentration limit below which the method is not sensitive enough to return a result. This value is called the detection limit. A detected result has a concentration above this limit, and a non-detect result has a concentration below this limit.

[9] C10 and C20 are sampled by the USGS. C30, C40, and C50 are currently sampled by Northern Water.

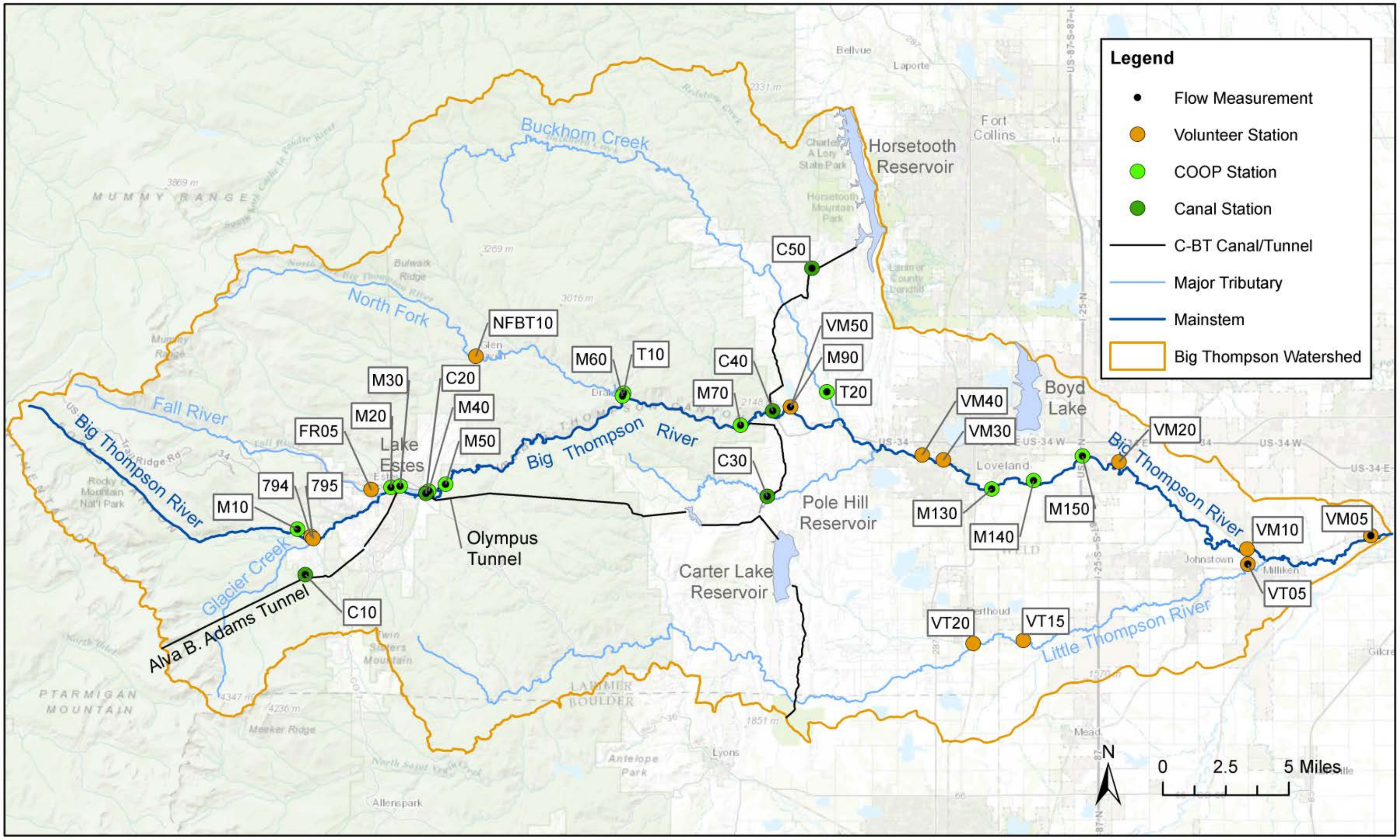

Figure 18. Locations of Sampling Stations

Table 2. Water-Quality Monitoring Stations

Station ID	Location Type	General Description	Station type	Stream Segment ID	Assessment Purpose
M10	Mainstem Big Thompson	Upstream	COOP	COSPBT01	Point farthest upstream.
795	Mainstem Big Thompson	Upstream	Volunteer	COSPBT01	Upstream of confluence with Glacier Creek
794	Tributary	Glacier Creek	Volunteer	COSPBT02	Tributary Input
FR05	Tributary	Fall River	Volunteer	COSPBT02	Tributary Input
M20	Mainstem Big Thompson	Upstream of Estes Park Sanitation District	COOP	COSPBT02	Impacts of runoff in Estes Park
C10	Canal	Adams Tunnel – East Portal	Canal	n/a	East slope influent C-BT water quality from west slope Three Lakes
M30	Mainstem Big Thompson	Downstream of Estes Park Sanitation District	COOP	COSPBT02	Effects of Estes Park Sanitation District effluent
C20	Canal	Olympus Tunnel	Canal	n/a	Lake Estes outflows; mixing of water from C-BT and Big Thompson watershed

Station ID	Location Type	General Description	Station type	Stream Segment ID	Assessment Purpose
M40	Mainstem Big Thompson	Downstream of Olympus Dam	COOP	COSPBT02	Assess baseline for Big Thompson River below Lake Estes and upstream of Upper Thompson Sanitation District
M50	Mainstem Big Thompson	Downstream of Upper Thompson Sanitation District	COOP	COSPBT02	Assess effects of Upper Thompson Sanitation District effluent
M60	Mainstem Big Thompson	Upstream of Confluence with North Fork	COOP	COSPBT02	Effects of upper canyon watershed inputs
NFBT10	Tributary	Middle reach of North Fork Big Thompson	Volunteer	COSPBT02	Water quality in middle reach of North Fork.
T10	Tributary	North Fork Big Thompson	COOP	COSPBT07	Tributary input
M70	Mainstem Big Thompson	Upstream of Dille diversion	COOP	COSPBT02	North Fork and lower-canyon watershed inputs
C30	Canal	Hansen Feeder Canal – canal outlet of Flatiron Reservoir	Canal	n/a	Water quality for Hansen Feeder Canal out of Flatiron Reservoir and upstream of Dille Tunnel diversions

Station ID	Location Type	General Description	Station type	Stream Segment ID	Assessment Purpose
C40	Canal	Hanson Feeder Canal – downstream of trifurcation	Canal	n/a	Changes in Hansen Feeder Canal downstream of Dille Tunnel
C50	Canal	Hansen Feeder Canal – upstream of Horsetooth Reservoir	Canal	n/a	Input water to Horsetooth Reservoir
M90	Mainstem Big Thompson	Upstream of Loveland drinking water intake	COOP	COSPBT03	Big Thompson water quality upstream of Loveland Drinking Water intake; program comparison with volunteer site VM50
VM50	Mainstem Big Thompson	Upstream of Loveland drinking water intake	Volunteer	COSPBT03	Big Thompson water quality upstream of Loveland Drinking Water intake; program comparison with coop site M90
T20	Tributary	Buckhorn Creek	COOP	COSPBT07	Tributary Input
VM40[a]	Mainstem Big Thompson	At Wilson St Bridge — above the Mariano Exchange Ditch	Volunteer	COSPBT04a	Water quality in the Big Thompson River before Mariano Exchange Ditch
VM30[b]	Mainstem Big Thompson	Downstream of Mariano Exchange Ditch	Volunteer	COSPBT04a	Effects of Mariano exchange ditch

Station ID	Location Type	General Description	Station type	Stream Segment ID	Assessment Purpose
M130	Mainstem Big Thompson	Upstream of Loveland WWTP	COOP	COSPBT04b	Water quality upstream of Loveland WWTP effluent
M140	Mainstem Big Thompson	Downstream of Loveland WWTP	COOP	COSPBT04c	Monitor effects of Loveland WWTP effluent
M150	Mainstem Big Thompson	At I-25	COOP	COSPBT05	Monitor downstream changes in Big Thomson, end of the COOP program
VM20	Mainstem Big Thompson	East of I-25	Volunteer	COSPBT05	Assess baseline conditions upstream of proposed permitted WWTP
VM10	Mainstem Big Thompson	Upstream of confluence with Little Thompson.	Volunteer	COSPBT05	Water quality of Big Thompson before confluence with Little Thompson
VT20	Tributary	Little Thompson River – middle reach	Volunteer	COSPBT09	Upstream of Berthoud WWTP.
VT15	Tributary	Little Thompson River— Lower Reach	Volunteer	COSPBT09	Downstream of Berthoud WWTP.

Station ID	Location Type	General Description	Station type	Stream Segment ID	Assessment Purpose
VT05	Tributary	Little Thompson River – near confluence	Volunteer	COSPBT09	Little Thompson tributary input, effects of Johnstown and Berthoud WWTP;
VM05	Mainstem Big Thompson	Near confluence with South Platte	Volunteer	COSPBT05	Assess conditions at the end of the system and Town of Milliken WWTP

[a] Results for this station include results from VM45, which was actually collected at Namaqua Park —in 2008 only.
[b] Results for this station include results from VM41, which was actually collected at South of Wilson St. Bridge, below the Mariano Exchange Ditch —in 2008 only.

2.1.2 Parameters

The parameter list evaluated in this report was developed by the Forum's Science and Monitoring Committee. The parameters fall into five general categories (flow rate, metals, general parameters, nutrients, and microbiological parameters). The parameters included in this report are listed below, along with a brief basis for inclusion.

Flow Rate –- The Forum's database includes flow records for 20 of the 31 monitoring stations considered in this report (Figure 18). Measurement frequency varies from continuous to approximately monthly. Thirteen of these stations are the COOP monitoring stations, five are C-BT canal stations, and two are volunteer stations. These flow rate data were including in this report to support evaluation of the site hydrology (natural and operational) and to estimate loading rates.

Metals – The parameter list includes six metals:

- Cadmium,
- Copper,
- Lead,
- Mercury,
- Selenium, and
- Zinc.

This report evaluates total concentrations of mercury and dissolved concentrations of the remaining five. These six metals are included in the parameter list because they are on the 2012 303(d) List for the Big Thompson watershed (WQCD, 2012a). Cadmium, copper, selenium, and zinc are all on the 2012 303(d) List for river segments as shown on Figure 8a-c. Three water bodies that receive water from the Big Thompson River and/or the C-BT system (Horsetooth Reservoir, Carter Lake, and Boyd Lake; Figure 1) are on the 2012 303(d) List for non-attainment of aquatic life use due to accumulation of mercury in fish tissue. Horsetooth Reservoir is also on the 2012 303(d) List for copper and arsenic. Lastly, Lake Estes is on the 303(d) List for copper and lead.

General Parameters – There are eleven general parameters included in this assessment:

- Alkalinity (a measure of a water's buffering capacity against changes in pH),
- Chlorophyll *a* (used as a measure of phytoplankton abundance),
- Dissolved oxygen (a measure of gaseous oxygen dissolved into water),
- Hardness (a measure of the mineral content of water, usually dominated by calcium [Ca^{2+}], and magnesium [Mg^{2+}]),
- pH (a measure of hydrogen ion activity in water; water with pH< 7 is acidic, water with pH>7 is basic),

- Specific conductivity (a measure of the concentration of ions in solution),
- Sulfate[10], (an oxidized anionic form of sulfur)
- Water Temperature,
- Total organic carbon (TOC; a measure of naturally occurring organic matter [terrestrial sources and in situ algal sources] plus organic matter from anthropogenic sources [including wastewater effluent and agriculture runoff]),
- Total suspended solids (TSS; a measure of mass of solids in a water sample), and
- Turbidity (a measure of light refraction of solids in a water sample; a measure of suspended matter.)

These parameters are included in this report because they provide a wide-spectrum review of the overall physical, chemical, and biological conditions present in the watershed. Additionally, pH and temperature are directly relevant to evaluation of the toxicity of ammonia. Similarly, hardness is used for the evaluation of the toxicity of metals. Sulfate was added to this list since the 2010 State of the Watershed Report because it is now on the 303(d) List for the upper portion of the Little Thompson River. Finally, TOC is one of the most important water-quality parameters for drinking water treatment plants.

Nutrients – The parameter list includes four nitrogen and three phosphorus parameters:

- Total nitrogen,
- Ammonia nitrogen,
- Total Kjeldahl nitrogen (TKN; sum of organic nitrogen plus ammonia), and
- Nitrate + nitrite.
- Total phosphorus,
- Dissolved phosphorus, and
- Orthophosphate.

The nitrogen and phosphorus parameters listed above are included in this report because the Forum has identified nutrients as constituents of concern for the watershed (Buirgy, 2007). As of August 10, 2015, in-stream interim nutrient criteria for total phosphorus are applicable to segments 1, 2, 6, 7, 8, 9, and 10 of the Big Thompson watershed (WQCD, 2015b). Additionally, the WQCD adopted the Nutrient Management Control Regulation (Reg. 85, WQCD, 2012b) in 2012, though applicability varies by permit.

[10] Sulfates are an essential plant nutrient and are naturally occurring, often resulting from decay of organic matter. Sulfates can be introduced to rivers at higher than natural concentrations by WWTPs, fertilized agricultural lands, or atmospheric deposition. Sulfates can also be present in surface water at high concentrations due to water from rock or soil containing high sulfur minerals such as gypsum. Pierre Shale, a source of selenium, can also be a source of sulfate.

Microbiological Parameters – The parameter list includes two measures of bacteria:

- Total Coliforms, and
- Escherichia Coliforms (*E. Coli*).

These parameters are included in this report because *E. Coli* is on the 303(d) List for the Little Thompson River.

2.1.3 Data Treatment

Data processing is a necessary initial step for investigations using analytical laboratory results. This processing generates a clean set of data, consisting of a single result for a given parameter at a given sampling station on a given sampling date/time. Datasets often include quality control samples, such as field and laboratory duplicates, replicate analyses of the same sample, and legacy errors such as inadvertently duplicated entries with slight differences. To generate a dataset useable for calculations and evaluation, it is advisable to develop a list of data rules to be applied consistently to the dataset. This approach allows for clear documentation, reproducibility of results, and the opportunity to adjust the data rules in the future if the database is modified or new information suggests a need for revisions. This section describes the data rules that were applied to generate the clean dataset used in this report.

Duplicates

For some parameters and stations evaluated, there were duplicate entries in the database—meaning multiple results for a given station, sampling date, parameter, and sampling fraction. These samples were comprised of field duplicates and field replicates. A single result for each discrete station/date/parameter/fraction combination was selected by applying the following rules:

1. If all of the duplicate results for a given station, date, parameter, and fraction are below detection limits, the lowest detection limit was taken, and the result were designated as a non-detect.

2. If at least one detected result was found, the maximum detected result was taken.

Missing Totals

In some cases, the analytical result for a parameter of interest was not available; however, the analytical results for the various fractions comprising that parameter were available. For example, in some cases TKN was not reported; however, ammonia and organic nitrogen were available. To fully utilize the available data, summing of analytical results was performed as necessary. The calculation of sums was done using the following approach:

1. If sub-analyte A and sub-analyte B were both detected, the direct sum was used and reported as detected.

2. If sub-analyte A and sub-analyte B were both below detection limits, the highest detection limit was reported, and the value was reported as non-detect.

3. If sub-analyte A was detected but sub-analyte B was below detection limits, the value for sub-analyte A was reported for the sum.

Non-Detect Results

In analytical chemistry, the detection limit is defined as the lowest quantity of a substance that can be distinguished from the absence of that substance by the test method (MacDougall and Crummet, 1980). In cases where the chemical concentration is below the detection limit, the laboratory will report the result as non-detect. For many of the parameters in this report existing concentrations are often below detection limits. Detection limits at or above concentrations of interest (e.g. regulatory limits) or high frequency of non-detect results can bias the findings of an analysis. Therefore, it is important to understand the range of detection limits in the dataset and the frequency of non-detect results to appropriately design analyses and interpret results.

In recognition of this issue, the summary statistics presented in Appendix A1 present the range of detection limits and the percent of detection for each station and parameter. Based on those results, the following patterns were observed:

- Detection limits were generally higher at Volunteer sampling stations as compared to COOP sampling stations for:
  - Cadmium, Copper, Lead, Selenium, and,
  - Ammonia.

- High percentages of non-detect results (>80%) were observed for certain parameters at many stations:
  - Cadmium, copper, lead, mercury, selenium, zinc,
  - Ammonia, orthophosphate, total phosphorous, and
  - TSS.

These detection limit observations are considered in analysis of results in this report. In general, non-detect results are set to half the detection limit for analyses in this report, with two exceptions. First, in plots of concentration as a function of time, non-detect results are set to the full detection limit, but represented by a different (hollow) symbol to allow for an informed review of the dataset. Second, for ammonia, TKN and orthophosphate, loading estimates were generated in two ways: (1) setting non-detect results to half detection limits (consistent with other analytes), and (2) setting non-detect results to zero. This approach allowed for an assessment of the effect of detection limits on the results for these parameters with higher frequencies of non-detection. This approach is generally consistent with treatment of non-detect results in the previous watershed reports (Jassby and Goldman, 2003; Haby and Loftis, 2007, Hydros, 2011).

Database Issues

The project 15-year Access database was in generally good order when provided to Hydros. The following paragraphs provide a description of (and the response to) issues identified in the project database. Overall, the data review was intended to err on the side of inclusion.

1) Chlorophyll *a* Data:

Beginning mid-June 2013, the Fort Collins water-quality laboratory began to experience difficulties with the analysis of chlorophyll *a*. As a result of these difficulties, nearly all data from 2013 and 2014 were non-detect. Upon review, it was determined that these non-detect results were not representative of actual conditions. Because of this, the Forum decided to exclude all chlorophyll *a* data from the Fort Collins water-quality laboratory post June 20, 2013.

2) Total Organic Carbon Data

There are two primary methods for the analysis of organic carbon. The first method utilizes the wet-chemical (persulfate-ultraviolet) oxidation method, the second method utilizes high-temperature combustion. Both methods generate carbon dioxide, which is the form of carbon measured in these analyses. Billica (2014) found that analyses performed via the combustion method generated higher TOC values; this was likely the result of greater recovery from particulate organic carbon. To avoid biasing the TOC data due to analytical methodology differences, it was decided to exclude the combustion method data from the analysis. Northern Water identified select data from the USGS NWQL for exclusion from the analysis (Shelley, 2015a, personal communication).

3) TSS Sample Fraction Codes

TSS data from C10 and C20 in 2013 had erroneous sample fraction designations in the database. These were modified in the processed dataset to avoid duplicate, erroneous results.

4) Suspect Data

A small number of data points were identified in the analysis as being suspect. Suspect points were identified by visual inspection and comparison to companion data. The disposition of these suspect data was determined using a 'best professional judgement' step. Treatment of suspect data erred on the side of including the results in the face of uncertainty. A complete summary of data excluded as suspect is provided in Appendix A3. These include:

- Five samples[11] for total phosphorous were identified as having a units error. Originally reported in the database as 5 mg/L, these data were retained but the values were corrected to 0.05 mg/L.
- One hardness value at station VM50 was excluded. The reported value of 829 mg/L on 4/16/2014 was more than 20 times greater than any other hardness value at this station, and this was not supported by other same-sample observations.
- Five samples[12] for pH were identified as suspect. These samples either had pH values less than 2 or greater than 11. These extreme pH values are rare in natural waters and most likely represent instrument error.
- Dissolved zinc data from WY2014 from C30, C40, and C50 were identified as contaminated by Northern Water. These were disqualified from the dataset.
- Dissolved zinc data from 2014 at all Volunteer monitoring stations were identified as suspect. These values were consistently and unrealistically high across the watershed.

2.2 STATISTICAL AND GRAPHICAL METHODS

This section provides a detailed description of the graphical presentations and statistical analyses of the data in this report.

2.2.1 Concentration Figures

A primary objective of this assessment is to review the temporal (including seasonality[13]) and spatial patterns in the water-quality dataset. Consistent with the Hydros (2011) report, two general plot types were developed and generated uniformly for all focus parameters: (1) concentration time-series plots and (2) concentration box plots.

The concentration time-series plots allow for visual review of temporal patterns in the dataset. These plots are presented in Appendix C1. The time-series plots present the individual concentration results over the full 15 year period of record for a given station and parameter on a scatterplot. Additionally, these plots show seasonality through data point color and shape.

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[11] Station 794 on 7/12/2011 and 9/13/2011; Station 795 on 8/9/2011 and 9/13/2011; Station VM10 on 11/5/2014.

[12] Station 794 on 10/24/2007, Station VM30 on 10/18/2005; Station VM50 on 11/16/2004, Station VM05 on 5/4/2010 and Station VM20 on 4/6/2010.

[13] Seasonality was defined by the Forum Science and Monitoring Committee, based on a detailed understanding of the patterns in the datasets. Three seasons were defined as follows: Fall (August through October); Winter (November through March); and Summer (April through July).

The plots also show the patterns in analytical detections, with non-detect results included at the full detection limit but designated by a hollow symbol. Where applicable, a compliance standard level (or interim criteria value for nutrients) is also indicated on these plots. Acute standards are shown for metals. Compliance values are discussed in greater detail in Section 2.2.3. Finally, where the dataset supported statistical trend testing, the resulting linear trend across the full dataset is plotted. It is important to note that this line does not necessarily indicate a statistically significant trend, and findings from the trend tests (described in Section 2.2.2) are discussed in the data analysis sections. An example time-series concentration plot is shown below in Figure 19.

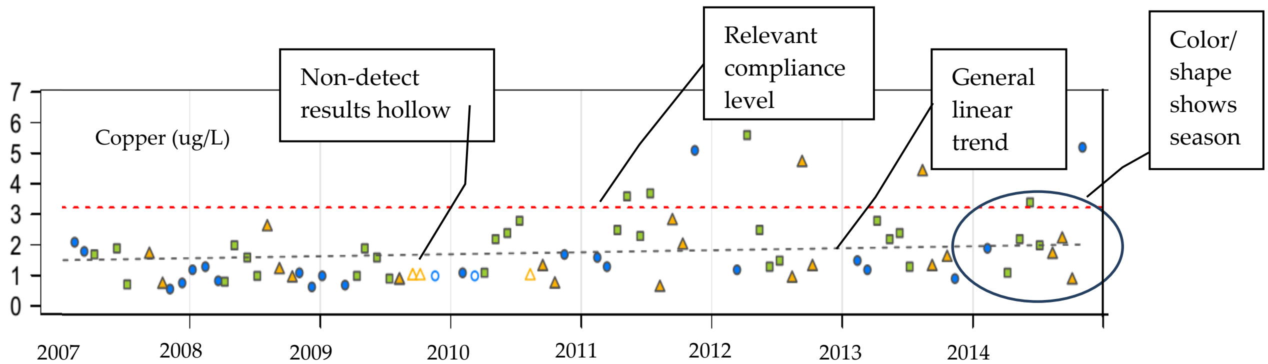

Figure 19. Example Concentration Time-Series Plot (Truncated to Exclude 2000-2006)

In addition, at the bottom of each panel on the time-series concentrations plots, there is a small station location map (Figure 20). This was added for this report to support informed review of the plots.

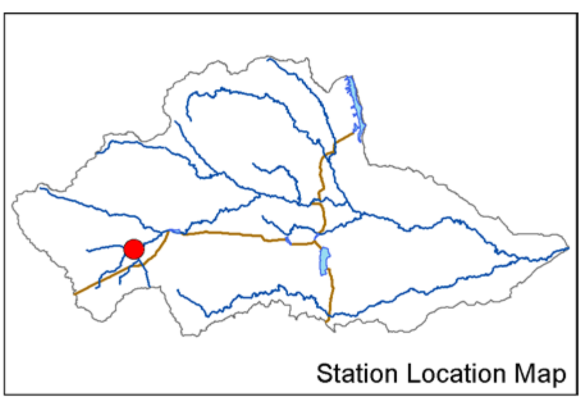

Figure 20. Example Station Location Map, Showing M20

The concentration box plots allow for visual review of the spatial trends in the dataset. These plots are presented in Appendix C2. The concentration box plots essentially present visual statistical summaries of the full fifteen year dataset for a given parameter across the watershed. For each station, the concentration results are shown using a box and whisker plot. These plots provide an indication of both the range and central tendency of the measured data. Figure 21 provides an explanation of the boxplot construction.

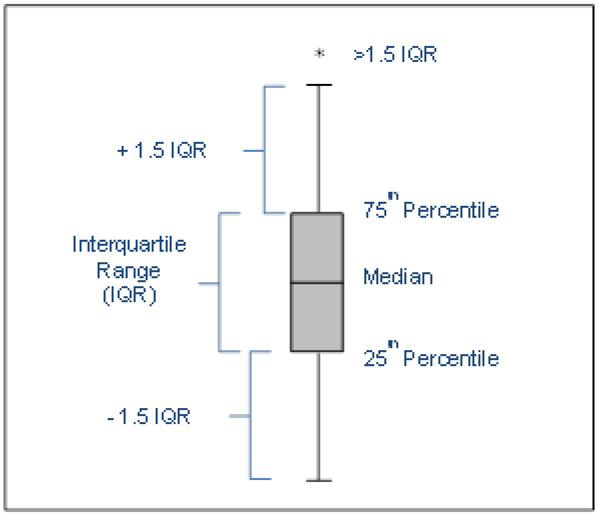

Figure 21. Example Box and Whisker Plot

The boxplots are presented on panel figures comprised of four subplots. The upper, largest plot presents data for the Big Thompson River. Stations on the mainstem of the Big Thompson River are designated with grey-filled boxes. Hollow boxes represent inflows to or outflows from the river. The inflow/outflow direction is designated with arrows below the station names on the x-axis. Additionally, three small subplots are included on each figure to show the C-BT canal system, Little Thompson River, and the North Fork of the Big Thompson.

2.2.2 Concentration Trend Testing

Testing for statistically-significant trends in concentration over the period of record at each station was another important objective of this assessment. To accomplish this, the Seasonal Mann-Kendall trend test was applied. This is a robust, non-parametric test that accounts for seasonal variation without sensitivity to outliers or non-normality in the data (Helsel and Hirsch, 1992). The test was run using R, an open source programming language and software environment for statistical computing and graphics. The Wq package, Version 0.2-8 (Jassby and Cloem, 2010), provided the functional code to run the test in R.

Trend testing was run for all parameters and stations, and returned values estimating the statistical significance (raw p-values[14]) and magnitude (Sen slope[15]) of the trends in the dataset. The "seasons" in this test were set to 12 per year (monthly). This temporal interval was the shortest duration supported by the data and the method (note: the method ignores missing data), and minimized potential error associated with assignment of larger "seasons" that may not accurately describe the annual patterns in the dataset. The test results were not considered if all data for the parameter/station were below detection limits. Further, non-detect results were set to half the detection limit. A confidence interval of 90% (critical p-value = 0.10) was set by the Forum's Science and Monitoring committee as a threshold for identifying potential trends. Lastly, interpretation of trending in the results should always consider a visual review of the time-series dataset, and that approach was followed in the data analysis section (Section 3) of this report.

A table summarizing the results of the Seasonal Mann-Kendall testing is presented in Appendix E. For each station and parameter, this table presents: the number of samples, the percent detection, the p-values (with p-values < 0.1 shaded), and the Sen slopes (expressed as a percent of the mean for relative comparison of magnitude). Additionally, the Sen slopes are represented on the concentration time-series plots (Appendix C1). Slopes, however, were not plotted on the concentration time-series plots if a station/parameter had three or fewer years of data. Note: Where adequate years of data were available, the Sen slopes are presented on the plots regardless of the findings or interpretations of significance of the trend, per direction of the Forum.

