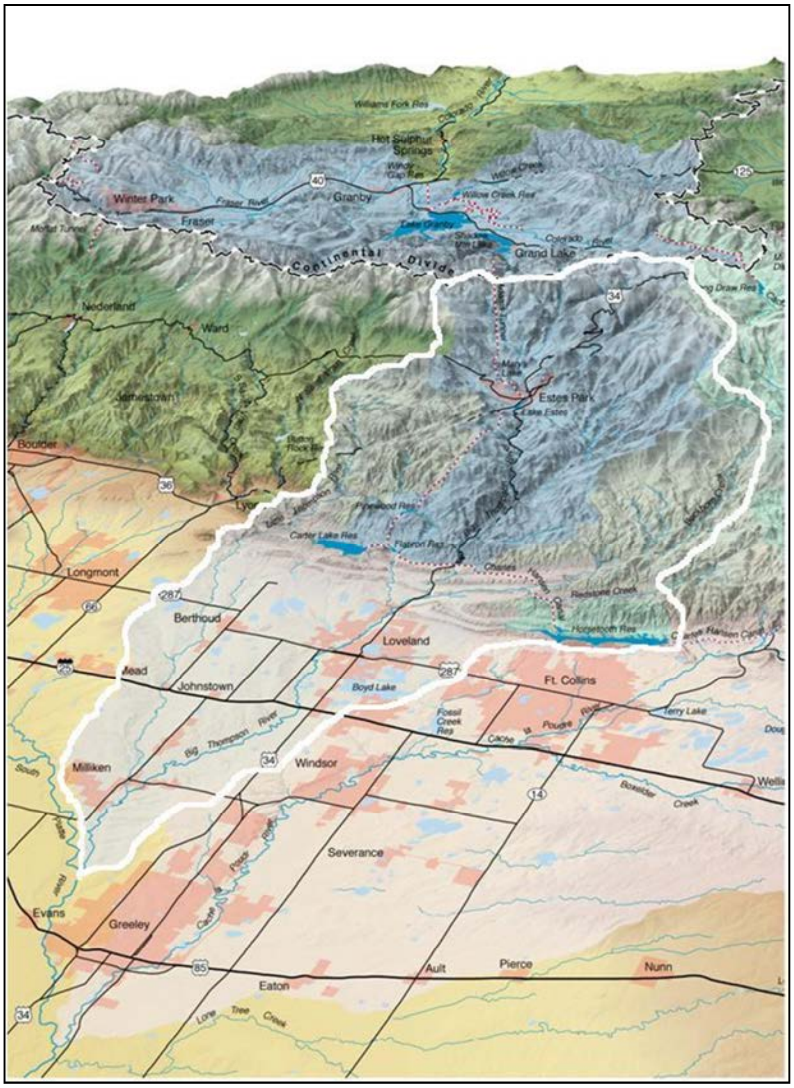
BIG THOMPSON STATE OF THE WATERSHED
2010 Report



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February 4, 2011

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ACRONYMS AND ABBREVIATIONS

ATSDR	Agency for Toxic Substances and Disease Registry
C-BT	Colorado-Big Thompson
COOP	Cooperative
CWAP	Clean Water Action Plan
DBP	Disinfection By-products
E. Coli	Escherichia Coli
EPA	U.S. Environmental Protection Agency
H_2S	Hydrogen Sulfide
IQR	Inter-quartile range
JFA	Joint Funding Agreement
ND	Non-detect
NFRWQPA	Northern Front Range Water Quality Planning Association
NH_3	Ammonia
ROS	Regression on Order Statistics
SIM	STORET Import Module
SRP	Soluble Reactive Phosphate
TKN	Total Kjeldahl Nitrogen
TMDL	Total Maximum Daily Load
TOC	Total Organic Carbon
TSS	Total Suspended Solids
USGS	U.S. Geological Survey
WQCD	Water Quality Control Division
WWTP	Wastewater Treatment Plant
WY	Water Year

ACKNOWLEDGEMENTS

Hydros Consulting would like to offer thanks to the Big Thompson Forum for the opportunity to develop this assessment. Additionally, we would like to thank the members of the Forum's Science and Monitoring Committee, John Bartholow, Judy Billica, Jim Loftis, Al Paquet, Jen Stephenson, and Esther Vincent for excellent guidance and thorough, thoughtful reviews of the draft report. We are also very grateful to the Forum's Program Director, Zack Shelley, for excellent and tireless support and coordination throughout the effort. Finally, we offer thanks to Integral Consulting staff for exceptional database, graphics, and coding technical support.

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 supports the Forum's efforts to identify and evaluate strategies for watershed management and protection in the process of maintaining a comprehensive watershed management plan.

SITE DESCRIPTION

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. The ecosystems, water uses, population density, and water quality vary widely across the watershed. The Big Thompson 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 other side of the continental divide.

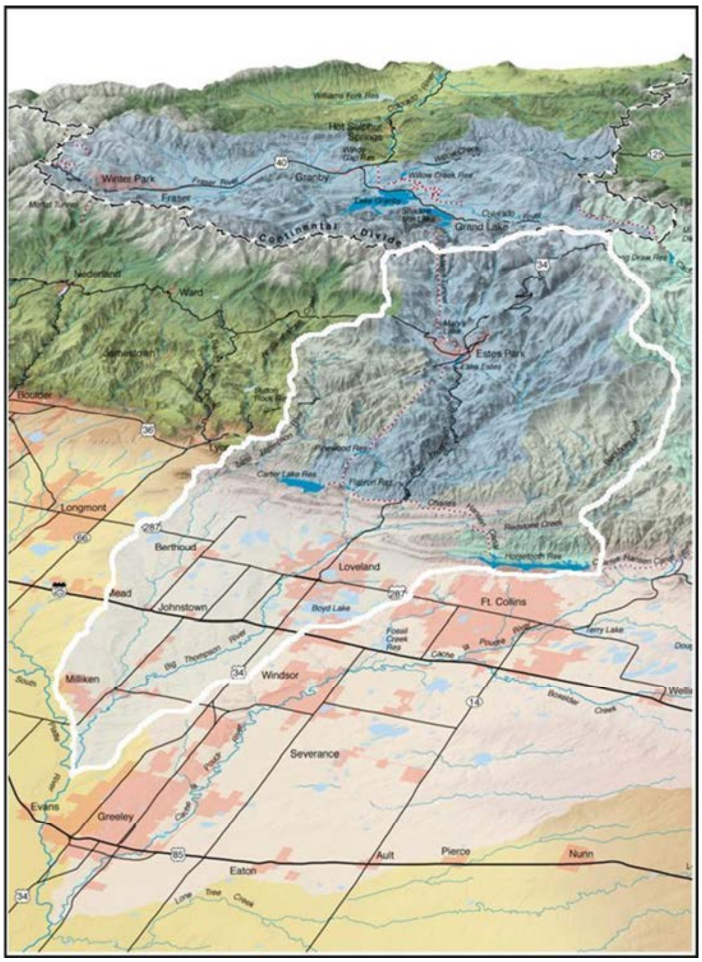

Figure ES 1. Big Thompson Watershed.

Flow in much of the Big Thompson River is highly regulated and managed by diversions and reservoirs. The effect of this regulation is apparent in the flow record. The highest peak flow rates are observed in the upper portion of the watershed, while lower peak flow rates and annual volumes are typically observed at the lower end of the watershed.