2.2.3 Compliance Analysis and Standards

The water-quality data were assessed relative to Colorado's applicable numeric water-quality standards, in accordance with State Regulation 38 (WQCD, 2015b) and State Regulation 31 (WQCD, 2013). It should be noted that all 15 years of record were evaluated against the most recently published Colorado water-quality regulations, adopted August 10, 2015, but not effective until December 31, 2015. Standards have changed over time, and this analysis is not intended to assess actual compliance during each year of record. The information provided does not constitute a legal interpretation of current or historical compliance. Instead, this

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[14] P-values are a measure of the statistical significance of the apparent trend. A lower p-value indicates greater confidence that the observed trend is statistically significant. For example, a p-value of 0.05 corresponds to a finding that the observed trend is statistically significant at a 95% confidence value.

[15] The Sen slope (also called Theil or Theil-Sen slope) is the median slope joining all pairs of observations and represents an estimate of the magnitude of the trend in the dataset.

analysis assesses patterns in the dataset relative to the most recent water-quality standards for informational purposes only.

Of the parameters discussed in this report, numeric water-quality standards are presented in Regulation 38 for the following parameters in the Big Thompson watershed:

- Temperature,
- Dissolved Oxygen,
- pH,
- Sulfate,
- *E. Coli*,
- Ammonia,
- Cadmium,
- Copper,
- Lead,
- Mercury,
- Phosphorus (Total),
- Selenium, and
- Zinc.

Additionally, total nitrogen concentrations were compared to the interim numeric values in Regulation 31 (WQCD, 2013). The total phosphorus standards will be effective in segments 1, 2, 6, 7, 8, 9, and 10, as of December 31, 2015; however, total nitrogen standards have not yet been adopted in flowing segments of the Big Thompson watershed. For perspective, however, these thresholds were compared to observed data at all non-canal locations and are presented on the time-series concentration plots in Appendix C1.

Standards are assigned by stream segment; therefore, standards are specific to each sampling station. Further, the basis of standards is variable; some standards are:

- Numeric thresholds:
  - pH, *E. Coli*, mercury, sulfate, and selenium.
- Assessed seasonally:
  - Temperature, dissolved oxygen, and, *E. Coli* (for a subset of stations).
- Hardness dependent:
  - cadmium, copper, lead, and zinc.
- Based on season, temperature, and pH:
  - ammonia

For hardness-based aquatic life standards (cadmium, copper, lead, and zinc), the hardness value for each station was set as the 85th percentile result for the most recent five years (October 1, 2009 through September 30, 2014). As such, the resulting standard values for these metals were calculated constants for each station. This approach was recommended by the Forum Science and Monitoring Committee. A summary of the resulting applicable metals standards is presented in Table 3, and a summary of the non-metals standards is presented in Table 4. For some parameters, different standards apply to the different classifications (i.e., aquatic life, domestic water supply, agriculture, recreation); the standards presented in Tables 3 and 4 represent the most stringent classification for that parameter in that segment.

Table 3. Site Specific Water-Quality Criteria, Aquatic Life Acute and Chronic Standards for Metals (all units μg/L)

Seg.	Station	Hardness[1] (mg/L)	Cadmium (Dissolved)		Copper (Dissolved)		Mercury (Total)	Lead (Dissolved)		Selenium (Dissolved)		Zinc (Dissolved)	
			Acute	Chronic	Acute	Chronic	Chronic	Acute	Chronic	Acute	Chronic	Acute	Chronic
1	795	10	0.228	0.074	1.54	1.25	0.01	4.91	0.19	18.4	4.6	20.1	17.5
	M10	12	0.268	0.085	1.82	1.46	0.01	6.04	0.24	18.4	4.6	23.5	20.4
2	794	12	0.268	0.085	1.82	2.50	0.01	6.04	0.24	18.4	4.6	23.5	20.4
	FR05	20	0.419	0.125	2.95	2.50	0.01	10.8	0.42	18.4	4.6	36.4	31.5
	M20	22	0.455	0.135	3.23	2.50	0.01	12.0	0.47	18.4	4.6	39.4	34.2
	M30	24	0.491	0.144	3.50	2.50	0.01	13.3	0.52	18.4	4.6	42.5	36.8
	M40	25	0.509	0.148	11.0	7.50	0.01	13.9	0.54	18.4	4.6	44.0	38.1
	M50	28	0.562	0.162	11.0	7.50	0.01	15.8	0.61	18.4	4.6	48.4	42.0
	M60	31	0.614	0.175	11.0	7.50	0.01	17.7	0.69	18.4	4.6	52.8	45.8
	M70	26	0.526	0.153	11.0	7.50	0.01	14.5	0.57	18.4	4.6	45.5	39.4
3	M90	28	0.562	0.162	4.05	3.02	0.01	15.8	0.61	18.4	4.6	48.4	42.0
	VM50	24	0.491	0.144	3.50	2.65	0.01	13.3	0.52	18.4	4.6	42.5	36.8
4a	VM30	400	5.69	1.20	49.6	29.3	0.01	281	10.9	18.4	4.6	467	405
	VM40	400	5.69	1.20	49.6	29.3	0.01	281	10.9	18.4	4.6	467	405
4b	M130	400	9.15	1.20	49.6	29.3	0.01	281	10.9	18.4	5.5	467	405
4c	M140	400	9.15	1.20	49.6	29.3	0.01	281	10.9	18.4	4.6	467	405
5	M150	400	9.15	1.20	49.6	29.3	0.01	281	10.9	18.4	4.6	467	405
	VM05	400	9.15	1.20	49.6	29.3	0.01	281	10.9	18.4	4.6	467	405
	VM10	400	9.15	1.20	49.6	29.3	0.01	281	10.9	18.4	4.6	467	405
	VM20	400	9.15	1.20	49.6	29.3	0.01	281	10.9	18.4	4.6	467	405
7	NFBT10	14	0.306	0.096	2.11	1.67	0.01	7.20	0.28	18.4	4.6	26.8	23.3
	T10	18	0.382	0.116	2.67	2.07	0.01	9.58	0.37	18.4	4.6	33.2	28.8
	T20	312	4.6	0.99	39.3	23.7	0.01	217	8.47	18.4	4.6	378	328

Seg.	Station	Hardness[1] (mg/L)	Cadmium (Dissolved)		Copper (Dissolved)		Mercury (Total)	Lead (Dissolved)		Selenium (Dissolved)		Zinc (Dissolved)	
			Acute	Chronic	Acute	Chronic	Chronic	Acute	Chronic	Acute	Chronic	Acute	Chronic
9	VT05	400	9.15	1.20	49.6	29.3	0.01	281	10.9	18.4	12.3	467	405
	VT15	400	9.15	1.20	49.6	29.3	0.01	281	10.9	18.4	12.3	467	405
	VT20	400	9.15	1.20	49.6	29.3	0.01	281	10.9	18.4	12.3	467	405

[1]Calculated as 85th percentile of site data. For hardness based standards, 400 is maximum value.

Table 4. Site Specific Water-Quality Criteria, Non-Metals

Seg.	Station	Nutrients (All mg/L)				Microbiological (cfu/100 mL)	General mg/L	stu	mg/L	Classification
		TN*	TP	Ammonia	Nitrate (Water Supply)	E. Coli (Recreation)	DO	pH	Sulfate (Domestic Water Supply)	Temperature
1	795	1.25*	0.11	Var.	10	126	6.0, 7.0[2]	6.5 to 9.0	250	Cold 1
	M10	1.25*	0.11	Var.	10	126	6.0, 7.0[2]	6.5 to 9.0	250	Cold 1
2	794	1.25*	0.11	Var.	10	126	6.0, 7.0[2]	6.5 to 9.0	250	Cold 1
	FR05	1.25*	0.11	Var.	10	126	6.0, 7.0[2]	6.5 to 9.0	250	Cold 1
	M20	1.25*	0.11	Var.	10	126	6.0, 7.0[2]	6.5 to 9.0	250	Cold 1
	M30	1.25*	0.11	Var.	10	126	6.0, 7.0[2]	6.5 to 9.0	250	Cold 1
	M40	1.25*	0.11	Var.	10	126	6.0, 7.0[2]	6.5 to 9.0	250	Cold 1
	M50	1.25*	0.11	Var.	10	126	6.0, 7.0[2]	6.5 to 9.0	250	Cold 1
	M60	1.25*	0.11	Var.	10	126	6.0, 7.0[2]	6.5 to 9.0	250	Cold 1
	M70	1.25*	0.11	Var.	10	126	6.0, 7.0[2]	6.5 to 9.0	250	Cold 1
3	M90	1.25*	0.11*	Var.	10	126	6.0, 7.0[2]	6.5 to 9.0	250	Cold 2
	VM50	1.25*	0.11*	Var.	10	126	6.0, 7.0[2]	6.5 to 9.0	250	Cold 2

		Nutrients (All mg/L)				Microbiological (cfu/100 mL)	General			
							mg/L	stu	mg/L	Classification
Seg.	**Station**	**TN***	**TP**	**Ammonia**	**Nitrate (Water Supply)**	**E. Coli (Recreation)**	**DO**	**pH**	**Sulfate (Domestic Water Supply)**	**Temperature**
4a	VM30	1.25*	0.11*	Var.	10	126, 630[1]	6.0, 7.0[2]	6.5 to 9.0	250	Cold 2
	VM40	1.25*	0.11*	Var.	10	126, 630[1]	6.0, 7.0[2]	6.5 to 9.0	250	Cold 2
4b	M130	2.01*	0.17*	Var.	10	126, 630[1]	5	6.5 to 9.0	250	Warm 2
4c	M140	2.01*	0.17*	Var.	100	126, 630[1]	5	6.5 to 9.0	--	Warm 2
5	M150	2.01*	0.17*	Var.	100	205, 630[1]	5	6.5 to 9.0	--	Warm 2
	VM05	2.01*	0.17*	Var.	100	205, 630[1]	5	6.5 to 9.0	--	Warm 2
	VM10	2.01*	0.17*	Var.	100	205, 630[1]	5	6.5 to 9.0	--	Warm 2
	VM20	2.01*	0.17*	Var.	100	205, 630[1]	5	6.5 to 9.0	--	Warm 2
7	NFBT10	1.25*	0.11	Var.	10	126	6.0, 7.0[2]	6.5 to 9.0	250	Cold 1
	T10	1.25*	0.11	Var.	10	126	6.0, 7.0[2]	6.5 to 9.0	250	Cold 1
	T20	1.25*	0.11	Var.	10	126	6.0, 7.0[2]	6.5 to 9.0	250	Cold 1
9	VT05	2.01*	0.17	Var.	10	126	5	6.5 to 9.0	250	Warm 2
	VT15	2.01*	0.17	Var.	10	126	5	6.5 to 9.0	250	Warm 2
	VT20	2.01*	0.17	Var.	10	126	5	6.5 to 9.0	250	Warm 2

* These noted nutrient criteria values are not currently applicable standards for the noted segments, but are used in this report 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). There are currently no applicable site-specific TN standards for any segment on the Big Thompson watershed.

-- Indicates no applicable standard at this location.

VAR Indicates ammonia standard value depends on pH, temperature and season.

[1] First value is for period of 5/1 to 10/15; second value is for period 10/16 to 4/30.

[2] First value is for non-spawning time period, second value is for spawning period.

Non-detect results were not compared to compliance values, though they are included in the denominator of calculations of percent compliance. In other words, regardless of the detection limit value, non-detect results were considered to be in compliance for this analysis. This handling of non-detects is consistent with the listing methodology used by WQCD for the 2016 303(d) listing process. In the listing methodology, non-detect values are treated as zeroes for the purpose of compliance analysis (WQCD, 2015a).

The compliance assessment results for each station are presented in Appendix F as percent exceedances for each parameter for the complete data set. For parameters with exceedances, results are summarized for each year of record in a separate table in Appendix F. Additionally, acute compliance levels are presented on the time-series concentration plots in Appendix C1.

2.2.4 Loading Calculations

Loading in flowing waters refers to the mass of a parameter passing a given location over a given time interval. Loading calculations were generated for nutrient parameters and TOC for stations with adequate flow records. Loads were calculated on a monthly basis and summed to generate seasonal and annual loads. As such, for each month average flow rates and concentrations were generated from the full dataset to support the calculations. Non-detect results were set to half the detection limit prior to development of average concentrations. For TKN, ammonia, and orthophosphate, loading calculations were also run with non-detect results set to zero. This allowed an assessment of the effects of frequent non-detect results and variable detection limits on the loading calculations.

To calculate monthly loads, values for both flow rate and concentration were needed for each month. Representative monthly flows and concentrations were calculated as the arithmetic mean of all data in a given month. Flow rates for months with no flow records were estimated using linear regressions with proximal stations. Concentrations for months with no sampling data were estimated by interpolation between the previous and subsequent observed result. Non-detect results were set to half the detection limit in the calculation of the averages.

The loading estimates for 2013 do not account for loads associated with the September 2013 flood event. It is recognized that the extremely high flows would be associated with large loadings. However, as shown in Appendix B2, samples were not collected during the rising limb, peak or falling limb of the flood (for safety reasons). Sampling occurred just before and approximately 4-6 weeks following the start of the event. While flow rates could be estimated with correlations between stations and estimates of peak flows, loading calculations cannot be completed without water-quality data. It is reasonable to expect that observed water-quality outside of the flooding period would not be representative of water quality during the flood. Therefore, loading estimates for 2013 exclude the September flood. Section 3 acknowledges high sediment loads and further discusses expected water quality conditions during the flooding.

Loading estimates are presented in two ways to allow for both spatial and temporal (including seasonal) review. First, the annual loading results are presented as box plots, with all stations presented on a single figure for a given parameter. These plots, presented in Appendix D1, follow the general format described above (Section 2.2.1) for concentration box plots. Second, the loading estimates are presented annually by station with the seasonal breakdown for each year of data. These figures are called loading bar graphs and are presented in Appendix D2. In contrast to other data presentations that provide a full 15-year data record, loading bar graphs are limited to the most recent 10 years. An example segment of a bar graph is shown below in Figure 22.

Annual loading estimates are also presented in tabular form in Appendix D3. The table groups estimates by station and parameter. The table also presents annual flow-weighted mean concentrations, which were estimated by dividing the total annual load by the annual flow volume.

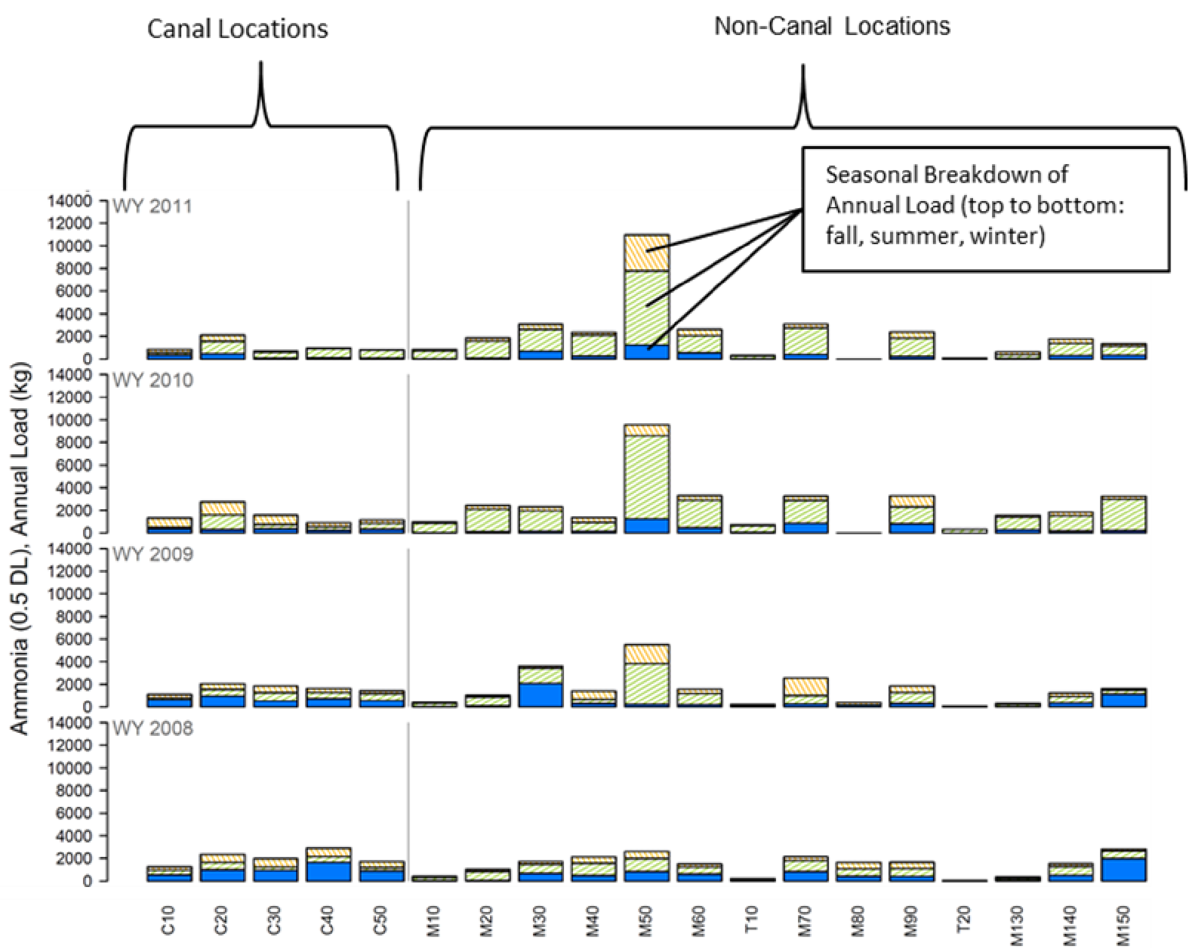

Figure 22. Example Loading Bar Graph

3 DATA ANALYSIS

This section presents discussions of water quality across the watershed based on review of the time-series plots, concentration box plots, loading analysis, trend testing, and compliance analysis. The discussions are organized by parameter group (flow rate, nutrients, metals, microbiological parameters, and general parameters). Following the parameter group sections, the observed effects of fires and flooding in the recent five years are discussed. Finally, a comparison between COOP and Volunteer data is presented. Analysis presented here is based on supporting figures and tables as presented in Appendices A through G:

Appendix A. Summary Statistics and Analytical Methods
- A1. Summary Statistics Tables
- A2. Summary of Analytical Methods
- A3. List of Data Excluded from Analysis

Appendix B. Flow Rate Figures
- B1. Time-series Flow Rate Records
- B2. 2013 Focus – Observed Flow Rates
- B3. Flow Volume Box Plot

Appendix C. Concentration Figures
- C1. Time-series Concentration Plots
- C2. Concentration Box Plots

Appendix D. Loading Calculation Results
- D1. Loading Box Plots
- D2. Loading Bar Graphs
- D3. Annual Loading Tables

Appendix E. Statistical Analysis of Long-Term Concentration Trends
Appendix F. Compliance Assessment Results
Appendix G. Comparison of COOP and Volunteer Monitoring Results

3.1 FLOW RATES

Flow records were compiled and reviewed for the 13 COOP, five canal, and two volunteer stations shown in Figure 18. The frequency of flow rate measurements varies from monthly to daily. Flow rate records were plotted in three ways to show temporal and spatial patterns. First, all observed flow rates were plotted for each station for the period of record (WY2000-WY2014). These plots are presented in Appendix B1. Second, Appendix B2 provides hydrographs focusing on 2013 for greater resolution on flow records before, during, and after the flood of September 2013. Third, box plot and seasonal bar graphs were generated using flow volume totals for each station (Appendix B3).

3.1.1 Typical Patterns

Flow patterns across the watershed vary in response to natural runoff, diversions and returns, and land use (Figure 23). At the top of the watershed in Rocky Mountain National Park, annual hydrographs are dominated by the snowmelt peaks in spring. Snowmelt-driven flow rates above Lake Estes (e.g., M20) typically peak between May and June (note that these months are included in the summer season for seasonality analysis). Below Lake Estes (e.g, M40), the snowmelt hydrograph peaks are still apparent, but are diminished by operation of the reservoir and C-BT diversions to the Olympus Tunnel. Downstream of the mouth of the canyon, in the more populated areas (e.g., M130) from Loveland to the South Platte, the snowmelt hydrograph peaks are apparent, but often reduced relative to the upper watershed (e.g., 2011 in Figure 23). The greater percent of impervious surfaces present in the urban areas results in a "flashier" flow rate response in the river, reacting to precipitation events with sharp hydrograph peaks (see M130 and VM05 in Figure 23). Toward the downstream end of the watershed, baseflow rates tend to be higher and relatively consistent (e.g., VM05 winter months on Figure 23), reflecting greater contributions from groundwater and WWTP effluent. Lastly, the canal stations (e.g., C10) show flow patterns driven by demands of the C-BT system.

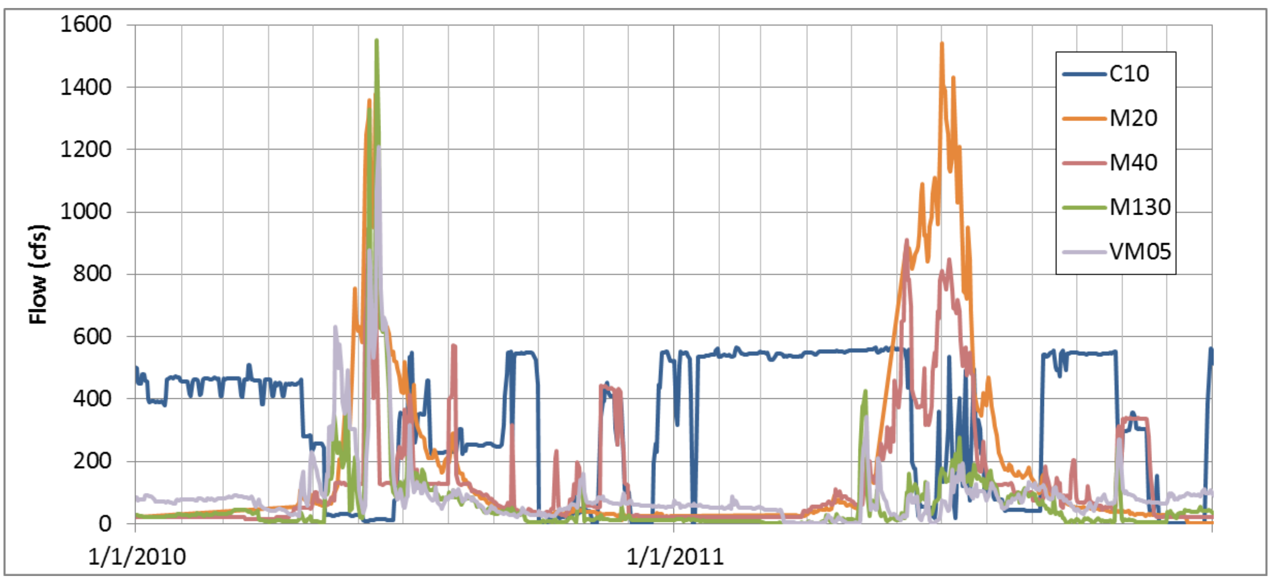

Figure 23. Hydrographs C10, M20, M40, M130, VM05; 2010 and 2011

Over the 15 year record, observed flow rates across the watershed have ranged from zero to an estimated 21,300 cfs on the Big Thompson downstream of the North Fork during the September 2013 flood (Jacobs, 2015). Natural peak flows in the recent five years, as indicated by flow rates above Lake Estes, have included very high and low snowmelt runoff peaks. The highest flow rates during snowmelt runoff in the recent 15 years were measured at M20 in 2011. In contrast, 2012 snowmelt runoff at M20 was one of the lowest peaks in the recent 15 years, comparable to 2002.

Generally, annual flow volumes increase along the mainstem of the Big Thompson from the headwaters to below the Trifurcation structure, as measured at M90 (Figure 24). There is a small decrease in median annual flow volumes just below Lake Estes (M40), reflecting diversions. A larger decrease in annual flow volumes is apparent downstream of the mouth of the canyon in Loveland at M130 (Figure 24). This drop in flow volumes reflects the effects of major irrigation and municipal water diversions, including the City of Loveland drinking water treatment plant intake (below M90) and a number of diversion ditches including Home Supply, Handy, South Side, Louden, Big Barnes, Chubbuck, and Farmers. Annual median flow volumes remain lower than those in the canyon out to the confluence with the South Platte.

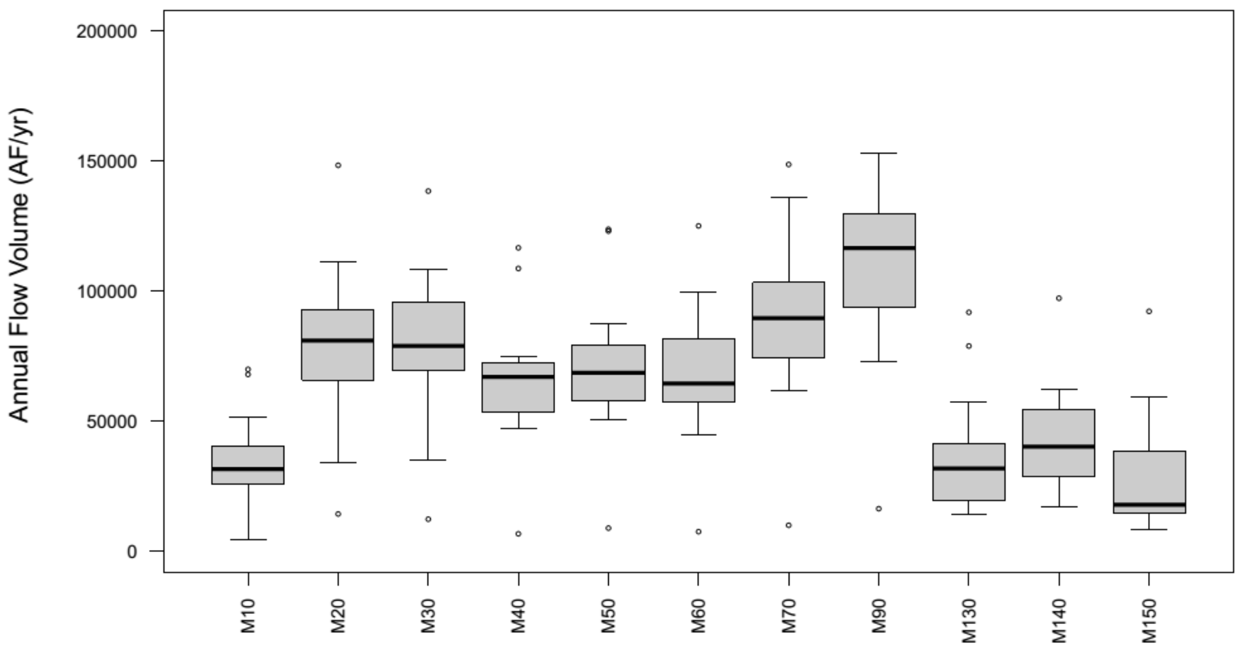

Figure 24. Box Plot Summary of Mainstem Annual Flow Volumes (AF/yr; WY2000-WY2014)

Unlike the river locations, C-BT canal locations exhibit no consistent seasonal patterns in the dataset, reflecting the water management control of this system (e.g., C10, Figure 23). As seen in Figure 3, annual flow volumes through the canals are the highest within the watershed. The canals generally have high flow rates in winter months (as compared to the mainstem of the Big Thompson River), when Horsetooth Reservoir and Carter Lake are being filled.

3.1.2 September 2013 Flooding

As described in Section 1.2.2, a week of record-breaking rainfall totals in September of 2013 resulted in extensive flooding across the Front Range. Recorded and estimated peak flow rates in the Big Thompson watershed for this event are presented in Table 5. Estimates developed for CDOT and the CWCB indicate that this was a 100- to more than 500-year flood in the Big Thompson and the Little Thompson rivers (CH2MHill2014, Jacobs, 2014, and Jacobs, 2015). These are estimates since all gages were exceeded, and in many cases, gages were destroyed during the event. Available gage data from calendar year 2013 are plotted in Appendix B2.

Table 5. Peak Discharge Estimates for Selected Locations during the September 2013 Floods (CH2MHill 2014, Jacobs, 2014, and Jacobs, 2015).

River	Location	Peak Flow Rate (cfs)	Estimated Event Size (Return Frequency)
Big Thompson Mainstem	Lake Estes (Olympus Dam)	5,330	~100-Yr
	Big Thompson at Drake above North Fork	12,500	100 to 500-Yr
	Big Thompson below Drake	14,800	100 to 500-Yr
	Big Thompson at 287	21,300	100-Yr
	Big Thompson at I-25	19,600	~100-Yr
	Lake Estes (Olympus Dam)	5,330	~100-Yr
North Fork of the Big Thompson	N. Fork Big Thompson, upstream of Drake	18,400	>500-Yr
Buckhorn Creek	Buckhorn Creek at Masonville	11,000	~100 Yr
Little Thompson	Little Thompson River above West Fork	2,680	>500-Yr
	Little Thompson River below West Fork	7,800	>500-Yr
	Little Thompson River above Confluence with Big Thompson	14,500	~100-Yr

The September 2013 flooding also increased the baseflow into the Big Thompson and Little Thompson Rivers, particularly in the downstream areas (e.g., M130 and downstream). These reaches are located in broad alluvium filled valleys (Figure 7). These alluvial deposits were recharged by the flood event, increasing groundwater levels and resulting in greater inflow of groundwater to the river. This is particularly apparent in the 2013-2014 winter flow data. In the upper watershed, baseflow rates through the post-flood winter were similar to previous years (e.g. M20, M40). In contrast, baseflow rates were much higher in the lower part of the watershed (e.g., M130, VM05); as shown in Figure 25. It appears, from the end-of-2014 data, that baseflow continued to be higher in the second year following the flood; however, the long-term duration of this effect will have to be evaluated with additional data in the future.

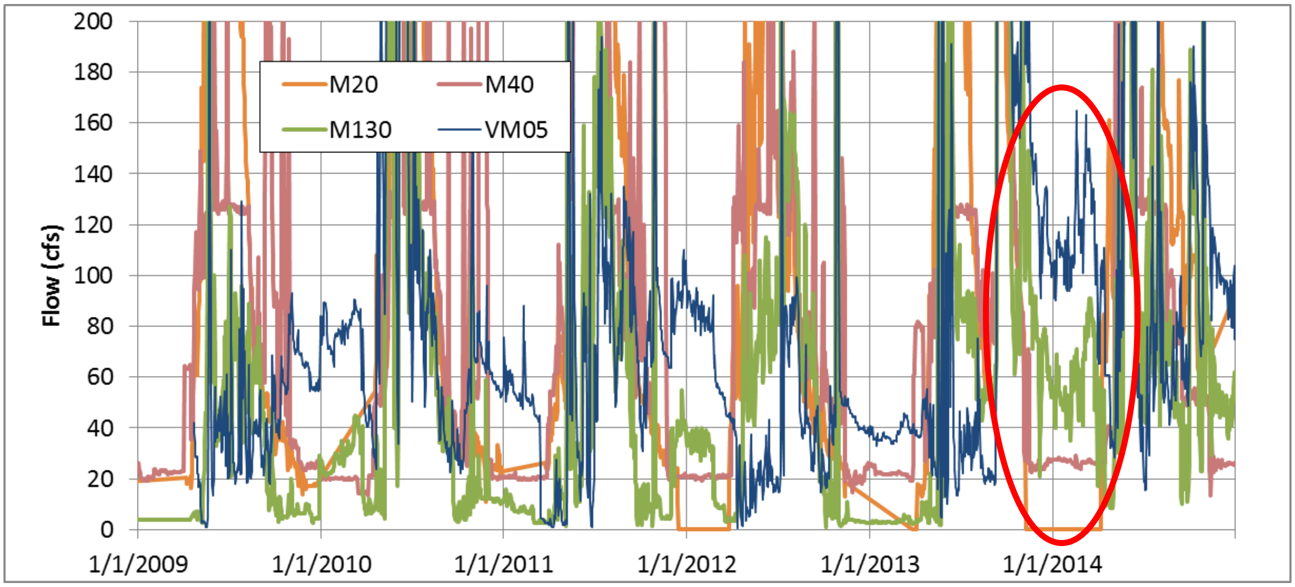

Figure 25. Hydrographs M20, M40, M130, VM05; 2009-2014; Focus on Lower Flow Rates, Post-Flood Winter Flows Circled

3.2 NUTRIENTS

The Forum has identified nutrients as constituents of concern for the watershed (Buirgy, 2007). This was further supported by the previous State of the Watershed Report (Hydros, 2011). Seven measures of nutrients are included in this data review:

- Nitrogen parameters:
  - Ammonia nitrogen,
  - Total Kjeldahl nitrogen (TKN; = organic nitrogen + ammonia nitrogen),
  - Nitrate + nitrite, and
  - Total nitrogen (= TKN + nitrate + nitrite).

- Phosphorus parameters:
  - Total phosphorus,
  - Dissolved phosphorus, and
  - Orthophosphate.

Nitrogen and phosphorus are macronutrients and serve as chemical building blocks for plant and animal life; however, in excess, they can lead to degradation of water quality through the effects of over fertilization (eutrophication) and toxicity.

- Nitrogen exists in various forms in natural waters as it moves through the nitrogen cycle, including: dissolved nitrogen gas (N_2), organic nitrogen, ammonia, ammonium ion, nitrite, and nitrate. Certain forms of nitrogen can be toxic to fish or animals at elevated concentrations (e.g., ammonia can be toxic to fish when present in the un-ionized form [NH_3], which is dominant at higher pH; and nitrate in drinking water can be toxic to infants. Ammonia can also lead to oxygen depletion and increased nitrate concentrations through nitrification.

- Phosphorus is naturally a fairly scarce resource in most environments; however, many human activities increase phosphorus loading to surface waters. Sources include human and animal wastes, fertilizer, phosphate detergents, and anthropogenic soil erosion. Between nitrogen and phosphorus, phosphorus is generally the more-limited nutrient in natural waters, making it the primary controlling nutrient for eutrophication; however, this can vary depending on local aquatic systems and sources (Walker, 1992). Orthophosphate is the form that is most readily available to plants. Dissolved phosphorus includes both orthophosphate and non-particulate organic and inorganic phosphorus.

This section describes the findings of concentration plotting, the trend analysis, loading calculations, and the compliance analysis for nutrients.

3.2.1 Nutrient Concentrations

Nutrient concentrations are presented on time-series concentration plots (Appendix C1, Figures C1-32 through C1-93) and concentration box plots (Appendix C2, Figure C2-9 through C2-15). The following subsections describe and discuss patterns observed in the concentrations dataset for nitrogen and phosphorus nutrients.

The concentrations and seasonality of nutrients vary widely across the watershed. Observed concentrations of nitrogen and phosphorus parameters vary by almost three orders of magnitude (e.g., Figure 26). Lower nutrient concentrations are typically observed in the upper sub-watersheds, and the higher concentrations are typically observed in the lower part of the watershed. There are a few noteworthy patterns in these concentration variations across the watershed:

- **Increase at M140:** There is a clear jump in total nitrogen and total phosphorus concentrations in the lower watershed, starting at M140, which is located below the outfall for the Loveland WWTP (e.g., Figure 26). The maximum concentrations of ammonia, nitrate plus nitrite, TKN, orthophosphate, and dissolved phosphorus were also observed at M140.

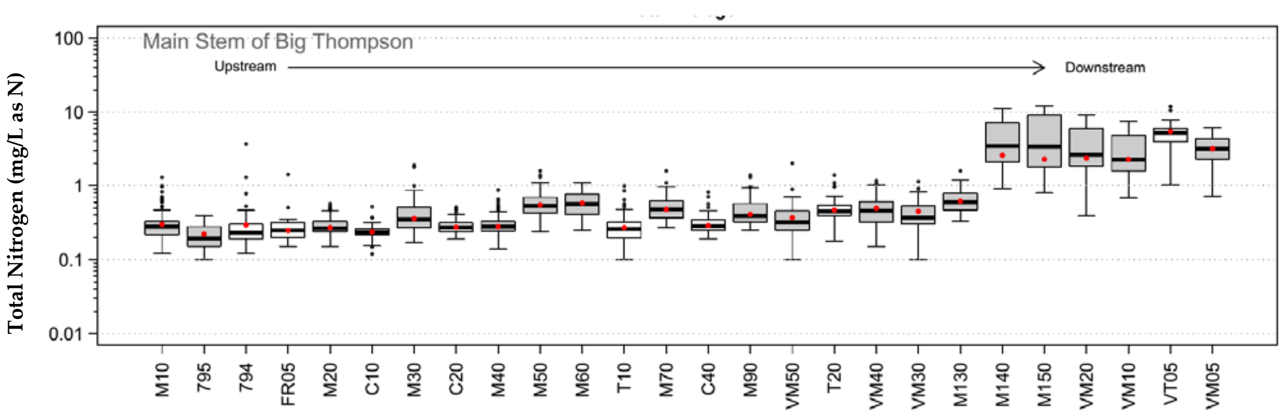

Figure 26. Box Plot of Total Nitrogen Concentrations (mg/L) in the Big Thompson River, WY2000-WY2014

Grey-shaded boxes indicate mainstem locations. Unshaded boxes indicate inflows. Red dots indicate median for recent 5 years of record (WY2010-WY2014). Note logarithmic scale.

- **Below WWTPs:** As shown on Appendix Figures C2-15 and C2-11, total nitrogen and total phosphorus concentrations increase below each of the major WWTPs in the watershed: M30 (below the Estes Park Sanitation District effluent), M50 (below the Upper Thompson Sanitation District effluent), substantially at M140 (below the Loveland WWTP effluent), and at VT15 (below the Berthoud WWTP). These increases below WWTPs reflect increases in nitrate and/or ammonia, TKN, orthophosphate, and dissolved phosphorus. The larger increase below M140 reflects large amounts of treated wastewater as well as reduced dilution due to major water diversions from the river upstream of the outfall.

- **C-BT Canal Stations:** Nitrogen and phosphorus parameter concentrations in the C-BT canal stations (C10, C20, C30, C40, and C50) remain fairly consistent across the watershed, showing only a slight increase moving downstream. Total nitrogen and total phosphorus concentrations entering the watershed from the west slope at C10 are comparable to those in the upper Big Thompson watershed. Orthophosphate, ammonia, and nitrate concentrations at C10, however, are even lower than those in the upper Big Thompson watershed.

- **Tributaries vs. Mainstem:** Data from Glacier Creek (794) and Fall River (FR05) indicate that these upper watershed tributaries have generally similar nutrient concentrations to the mainstem of the Big Thompson where they enter. Nutrient concentrations from Buckhorn Creek (T20) are also generally comparable to the mainstem waters at the confluence, though Buckhorn Creek nitrate and total nitrogen tend to be slightly higher.

The North Fork (T10), exhibits low nutrient concentrations more consistent with the upper watershed than with the Big Thompson at their confluence. This reflects the largely pristine, high mountain watershed of the North Fork. Finally, the Little Thompson River (VT05) brings in higher concentrations of total nitrogen, ammonia, nitrate, and TKN (relative to Big Thompson River water quality just upstream of the confluence); though it brings in lower concentrations of total phosphorus and orthophosphate.

Seasonal patterns in nitrogen and phosphorus compound compositions vary across the system. At the upstream end of the system (M10 and M20) and in the major upper-watershed tributaries of North Fork (T10) and Buckhorn Creek (T20), total phosphorus and TKN concentrations are typically highest during the spring snowmelt runoff period (May – June) due to the mobilization of natural organic and inorganic materials within the watershed. Nitrate plus nitrite is highest in the winter, possibly reflecting baseflow sources. Similar patterns are observed in water coming from the West Slope (C10; Adams Tunnel). However, TKN at C10 is often highest in the fall (August – September), likely reflecting late summer algal growth in west slope C-BT system reservoirs. Beginning at M30 (downstream of Estes Park Sanitation District) seasonal nutrient concentrations patterns reflect the influence of more anthropogenic sources, including WWTP effluent. Below major WWTPs, total nitrogen, nitrate, ammonia, total phosphorus, and orthophosphate concentrations tend to be lower in summer months and higher in the winter. This reflects dilution and lesser uptake of nutrients by periphyton in winter months.

Very few samples were collected during the 2013 flood hydrograph (see Appendix B2 for comparisons of sampling dates and increased flow rates). Upper watershed samples (e.g., M10) indicate increased total phosphorus, total nitrogen, and TKN concentrations in the post-flood fall 2013 samples. Nitrate (and total nitrogen, which includes nitrate) was also higher than typical at M10 in the early spring of 2014 following the flood. While it is expected that high suspended solids concentrations transported organic matter containing both nitrogen and phosphorus, resulting sample concentrations in the fall of 2013 were not particularly elevated above typical concentrations in the watershed below M30. This reflects the timing of sampling and the typical effects of WWTPs and dilution effects on the tail end of the flood hydrograph. Sampling did occur at C10 during the flood event, and these samples show spikes in nitrogen and phosphorus for those samples, but no post-flood effects.

Post-flood, the increased baseflow rates resulted in increased winter flow rates in the lower watershed (Figure 25); this served to dilute phosphorus and nitrogen from WWTP effluent. This winter-time dilution is most apparent in reduced nutrient concentrations in the mainstem of the Big Thompson river from M140 (located below the Loveland WWTP outfall) to the confluence with the South Platte. As an example, total phosphorus concentrations at M140 are presented in Figure 27. Because baseflow had not returned to pre-flood conditions by the end of 2014 (Figure 25), the duration of this effect is currently uncertain.

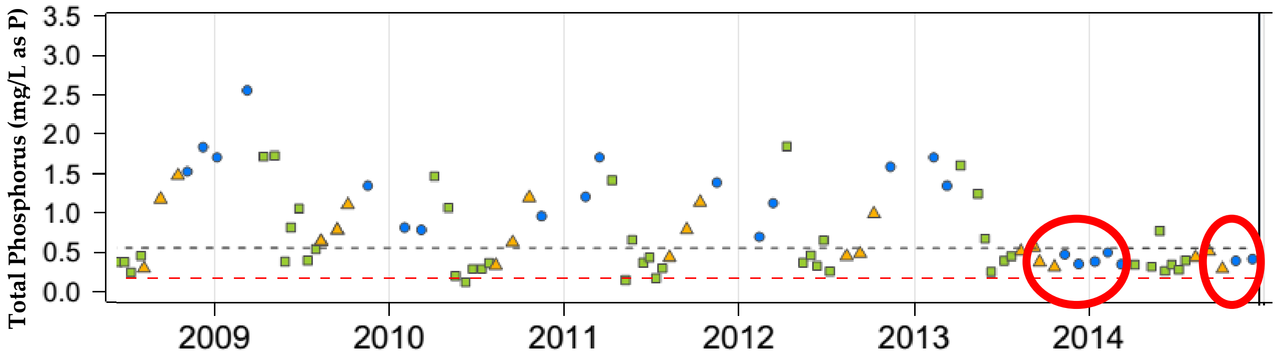

Figure 27. Total Phosphorus Concentrations (mg/L) at M140, 2009-2014, Post-Flood Winter Concentrations Circled

(Symbol colors indicate season; red dashed line indicates the interim nutrient stream standard [not currently applicable]; black dashed line indicates long-term linear trend [not statistically significant].)

Apparent effects of wildfires on nutrient concentrations in the Big Thompson River are limited in this dataset. At M10 (the nearest gage to the October 2012 Fern Lake fire), higher than typical concentrations of TKN and total phosphorus are apparent in spring runoff samples. Subsequent effects are not as clear and are difficult to discern from possible post-flood effects. Data at the next downstream mainstem station with data through this period (M20) are not as definitive, suggesting the duration and spatial extent of the effects of the Fern Lake fire on nutrient concentrations was very limited. More detailed discussion of effects of the wildfires on water quality is presented in Section 3.6.1.

3.2.2 Nutrient Concentration Trends

Concentration time-series data for nutrients were evaluated for statistically-significant trends applying Seasonal Mann-Kendall testing, as described in Section 2.2.2. The trend testing assesses whether or not there is a statistically-significant trend of increasing or decreasing concentration from 2000 through 2014. The testing also indicates the magnitude of trends. Using the generally inclusive significance threshold of p-values less than or equal to 0.10 (90% confidence level), trends were evaluated for all nutrients across the system, as listed in Appendix E. The trends were further assessed with a review of the time-series plots and additional testing to assess whether trends were influenced by the recent flood results. The following presents highlights of the findings generated from this analysis.

In the upper-most portions of the watershed (M10, 794, M20, M30), statistically-significant trends of decreasing nitrate concentrations from 2000-2014 were found (e.g., Figure 28). The decrease is on the order of 2 to 6 µg/L per year and the trends meet a 99% confidence threshold. Over the 15-year period, this corresponds to a decrease of 25 to 55% of the median concentrations. This finding agrees well with recently published findings of a long-term study in the Colorado Front Range (Mast et al., 2014). Mast et al. (2014) found that stream nitrate concentrations below Loch Vale (a high elevation location in Rocky Mountain Nation Park) increased in the early 1990's but have been decreasing since the early 2000s. Nitrate concentrations were found to have decreased by over 40% since the peak in the early 2000s. This is reported by Mast et al. (2014) to be coincident with an observed decline in nitrogen oxides in the atmosphere in response to USEPA-mandated regulatory limits on vehicle and stack emissions.

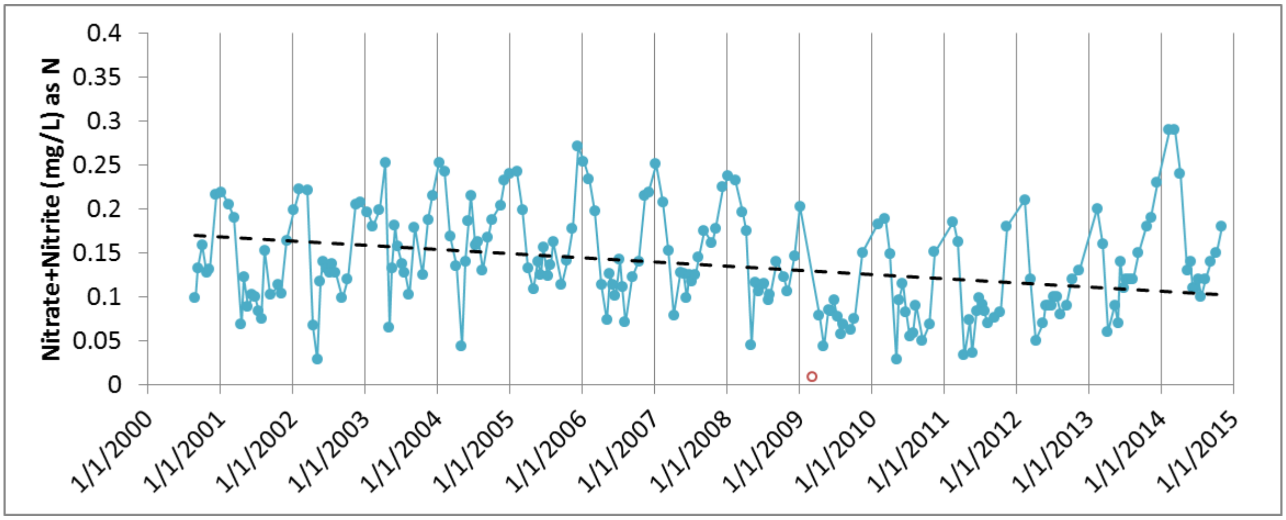

Figure 28. Nitrate + Nitrite Concentrations (mg/L) at M20 (Trend slope shown as black dotted line)

At M30 (located below the outfall of the Estes Park Sanitation District), there is a larger decreasing trend in total nitrogen that is comparable in magnitude to the decreasing trend in TKN found at the same location (-13 µg/L per year). This may reflect historical improvements in treatment at the Estes Park Sanitation District WWTP.

Canal stations C10, C20, C30, and C40 all show statistically-significant decreasing trends for ammonia. The confidence on this trend is greatest at C10; however, all of these trends are very small in magnitude (0.3 to 0. 4 µg/L per yr). T10, C20, C40, and M130 show statistically-significant increasing trends for total phosphorus concentrations. These were generally small (0.1 to 0.3 µg/L per year). These increasing trends in total phosphorus match trends in orthophosphate for M130 and T10. For C20 and C40, the total phosphorus trends match trend directions for TOC concentrations at these locations (discussed in Section 3.5.2), suggesting increasing organic phosphorus.

At C50, the inflow to Horsetooth Reservoir, the data indicate statistically-significant decreasing trends for both orthophosphate and total phosphorus concentrations, though the magnitude of the trends is small (0.04 ug/L per yr and 0.3 ug/L per yr, respectively) . Statistically-significant trends were not exhibited for the other nutrient parameters at this site.

3.2.3 Nutrient Loading

Nutrient loading analysis results are summarized in Appendix D Figures D1-2 through D1-11 (box plot figures) and D2-2 through D2-11 (bar graph figures). Nitrogen and phosphorus load calculation results reflect expected patterns based on flow and concentration data. Specifically, nutrient loads increase below major WWTPs. Due to a jump in nutrient concentrations, annual nutrient loads in the lower part of the watershed below M140 are comparable to or higher than upstream loads despite lower flow rates. Loads from tributaries with multiple years of flow records (North Fork and Buckhorn Creek) are low relative to mainstem locations. Canal locations have relatively high nutrient loads in spite of relatively low concentrations, due to high volumes.

Loading results were reviewed to help assess the relative composition of total nitrogen and total phosphorus across the watershed. As shown in Figure 29 through Figure 31, TKN (organic nitrogen plus ammonia) comprises the majority of the total nitrogen load from the headwaters to M130 and in the canals. Because ammonia is a small fraction of the TKN, this indicates that the total nitrogen is dominated by organic nitrogen in these areas. From M140 to the confluence with the South Platte and in the Little Thompson (VT05), the pattern changes. In these reaches, nitrate comprises the greater fraction of the total nitrogen load, reflecting WWTP loading and possibly the influences of livestock.

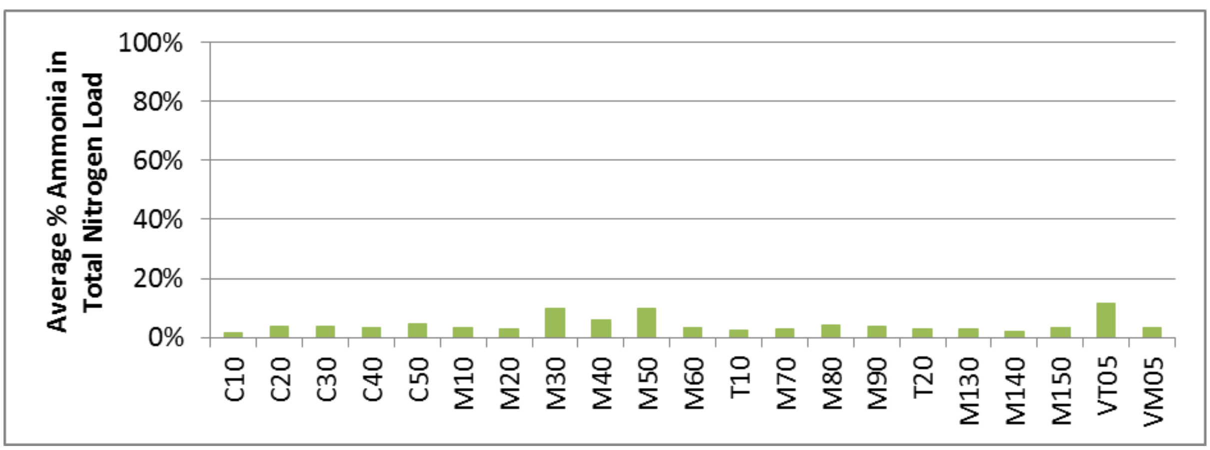

Figure 29. Average Ammonia Fraction in Total Nitrogen Load, 2000-2014

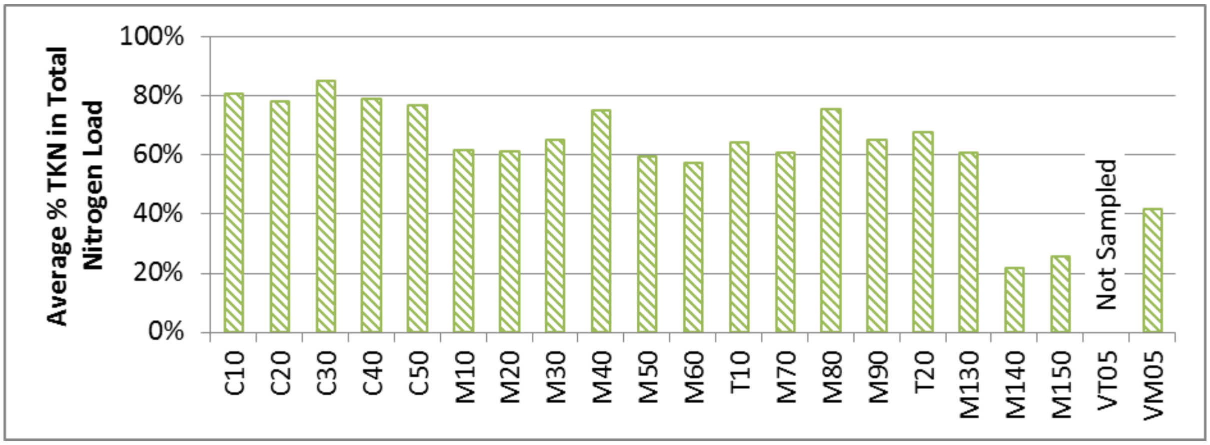

Figure 30. Average TKN Fraction in Total Nitrogen Load, 2000-2014

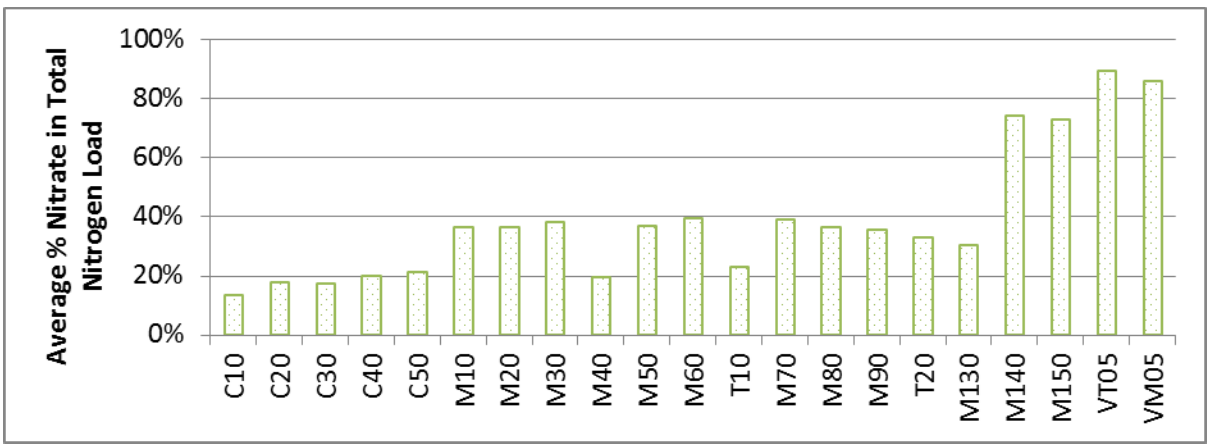

Figure 31. Average Nitrate plus Nitrite Fraction in Total Nitrogen Load, 2000-2014

Phosphorus loading data were reviewed to assess the relative fraction of particulate phosphorus and orthophosphate in total phosphorus across the watershed (Figure 32 and Figure 33). The C-BT canal system carries more particulate phosphorus than dissolved phosphorus (as calculated by the difference between the total phosphorus and the dissolved phosphorus). On the average, the particulate fraction comprises nearly 70% of the total phosphorus at the upstream canal locations. In contrast, the particulate fraction comprises less than 20% of the load observed from M140 to the South Platte. In fact, as shown in Figure 32, the relative decrease in the particulate fraction (and corresponding increase in dissolved fraction) of total phosphorus load can be seen below each major WWTP outfall (M30-Estes Park Sanitation District, M50- Upper Thompson Sanitation District, and M140-Loveland WWTP), though the effects are most dramatic at M140. The fraction of orthophosphate in the dissolved phosphorus also increases below each major WWTP outfall (M30, M50, and M140Figure 33), since orthophosphate generally makes up a significant fraction of the total phosphorus in raw domestic wastewater. Orthophosphate is the form most readily available to aquatic plants/algae, and is an important parameter in assessment of eutrophication.