Water quality in the Big Thompson watershed is potentially affected by 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 and urban and suburban stormwater runoff. In 2007, the Forum identified nutrients (phosphorus and nitrogen) as the priority pollutants of concern for the watershed (Buirgy, 2007). In addition, various segments of the Big Thompson River and its tributaries are on Colorado's most recent 303d list[1] of impaired waters. The listed parameters are copper, cadmium, selenium, zinc, dissolved oxygen, Escherichia Coli (*E. Coli*), pH, and temperature (WQCD, 2010).

ASSESSMENT

This assessment builds on two previous State of the Watershed reports that included analysis of data from the flowing water sites: Jassby and Goldman (2003) and Haby and Loftis (2007). Insights developed in those reports are reevaluated in this assessment, with a larger (greater spatial coverage and longer duration) dataset. Specifically, this report seeks to answer the following questions:

1. What is the current state of water quality in rivers and streams as indicated by data in the Forum's database?
2. What are the statistically significant trends with time in water quality concentrations across the watershed over the full record?
3. What are the estimated annual and seasonal loads of select water quality parameters? What are the spatial and temporal patterns in the loading results?
4. To what extent have water quality observations been out of compliance with applicable standards? To what extent have nutrient concentrations exceeded the current draft Colorado WQCD numeric nutrient criteria[2]?
5. What improvements should be made to the Forum's data collection program and database to improve understanding of the system?

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[1] "This regulation establishes Colorado's List of Water-Quality-Limited Segments Requiring Total Maximum Daily Loads ("TMDLs"). The list of Water-Quality-Limited Segments Requiring TMDLs fulfills requirements of section 303(d) of the federal Clean Water Act which requires that states submit to the U.S. Environmental Protection Agency a list of those waters for which technology-based effluent limitations and other required controls are not stringent enough to implement water quality standards" (WQCD, 2010). At this point, TMDLs have not been developed for any segments of the Big Thompson Watershed, and the timing of TMDL development remains uncertain. Of the 303d listings, the high priority listings are for segments COSPBT01 (copper), COSPBT02 (pH, Cu, Cd, Zn, and *E. Coli*), COSPBT07 (copper), COSPBT08 (temperature and dissolved oxygen), and COSPBT09 (*E. Coli* only).

[2] The Colorado Water Quality Control Division (WQCD) is working to develop nutrient criteria appropriate for Colorado lakes and streams (anticipated for completion and ruling in June 2011). The draft nutrient criteria as of October 13, 2010 were used in this analysis. These draft criteria are not current standards and were assessed for information purposed only.

The Forum's records of water quality and flow rates from rivers and streams in the Big Thompson watershed from water year (WY)[3] 2000 through WY 2009 provided the data for this assessment. These data were retrieved from the Forum's recently developed NP STORET database. The assessment focused on flow rates, select metals, general parameters, nutrients, and microbiological parameters. In total, 25 water quality parameters were assessed at 31 sampling stations across the watershed, comprising a total of over 78,000 records. These sampling stations are a part of the Forum's two major water quality monitoring and assessment programs, the Forum's Cooperative Monitoring Program (COOP) and the Forum's Volunteer Monitoring Program (Volunteer). Sampling station locations are shown in Figure ES-2.

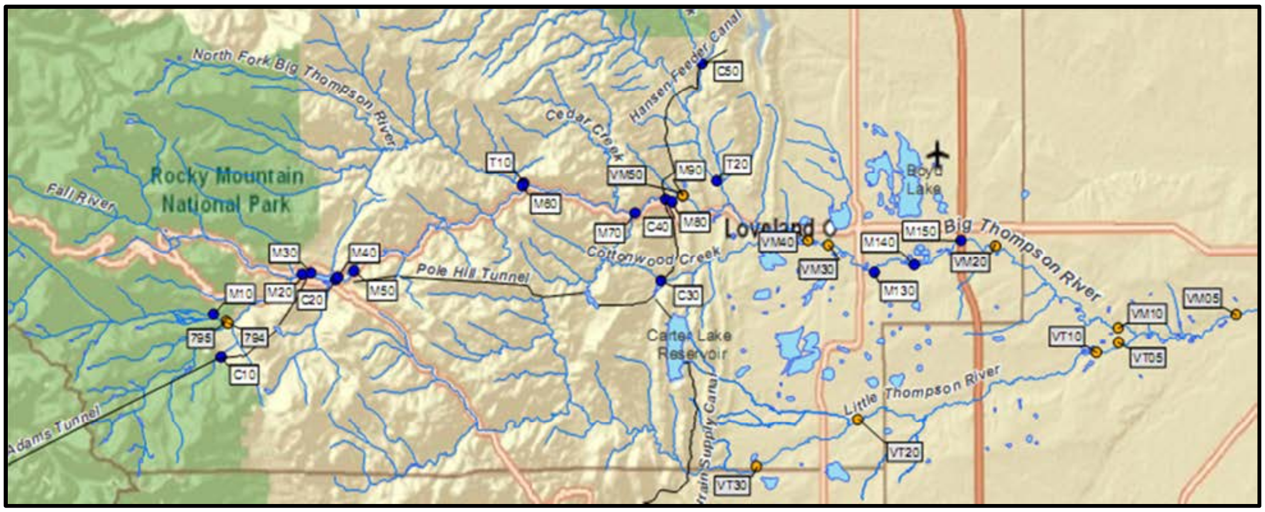

Figure ES 2. Sampling Station Locations. *(Blue dots are COOP stations; orange dots are Volunteer)*

Evaluation of the data began with a critical review of the contents of the database to generate a 'clean' dataset useable for calculations and statistical analysis. This clean dataset was used to generate estimates of annual and seasonal loads for nutrients and TOC. The dataset was also subjected to testing to assess the statistical significance of any long-term trends in water quality over the period of record. Finally, the dataset was evaluated against current Colorado water quality standards (Regulation 38, WQCD, 2010b), and total nitrogen and total phosphorus data were compared to the draft nutrient criteria[4].

[3] 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).

[4] In October 1997, a Clean Water Action Plan (CWAP) was initiated by EPA to address nutrient over-enrichment in the nation's surface waters. The CWAP includes the development of water quality nutrient criteria as one of its objectives. The criteria are to be region-specific for different types of water bodies, in recognition of the large variation in nutrient conditions across the country. As a result, the Colorado WQCD is working to develop nutrient criteria appropriate for Colorado lakes and streams, anticipated for completion and ruling in June 2011. The draft nutrient criteria as of October 13, 2010 were used in this analysis.

Nine distinct data products were generated to support evaluation of the dataset:

- Summary statistics tables for all stations and analytes,
- Concentration time-series plots for all parameters and locations,
- Box plots summarizing concentration results spatially,
- Flow rate time-series plots for all stations with flow records,
- Box plots summarizing loading results spatially,
- Bar graphs summarizing loading results seasonally and annually,
- A summary table presenting estimated annual loads and flow-weighted mean concentrations,
- A summary table of statistical testing results, and
- Summary tables of the compliance assessment results.