Figure 32. Average Particulate Phosphorus Fraction in Total Phosphorus Load, 2000-2014

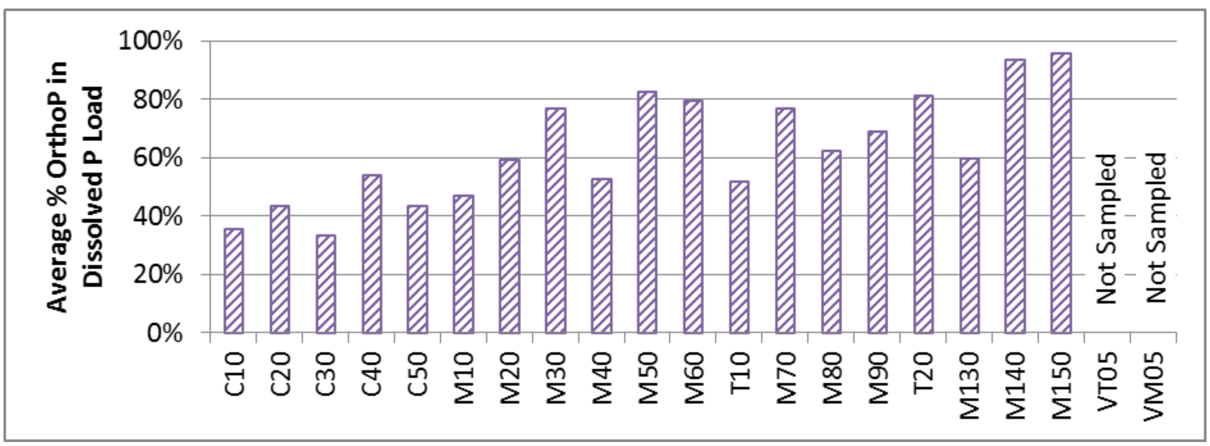

Figure 33. Average Fraction of Orthophosphate in Dissolved Phosphorus Load, 2000-2014

3.2.4 Nutrient Compliance

As described in Section 2.2.3, ammonia data were compared to applicable acute and chronic aquatic life Colorado WQCD water-quality standards (Regulation 38), while nitrate data were compared to applicable domestic water supply or agriculture standards. Total nitrogen and total phosphorus concentrations were compared to the interim Colorado WQCD numeric nutrient criteria. These interim criteria were not applicable to any reach in the watershed for the period assessed. Total phosphorus standards have since been adopted (as of August 10, 2015; WQCD, 2015b) for segments 1, 2, 6, 7, 8, 9, and 10 of the Big Thompson watershed. A total nitrogen standard has not yet been adopted for any segment in the Big Thompson watershed.

Therefore, these comparisons of data from WY2000-WY2014 were made for informational purposes only. Assessments against standards and interim criteria are summarized in Appendix F.

Nitrate standards are very high relative to typical natural concentrations (10 mg/L standard for protection of domestic water supplies [applicable primarily in the upper watershed through M130 and in the lower Little Thompson River], and a 100 mg/L standard for protection of agriculture [livestock] water supplies [applicable primarily in the lower watershed from M140 to the South Platte]; Table 4). Comparison of observed data to these standards indicated only one exceedance at any location in the 15 year record. Specifically, there was one recent summer observation at the downstream end of the Little Thompson River (VT05) with a nitrate concentration greater than 10 mg/L.

For ammonia, the standard varies as a function of pH (and in some cases temperature), as described in Section 2.2.3. There are a few historical exceedances in 2003 and 2004 below the Loveland WWTP outfall at M140 and M150; however, there are no recent issues. Across the watershed, ammonia concentrations tend to be in compliance with acute and chronic aquatic life standards.

The interim numeric criteria for total nitrogen and total phosphorus indicate potential future areas of concern at the downstream end of the watershed, beginning at M140, below the Loveland WWTP outfall. Data from all stations between M140 and the confluence with the South Platte would have exceeded the interim total nitrogen and total phosphorus values (2.01 mg/L and 0.17 mg/L, respectively, at these stations, and assessed as an annual median) in 60 to 100% of the years with historical data. This is also seen on the Little Thompson River starting at VT15. The percent of years in the observed dataset (2000-2014) with annual median concentrations greater than the interim criteria are plotted for each station in Figure 34. Stations in this figure are ordered roughly from upstream to downstream. As of December 31, 2015 (WQCD, 2015b), the interim total phosphorus standard will be applicable from M10 through M70, as well as tributary location T10, T20, NFBT10, and the Little Thompson locations (VT05, VT15, and VT20). Therefore, in the near-term, the key area of concern will be the Little Thompson River. Note that implementation of Regulation 85 (Nutrients Management Control Regulation, adopted in 2012) is expected to result in future total phosphorus and nitrogen reductions in effluent from the WWTPs within the watershed.

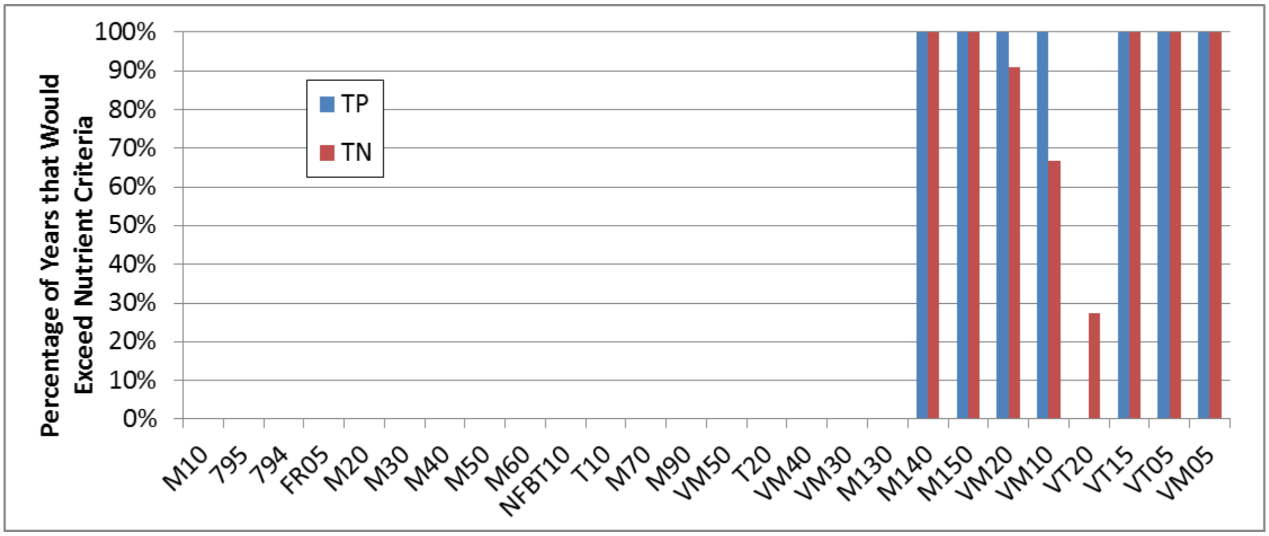

Figure 34. Summary of Data Comparison to Interim Nutrient Criteria, 2000-2014

3.3 METALS

Ten segments of the Big Thompson watershed are on the 2012 (current) 303(d) List (WQCD, 2012a) for copper, cadmium, selenium, and zinc (Figure 8, Table 1). In addition to these stream segments, lakes and reservoirs within the watershed are listed for arsenic, copper, lead, and mercury (in fish tissue). The metals considered in this assessment are:

- Cadmium (dissolved),
- Copper (dissolved),
- Lead (dissolved),
- Mercury (total),
- Selenium (dissolved), and
- Zinc (dissolved).

The metals considered in this report are ubiquitous, naturally occurring elements in the crust of the earth. Concentrations of these metals in rock and soils of the watershed are typically low. Elevated concentrations of these metals can occur due to mineral deposits or as the result of human activities. Copper, selenium, and zinc are essential elements for plants and animals (including humans); however, elevated concentrations can be toxic. Cadmium, lead, and mercury, however, are not essential and have forms identified as being carcinogenic or potentially carcinogenic (ATSDR 1999, 2003, 2004, 2005, and 2008). Of these metals, selenium and certain forms of mercury are known to bioaccumulate (ATSDR 2003 and 2008). All of these metals are present naturally; however, anthropogenic activities have greatly affected the distribution and cycling of these metals in the environment.

Cadmium is primarily released as a by-product of mining and manufacturing processes. Anthropogenic lead emissions were primarily driven by the combustion of lead-containing gasoline and lead-based paint. Mercury is released as a by-product of mining activities and during the combustion of fossil fuels. Certain geologic formations, such as the Pierre shale occurring on the Plains portion of the watershed, are known to be enriched in selenium. Anthropogenic releases of selenium are dominated by fossil fuel combustion and irrigation return flows in areas underlain by Pierre shale. Lastly, zinc releases are driven by mining and metal production activities.

Copper sulfate was historically used in the C-BT canals in the Big Thompson watershed to control periphyton (attached algae) and aquatic plants, with Northern Water's use dating back to around 1964. However, both Northern Water and the U.S. Bureau of Reclamation (USBR) have discontinued the use of copper sulfate in the C-BT canals. Northern Water discontinued its use in April 2008 (Hydros, 2011), while the USBR discontinued its use sometime before June 2012 when the Pole Hill canal was covered over (personal communication between J. Billica, Northern Water, and Tony Curtis, USBR, 5/8/15). Because of the 303(d) listings for copper in downstream stream segments, the use of copper-containing aquatic herbicides in C-BT canals is not allowed under the USBR's EPA NPDES Pesticide General Permit or Northern Water's Colorado Pesticide General Permit. However, the City of Loveland occasionally uses copper sulfate for algal biomass control in Green Ridge Glade Reservoir (adjacent to their WTP near site M90 and VM50) which can discharge augmentation water back to the Big Thomson River.

This section describes the findings of concentration plotting, trend analysis, and the compliance analysis for metals.

3.3.1 Metals Concentrations

Metal concentrations are presented on time-series concentration plots (Appendix C1, Figures C1-1 through C1-31) and concentration box plots (Appendix C2, Figure C2-1 through C2-6). The following subsections describe and discuss patterns observed in the concentrations dataset for the six metals of interest.

The concentrations and patterns in metals concentrations vary across the watershed. Lower concentrations are typically observed in the upper sub-watersheds, and higher concentrations are typically observed at in the lower part of the watershed. The upstream-to-downstream concentrations changes are relatively small in magnitude. Nonetheless, there are a few noteworthy patterns in these concentration variations across the watershed:

- **Geology Driven Selenium Concentrations:** The most readily apparent trend in metals concentrations is the large increase in selenium concentrations observed downstream of station M90 (Figure 35). The increase is driven by a change in geology. The Pierre shale is known to be enriched in selenium and is a major component of the geology from the edge of the mountains east to the confluence with the South Platte (Figure 7). Selenium is contributed to the river primarily by influent groundwater. The highest concentrations of selenium are observed in the Little Thompson, which has a greater proportion of watershed underlain by Pierre shale. In addition, the highest selenium concentrations are observed in winter when the ratio of influent groundwater to in-stream flows is the highest.

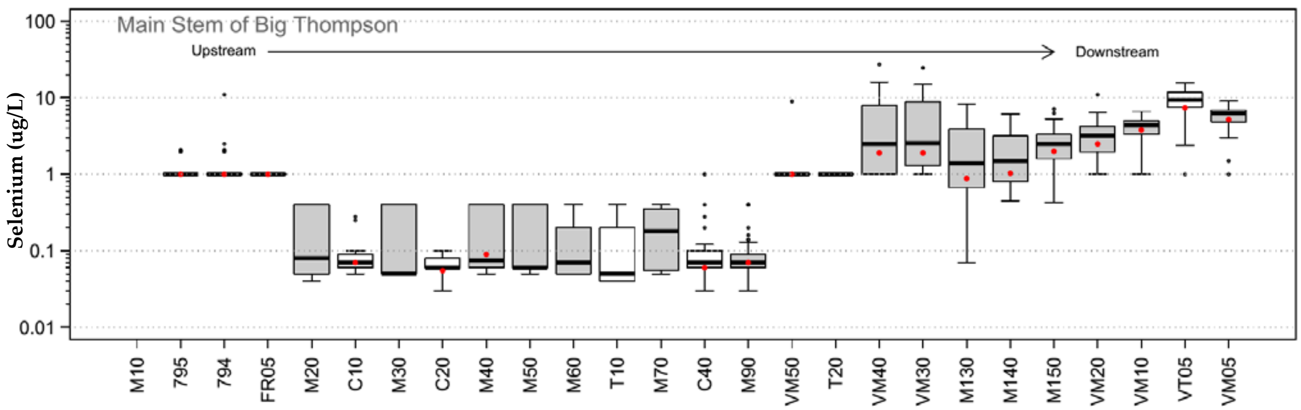

Figure 35. Box Plot of Dissolved Selenium Concentrations (µg/L) in the Big Thompson River, WY2000-WY2014

Grey-shaded boxes indicate mainstem locations. Unshaded boxes indicate inflows. Red dots indicate median for recent 5 years of record (WY2010-WY2014). Note logarithmic scale.

- **Mercury Seasonality:** In contrast to the other metals, mercury is evaluated as a total concentration (dissolved plus particulate forms). The highest total mercury concentrations are associated with the snowmelt period of late spring/early summer (e.g., Appendix C1, Figure C1-5). This peak in concentration is associated with increased sediment transport and mobilization of the winter-time load of atmospherically-deposited mercury.

- **Highly-Censored Data:** "Censored" is a term used to describe analytical results below the detection limit. Much of the metals data are highly censored. This applies especially to the dissolved cadmium results and the results of the Volunteer monitoring program. The pattern of censoring is illustrated in the results for dissolved lead (Figure 36). In this figure, the "collapsed" boxes at 1 µg/L (shown at all Volunteer monitoring stations) are stations dominated by non-detect data. As can be seen in the results from the COOP stations, the ambient concentrations of lead in the Big Thompson are typically near or below 0.1 µg/L. While the highly-censored lead, cadmium, and copper datasets from the Volunteer monitoring program limit assessment relative to the COOP program, they still provide some useful information at most locations for comparison to standards. The exceptions to this are copper at VM50, NFBT10, FR05, and 794 (also cadmium at 794). For these Volunteer stations/parameters, the detection limit is near or above the calculated standard. As such, it is recommended that a method with lower detection limit be applied to these cases.

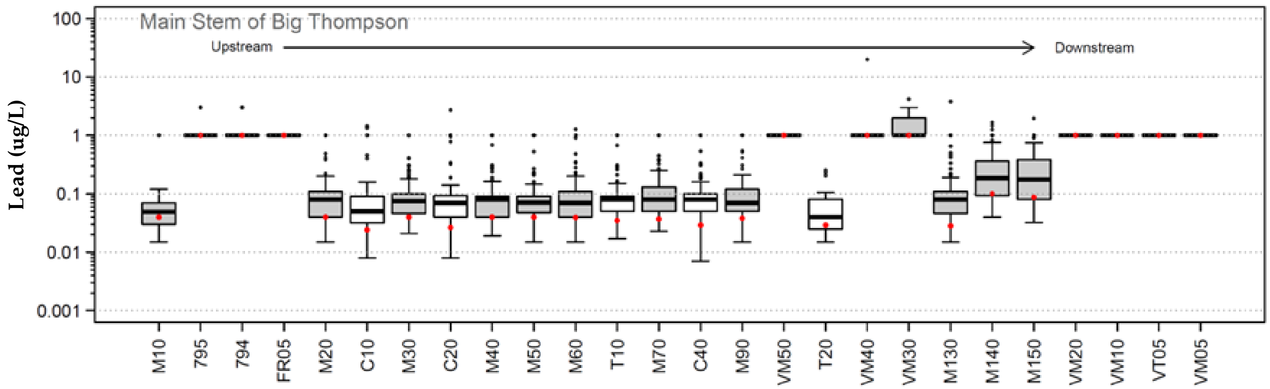

Figure 36. Box Plot of Dissolved Lead Concentrations (µg/L) in the Big Thompson River, WY2000-WY2014

Grey-shaded boxes indicate mainstem locations. Unshaded boxes indicate inflows. Red dots indicate median for recent 5 years of record (WY2010-WY2014). Note logarithmic scale.

- **WWTP Influences on Lead:** The Big Thompson watershed does not have major industrial or mining point sources for metals; rather, the sources are smaller and more disperse. This is apparent in the limited concentration variability across the watershed for most metals (except selenium, as discussed earlier). There are two exceptions to this in the lead dataset. First, as shown in Figure 36, there is a small upstream-to-downstream increase in lead concentrations. Second, at M140, an increase in concentrations is observed, likely reflecting WWTP effluent loading of lead to the river.

- **Fire Effects:** Within the Forum database, there are no definitive patterns in metals data associated with the 2012 fire upstream of M10 or 2011 and 2012 fires upstream of T20. Fire effects are discussed further in Section 3.6.

- **September 2013 Flood Effects:** Metals concentrations are expected to have increased during the 2013 flooding; however, sampling was not conducted on the river during the flooding event due to access and safety issues. There are some indications of short-term increases in some metals concentrations (e.g., lead) in the upper watershed and C-BT canals based on sampling following the peak of the September 2013 flood. Further, there may be a decrease in selenium concentrations in the lower watershed following the flood, suggesting dilution of Pierre shale-contacting groundwater by groundwater from other saturated areas. Flood effects on water quality are discussed in greater detail in Section 3.6.

3.3.2 Metals Concentration Trends

Concentration time-series data were evaluated for statistically-significant trends applying the Seasonal Mann-Kendall approach, as described in Section 2.2.2. The trend testing assesses whether or not there is a statistically-significant trend of increasing or decreasing concentration from 2000-2014. The testing also indicates the magnitude of trends. Using the generally inclusive significance threshold of p-values less than or equal to 0.10 (90% confidence level), trends were evaluated, and results are presented in Appendix E. Only two metals, copper and lead, show statistically significant trends that consistently occur at multiple stations.

In the upper watershed, ten stations (the mainstem stations M20 through M90, T10 and canal stations C10 and C20) show statistically-significant increases in copper concentrations. The magnitude of the increases is relatively low (0.05 μg/L to 0.1 μg/L per year, or roughly 2 to 7% of the mean annual concentration), and the reason for this pattern is uncertain. Station M20 is upstream of all C-BT system components, indicating a natural background source of copper. There is a trend of decreasing copper concentrations at C30 with a magnitude of 0.06 μg/L per year. In spite of no statistically-significant trend in copper at C40, and C50, time-series plots for these stations (Appendix C1, Figures C1-16 and C1-17) show lower copper concentrations in 2014, likely reflecting the discontinued use of copper sulfate within the C-BT canals.

Lead concentrations have statistically-significant decreases at all the mainstem stations from M20 through M150, all the canal stations, and at T10. However, the magnitude of this decrease is very small (typically around -0.005 μg/L per year, or ~2.6% of the annual mean). This may reflect reduced atmospheric loading of lead from leaded petroleum products.

3.3.3 Metals Compliance

Metals concentration data in the Forum database were evaluated against both acute and chronic aquatic life metals standards (Appendix F). No acute or chronic exceedances were identified for cadmium over the entire period of record, but other metals show at least some exceedances:

- **Cadmium:** No acute or chronic exceedances were identified for cadmium over the entire period of record. Results were largely below detection limits, but most detection limits were below calculated standards. From this dataset, the basis for 303(d)-listing of cadmium in Segment 2 of the upper watershed is uncertain. Removal of the cadmium listing is proposed for the upcoming December 2015 rulemaking hearing (WQCD, 2015c).

- **Copper:** There is a high frequency of exceedances of the aquatic life copper standard (61% for chronic and 41% for acute) in the most upstream station in the watershed (M10). The low hardness values at this station results in very low copper water-quality standards. However, moving downstream the increase in hardness rapidly results in decreases in the fraction of samples above the standards, dropping to 11% chronic and 6% acute exceedances by station M20. There is also a relatively high frequency of chronic copper standard exceedances (22%) at M90. The City of Loveland occasionally uses copper sulfate for algal biomass control in Green Ridge Glade Reservoir (adjacent to their WTP near site M90), which can discharge augmentation water back to the Big Thomson River. Based on this dataset, the basis for the 303(d)-listing of the lower Little Thompson River (Segment 9) for copper is uncertain. It is currently expected that the lower Little Thompson River will be de-listed for copper for the 2016 303(d) List, consistent with the findings of this review (Billica, 2015, personal communication). The final revised listings, however, will not be set until after the December, 2015 hearing (WQCD, 2015c).

- **Lead and Zinc:** Like copper, lead and zinc have hardness-dependent standards, but fewer exceedances. Lead exhibits no exceedances in the recent seven years across the entire watershed. Zinc exhibits exceedances in upper watershed only at 794 in 2003. From this dataset, the basis for the current 303(d)-listing of zinc for much of the upper watershed (Segment 2) is uncertain. Removal of zinc from the 303(d) list for this segment is proposed for consideration in December, 2015 (WQCD, 2015c).

- **Selenium:** For selenium, there are very few exceedances of the acute standard (18.4 μg/L), but relatively high frequencies of exceedance of the chronic standards (ranging from 4.6 to 13.1 μg/L, depending on the segment; Table 4) in some areas. The more frequent exceedances (26 to 77%) all occur at downstream stations associated with influent groundwater from the Pierre shale (VM40, VM30, VM10, VT20, VM05). These patterns are consistent with the current and proposed 303(d) listings for the watershed.

- **Mercury:** There are occasional exceedances of the chronic aquatic life total mercury standard across much of the watershed, including M10, M20, M60, M70, M90, M130, M150, and T10. These occasional exceedances are only present in one or two of the years of record at these stations, with the exception of M10 which has exceedances in four of the eight years with mercury data.

3.4 MICROBIOLOGICAL PARAMETERS

Two microbiological parameters are included in this analysis:

- Total coliforms, and
- *E. Coli*.

Total coliforms and *E. Coli* are indicators of the potential presence of pathogens. Water-quality standards exist for *E. Coli* to protect recreational and domestic water supply uses of surface waters; the "primary contact" recreational use standard is more stringent than the domestic water supply use standard. Total coliforms is a measure of the concentration of coliform bacteria present in the water; and is often sampled as an inexpensive potential indictor of fecal contamination and related pathogens. These bacteria can come from the feces of warm-blooded animals and humans or from bacteria naturally present in soils. *E. coli* is a sub-group of the total coliform group, and its presence indicates fecal contamination from warm blooded animals (Birge, 1992). As such, it is a better indicator of the potential presence of harmful pathogens. Most *E. Coli* bacteria themselves are harmless and are naturally found in the intestines of people and warm-blooded animals; however, some strains can cause severe illness (http://water.epa.gov/drink/contaminants/index.cfm).

3.4.1 Microbiological Parameter Concentrations

Patterns in concentrations for total coliforms and *E. Coli* are similar across the watershed. Concentrations generally increase from upstream to downstream on both the Big Thompson and Little Thompson Rivers (Figure 37 and Appendix Figure C2-8). The concentrations in the Adams Tunnel (C10) are generally low relative to even the upper watershed concentrations. Across the watershed, including C-BT canal locations, both total coliforms and *E. Coli* show similar seasonal patterns of lower concentrations in winter and elevated concentrations in summer and fall (Appendix Figures C1-32 through C1-62). The highest concentration results for both total coliforms and *E. Coli* were observed on the Little Thompson at VT20. VT20 is downstream from Berthoud Estates WWTP and two minor WWTPs (Ranches/Vaquero Estates and River Glenn HOA). There may also be livestock sources of bacteria in this reach. Concentrations in T20 (Buckhorn Creek) are also noteworthy in that they are consistently high relative to the upstream mainstem concentrations at VM50/M90.

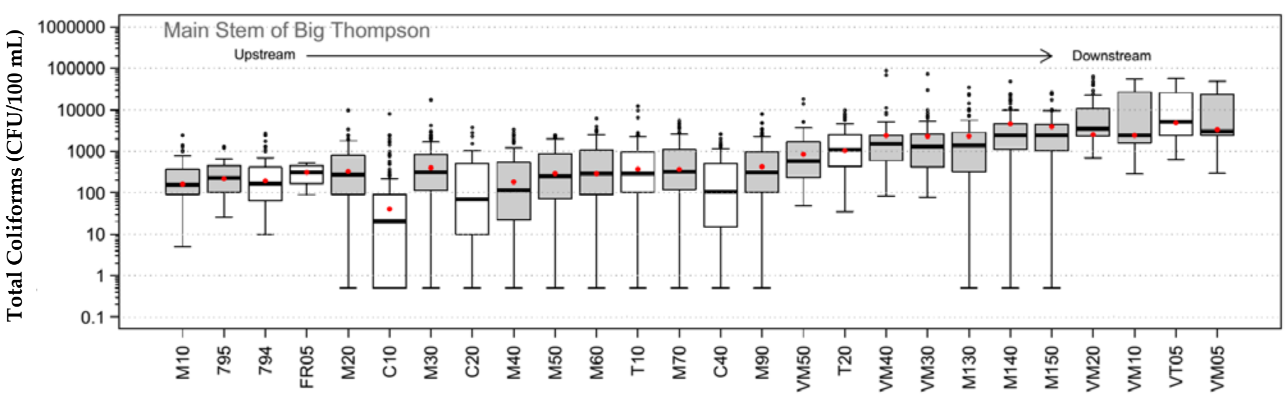

Figure 37. Box Plot of Total Coliform Concentrations (CFU/100mL) in the Big Thompson River, WY2000-WY2014

Grey-shaded boxes indicate mainstem locations. Unshaded boxes indicate inflows. Red dots indicate median for recent 5 years of record (WY2010-WY2014). Note logarithmic scale.

Coliform data do not show any clear patterns of effects from the flood or fires, with the possible exception of short-lived higher concentrations of *E. Coli* in the fall of 2013 following the flood in the upper watershed (M10 to M40).

3.4.2 Microbiological Parameter Concentration Trends

Concentration time series data for microbiological parameters were evaluated for statistically significant trends applying the Seasonal Mann-Kendall approach, as described in Section 2.2.2. Using the fairly inclusive criteria of p-values less than or equal to 0.10 (90% confidence level), statistically significant trends were identified for both total coliforms and *E. Coli*, as listed in Appendix E. The trends were further assessed with a review of the time-series plots.

Statistically-significant trends of increasing total coliforms were observed at most stations along the Big Thompson mainstem (M20 through M150), in the C-BT canals (C10 through C50), and at the end of the North Fork (T10). All of these increasing trends reflect occasionally higher summer or fall concentrations. The larger slopes on the increasing trends are at M130, M140, and M150. Statistically-significant trends for increasing *E. Coli* were found at five locations (794, T10, M130, M140, and M150), but the magnitude of these trends is small.

3.4.3 Microbiological Parameter Compliance

Of the microbiological parameters evaluated, water-quality standards only exist for *E. Coli*. The data were compared to the Class E (Existing Primary Contact) and Class U (Undetermined Use) recreational use standard of 126 cfu/100 mL. For stations downstream of M90, the data were assessed on a seasonal basis with a standard of 126 cfu/100 mL for May 1 through October 15[16], and a standard of 630 cfu/100 mL for October 16 through April 30. The percent exceedances are summarized in Appendix F.

Exceedances of *E. Coli* standards have occurred at most locations across the watershed, though exceedances are infrequent in the upper reaches and central mainstem. In the lower watershed, beginning with T20 (Buckhorn Creek), the frequency of exceedances generally increases downstream, with the most frequent exceedances on the mainstem observed at the downstream end (VM05), after the confluence with the Little Thompson River.

[16] For stations in segment 5, the May to October criterion is 205 cfu/100 mL. For a complete summary see Table 4.

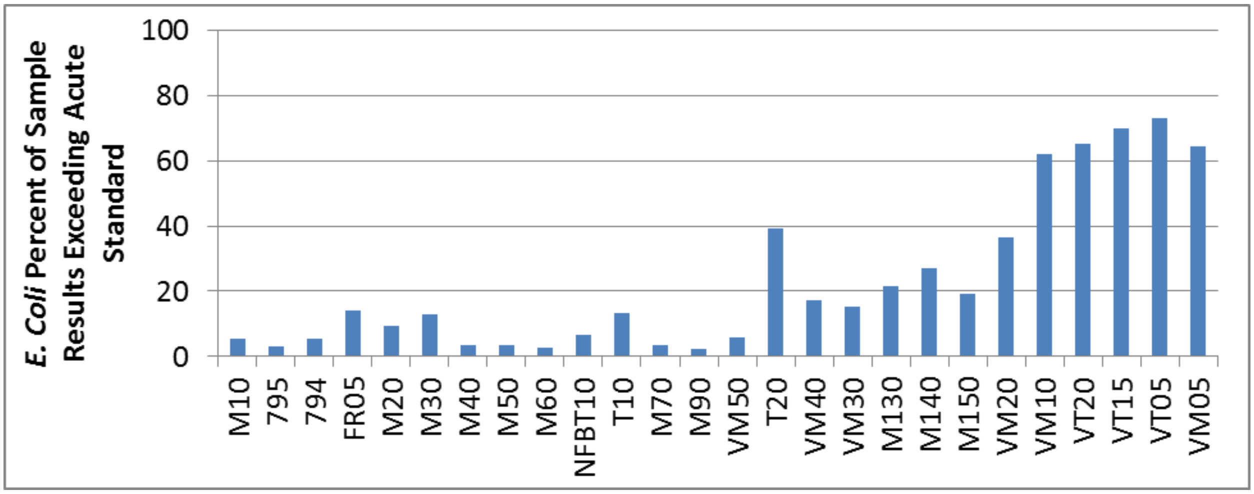

Figure 38. Summary of Data Comparison to *E. Coli* Standards, 2000-2014

The lower Little Thompson River is on the 303(d) List for *E. Coli*. The Little Thompson River exhibits a high frequency of *E. Coli* standard exceedances (>60%) at all locations, with increasing frequency moving downstream (VT20, VT15, and VT05; Figure 38). This may reflect livestock sources of bacteria in this reach.

3.5 GENERAL PARAMETERS

There are 11 general parameters included in this assessment:

- Alkalinity,
- Chlorophyll *a*,
- Dissolved oxygen,
- Hardness,
- pH,
- Specific conductivity,
- Sulfate,
- Temperature,
- TOC,
- TSS, and
- Turbidity.

These parameters provide a broad view of the overall physical, chemical, and biological conditions present in the watershed. This section describes the findings of concentration plotting, the trend analysis, loading calculations, and the compliance analysis for these parameters.

3.5.1 General Parameter Concentrations

Concentration trends for general parameters across the watershed are shown on box plot Figures C2-16 through C2-26. Time series plots of the general parameters are presented in three groups. Alkalinity, dissolved oxygen, hardness, pH, and specific conductivity presented in Figures C1-94 through C1-124. TDS, temperature, TOC, TSS, turbidity, and sulfate are presented in Figures C1-125 through C1-155. Chlorophyll *a* is presented on Figures C1-63 through C1-93. Spatial and seasonal concentration patterns are summarized as follows:

- **Temperature and dissolved oxygen** generally show expected seasonal and spatial patterns across the watershed. Temperature shows a general increasing trend from upstream to downstream (Figure C2-22). Dissolved oxygen concentrations show a general decrease from upstream to downstream, largely reflecting decreased saturation levels due to increasing water temperature (Figure C2-18). Dissolved oxygen in the C-BT canal system, however shows a small increase from upstream to downstream, reflecting slightly depressed dissolved oxygen concentration (relative to M20) upon entry to the watershed (C10). Figure C2-18 suggests lower median dissolved oxygen at VM50, VM20, VM10, and VT05; however, concentration time series plots for these locations (Figures C1-94 through C1-124) show that these Volunteer sampling stations have fewer samples in the winter (compared to COOP monitoring) when concentrations tend to be higher. This can be seen in comparison of medians from the nearly collocated Volunteer and COOP locations (VM50 and M90), showing a lower median for VM50.

- **Specific conductivity, hardness, and alkalinity** are all different measures of dissolved species in solution. These parameters show similar relative patterns across the watershed, with increasing values moving downstream, and a large increase at VM40 (e.g., Figure 39), which includes high concentrations from the tributary Buckhorn Creek (T20). Elevated concentrations are also apparent in the observations on the Little Thompson River. All of the locations with elevated TDS, specific conductivity, hardness, and alkalinity are located in areas of sedimentary bedrock geology (Figure 7). Additionally, there are several quarries in the Buckhorn Creek watershed (e.g., Arkins Park Stone Quarry, Colorado Flagstone Quarry, and Old Wild Gypsum Quarry) that might help explain these observations. Gypsum (calcium sulfate, $CaSO_4 \bullet 2\ H_2O$) is a common and soluble evaporite mineral in sedimentary rocks that may contribute to these elevated values.

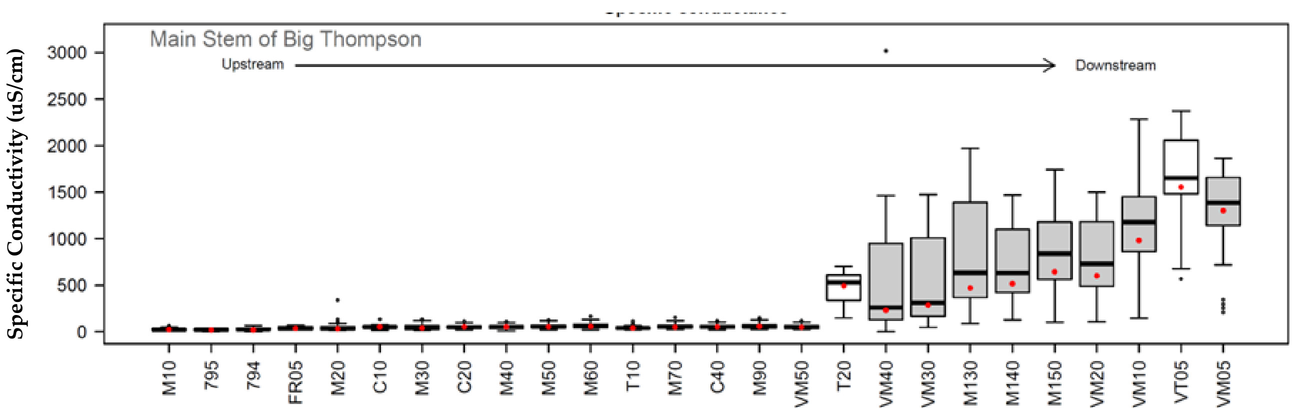

Figure 39. Box Plot of Specific Conductivity (uS/cm) in the Big Thompson River, WY2000-WY2014

Grey-shaded boxes indicate mainstem locations. Unshaded boxes indicate inflows. Red dots indicate median for recent 5 years of record (WY2010-WY2014).

- **Seasonally, specific conductivity, hardness, and alkalinity** are higher in winter and early spring (included as "summer" in the seasonal definitions for this report). The concentrations of these parameters drop in the late spring / early summer due to dilution by the snowmelt runoff waters.

- **Sulfate** concentration patterns across the watershed are similar to those of specific conductivity, hardness, and alkalinity, reflecting sources of sulfate from evaporite minerals. Pierre shale can also be a source of selenium. The highest sulfate concentrations are observed in the Little Thompson River.

- **pH** shows a generally increasing trend from upstream to downstream (Appendix Figure C2-20), with median values ranging from ~7 to ~8.

- **TSS and turbidity** are generally measures of solids in suspension; and, given the very limited dataset for TSS, these parameters were considered together. Figure 40 illustrates a few patterns across the watershed. First, turbidity and TSS are generally low from the CB-T system (C10), relative to M20. The observed range of turbidity is fairly consistent moving downstream until M130, where there is an increase in both the median value and range observed (Appendix Figure C2-25). The highest TSS concentrations have been observed on the Little Thompson River at the location where it meets the Big Thompson (VT05). Urban, suburban, and agricultural runoff are possible sources. Currently TSS is only being collected at the canal stations. It is recommended that TSS sampling be added back to the Volunteer and COOP programs to collect some measure of solids concentrations to support evaluation of changing conditions.

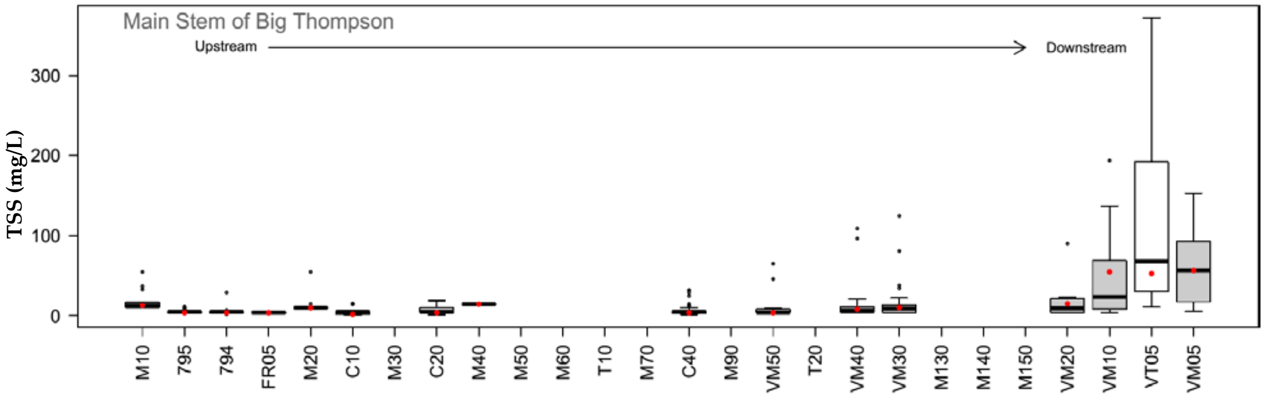

Figure 40. Box Plot of TSS (mg/L) in the Big Thompson River, WY2000-WY2014
Grey-shaded boxes indicate mainstem locations. Unshaded boxes indicate inflows. Red dots indicate median for recent 5 years of record (WY2010-WY2014).

- **Chlorophyll *a*** concentrations show some interesting spatial patterns.
  - The upper watershed (M20 and above) has generally low chlorophyll *a* concentrations. The upper basin tributary locations (T10 and T20) also have relatively low chlorophyll *a* concentrations.
  - The CB-T system carries higher chlorophyll *a* concentrations into the system at C10 (Adams Tunnel), as compared to M20, reflecting algae from the west slope Three Lakes system.
  - Below the City of Loveland, there is a general trend of increasing chlorophyll *a* concentrations, likely reflecting the input of nutrients as discussed in Section 3.2. Likewise, chlorophyll *a* concentrations increase sharply at VT05 on the Little Thompson, also possibly reflecting inputs of nutrients.
- **TOC** is one of the most important water-quality parameters for the drinking water treatment plants that treat Big Thompson River water and/or C-BT system water. TOC is important because it affects the optimization and efficiency of water treatment unit operations including coagulation and settling, and serves as the precursor for the formation of disinfection by-products (DBPs). DBPs are compounds that are formed when TOC reacts with chlorine at the water treatment plants and include carcinogenic compounds. Water treatment plants have regulatory requirements related to TOC removal and DBP concentrations in treated water. The following patterns, as shown in Figure 41, are apparent for TOC:
  - Median TOC concentrations along the Big Thompson River generally increase from upstream to downstream, with a small step increase at M140 (below the Loveland WWTP).

- o Increased TOC concentrations occur in the Big Thompson River each spring during the snowmelt runoff period due to the leaching of vegetation and soil organic material in the watershed. The peak TOC concentrations that occur in the upper watershed are comparable to peak TOC concentrations observed in the lower watershed (although the timing of the annual peaks may be different).

- o Median concentrations of TOC in the Little Thompson are comparable to those in the lower portion of the Big Thompson, though peak concentrations are often higher on the Little Thompson, possibly reflecting agricultural runoff.

- o TOC concentrations in C-BT water (C10, Adams Tunnel) reflect the conditions of the Three Lakes system. The median concentration is higher at C10 (3.7 mg/L) than at M20 (2.1 mg/L). In addition, TOC concentrations from the Adams Tunnel are less seasonally variable due to the dampening effect of mixing and residence time in the Three Lakes.

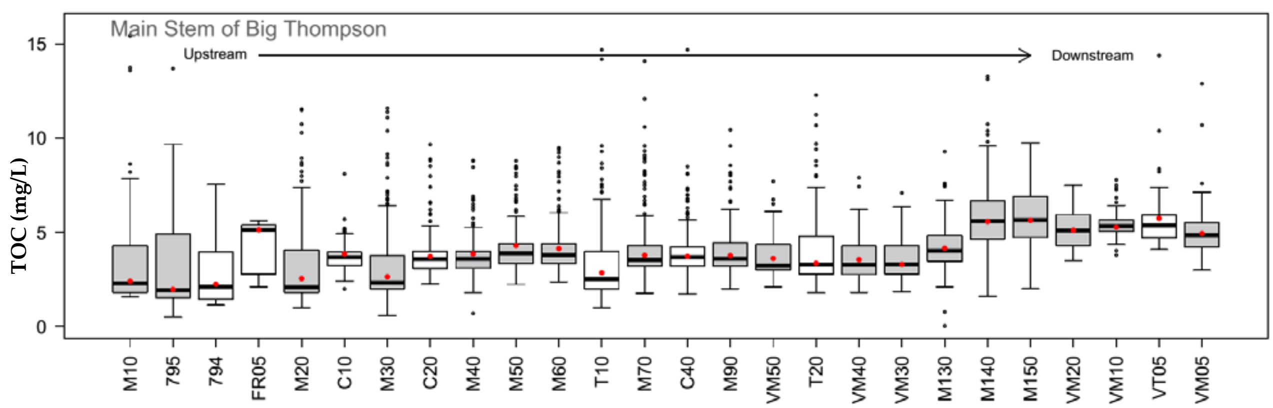

Figure 41. Box Plot of TOC (mg/L) in the Big Thompson River, WY2000-WY2014
Grey-shaded boxes indicate mainstem locations. Unshaded boxes indicate inflows. Red dots indicate median for recent 5 years of record (WY2010-WY2014).

- Concentrations of some general parameters were affected in near-fire areas. This is discussed further in Section 3.6.

  - o Buckhorn Creek (T20) showed some increases in sulfate, turbidity, TOC, hardness, and specific conductivity after the High Park Fire in June of 2012. Effects were generally limited to the first year after the fire, though continued effects on turbidity and TOC may be apparent in 2014 data at this location.

  - o Station M10 in the upper watershed downstream of the Fern Lake Fire exhibited increased post-fire concentrations of hardness, specific conductivity, and sulfate prior to the 2013 spring runoff. Elevated hardness and specific conductivity were still apparent in data collected prior to the 2014 spring runoff.

3.5.2 General Parameter Concentration Trends

Concentration time series data for the 11 general parameters were evaluated for statistically significant trends applying the Seasonal Mann-Kendall approach, as described in Section 2.2.2. Results were first screened against the fairly inclusive criteria of p-values less than or equal to 0.10 (90% confidence level), then reviewed in the time-series plots. Based on this review, noteworthy statistically-significant trends were identified for TOC and turbidity. Trends were also identified for pH, alkalinity, specific conductivity, and sulfate (Appendix E).

Statistically-significant trends of increasing TOC concentrations were found in the C-BT canal system (C10, C20, C30, C40 and C50) as well as in Big Thompson mainstem[17] (M20, M40, M50, M60, M70, M90, and M130). This finding is in agreement with findings from the 2010 State of the Watershed Report (Hydros, 2011), though it includes more stations. The magnitude of this increasing trend is very similar across the 11 stations, ranging from 0.02 to 0.09 mg/L per year. This finding of increasing TOC is important because it can directly affect drinking water treatment costs, operations, and regulatory compliance. These increasing trends include the reach from which the City of Loveland diverts water for drinking water treatment, as wells as inflows to major C-BT reservoirs including Horsetooth. Figure 42 presents this increase as observed at the inflow location for C-BT water from the west slope (C10). The increasing trend is apparent in this figure; however, visually it also appears to have plateaued in the last two or three years. This is supported by statistical testing, which indicates that the slope of the trend is greater when post-September 2013 data are excluded.

[17] A statistically-significant trend was also found for M10; however, excluding the post-2013 flood data, the trend at M10 is no longer significant. This suggests the finding was not a definitive indication of a long-term trend at this location.

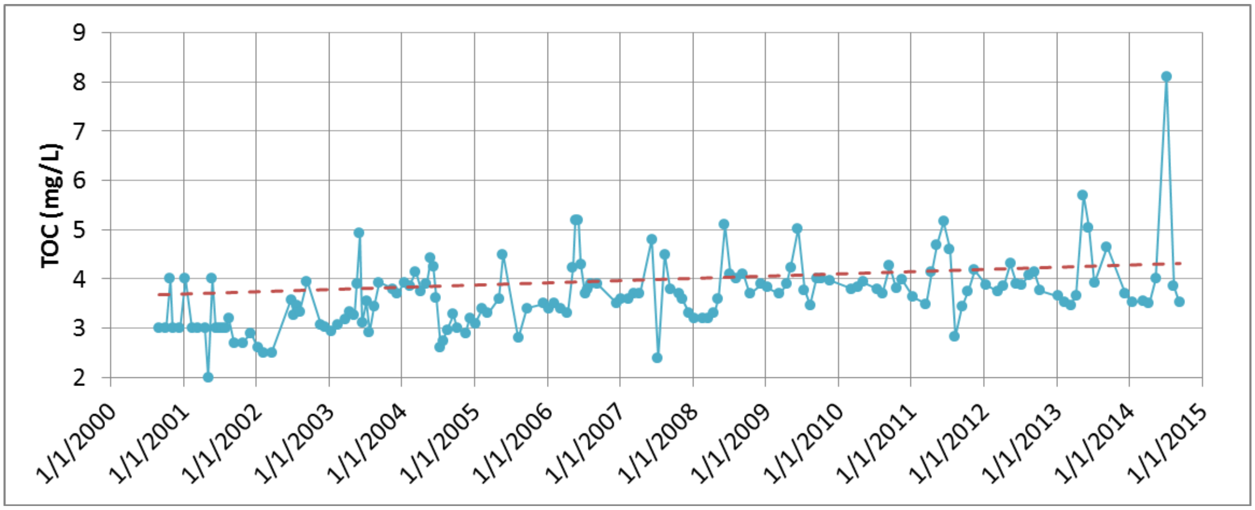

Figure 42. TOC Concentrations (mg/L) at C10 (Trend slope shown as red dotted line)

The cause of this increasing trend in TOC concentrations in water from the west and east slopes is hypothesized to be the large-scale tree death from the ongoing mountain pine beetle epidemic (Figure 43). The death and decay of large areas of trees results in an increase in the release of organic matter to the litter and soil, with an increased opportunity for leaching and transport of organic matter to surface water. Mikkelson et al. (2013) found increasing TOC concentrations in areas of Colorado with mountain pine beetle infestations. Comparing these data to control areas (without significant infestation), Mikkelson et al. (2013) distinguished this expected cause from other potential causes of increased TOC (i.e., increasing air temperatures and precipitation).

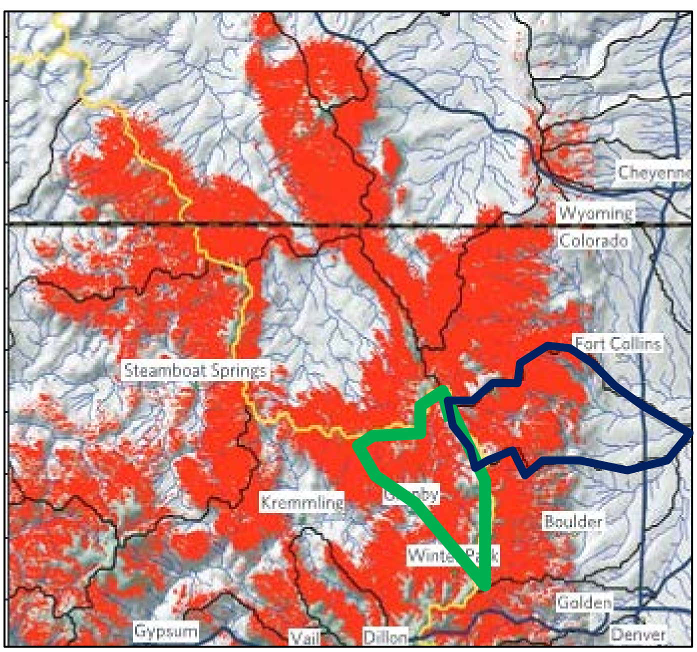

Figure 43. Mountain Pine Beetle Infestation Extent as of 2012 (Red Areas)

***Dark blue** outline is approximate Big Thompson watershed boundary; **Green** outline is approximate west-slope watershed for C-BT inflows from Adams Tunnel. Image from Mikkelson et al. (2013).*

In addition to the increasing trend of TOC at C50, small increasing trends of alkalinity, pH, specific conductance, and sulfate were found. All of these were small in magnitude (see Appendix E), but strongly statistically significant. The quality of water at C50 is important because it is the primary source of water to Horsetooth Reservoir.

The statistical testing indicates a long-term trend of increasing turbidity in the Big Thompson from M20 to M90, including the North Fork (T10) and Buckhorn Creek (T20). The trend has a fairly consistent magnitude across all of these locations of 0.1 to 0.2 NTU per year, corresponding to an annual increase of 2 to 5% of the mean at each location. Smaller magnitude increasing trends in turbidity were found for M10, C40, and C50 (≤ 0.05 NTU/yr). The statistical testing was run with and without the period following the 2013 flood to evaluate whether flood data were affecting the trend result. The results were nearly identical in both runs. It is difficult to identify a specific cause of this increase in turbidity, though it could relate to increasing anthropogenic activity and/or pine beetle effects. This trend was not seen in C-BT water entering from the west slope (i.e., C10).

Finally, there is a small-magnitude trend of decreasing pH at four mainstem stations (M20 through M60, VM50, T10, M130, and M150) and three canal locations (C10, C20, and C30). The trend is small, ranging from 0.1 to 0.4 percent of the mean each year at each location. These are noted for consideration in ongoing data collection and analysis. The cause of this small decrease in pH is uncertain, but could also be related to the pine beetle effects.

3.5.3 TOC Loading

Of the general parameters, loading was only assessed for TOC. Appendix D1 Figures D1-9 and D2-9 present the loading analysis results for TOC. The larger patterns in TOC loading track annual and seasonal discharge volumes in the canals and rivers (Appendix B3). In general, relative TOC loads across the system show similar patterns from year to year. The TOC loads at the Adams Tunnel (C10) and the canal sites C20 and C30 are significantly higher than the stream sites because of the significantly higher flows. The canals move large volumes of water in the late fall and winter months to fill Carter Lake and Horsetooth Reservoir, resulting in high winter TOC loads in the canals. Flows, and as a result, TOC loads decrease dramatically below M90 due to diversions, including the City of Loveland drinking water treatment plant intake. Station M140 shows a small relative increase in mean TOC load compared to the upstream station, corresponding to the increased TOC concentrations and flow from the Loveland WWTP effluent.

3.5.4 General Parameter Compliance

Of the general parameters, compliance was assessed for pH, temperature, sulfate, and dissolved oxygen. The percent exceedances for all years of data are summarized in Appendix F. Findings for each of these parameters are discussed below:

- **pH:** For pH, exceedances are occasionally observed in the uppermost watershed at stations M10, 794, FR05, and NFBT10, where low alkalinity is also observed. At these locations the exceedances tend to be values below pH 6 (as opposed to above pH 9). Exceedances of pH standards are also occasionally observed at M50, below the Upper Thompson Sanitation District effluent. Small magnitude exceedances are also occasionally observed across the Little Thompson and at volunteer monitoring stations from VM50 to VM30. Finally, the Forum does not have a monitoring station on the short 303(d)-listed segment (Fish Creek below Mary's Lake) for pH in the upper watershed (Figure 8), so no comment on that listing can be made here.

- **Temperature:** The temperature compliance evaluation should be cautiously interpreted. Continuous temperature data are needed to appropriately evaluate the river conditions relative to the acute and chronic standards, but there are only discrete measurements in the Forum database. Using this limited dataset, temperature exceedances appear to be rare across the watershed, with the only noteworthy occurrences being possible chronic temperature excursions in 2002 at T20, VM40, and VM30, reflecting low flow and high air temperature conditions that year. Given the elevation, the standards by reach, and the patterns in flow rates and diversions, this pattern matches the general expected area of greater sensitivity. Given the importance of water temperature to aquatic life and the variable flow rates in the Big Thompson River due to various diversions, it is recommended that continuous temperature gages be installed in several locations. These data would help support evaluation of the current 303(d) temperature listings across the watershed (Figure 8c). Alternatively, if such data are being collected through another program, it is recommended that these data be included in the Forum's next five-year data review. The City of Loveland will add a temperature monitoring station by September 30, 2016, to collect continuous ambient temperature data per their NPDES discharge permit.

- **Sulfate:** Recent changes to sulfate standards in Segments 4a and 9, effective December 31, 2015 (WQCD, 2015c), indicate exceedances could be expected in most years in these segments, with a high frequency of exceedances at M130 and on the Little Thompson River from VT20 to VT05. There are no observed exceedances of applicable sulfate standards in the other segments higher in the watershed (Segments 1, 2, 3, and 7). The upper portion of the Little Thompson River is 303(d)-listed for sulfate, but there are no data in the Forum database to assess this area. It is recommended that a sampling location be added to the Forum program upstream of the Culver Ditch diversion, unless another source of data for this reach can be identified and included in the Forum database.

- **Dissolved Oxygen:** Dissolved oxygen compliance findings show occasional summer or fall exceedances at VM50[18] and at a few other locations in the watershed (794, VM40, and VM30). Dissolved oxygen is 303(d)-listed for the upper portion of the Little Thompson (Figure 8a), but no data are available in the Forum database to evaluate dissolved oxygen in this area. It is recommended that a sampling location be added to the BTWF program upstream of the Culver Ditch diversion, unless another source of data for this reach can be identified and included in the BTWF database.