FINDINGS AND RECOMMENDATIONS

Technical Findings

Based on the results of calculations, statistical testing, and data products developed for this assessment, the key findings are summarized as follows:

- **WWTPs** – The effects of the major WWTPs in the watershed are apparent in both nitrogen and phosphorus concentration observations below each major outfall. The largest concentration and load increases are observed below the Loveland WWTP (M140) on the mainstem of the Big Thompson River and below the Berthoud (VT10) and Berthoud Estates (VT20) WWTPs on the Little Thompson River. Effects of upgrades to the WWTPs (Estes Park Sanitation District in 2005, Upper Thompson Sanitation District in 2007, and Loveland WWTP in 2004) are apparent in decreasing ammonia and Total Kjeldahl Nitrogen (TKN) concentrations in the river[5]. It should be noted that these observations of increased nutrient concentrations and loads below WWTPs contribute important information to understanding the system and sources of nutrients to the rivers and reservoirs; however, WWTPs are only currently regulated for ammonia (not total nitrogen, nitrate plus nitrite, or total phosphorus). As such, these observations and comparisons to the draft nutrient criteria are not indications of WWTP system discharge permit compliance issues.

- **C-BT System** – The water introduced to the Big Thompson watershed by the C-BT system (via the Adams Tunnel, C10) has generally similar or lower concentrations for most parameters, as compared to the water quality in the upper-most portion of the Big

[5] Neither phosphorus nor total nitrogen is currently regulated in WWTP discharge permits. Improvements to the Loveland WWTP targeted ammonia and *E. Coli*. Evaluation of WWTP effluent data and specific loads were beyond the scope of this assessment, but may be useful for future assessments.

Thompson watershed. Two noteworthy exceptions are total organic carbon (TOC) and chlorophyll *a*.

- TOC concentrations continue to show a statistically significant increase over the last ten years in portions of the east slope C-BT system assessed in this report (C10, C20, C30, and C40). Haby and Loftis also noted an increasing trend in TOC concentrations in their review of the watershed in 2007 (Haby and Loftis, 2007). The increasing trend, on the order of 0.1 mg/L-yr at C10 through C40, was not observed at C50, which flows to Horsetooth Reservoir. 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.
- The CB-T system carries relatively high chlorophyll *a* concentrations into the system at C10 (Adams Tunnel), as compared to M20. Chlorophyll *a* is a form of chlorophyll used in oxygenic photosynthesis that is used as a measure of phytoplankton abundance and an indicator of water quality.

- **Major Tributaries –**
  - Buckhorn Creek – The Big Thompson tributary, Buckhorn Creek (T20), exhibits relatively poor water quality and possible trends of concern. High concentrations of Total Dissolved Solids (TDS), specific conductivity, alkalinity, and hardness are observed, which may be related to multiple quarry operations in the drainage as well as the general geology of the drainage. Buckhorn Creek only contributes an average of 5% of the flow observed at M130, but the effects of the higher concentrations of these parameters are apparent at VM40. Additionally, *E. Coli* and ammonia concentrations are high relative to the upstream concentrations on the Big Thompson River, contributing to frequent exceedances of water quality standards for these parameters at T20. Further, *E. Coli* concentrations show higher values in recent years, though no statistically significant trend was identified.
  - North Fork of the Big Thompson River (T10) – The North Fork flows are roughly 25% of the flows observed at the upstream mainstem station M60, and the water quality is generally good. Nitrogen, phosphorus, and TOC concentrations from the North Fork are generally low, as are Chlorophyll *a* concentrations, as compared to the mainstem upstream station, M60. There are, however, observations of increased *E. Coli* concentrations in recent years, and a trend of increasing total coliforms.
  - Little Thompson – The Little Thompson water quality at VT05, where it joins the mainstem, is similar to the mainstem water quality in the lower watershed, with elevated concentrations of nutrients, TOC, chlorophyll *a*, selenium, and coliforms. Concentrations of these parameters generally increase from upstream to downstream on the Little Thompson. Of these parameters, phosphorus

concentrations are lower than upstream mainstem concentrations (at VM10), but still higher than watershed values upstream of Loveland. Ammonia, nitrate, and total nitrogen concentrations are even higher than those in the immediately upstream mainstem location (VM10). The Little Thompson also contributes elevated values of alkalinity, specific conductivity, hardness, and temperature to the mainstem, relative to VM10 observations.

- **Compliance** –The compliance analysis indicated issues with dissolved copper, selenium, *E. Coli*, and ammonia.
    - Acute and chronic copper exceedances are routinely observed in the upper watershed at station M10, where copper standards are lower due to low hardness[6]. Farther downstream along the mainstem, fairly routine periodic acute and chronic exceedances were observed at M80 and M90. Routine exceendances were also observed at the North Fork (T10) in 2006 and 2007; however, there have been no exceedances at M80, M90, or T10 since 2008. Exceedances even farther downstream are not seen due to relatively high hardness values resulting in much higher calculated standards. Copper sulfate has been used in the watershed as an algaecide by Northern Water and the U.S. Bureau of Reclamation. Northern Water copper sulfate applications occurred in the C-BT system in the area of the trifurcation, and would not have affected the upstream areas noted here. Further, applications by Northern Water were discontinued by 2008 in favor of a slurry form of hydrogen peroxide. Copper sulfate is still being used by the U.S. Bureau of Reclamation at Pole Hill near Lake Estes.
    - Dissolved selenium concentrations increase sharply in the lower foothills on the Big and Little Thompson Rivers, below which frequent exceedances are observed for both acute and chronic aquatic life standards. The selenium likely originates from naturally-occurring selenium-rich shale. This source naturally contributes loads to baseflows, and loading can be increased anthropogenically through agricultural irrigation and wastewater return flows[7].
    - Compliance issues for *E. Coli* (exceedances of standards to protect recreational use) increase from upstream to downstream, with frequent compliance issues occurring generally below M130 on the Big Thompson River and below VT20 on the Little Thompson River.

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[6] As discussed in the main document text (Section 2.2.5), for hardness-based standards (cadmium, copper, and zinc), the hardness value for each station was set as the 85th percentile result for the dataset for the most recent five years of record (October 1, 2004 through September 30, 2009). As such, the resulting standard values for these metals were constants for each station.

[7] The term "wastewater return flows", as used here, refers to treated drinking water released outside of the sewer system (via septic systems, lawn watering, etc.) which returns to the river via shallow groundwater flow.

  - Frequent and widespread exceedances of both acute and chronic aquatic life standards for ammonia were noted on the Big Thompson River mainstem (from M30 through M140) and on the Little Thompson River (starting at VT10).

- **Draft Nutrient Criteria** - A comparison of total nitrogen and total phosphorus data to the 2010 draft nutrient criteria indicates widespread results above the total nitrogen value. For phosphorus, values above the draft criteria are more prevalent in the downstream end of the system, below M140 on the Big Thompson River and below VT10 on the Little Thompson River. These findings indicate that implementation of phosphorous and nitrogen nutrient criteria, if set at draft values from 10/13/2010, would likely require many of the system WWTPs to modify their treatment processes to target nitrogen and phosphorus removal; however, direct WWTP effluent concentration and loading analysis was outside of the scope of this assessment.

- **Monitoring Program Comparability** – A simple comparison of results of the two sets of paired COOP and Volunteer monitoring stations revealed good comparability of results between the two sampling programs. The only exception was inconsistency in detection limits for dissolved copper and total mercury. The Volunteer monitoring program detection limits for those analytes are too high to allow for comparison of results and to fully assess compliance. Reduction of the Volunteer program detection limits for dissolved copper and total mercury is included in the program recommendations.

Program Recommendations

Several program improvements and special studies are recommended related to operation of the monitoring program and additional data evaluation for the next State of the Watershed Report. Recommendations for minor corrections and modifications to the database were also generated and are provided in Section 4.3 of the main report.