3.6 EVENT ANALYSIS

3.6.1 Fire Effects on Water Quality

As described in Section 1.2.1, there were major wildfires entirely or partially within the Big Thompson watershed in 2010, 2011, and 2012:

- **Cow Creek Fire**: June, 24, 2010: 1,200 acres in the upper North Fork drainage;
- **Crystal Fire:** April, 2011; 3,000 acres upper Buckhorn Creek and Horsetooth Reservoir watersheds;
- **High Park Fire:** June 9, 2012 – June 30, 2012; 87,000 acres parts of which included the upper Buckhorn Creek watershed; and
- **Fern Lake Fire:** October 9, 2012; 3,500 acres of the upper Big Thompson watershed upstream of M10.

A water-quality study of the effects of the Fern Lake Fire was completed by Northern Water in 2014 (Billica, 2014). That study was conducted to characterize the impacts to upper Big Thompson River water quality due to snowmelt and rainfall runoff originating from the Fern Lake Fire burn area. For this report, that study was updated by Dr. Billica of Northern Water to include data collected through WY2014. Water-quality and flow data from M10 (Figure 44), located just downstream of the Fern Lake Fire area below Moraine Park, were evaluated. In addition to routine sampling, storm event samples were collected at M10 on August 13, 2013 (a relatively minor rainfall event), September 10, 2013 (the start of the 2013 flood), and September 10, 2014 (a moderate fall precipitation event).

[18] Interestingly, station M90 (collocated station with VM50) does not show a similar pattern of excursions. This, however, amounts to a small possible discrepancy, since there are few exceedances in two of 15 years.

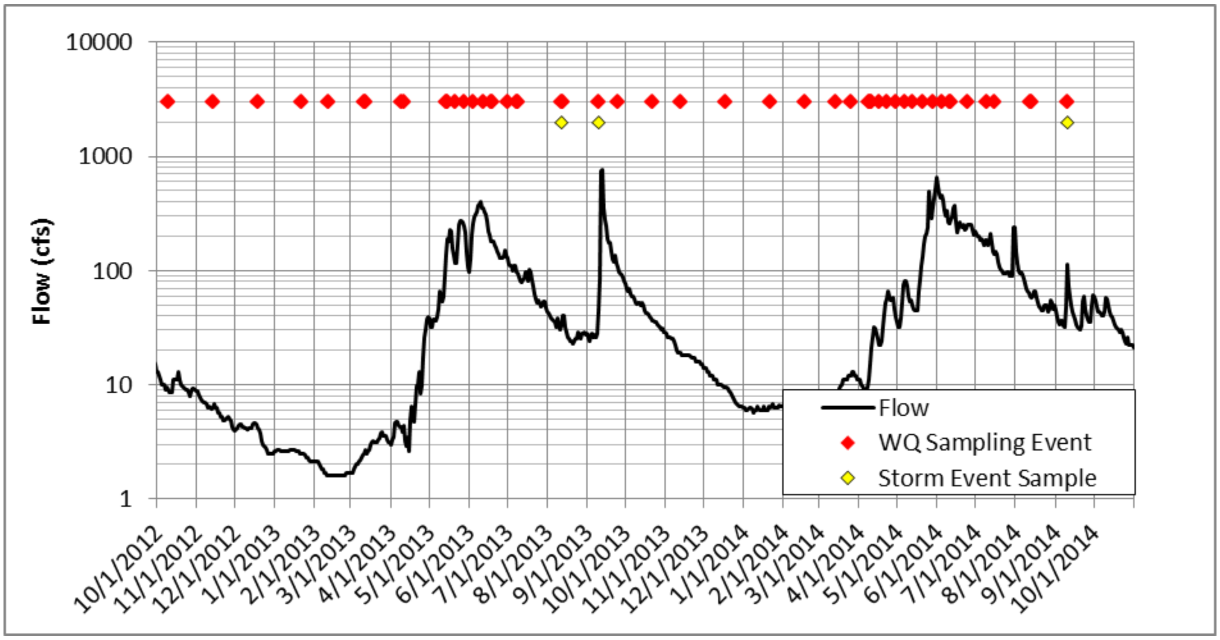

Figure 44. Daily Flow Rates and Sampling at M10 Following the Start of the Fern Lake Fire (October 9, 2012-May 31, 2013)

Findings from the analysis are as follows:

- **Increased Peak Major Ion Concentrations**: Major ion concentrations in the upper Big Thompson River typically increase over the fall and winter, and peak at the onset of spring runoff before being diluted by runoff flows. The peak April 2013 and late-March 2014 calcium, magnesium, sulfate (2013 only), and chloride concentrations at M10 were well above their typical peaks, and resulted in an elevated peak in specific conductivity (Figure 45). Similar patterns, though lesser in magnitude, were also observed at M20, but were no longer apparent at M30, located just below the Estes Park Sanitation District outfall (Appendix C Figures C1-98 and C1-100). An increase in major ions is often observed downstream of burn areas. This is particularly evident in streams with low pre-fire dissolved solids concentrations that drain granitic bedrock basins, such as that of the headwaters of the Big Thompson River.

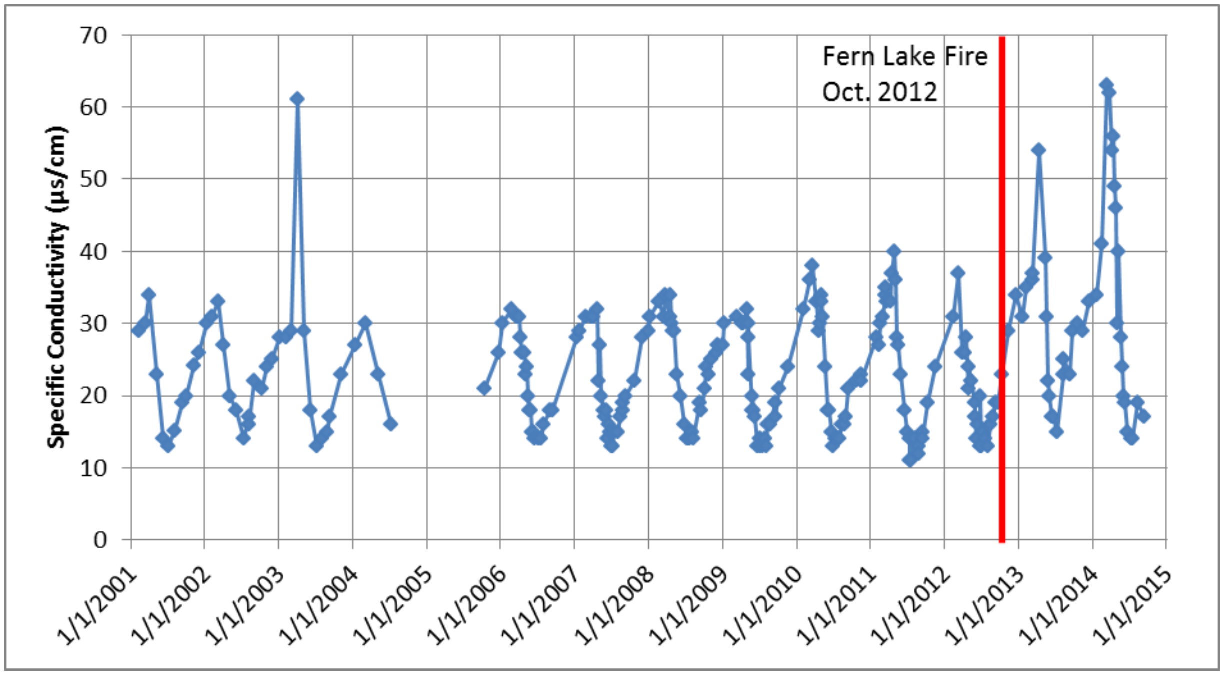

Figure 45. Specific Conductivity Data from M10, 2001-2014

- **Increased Peak Nitrate Concentrations in Second Year after Fire:** Nitrate concentrations at M10 reached relatively high levels in April 2014, resulting in the most dramatic water-quality change in the second year after the fire compared to the first year (Figure 46). Again, the same effect was observed to a lesser magnitude at M20, but not at M30 (Appendix C Figures C1-67 and C1-69), suggesting a limited spatial range of effect. Interestingly, this effect was not apparent in the spring immediately following the fire (2013). Nitrate concentrations at M-10 typically peak during the winter (Nov–Feb) and are generally lowest during the spring and summer before increasing again in the fall. The pattern observed in 2014 is different, with the peak concentrations occurring about one month before spring runoff (Figure 47). The impact of the elevated nitrate concentrations observed from mid-March through April, 2014 was likely minimized due to the fact that the flows during this time were low, resulting in relatively small nitrate loads that could be transported downstream. It is possible that the observed changes in nitrogen fluxes are related to post-fire changes in the soil microbial community and nitrogen cycling (Yeager, 2005).

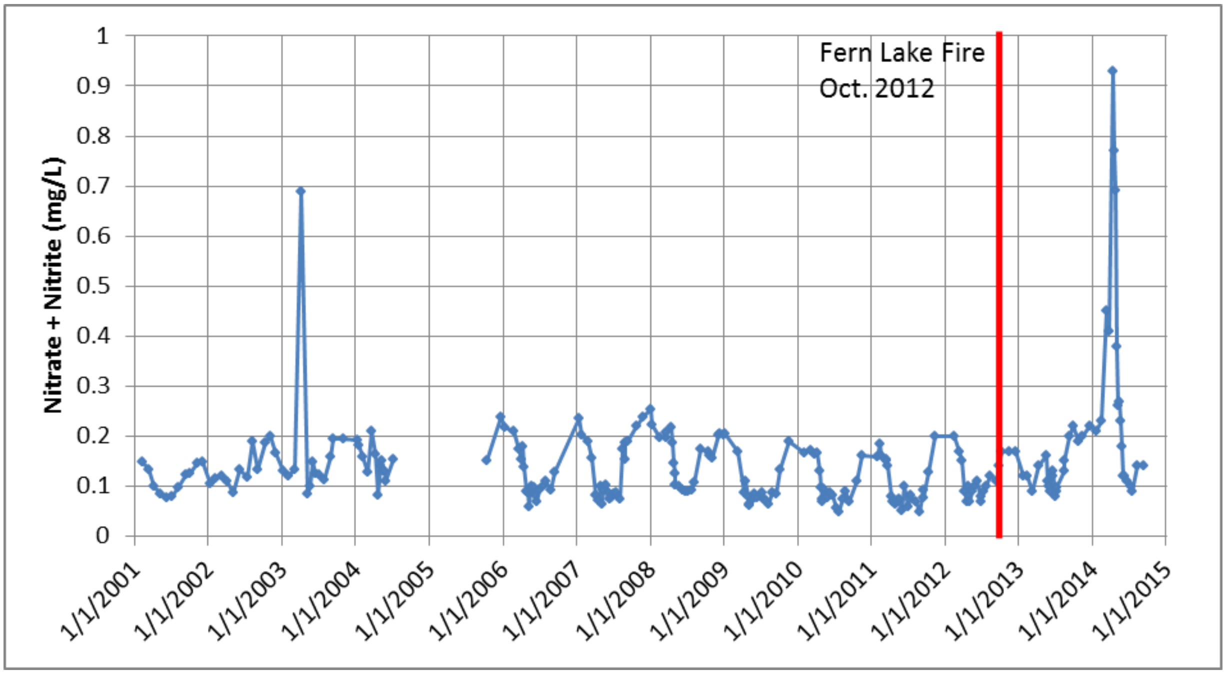

Figure 46. Nitrate + Nitrite Concentrations at M10, 2001-2014

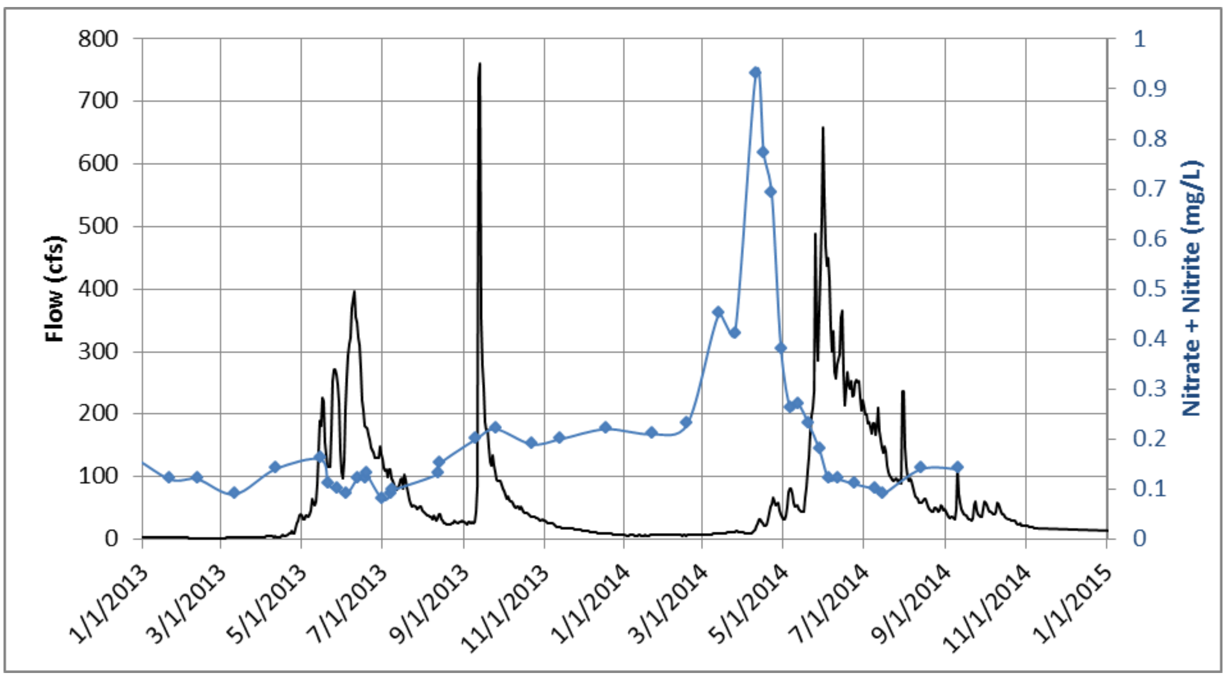

Figure 47. Nitrate + Nitrite Concentrations at M10 and Observed Daily Flow Rates, 2013-2014

- **Increased Spring Runoff Concentrations Limited to One Year after Fire:** Several parameters typically exhibit a peak concentration during the spring snowmelt runoff period including total phosphorus, TKN, TOC, and turbidity. Higher peak spring runoff concentrations were measured in 2013 for total phosphorus and TKN at M10 compared to typical peak concentrations during the spring runoff (Figure 48 and Figure 49). Peak turbidity was slightly elevated at M10 compared to more typical spring runoff peaks (Figure 50), while peak TOC concentrations during the 2013 spring runoff were in the typical range (Figure 51). By the next year in 2014, the peak spring runoff concentrations for total phosphorus, TKN, and turbidity had all returned to normal ranges. This indicates that post-fire impacts during the spring snowmelt runoff period are not persisting.

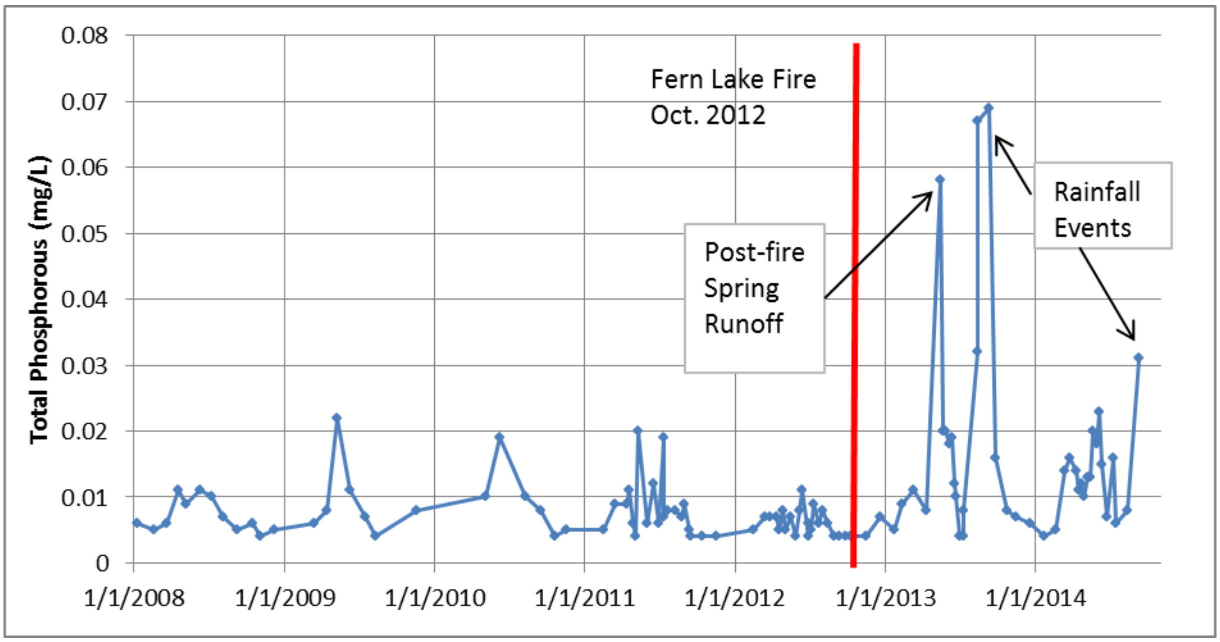

Figure 48. Total Phosphorus Concentrations at M10, 2008-2014

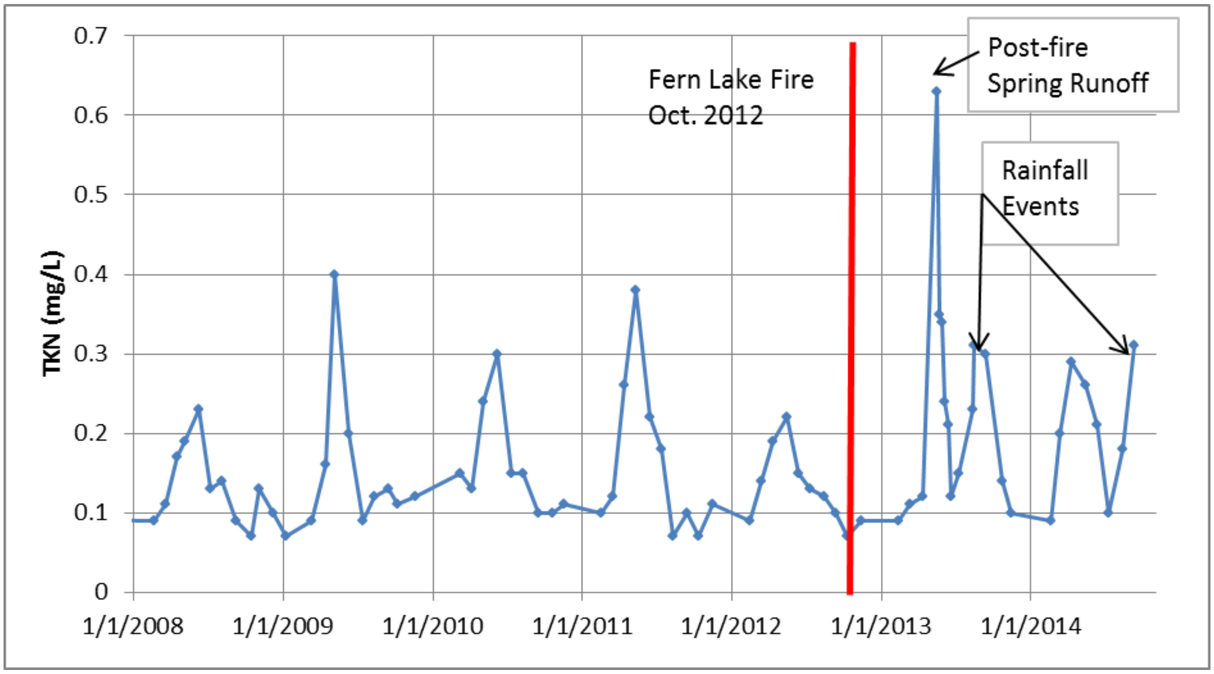

Figure 49. TKN Concentrations at M10, 2008-2014

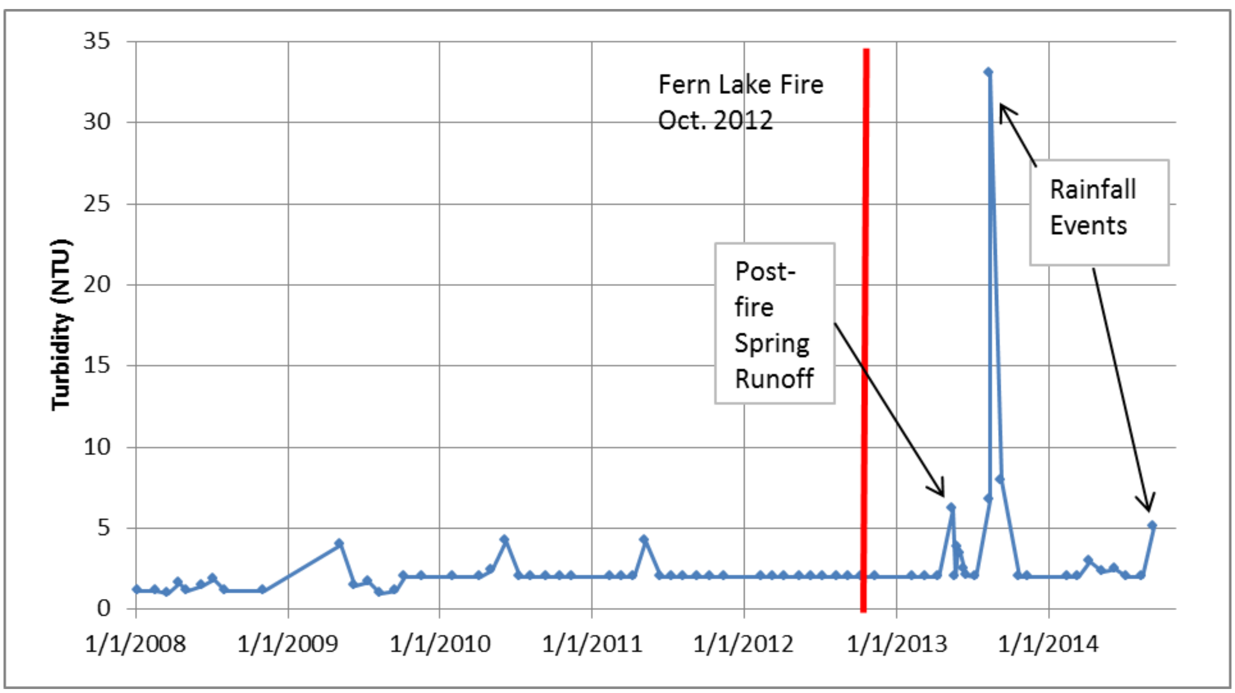

Figure 50. Turbidity Concentrations at M10, 2008-2014

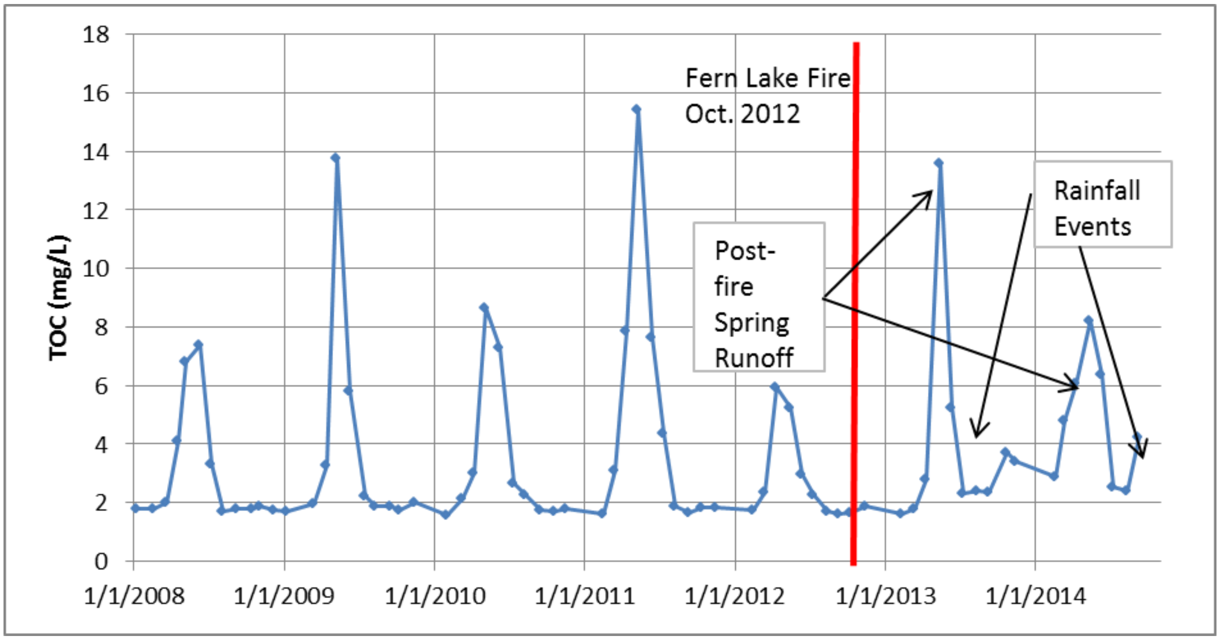

Figure 51. TOC Concentrations at M10, 2008-2014

- **<u>Summer Storm Event Concentrations May Be Elevated Post-Fire</u> :** Monitoring at M10 revealed increased levels of turbidity, total phosphorus, TKN, and TOC (in 2014 only) during storm events when compared to summer baseflow conditions. Comparisons are made to summer baseflow conditions since pre-fire monitoring did not target rainfall events and concentrations that occurred during "typical" pre-fire summer storm events are not known[19]. Also note that no increase in nitrate was observed during these storm events, contrary to what has been observed in studies on other Colorado wildfires.

In summary, as reported in Billica (2014), water-quality data collected in 2013 downstream of the Fern Lake Fire burn scar indicate that runoff from the burn area resulted in some water-quality changes in the Big Thompson River downstream of Moraine Park (at M10). However, the measured impacts were generally short-lived, not significant enough to be expected to impact aquatic life and drinking water supplies, and/or occurred in parameters (major ions) at concentrations that typically would not result in impacts to aquatic life or drinking water supplies. Data also indicate that the spatial extent of downstream water-quality effects is limited, with essentially no effects apparent at M30 (upstream of Lake Estes, but downstream of

[19] Additionally, the concentrations that are observed during a storm runoff event will depend on the specific timing of the sampling (one grab sample was collected for each event), so it is not known how the collected data relate to the maximum or flow weighted average concentrations for the event. None of the increased concentrations measured during the 2013 and 2014 storm-related events were extreme or exceptionally high.

the Estes Park Sanitation District outfall). The 2014 data indicate that the quality of water at M10 may continue to exhibit some small impact from the Fern Lake Fire. However, even if these impacts persist for several years, as research from other Colorado fires has observed, the data collected in 2014 indicate that these impacts should remain minimal at M10 and in downstream reaches.

Sampling stations NFBT10 and T10 are downstream from the Cow Creek Fire burn area. Data from these stations do not show any clear pattern of effect on water quality. This was a relatively small fire; however, this finding does not mean there were no localized effects. NFBT10 data do not contain pre-fire data for comparison, and station T10 is well downstream of the burn area. Further, neither of these stations targets storm-water sample collection.

Water-quality data from T20 (Buckhorn Creek, downstream of the Crystal and High Park fires) were reviewed to look for similarities and differences relative to M10 and the Fern Lake Fire. Water-quality response to wildfire is expected to vary depending on the extent and severity of the fire, the location in the watershed, and the subsequent hydrologic drivers. Data from T20 indicate increased sulfate (Figure 52), specific conductance, and hardness concentrations persisting after the June 2012 fire (High Park Fire) until early spring 2013. There is also an apparent, short-lived increase in orthophosphate and total phosphorus (Figure 53) in the spring of 2013 (not seen in 2014). Unlike M10, there was no second-year (or first-year) increase in early spring nitrate concentrations at T20. Lesser effects observed at T20 may reflect the fact that this sampling location is farther from the corresponding burn area than M10 is to the Fern Lake Fire burn area. Other researchers found that total nitrogen and total phosphorous transport from the High Park Fire to the Cache la Poudre River (located just to the north of Buckhorn Creek) was highly correlated with solids transport and precipitation events (Son et al., 2015).

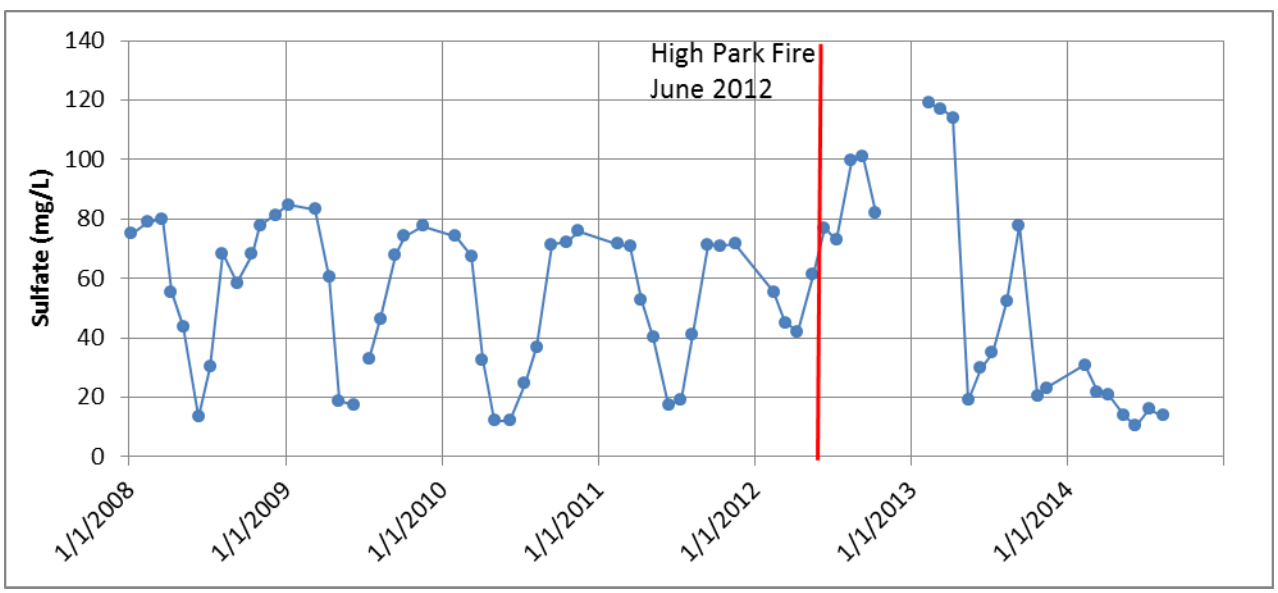

Figure 52. Sulfate Concentrations at T20, 2008-2014

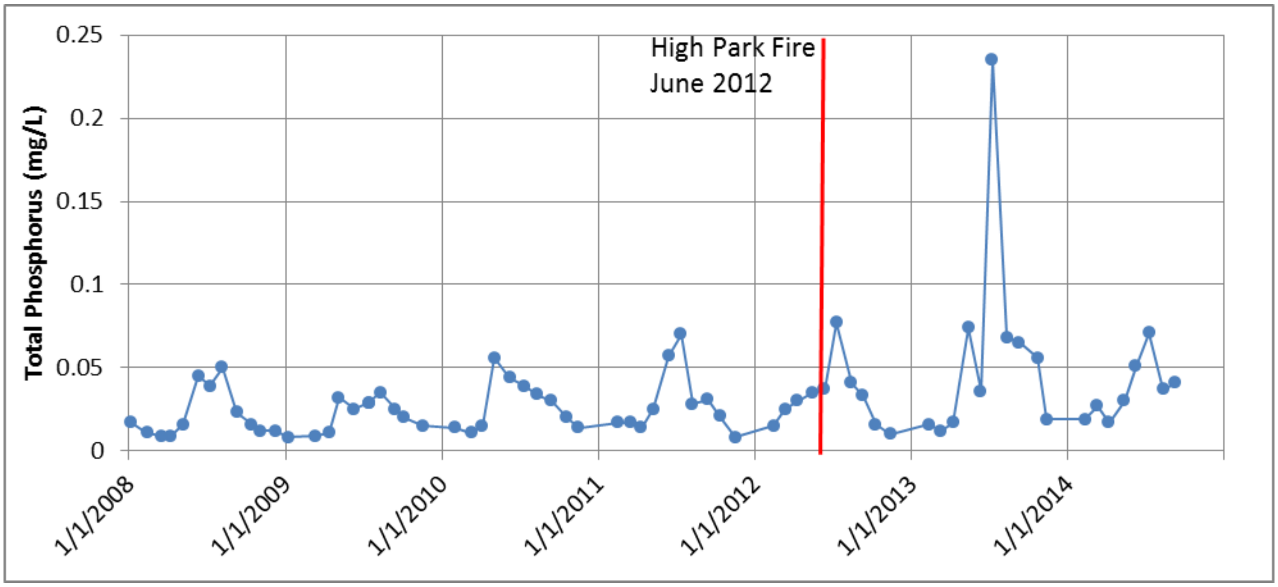

Figure 53. Total Phosphorus Concentrations at T20, 2008-2014

3.6.2 Flood Effects on Water Quality

As described in Section 1.2.2, the rainfall and associated flooding of September 2013 was a major event across the Front Range of Colorado. Pictures of the flooding (Figure 17 through Figure 15) indicate damage to infrastructure, and changes to stream channels are still visible in many locations. This section discusses concentration patterns apparent in the observed record from during and after the flood. Patterns were identified by visual review of time-series data.

There was no water-quality sampling at river locations during the flooding event, including the period of rising and peaking flood waters or the falling limb of the hydrograph. As shown for M130 in Figure 54, a scheduled sampling event immediately preceded the flooding event at most locations, and did not occur again until approximately six weeks after the flood. Samples were, however, collected in the canals (C10, C20, C30, C40, C50) at the start of the event (samples collected on Sept. 10, except C20 which was sampled on Sept 9; e.g., Figure 55). This provides some indication of water quality, though C20 through C50 largely reflect water quality in Grand Lake and the east slope C-BT reservoirs combined with Big Thompson water.

A full set of flow-rate and sample timing plots for 2013 is presented in Appendix B2. Note that pumping of West Slope water through the Adams Tunnel was stopped on September 11, while flow from Lake Estes to the Olympus Tunnel (C20 site) was stopped on September 13. Low flows (<60 cfs) in the Hansen Feeder Canal (sites C30, C40 and C50) were maintained through September and October with water from Pinewood Reservoir (which contained flood waters from Lake Estes), Flatiron Reservoir, and Carter Lake. Post-flood, regular C-BT operations resumed again in November, with Lake Estes water flowing through the Olympus Tunnel beginning in early November and limited pumping through the Adams Tunnel beginning in late November.

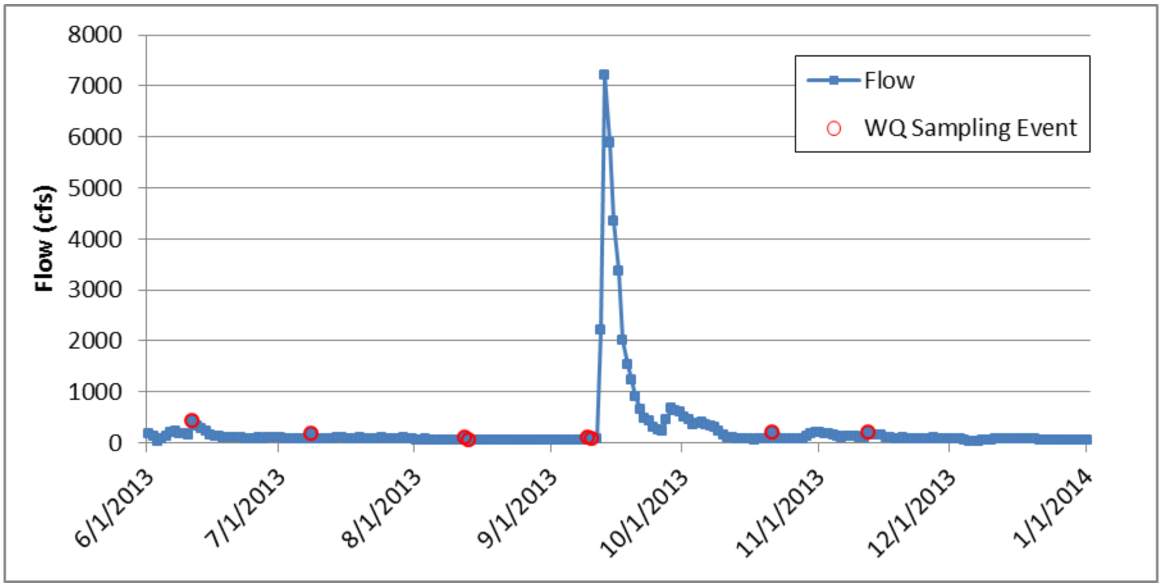

Figure 54. Flow Data and Water-Quality Measurement Dates at M130; June to December, 2013

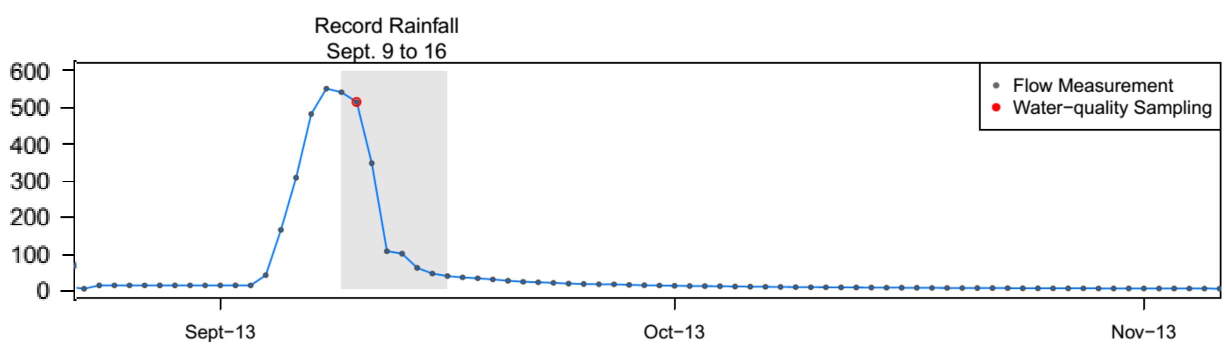

Figure 55. Flow Data and Water-Quality Measurement Dates at C10; September through November, 2013

Observed effects of the flood varied spatially, with different patterns observed in the canal locations, the upper watershed, and the lower watershed.

<u>C-BT Canal Locations</u>

The flooding event also occurred on the west slope; however, it was a much smaller event in that area. Pumping of west slope water through the Adams Tunnel did not take place for most of the flooding event (from September 11 to late November 2013). There was, however, a sample collected at C10 during the flood, before pumping was halted. This sample exhibits elevated ammonia (Appendix C1, Figure C1-68); however, no other parameters were unusually high or low for the season in that sample. Also, it should be noted that the East Portal Reservoir (where the C10 samples are collected) also received runoff water from the surrounding Wind River drainage during the flood, so ammonia in that one sample could reflect Wind River watershed effects. Subsequent samples in November also exhibited no clear persisting water-quality effect of the flood on water from the Adams Tunnel.

At the next downstream canal sampling location, C20 (Olympus Tunnel outflow from Lake Estes), some water-quality effects of the flood were apparent. At C20, increases (two to three times greater than typical) in ammonia, nitrate, and total nitrogen were observed in the fall and early winter months following the flood.

Increases during and after the flood were more apparent at C30 (Flatiron Reservoir outflow), and then generally decreasing at C40 and C50 (Horsetooth Reservoir inflow). Flows at these stations continued during the flood and through the fall, and were primarily impacted by flood waters that were discharged from Lakes Estes into the Olympus Tunnel and then flowed into Pinewood Reservoir before the Olympus Tunnel was shut off on Sept 13. Increased nutrient concentrations (orthophosphate, total phosphorus, total nitrogen, nitrate, and ammonia) were apparent in the fall of 2013, with effects extending to the early months in 2014. Increases in TSS, TOC, and sulfate followed a similar pattern. At C30, C40, and C50, sampling frequency for metals is greater, and the data indicate a possible increase in lead and selenium concentrations (for one or two samples at the time of the flood).

Overall, water-quality effects of the September 2013 flood were observed at canal locations downstream of Lake Estes. The observed increases in nutrients, TSS, TOC, sulfate, and possibly some metals reflect the quality of east slope flood waters that were discharged from Lakes Estes into the Olympus Tunnel and then flowed into Pinewood Reservoir before the Olympus Tunnel was shut off on Sept 13. All effects were fairly short-lived, with concentrations returning to typical ranges by 2014.

River Locations

Given the lack of data in the rivers during the flood and the lack of comparable events in the recent record, any estimation of water-quality concentrations during the event would be highly speculative. That said, high suspended solids concentrations are evident during the flood in all photographs in all areas of the watershed. With increased solids concentrations, one would expect increased metals concentrations. There were also likely high loads of phosphorus and organic carbon. A variety of chemicals, including pesticides, herbicides, BTEX compounds (benzene, toluene, ethylbenzene, xylene), and petroleum products were also likely washed into the rivers, though dilution would be significant.

Following the flood, the watershed adjusts to geomorphological changes and elevated groundwater levels begin to return to pre-flood elevations. High groundwater levels result in increased levels of baseflow in streams. In some areas, post-flood water-quality data indicate effects of these post-event conditions:

- **Short-term increases in post-flood concentrations in the upper watershed:** Increased concentrations of TSS, turbidity (e.g., Figure 56), and in some cases total phosphorus, total nitrogen, and nitrate were apparent in post-flood data in the upper watershed (from M10 through M130[20] as well as in the North Fork at T10). Increased hardness and specific conductivity were observed from the top of the watershed to M90. Increased sulfate was also observed from M60 to M90, including T10. All of these increased concentrations were apparent in the Forum dataset only until the end of 2013 or early spring of 2014. These increases are particularly evident in the M70, M90 (Figure 56), and M130 data. However, non-Forum-data observations in the river suggest that post-flood turbidity levels continued to be elevated into 2015, primarily as a result of river and road restoration and construction projects within the Big Thompson Canyon.

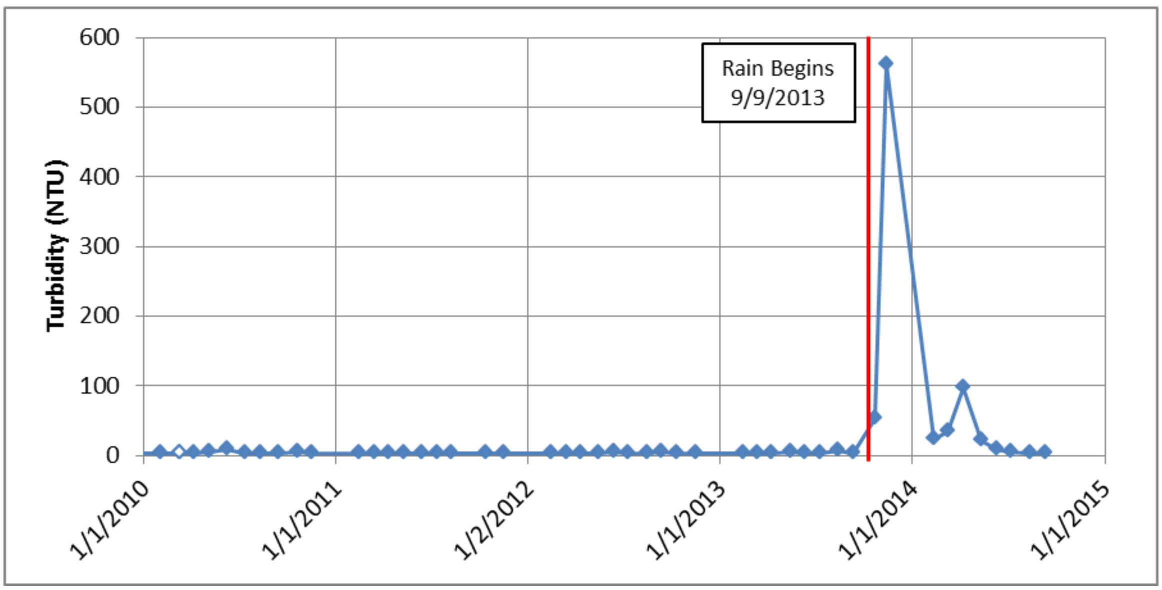

Figure 56. Turbidity at M90 Before and After 2013 Flood, 2010 through 2014

Upstream stations typically have low dissolved solids concentrations with correspondingly low specific conductivity, due to the bedrock geology. The increased dissolved solids concentrations post-flood likely represents the mobilization of dissolved solids from shallower soils and sediments. An example of this is shown in

[20] One exception to this was M30, located downstream of the Estes Park Sanitation District, where WWTP effluent appears to have obscured any post-flood water-quality signal in lower-flow rate months.

Figure 57 for M40 (downstream of Lake Estes). At this station, specific conductivities are very low during snowmelt (typically 20-40 µS/cm) and higher during the remainder of the year (50 to 70 µS/cm). In the winter of 2013, the specific conductivities increased to close to 100 µS/cm.

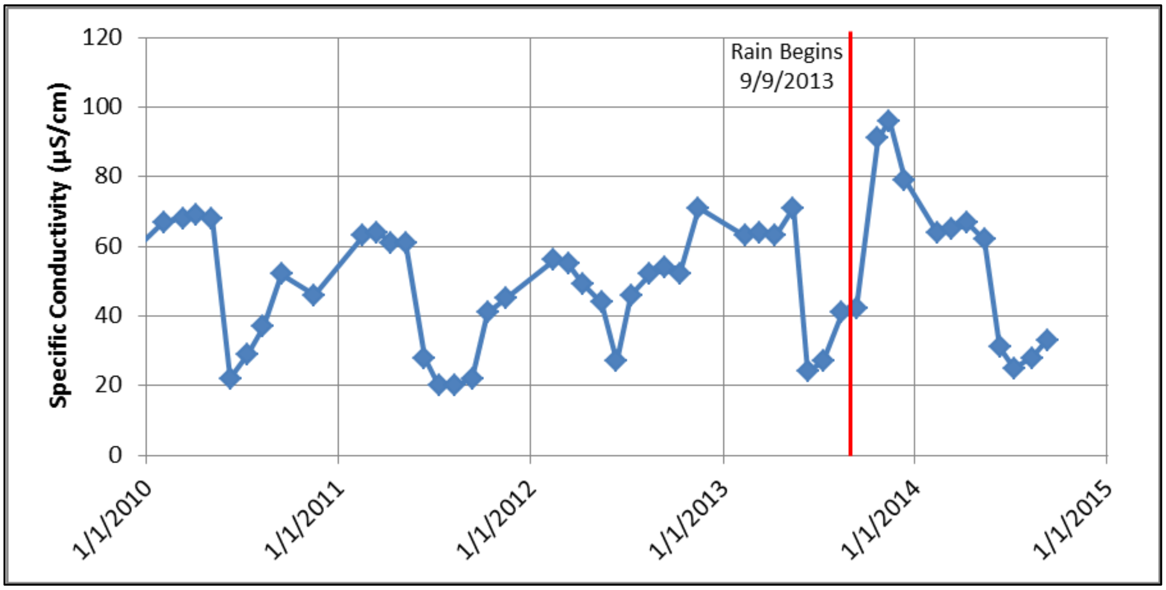

Figure 57. Specific Conductivity at Station M40 Before and After 2013 Flood, 2010 through 2014

- **Decreased concentrations of dissolved parameters in the lower watershed:** Increased baseflow rates (e.g., Figure 25) are expected to be responsible for reduced concentrations of nutrients and dissolved solids in the lower watershed, particularly during winter months. Following the 2013 flood, lower hardness, specific conductivity, nitrate, orthophosphate, and sulfate concentrations are apparent in the lower watershed (starting at M130 or M140 and including the Little Thompson River, depending on the parameter). Examples of these patterns are shown in Figure 58 and Figure 59 for hardness at M130 and orthophosphate at M140, respectively. Post-flood dilution effects were also seen for nitrate, hardness, specific conductivity, and sulfate at T20 (Buckhorn Creek), which typically has relatively high dissolved solids concentrations.

  As of the end of WY2014, most of these dilution effects in the lower watershed attributed to higher groundwater levels and corresponding higher baseflow were still apparent. The effects are likely to continue to decrease, but the duration will depend on the rate at which groundwater levels return to normal.

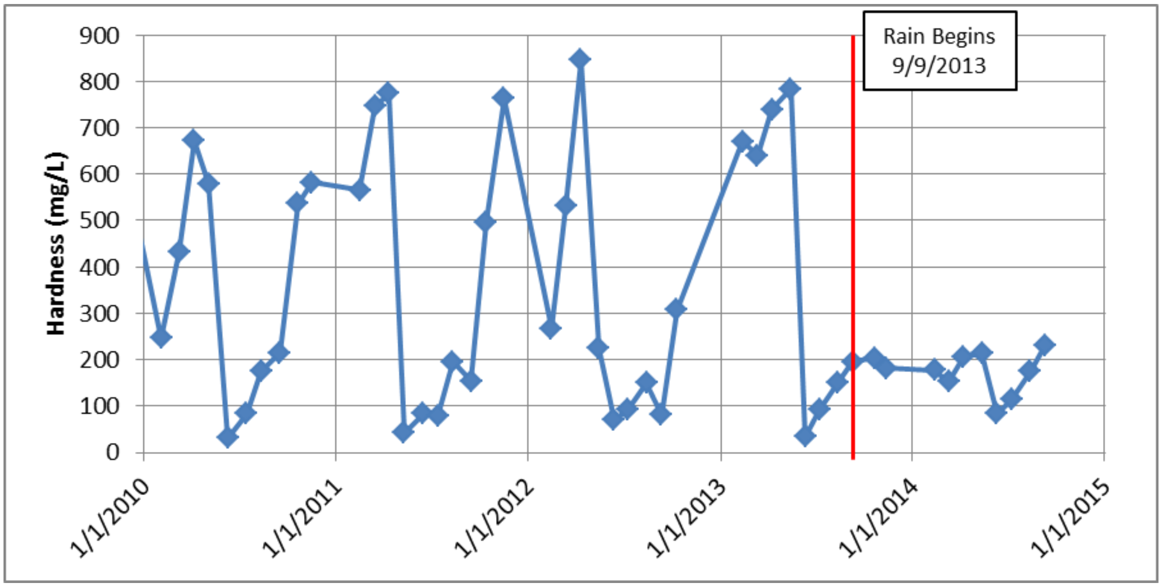

Figure 58. Hardness at Station M130 Before and After 2013 Flood, 2010 through 2014

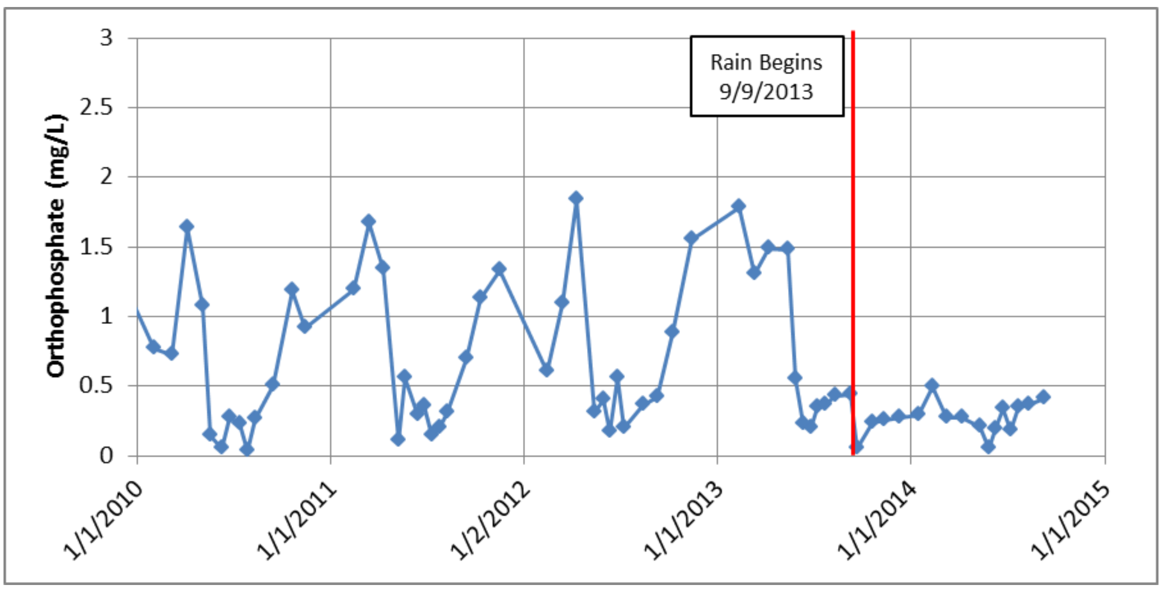

Figure 59. Orthophosphate at Station M140 Before and After 2013 Flood, 2010 through 2014

- **Post-flood decreases in selenium in the Little Thompson River:** Lower concentrations of selenium were observed in 2014 in the Little Thompson River (e.g., Figure 60) and at VM10 and VM05 at the downstream end of the Big Thompson River. It is difficult to definitively interpret the results since there was a gap in sample collection for these parameters at these locations from 2012-2014; however, the pattern is consistent across stations. This is expected to reflect flood-caused changes in groundwater inflows at the downstream end of the watershed. Increased groundwater inflows from areas with lower selenium (outside of Pierre shale areas) could explain this pattern.