- For the next State of the Watershed report, consider adding the assessment of parameters on Colorado's Monitoring and Evaluation List[8] (WQCD, 2010a) for the Big Thompson River segments. These currently include arsenic, lead, and sulfide (sulfide as un-dissociated H_2S [hydrogen sulfide]).

[8] "Colorado's Monitoring and Evaluation List identifies water bodies where there is reason to suspect water quality problems, but there is also uncertainty regarding one or more factors, such as the representative nature of the data. Water bodies that are impaired, but it is unclear whether the cause of impairment is attributable to pollutants as opposed to pollution, are also placed on the Monitoring and Evaluation List. This Monitoring and Evaluation list is a state-only document that is not subject to EPA approval." (WQCD, 2010a)

- Reduce copper detection limits for volunteer monitoring program sites, particularly upstream (794, 794, and VM50) where lower hardness results in standards that are well below the current detection limits. A detection limit of 1 ug/L or less is recommended.

- Either reduce detection limits on total mercury in the volunteer monitoring program or discontinue sampling for this parameter. The current detection limit is 100 ng/L, and the standard is 10 ng/L. Studies using 'clean' sampling techniques and low level analysis found total mercury concentrations in the water in Rocky Mountain National Park to be between 0.8 to 12 ng/L (Mast et al., 2005).

- Add collection of TSS or turbidity to the volunteer monitoring program. Turbidity would be preferable to match current data collection in the COOP program. Currently, there is a large information gap regarding transport of solids due to this difference in the COOP and volunteer programs.

- Consider alternative approaches to trend testing that test more specific hypotheses, as needed. The trend testing approach used in this report was a broad-based test for trends across the current 10-year dataset. This is a reasonable approach to screen for long-term trends; however, as the dataset grows, there are likely to be more short term trends of interest. For instance, in this assessment, the effects of recent changes to WWTP systems were apparent, but often not identified in long-term trending. As the understanding of the system grows, the ability to develop specific questions about specific reaches/stations over specific time-periods improves. This kind of hypothesis testing approach to trend testing could provide a more powerful and specific assessment of more focused questions.
- It would be useful to consistently upload any available USGS and U.S. Bureau of Reclamation flow records for the system into the Forum's NP STORET database. The less frequent flow measurements in the current database limit the accuracy of loading analyses.
- A focused study should be considered to determine whether other sources of water quality data in the watershed could add critical information to support future State of the Watershed assessments. This study should consider, at a minimum, data from the Colorado Water Quality Control Division, the City of Fort Collins, the City of Greeley, and Northern Water. Such a review could simultaneously allow for independent assessment of the 303d listings in the watershed.
- Flow monitoring at VT05 would be useful to assess the load from the Little Thompson River. Water from the Little Thompson River is of poorer quality than the Big Thompson River for some parameters (e.g., ammonia and nitrate plus nitrite), and flow records would allow for better quantification of the significance of this for the Big Thompson River.

1 INTRODUCTION AND BACKGROUND

This report, sponsored and supported by the Big Thompson Watershed Forum (the Forum), presents and assesses water quality information collected in rivers, streams, and canals in the Big Thompson watershed between water year (WY)[9] 2000 and WY 2009. 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 and dedicated to protecting and improving water quality in the Big Thompson watershed. The Forum is an ongoing collaboration of participants from the community, the private-sector, non-governmental groups, and government agencies. This assessment will support the Forum's efforts to identify and evaluate strategies for watershed management and protection in the process of maintaining a comprehensive watershed management plan. The work presented in this report was developed under the guidance and review of the Forum's Science and Monitoring Committee.

The following subsections provide a description of the watershed, the objectives of the report, and the organization of this report.

1.1 SITE DESCRIPTION

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). The ecosystems, water uses, population density, and water quality vary widely across this diverse watershed. The Big Thompson watershed also 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 Three Lakes system on the western slope to the eastern slope via the Adam's Tunnel. The Big Thompson system serves as a resource to more than 800,000 people, providing residential, industrial, commercial, agricultural, recreational, and wildlife habitat benefits.

The natural headwaters for the Big Thompson River originate in Rocky Mountain National Park, with a maximum elevation of 14,259 ft, and empty into the South Platte River on the eastern plains at an elevation of 4,670 ft. Figures 2a and 2b present the upper and lower subwatersheds for the Big Thompson River. The upper watershed (Figure 2a) includes the upper Big Thompson, upper Little Thompson, and the North Fork subwatersheds. The upper Big Thompson subwatershed contains the Adam's Tunnel outfall, the Town of Estes Park, Lake Estes, and the upper end of the Olympus Tunnel.

[9] 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).

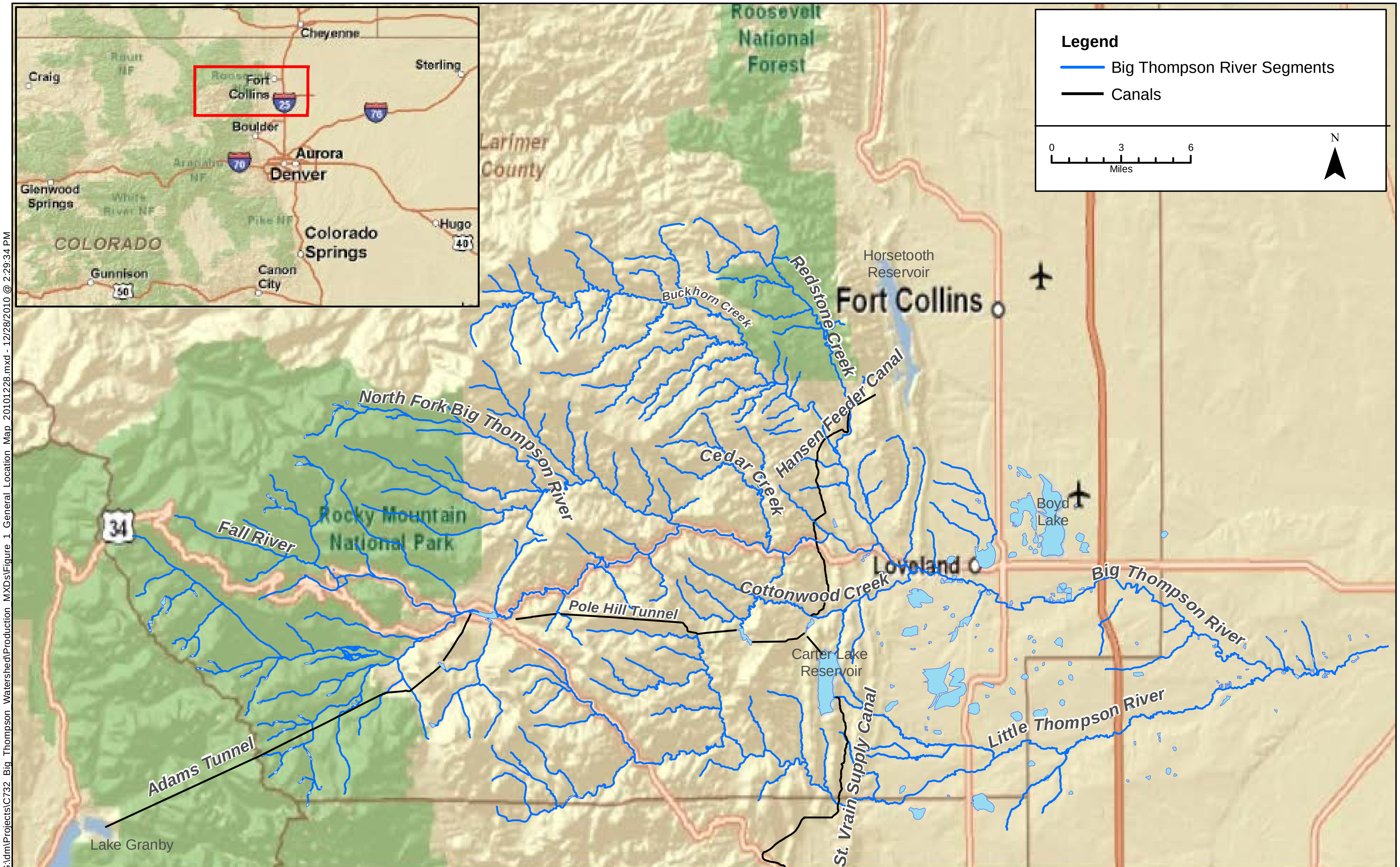

Figure 1.
Big Thompson 2010 Report
Location Map

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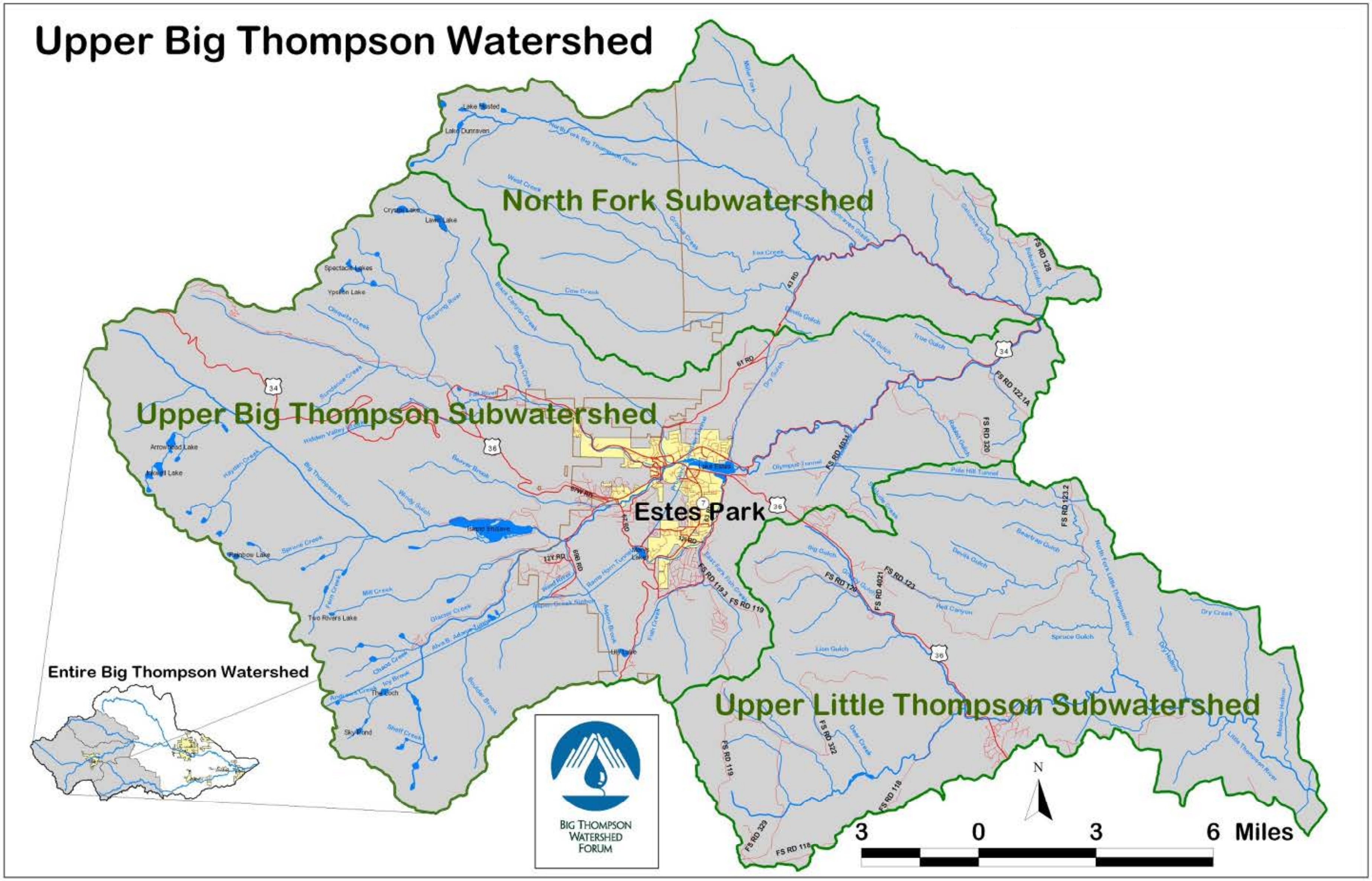

Image provided by Big Thompson Forum.