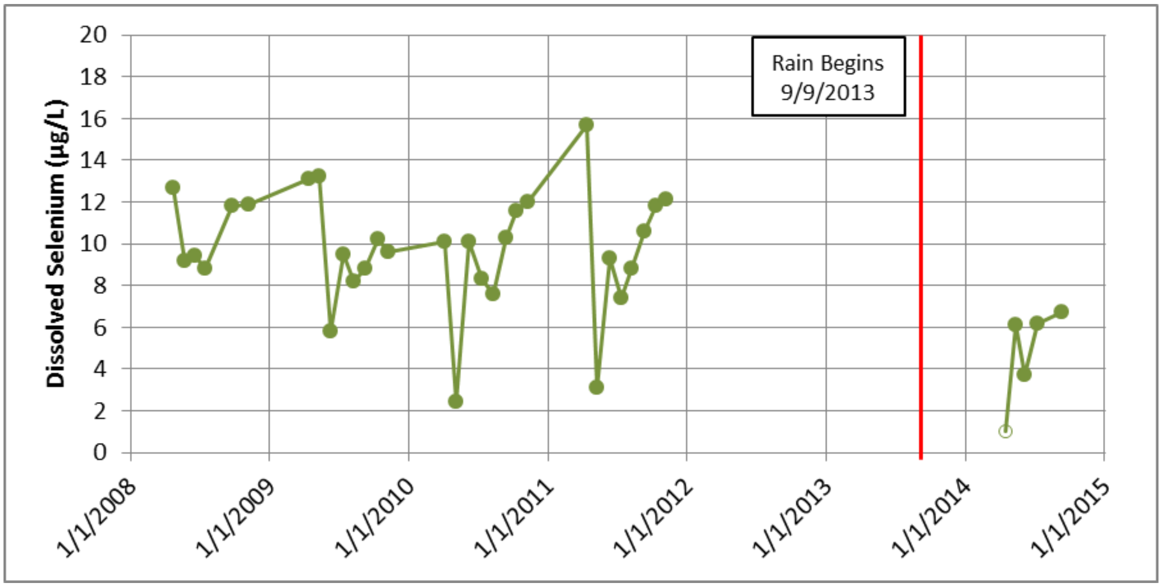

Figure 60. Selenium at Station VT05 Before and After 2013 Flood, 2008 through 2014 *(Hollow symbols indicate results below detection.)*

In summary, canal locations show relatively short-lived increases in nutrients, TSS, TOC, sulfate, and possibly some metals, during and immediately following the flood. There was no in-river sampling during the 2013 flood event, but post-flood effects were apparent in the dataset. Effects differed in the lower watershed compared to the upper watershed.

- Upper Watershed: In the upper watershed, increased TSS, turbidity, dissolved solids, and in some cases total phosphorus, total nitrogen, and nitrate were observed after the flood. These increases in the upper watershed reflect leaching from shallow soils and mobilization of solids available for transport following the high flood flows. The effect in the upper watershed was an increase in concentrations since typical concentrations tend to be quite low. Non-Forum-data observations in the river suggest that post-flood turbidity levels continued to be elevated into 2015, primarily as a result of river and road restoration and construction projects within the Big Thompson Canyon.

- Lower Watershed: In the lower watershed, downstream of M130/M140, increased baseflow appears to have resulted in decreased concentrations of hardness, specific conductivity, nitrate, orthophosphate, and sulfate, particularly in winter months. These effects have persisted into 2014 but are expected to diminish as groundwater levels return to normal. The response of decreased concentrations for many dissolved parameters in the lower watershed reflects dilution effects of more groundwater inflow (and groundwater from different areas) in these reaches where typical concentrations tend to be relatively high. The lower watershed also has more alluvial deposits (Figure 7) for storage of flood water as shallow groundwater.

Overall, there were no major or persistent adverse water-quality effects of the flood observed in the dataset, though periodic increases in turbidity continue to be observed (Shelley, 2015b, personal communication).

3.7 COMPARISON OF COOP AND VOLUNTEER SAMPLING RESULTS

The volunteer and COOP sampling programs differ in sampler training, analytical laboratories, and often analytical methods. Volunteer samples are collected by Forum staff and watershed science volunteers, and samples are analyzed by the US EPA Region 8 laboratories. COOP samples are collected by USGS staff, and samples are primarily analyzed by USGS laboratories. Loperfido et al. (2010) found systematic differences in water-quality sampling results between paid and volunteer samplers. Though the situation in the Big Thompson is not directly analogous to that study, a comparison of COOP and Volunteer monitoring data was made to identify any possible concerns.

At two locations in the watershed, there are roughly collocated COOP and volunteer monitoring stations:

- Moraine Park COOP station M10 is proximal to Volunteer location 795 (Figure 18);
- Just upstream of the Loveland WWTP, COOP station M90 is proximal to the Volunteer station VM50 (Figure 18).

Sampling at these paired stations rarely occurs on the same day; limiting the potential for direct comparison. Therefore, the complete sets of results for paired stations were plotted together in time-series graphs for visual comparison. Statistical testing was not conducted in the comparison.

The previous report focused this comparison on a subset of lab and field parameters (per direction of the Forum): TOC, chlorophyll *a*, copper, *E. Coli*, total phosphorus, specific conductivity, and dissolved oxygen. For this report, the plots were generated for all parameters having data at both stations. As a result, the following parameters were added to the list: total coliforms, alkalinity, hardness, pH, specific conductivity, temperature, sulfate, selenium, lead, orthophosphate, ammonia, TKN, nitrate + nitrite, and total nitrogen. The full set of comparison plots are presented in Appendix G.

For the metals, comparison of the sampling programs was possible for copper, lead, and selenium. For all of these metals, the Volunteer program has detection limits higher than those of the COOP program. As a result, the COOP data for these parameters at these stations are mostly detected, and the Volunteer data are mostly non-detect. The higher detection frequencies in the COOP program provide better data resolution. For selenium and lead, the Volunteer program detection limits are below the applicable standard at these locations; therefore, there is some utility in the non-detect results. For copper however, the Volunteer program detection limits are well above both the acute and chronic standard at VM50, limiting utility of the non-detect results (Figure 61). Based on this, it is recommended that the Volunteer program lower detection limits for copper (and possibly lead which is very close to the calculated standard) or discontinue sampling of this parameter at stations paired with the COOP program.

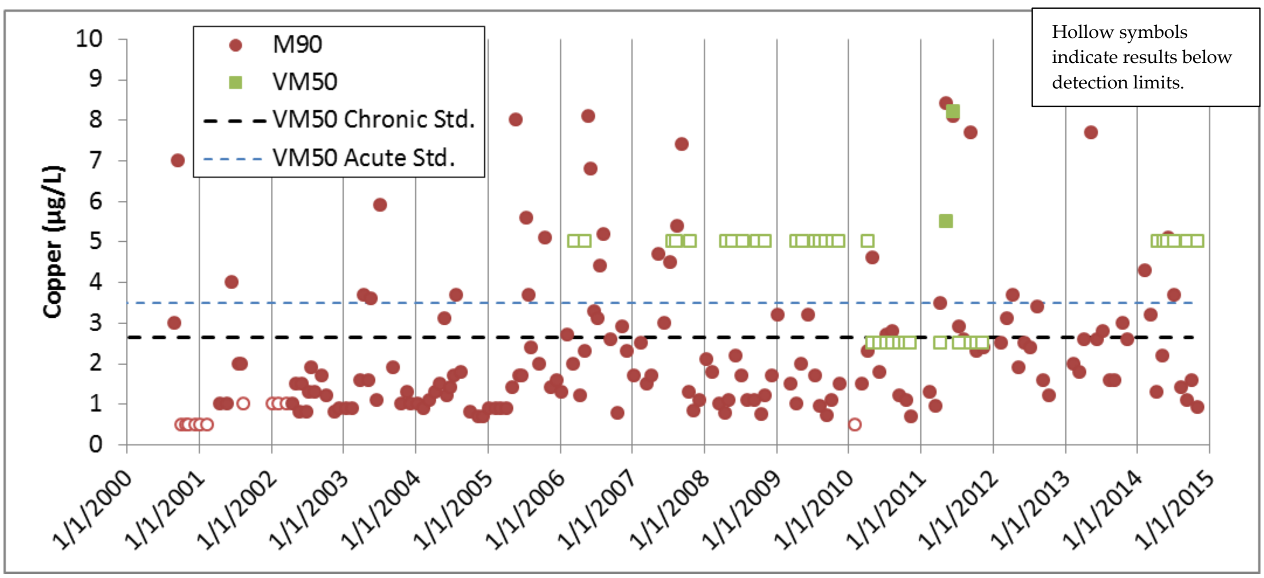

Figure 61. Copper Concentrations at M90 (COOP) and VM50 (Volunteer) Shown with Applicable Estimated Acute and Chronic Standards, 2000-2014

Nutrient results from the Volunteer and COOP programs at these locations are comparable, with the exception of ammonia, which had patterns similar to those observed for the metals. Specifically, the Volunteer program had detection limits greater than that of the COOP program, resulting in Volunteer data being primarily non-detect and the COOP data being mostly detected. This limits the comparability of the data; however, the Volunteer detection limits are well below the applicable ammonia standards at these locations.

For the remaining compared parameters (TOC, chlorophyll *a*, *E. Coli*, total coliforms, alkalinity, hardness, pH, specific conductivity, temperature, sulfate, specific conductivity, and dissolved oxygen), the Volunteer and COOP programs have very comparable results. Specific conductivity data from M90 and VM50 are presented as an example in Figure 62.

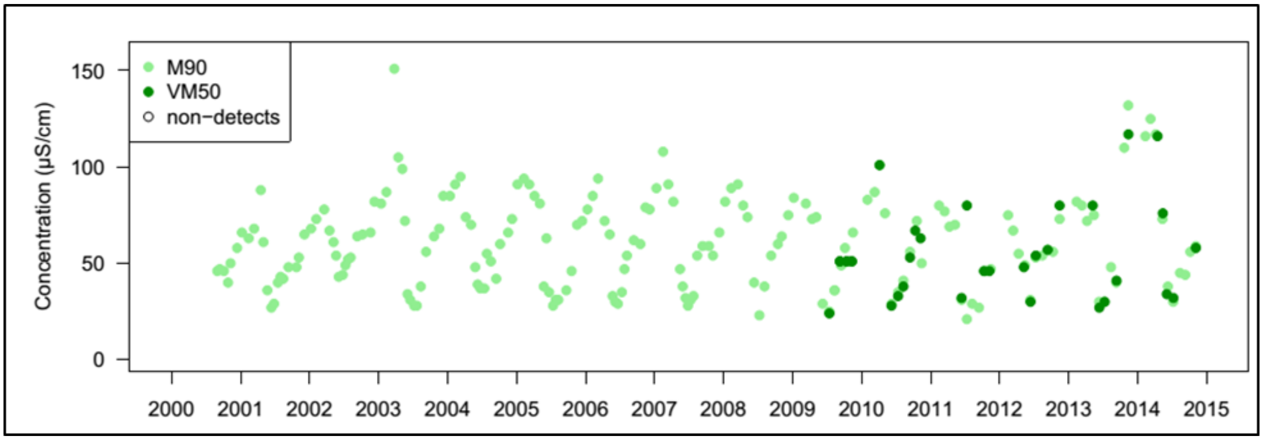

Figure 62. Specific Conductivity at M90 (COOP) and VM50 (Volunteer), 2000-2014

Based on this comparison, no concerns are raised about the quality of the data collected by either the Volunteer or COOP monitoring program. For cost savings, the Volunteer program could justifiably reduce the frequency of sampling of all of these parameters that are also reported by the COOP program at these paired locations in the future. As noted above, reduction in Volunteer program detection limits for copper (and secondarily for lead) is recommended at these locations if Volunteer sampling for these parameters is continued.

4 SUMMARY OF FINDINGS AND RECOMMENDATIONS

This report, sponsored and supported by the Big Thompson Watershed Forum (the Forum), presents and assesses water-quality data collected at flowing water sites in the Big Thompson watershed for WY2000 through WY2014. The recent five years (2010-2014) were eventful in the Big Thompson watershed, including wildfires and record flooding. These types of disturbances can have significant effects on water quality and were a focus in the data analysis.

Additionally, natural peak flows in the recent five years have included very high and low snowmelt runoff peaks. At M20, the highest flow rates during snowmelt runoff in the recent 15 years were measured in 2011. In contrast, 2012 snowmelt at M20 resulted in one of the lowest peaks in the recent 15 years, comparable to the drought year of 2002. All of these conditions provide a good opportunity to observe water-quality response to a range of perturbations.

Overall, the state of the watershed varies from good in the upper watershed to fair in the lower watershed. The key findings are summarized for each of the major assessment objectives. Patterns, long-term trends, compliance issues and the observed fire and flood effects are summarized in the following subsections, followed by program recommendations.

4.1 PATTERNS

Detailed review and analysis of flow and water-quality data from canals, rivers, and tributaries in the Big Thompson watershed reveal some consistent patterns for the upper watershed, lower watershed, C-BT canals, major tributaries, and below WWTPs:

Upper Watershed: The upper watershed is generally characterized by good water quality. This reflects the igneous and metamorphic rock of the subsurface geology, low populations, and natural runoff patterns (dominated by the annual snowmelt runoff hydrograph). Concentrations of dissolved solids, metals, nutrients, chlorophyll *a*, TOC, suspended solids, and coliforms all tend to be low, especially relative to the lower watershed. TOC concentrations peak during the spring snowmelt runoff period, with the magnitude of these peaks (but not necessarily the timing of peaks) similar to the TOC peaks observed in the lower watershed.

Lower Watershed: The water quality in the lower watershed is generally fair. It is characterized by higher populations, urban development, agriculture and livestock, more WWTP effluent, more alluvial groundwater, and sedimentary subsurface geology, including the Pierre shale. The lower watershed exhibits lower annual flow rates, with a sharp decrease between M90 and M130 due to the City of Loveland drinking water treatment plant intake and numerous irrigation ditch diversions. Snowmelt runoff signals are minimized in the lower watershed, and the greater percent of impervious surface area is apparent in the somewhat “flashy” response of flow rates to precipitation. Relative to the upper watershed, the lower watershed exhibits notably higher concentrations of dissolved solids, nutrients, chlorophyll *a*, TOC, suspended solids, and coliforms. Selenium is also consistently higher in the lower watershed due to the underlying Pierre shale.

C-BT Canals: Water quality in the C-BT canals is good and reflects the conditions in Grand Lake on the west side of the continental divide. Average annual volumes of water delivered from the Adams Tunnel into the Big Thompson watershed are much greater than natural runoff volumes. These flows do not follow consistent seasonal patterns. Water quality in the canals is generally comparable to that of the upper-most Big Thompson watershed, with low nutrients, TOC, metals, and suspended solids. Differences include lower coliforms, orthophosphate and nitrate, and slightly higher chlorophyll *a*, TOC, and dissolved solids (specific conductivity, alkalinity, and hardness) from the Adams Tunnel.

Major Tributaries: Major tributaries with sampling data in the Big Thompson watershed include Glacier Creek, Fall River, the North Fork, Buckhorn Creek, and the Little Thompson River.

- ***Glacier Creek, Fall River, and the North Fork*** drain fairly pristine high-mountain granitic watersheds. As such, the water quality from these tributaries tends to be good and similar to that of the upper watershed on the mainstem of the Big Thompson River.
- ***Buckhorn Creek*** also exhibits low nutrients, TOC, and chlorophyll *a*; however, measures of dissolved solids are more similar to lower watershed conditions. Specifically, Buckhorn Creek has high alkalinity, hardness, specific conductivity and sulfate. This is indicative of the change in subsurface geology from granitic rock in the upper watershed to sedimentary rock. Additionally, there are several quarries in the Buckhorn Creek watershed (e.g., Arkins Park Stone Quarry, Colorado Flagstone Quarry, and Old Wild Gypsum Quarry).
- ***The Little Thompson River*** exhibits water quality similar to that observed on the mainstem of the Big Thompson in the lower watershed. This includes elevated concentrations of TOC, chlorophyll *a*, sulfate, and coliforms. Ammonia, nitrate, dissolved solids, and selenium concentrations are also elevated in the Little Thompson River and tend to be greater than those in the lower Big Thompson. Phosphorus concentrations tend to be lower in the lower Big Thompson as compared to the Lower Big Thompson River.

Below WWTPs: WWTPs serve an important function in the watershed, treating wastewater and returning it to the river. For many rivers, including the Big Thompson, WWTPs represent major point sources for loading of nutrients, organic matter, and sometimes metals. In the Big Thompson watershed, total nitrogen and total phosphorus concentrations increase at stations below each of the major WWTPs in the watershed: M30 (below the Estes Park Sanitation District effluent), M50 (below the Upper Thompson Sanitation District effluent), significantly at M140 (below the Loveland WWTP effluent), and at VT15 (below the Berthoud WWTP). These increases largely reflect loading of nitrate and orthophosphate, which are forms of nutrients that are readily available for algae and plant growth. Implementation of the recent Regulation 85 for nutrients is expected to reduce nitrogen and phosphorus in the treated WWTP effluent by 2020 within the watershed basin.

4.2 LONG-TERM TRENDS

Testing of the 15-year record for statistically-significant trends revealed two key findings:

Increasing TOC in canals and the upper watershed: Statistically-significant trends of increasing TOC concentrations were found in the C-BT canal system (C10, C20, C30, C40 and C50) as well as in much of the Big Thompson upper watershed mainstem (M20 to M130). This finding is in agreement with findings from the previous State of the Watershed report (Hydros, 2011), but it includes more stations. The magnitude of this increasing trend ranges from 0.02 to 0.09 mg/L of TOC per year. This finding of increasing TOC is important because it can directly affect drinking water treatment costs, operations, and regulatory compliance. These increasing trends include the reach from which the City of Loveland diverts water for drinking water treatment, as well as inflows to major C-BT reservoirs including Horsetooth. Further trend testing suggests that the increasing trend may have recently begun to plateau. The cause of this increasing trend in TOC concentrations in water from the west and east slopes is hypothesized to be the large-scale tree death from the ongoing mountain pine beetle epidemic. This finding agrees with recent published research from Colorado (Mikkelson et al., 2013).

Decreasing nitrate at the top of the upper watershed: In the upper-most portions of the watershed (M10, 794, M20, and M30), statistically-significant long-term trends of decreasing nitrate concentrations were found. Over the 15-year period, the trend corresponds to a decrease of 25 to 55% of the median concentration. This finding agrees with recently published findings of a long-term study in the Colorado Front Range (Mast et al., 2014). That study found that nitrate in streams in Rocky Mountain Nation Park increased in the early 1990’s but has been decreasing since the early 2000s, coincident with EPA-mandated decreases in nitrogen oxide emissions from vehicles, industry, and power plants. Interestingly, there is also a statistically-significant long-term trend of decreasing lead concentrations across the watershed that may relate to long-term reductions in atmospheric emissions and subsequent deposition.

4.3 COMPLIANCE

Comparison of the Forum’s water-quality dataset to relevant standards produced a few noteworthy findings:

Acute and chronic copper exceedances at the top of the watershed: There is a high frequency of copper standard exceedances (61% for chronic and 41% for acute) in the most upstream station in the watershed (M10). The low hardness values at this station results in very low copper water-quality standards. However, moving downstream, the increase in hardness rapidly results in decreases in the fraction of samples above the standards, dropping to 11% chronic and 6% acute exceedances by station M20. There is also a relatively high frequency (22%) of chronic-standard copper standard exceedances at M90. The City of Loveland occasionally uses copper sulfate for algal biomass control in Green Ridge Glade Reservoir (near site M90), which can discharge augmentation water back to the Big Thomson River.

Lower watershed exceeds chronic standard for selenium: The lower watershed, including the Little Thompson River, exhibit relatively high frequencies of exceedance of the chronic selenium standard. This reflects the effects of the selenium-rich Pierre shale in this area.

Frequent exceedances of *E. Coli* in the lower watershed and Little Thompson River: *E. Coli* exceedances are infrequent in the upper reaches and in the central mainstem of the Big Thompson River. In the lower watershed, beginning with T20 (Buckhorn Creek), the frequency of exceedances generally increases downstream. The most frequent exceedances (>60%) are observed on the Little Thompson River (VT20, VT15, and VT05). This may reflect livestock sources of bacteria in this reach.

Recently-updated sulfate standards indicate issues at M130 and on the lower Little Thompson River: Recently adopted standards, effective December 31, 2015 (WQCD, 2015c), apply water supply standards to segments 4b and 9. As a result, exceedance of sulfate standards are anticipated in these reaches most years, based on existing data,

The Forum's dataset does not support 2012 303(d) listings of cadmium, copper, and zinc: Based on review of the Forum's dataset, the basis for 303(d)-listing of copper for the lower Little Thompson River is uncertain. Likewise, the Forum's dataset does not support 303(d)-listing of cadmium and zinc in much of the upper watershed. This agrees with the currently-proposed changes to the 303(d) listings for cadmium and zinc, as of August 2015. It is also currently expected that the lower Little Thompson River will be de-listed for copper for the 2016 303(d) List, again consistent with the findings of this review (Billica, 2015, personal communication). The final revised listings, however, will not be set until after the December, 2015 hearing (WQCD, 2015c).

Interim Nutrient Criteria review suggests possible future challenges: The interim numeric criteria for total nitrogen and total phosphorus indicate potential future areas of concern at the downstream end of the watershed. High frequencies of years exceeding the nutrient criteria (>50%) begin at M140 below the Loveland WWTP outfall on the Big Thompson River and VT15 below the Berthoud WWTP on the Little Thompson River. The data used in this comparison (WT2000-WY2014) were not collected at a time when nutrient standards were effective for the

Big Thompson. Total phosphorus standards were adopted for some stream segments within the Big Thompson River watershed (1, 2, 6, 7, 8, 9, and 10) on August 10, 2015 (effective December 31, 2015), but total nitrogen standard have not yet been adopted for any segment (WQCD, 2015b). Based on the Forum database, total phosphorus is expected to be a concern on the Little Thompson River and at the downstream end of the Big Thompson when these standards become effective in 2016. However, implementation of Regulation 85 should result in future phosphorus and nitrogen reductions in effluent from WWTPs within the watershed.

4.4 FIRE EFFECTS

There were four major wildfires entirely or partially within the Big Thompson watershed in recent years:

- **Cow Creek Fire:** June 2010,
- **Crystal Fire:** April 2011,
- **High Park Fire:** June 2012, and
- **Fern Lake Fire:** October 2012.

Water-quality data collected downstream of these locations indicate some water-quality effects for some of the fires (High Park and Fern Lake), including increased specific conductivity, nitrate, TOC, TKN, total phosphorus, and sulfate (varying for the different fires). However, the measured effects were generally short-lived and not significant enough to impact aquatic life and drinking water supplies (Billica, 2014). Data also indicate that the spatial extent of downstream water-quality effects was limited. Fires in the future, however, could have greater adverse impacts, depending on their location, extent, and severity.

4.5 FLOOD EFFECTS

In September 2013, a week of record-breaking rainfall resulted in extensive flooding along the Front Range. Rainfall amounts over a seven-day period exceeded 15 inches near Estes Park. The flood is estimated to have been a 100- to more than 500-year flood in the Big Thompson and Little Thompson Rivers (CH2MHill 2014, Jacobs, 2014, and Jacobs, 2015). Damage from flash flooding and debris flows was extensive.

There was no in-river sampling during the 2013 flooding event due to safety and access issues, but post-flood effects were apparent in the dataset. Some samples were collected in the C-BT canals during the flooding event. Overall, there were no major or persistent adverse water-quality effects of the flood observed in the Forum dataset, though there have been reports of periodic high turbidity continuing into 2015 (Shelley, 2015b, personal communication). Such high turbidity may reflect resuspension of material moved into riverbeds during the flooding or resuspension during in-river, post-flood repair activities with heavy machinery. Such events could easily be missed by the pre-scheduled Forum data collection. Observed effects differed in the lower watershed compared to the upper watershed:

- C-BT canal locations downstream of Lake Estes exhibited short-lived increases in nutrients, TSS, TOC, sulfate, and possibly some metals, during and immediately following the flood. This largely reflected east-slope watershed runoff into Lake Estes, as opposed to west-slope water quality from the Adams Tunnel. Pumping of west slope water through the Adams Tunnel was stopped on September 11, 2013 and restarted in late November 2013.
- In the upper watershed, where concentrations tend to be low, increased TSS, turbidity, dissolved solids, and in some cases total phosphorus, total nitrogen, and nitrate were observed after the flood. These increases in the upper watershed reflect leaching from shallow soils and mobilization of solids available for transport following the high flood flows. In the upper watershed, Forum data suggest that concentrations had largely returned to typical levels by the end of WY2014. However, periodic elevated turbidity has been reported into 2015 outside of this dataset, particularly during storm events and in response to post-flood recovery work in the river.
- In the lower watershed, downstream of M130/M140, increased baseflow appears to have resulted in decreased concentrations of hardness, specific conductivity, nitrate, orthophosphate, and sulfate. These decreases were particularly evident in winter months. These effects have persisted into 2014 but are expected to diminish as groundwater levels return to normal. The decreased concentrations reflect dilution from greater groundwater inflow (and groundwater from different areas) in these reaches where typical concentrations tend to be relatively high. Elevated suspended solids and turbidity have also been reported into 2015 outside of this dataset, particularly during storm events or in response to post-flood recovery work in the river.

4.6 PROGRAM RECOMMENDATIONS

Overall, the Forum monitoring program is well-conceived and well-managed, generating a very useful dataset to support evaluation of water quality across the watershed. Further, comparisons of data from collocated COOP and Volunteer monitoring stations indicated good agreement between program results. Through the process of developing this report, several recommendations for program improvements were generated for consideration by the Forum:

- **Lower Volunteer Program Detection Limits for Some Metals:** Detection limits for metals in the Volunteer program are consistently higher than those in the COOP program and, in many cases, result in consistent non-detect results. Reducing detection limits to match those of the COOP program would improve comparability of the datasets. A more limited approach would be to reduced detection limits for metals for cases where the detection limit is above the corresponding standard. Specifically, this would include reducing detection limits for copper at VM50, NFBT10, FR05, and 794, and cadmium at 794.

- **Reduce frequency of Volunteer sampling at nearly-collocated COOP stations:** For cost savings, the Volunteer program could justifiably reduce frequency of sampling at stations VM50 and 795, which are also sampled at the nearly-collocated COOP program locations.
- **Add TSS sampling back to Volunteer and COOP programs:** TSS samples are currently only collected in the canal locations. It is recommended that TSS sampling be added back to the Volunteer and COOP programs to collect some measure of solids concentrations to support evaluation of changing conditions.
- **Develop an event-response sampling plan:** Consider developing an event-response plan, if one does not exist, to increase chances of capturing some samples during or shortly after major events like fires or floods. Such planning would include advanced preparation of sample packs for a subset of parameters, SOPs, safety training, and a list of typically easier-access locations for consideration.
- **Add continuous temperature monitoring or locate other data sources**: Given the importance of water temperature to aquatic life and the variable flow rates in the Big Thompson River due to various diversions, it is recommended that continuous temperature gages be installed in several locations. These data would help support evaluation of the current 303(d) temperature listings across the watershed. Alternatively, if such data are being collected through another program, it is recommended that these data be included in the next five-year data review. Specific locations for installation of gages should be identified following review of any other available continuous temperature data. Note that the City of Loveland is installing continuous temperature monitoring upstream of its WWTP to meet compliance requirements by September 30, 2016. All major WWTPs have this monitoring requirement in their most recent permits, which could provide useful information.

- **Add a sampling station upstream of the Culver Ditch Diversion on the Little Thompson River:** The upper Little Thompson River, upstream of the Culver Ditch diversion is 303(d)-listed for sulfate, temperature, and dissolved oxygen. There are currently no data for this part of the watershed in the Forum database. It is recommended that a sampling station be added upstream of the Culver Ditch diversion to collect data on these parameters at a minimum.
- **Recommendations for Next Five-Year Review:**
  - Revisit approach to presentation of seasonal loading. These bar-graph figures are challenging to interpret and could likely be improved with definition of more specific review objectives. Alternatively, the load calculations could be entirely

eliminated from the next watershed review since they are generally better suited to support more focused studies conducted to address specific issues.

- Present trend lines on concentration plots only where they are found to be statistically significant.
- Consider spatial analysis of land-use GIS coverages to support interpretation of water-quality results and changes over time.
- Consider updating season definitions in the next report to attempt to distinguish snowmelt runoff from the "summer" group.
- Consider adding discussion of Colorado's Monitoring and Evaluation (M&E) List to the next report, in addition to the 303(d) List, since the M&E List indicates parameters of potential concern for each stream segment.
- Depending on the outcome of the pending 303(d) listing process, arsenic and manganese may need to be added to the analyte list for the next report and cadmium and zinc may be removed. The 2015 proposed 303(d) listings include these changes, but the list will not be final until after the hearing, scheduled for December 2015 (WQCD, 2015c).

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