Figure 2a. Upper Big Thompson Subwatersheds

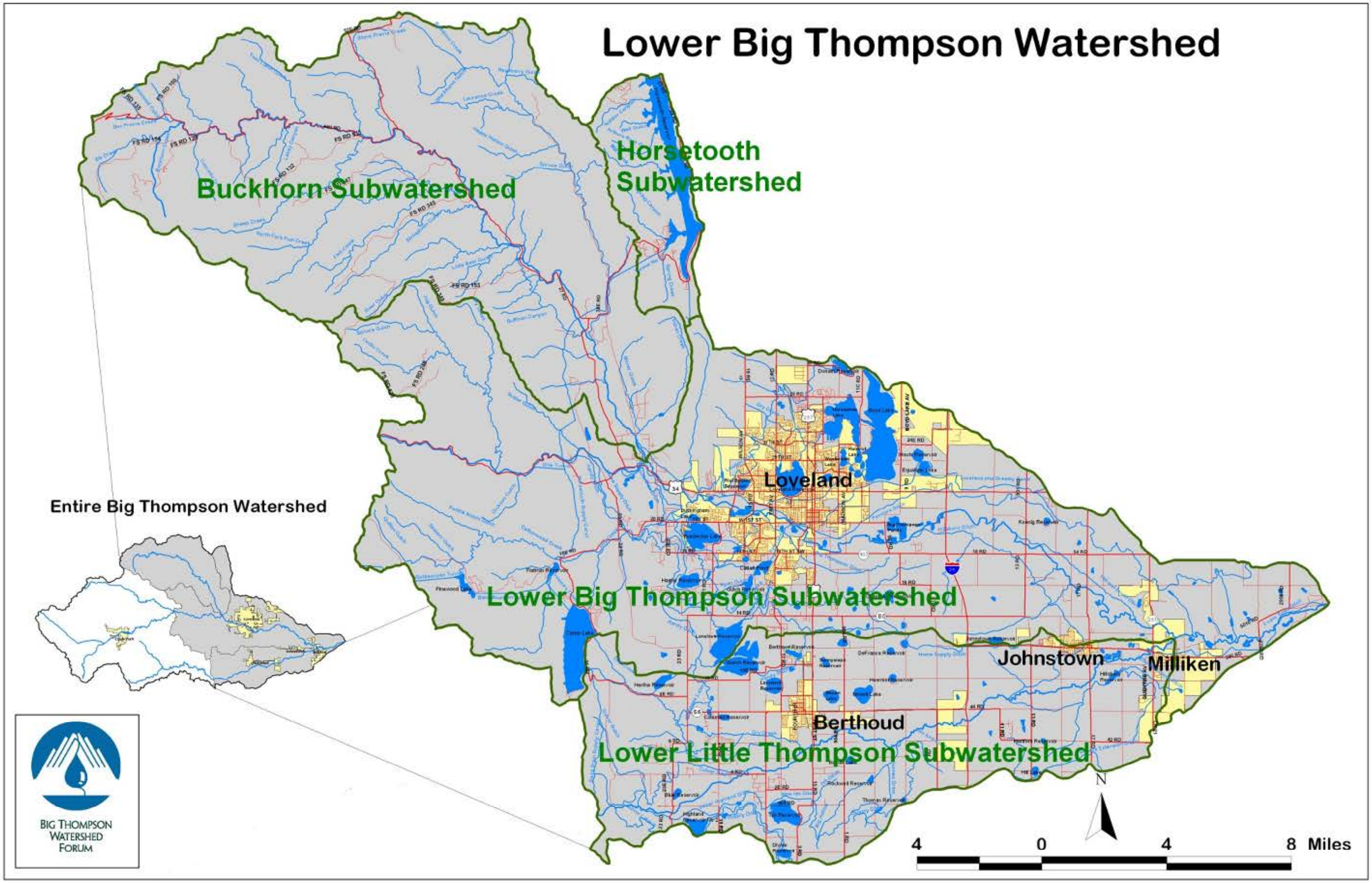

Image provided by Big Thompson Forum.

Figure 2b. Lower Big Thompson Subwatersheds

The lower Big Thompson (Figure 2b) 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 subwatersheds. The Lower Big Thompson subwatershed includes the "trifurcation" structure. . Water diverted through the Dille Tunnel serves three purposes: 1) it can 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) it can also be used to "skim" water and pass it through the Big Thompson Power Plant to generate electricity; and, 3) it can be used to 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 3 presents a simplified diagram of the trifurcation structure (numerous diversions above and below the Dille Tunnel along the Hansen Feeder Canal are not shown).

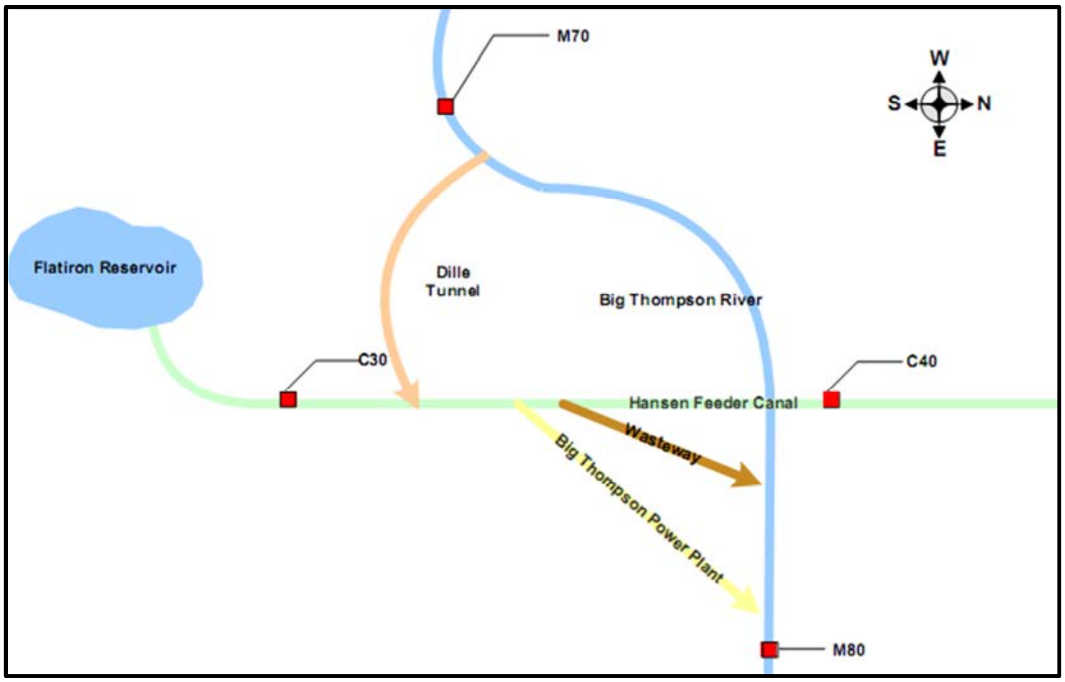

Figure 3. Simplified Depiction of Trifurcation

Factors potentially stressing water quality in the Big Thompson Watershed include population growth, discharge from wastewater treatment plants, power plants, diversions and return flows, livestock and ranching activities, agriculture, septic systems, transbasin imports, impoundments, and stormwater runoff. Figure 4 presents a map of major and minor wastewater treatment plants (WWTPs) in the watershed.

In 2007, the Forum identified nutrients (phosphorus and nitrogen) as the priority pollutants of concern for the watershed (Buirgy, 2007). In addition, various segments of the Big Thompson

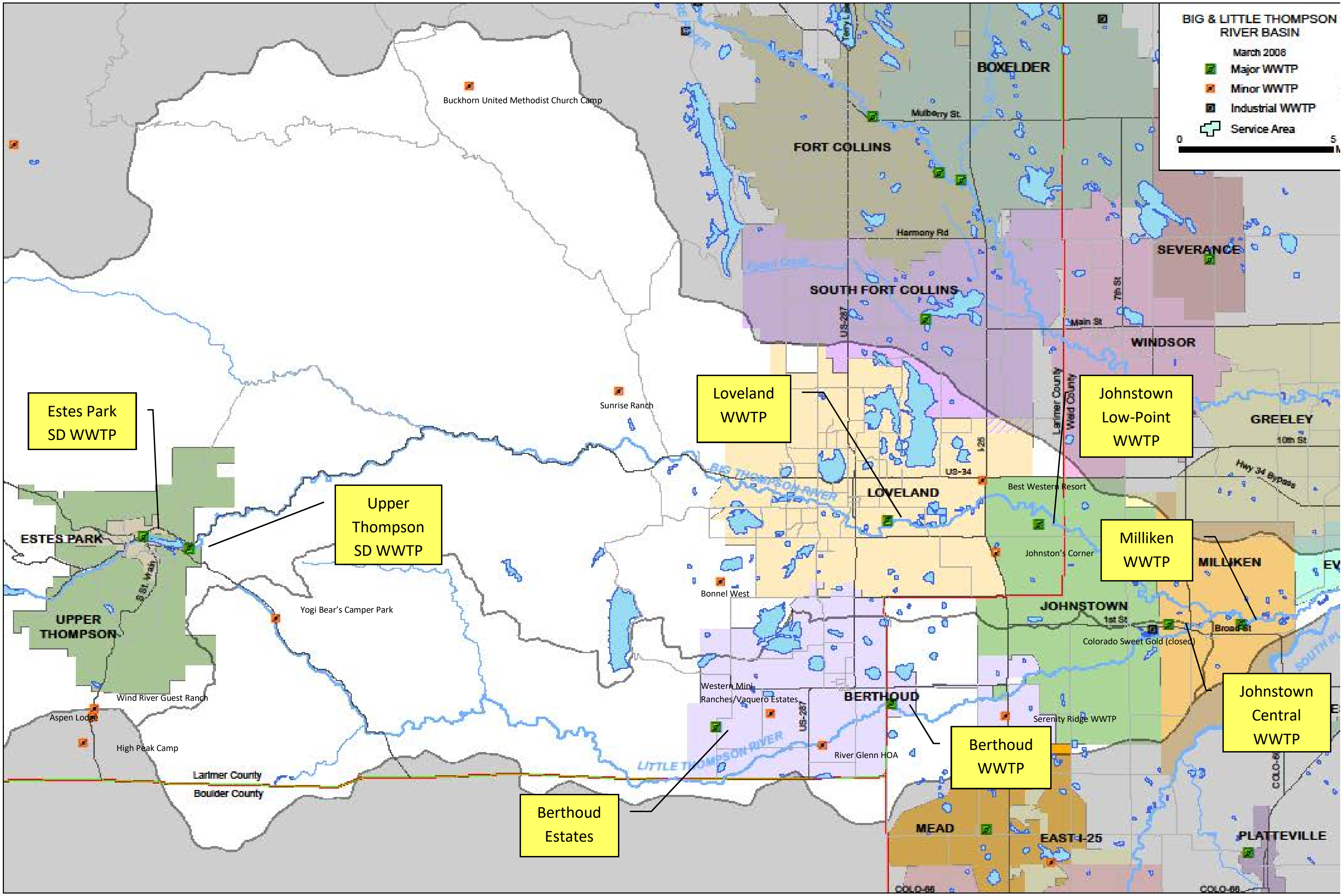

Image adapted from NFRWQPA
(http://www.nfrwqpa.org/pdf/208_Plan_Update/Big_&_Little_Thompson_Basin.pdf)

Figure 4. Wastewater Treatment Plants in the Big Thompson Watershed

River and its tributaries are on Colorado's most recent 303d List[10] of impaired waters. The listed parameters are copper, cadmium, selenium, zinc, dissolved oxygen, Escherichia Coli (*E. Coli*), pH, and temperature (WQCD, 2010a). Figures 5 and 6 present these listings spatially. Table 1 presents the listings as described by WQCD (2010), including designations of the WQCD's relative priority for each listing. Note in review of the table and figures that a presumed exceedance in one location can trigger listing of the entire segment.

[10] "This regulation establishes Colorado's List of Water-Quality-Limited Segments Requiring Total Maximum Daily Loads ("TMDLs"). The list of Water-Quality-Limited Segments Requiring TMDLs fulfills requirements of section 303(d) of the federal Clean Water Act which requires that states submit to the U.S. Environmental Protection Agency a list of those waters for which technology-based effluent limitations and other required controls are not stringent enough to implement water quality standards" (WQCD, 2010). At this point, TMDLs have not been developed for any segments of the Big Thompson Watershed, and the timing of TMDL development remains uncertain. Of the 303d listings, the high priority listings are for segments COSPBT01 (copper), COSPBT02 (pH, Cu, Cd, Zn, and *E. Coli*), COSPBT07 (copper), COSPBT08 (temperature and dissolved oxygen), and COSPBT09 (*E. Coli* only).

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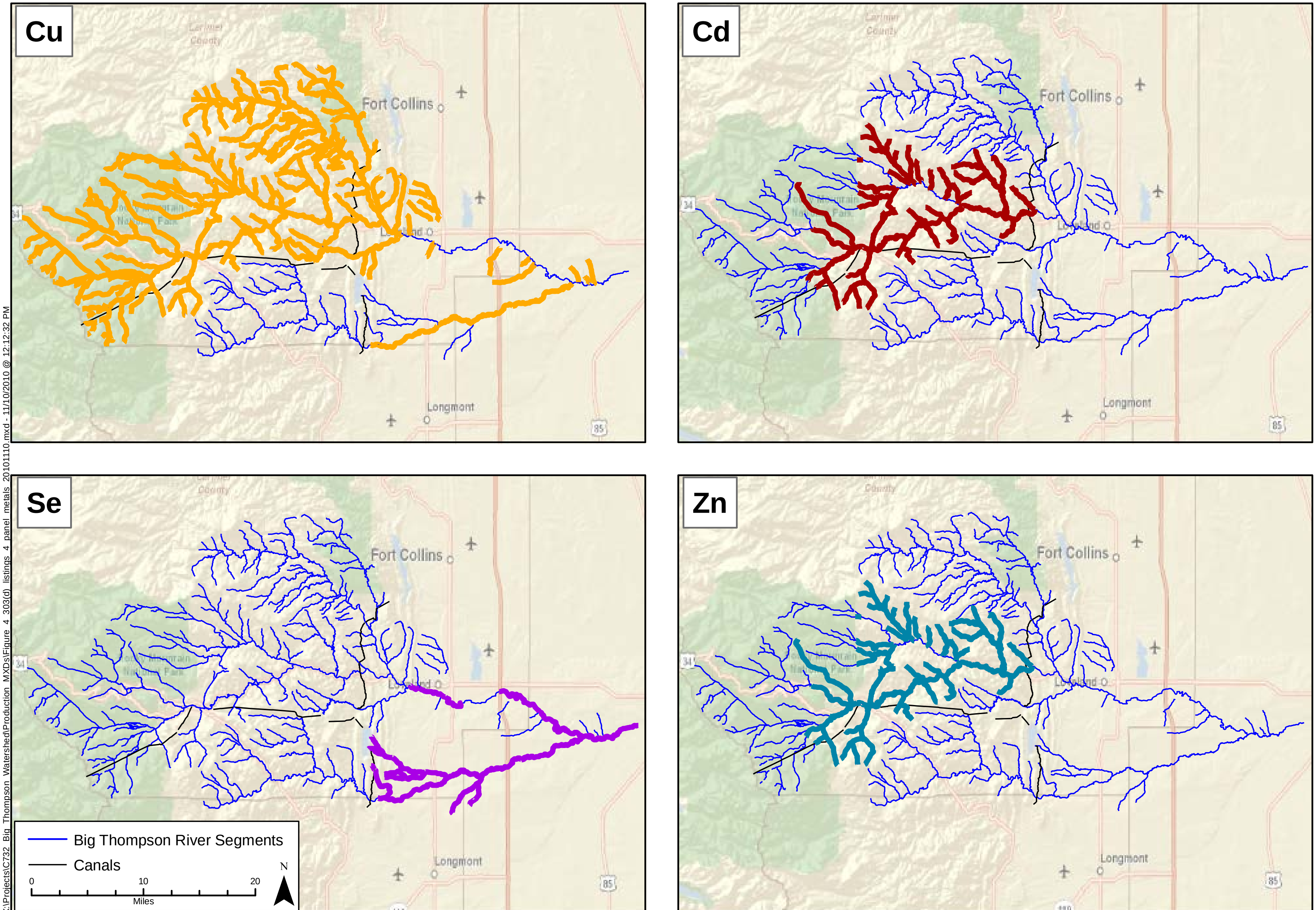

Figure 5.
Big Thompson 2010 Report
303(d) Listings for Metals

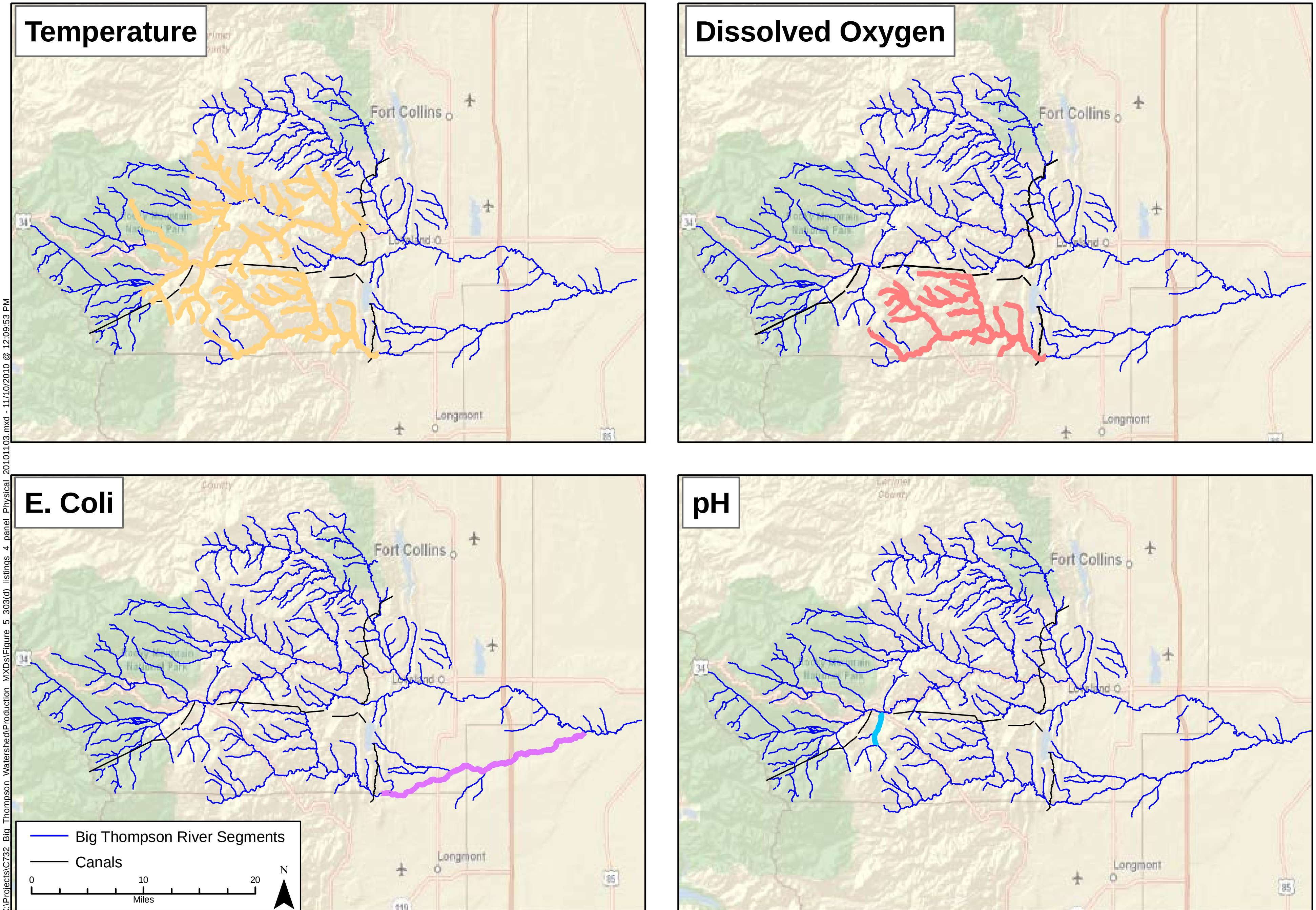

Figure 6.
Big Thompson 2110 Report
303(d) Listings for Temperature, DO, pH, and E. Coli

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Table 1. 303d Listings for Big Thompson Watershed Streams and Rivers.
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	M
4a	COSPBT04a	Mainstem of the Big Thompson from the Big Barnes Ditch diversion of the Greeley-Loveland Canal diversion.	all	Selenium	M
4b	COSPBT04b	Big Thompson River, Greeley-Loveland Canal diversion to CR11H	all	Selenium	M
5	COSPBT05	Big Thompson River, I-25 to S. Platte River	all	Selenium	L
6	COSPBT06	All tributaries to the Big Thompson River, from Home Supply Canal to the confluence with the South Platte River.	all	Copper	M

Table 1. 303d Listings for Big Thompson Watershed Streams and Rivers.
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
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
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	L

1.2 REPORT OBJECTIVES

This report supports the Forum's ongoing efforts to maintain a comprehensive watershed management plan through review, presentation, and analysis of the flow rate and water quality data in the streams, rivers, and canals of the Big Thompson watershed. This assessment builds on two previous State of the Watershed reports that included analysis of data from the flowing water sites: Jassby and Goldman (2003) and Haby and Loftis (2007). Insights developed in those reports are reevaluated in this assessment with a larger (greater spatial coverage and longer duration) dataset. Specifically, in assessment of the current state of the watershed, this report attempts to answer the following questions through clear tabular and graphical summaries of the data and scientifically-defensible data analysis:

1. What is the current state of water quality in rivers and streams as indicated by data in the Forum's database?
2. What are the statistically significant temporal trends in water quality concentrations across the watershed?
3. What are the estimated annual and seasonal loads of select water quality parameters collected by the Forum? What are the spatial and temporal patterns in the loading results?
4. To what extent have water quality observations been out of compliance with applicable standards? To what extent have nutrient concentrations exceeded the current draft Colorado WQCD numeric nutrient criteria[11] anticipated for implementation in June 2011?

Additionally, this assessment tested and applied the Forum's newly developed database, generating recommendations for corrections and improvements. Recommendations are offered in this report for minor modifications to the monitoring program and future focused studies to provide additional insight to support watershed management decisions. 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.

[11] In October 1997, a Clean Water Action Plan (CWAP) was initiated by EPA to address nutrient over-enrichment in the nation's surface waters. The CWAP includes the development of water quality nutrient criteria as one of its objectives. The criteria are to be region-specific for different types of water bodies, in recognition of the large variation in nutrient conditions across the country. As a result, the Colorado WQCD is working to develop nutrient criteria appropriate for Colorado lakes and streams, anticipated for completion and ruling in June 2011. The draft nutrient criteria as of October 13, 2010 were used in this analysis.

1.3 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 is the introductory section.
- Section 2 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 presents the analysis of the data. These discussions are organized by parameter group (as opposed to organization by analysis/calculation type) to allow for a more "full-picture" evaluation of the state of the watershed for each parameter. The final section of Section 3 presents a brief cross-program comparison of sampling results.
- Section 4 summarizes the findings and recommendations generated by the analyses.
- Section 5 provides references cited.

The supporting appendices are organized as follows:

- Appendix A presents summary statistics tables for all of the parameters, including flow rate.
- Appendix B presents concentration and flow time series plots and concentrations box plots.
- Appendix C presents graphical results of the loading analysis, including loading box plots and bar graphs. A tabular presentation of the loading results is provided. Additionally, the flow volume box plot is presented here.
- Appendix D presents a tabular summary of the results from the statistical concentration trend testing.
- Appendix E presents tables that summarize the compliance assessment standards and results.
- Appendix F presents figures supporting a simple comparison of COOP and volunteer monitoring results.

2 DATASET AND DATA TREATMENT

This section presents the dataset considered in this assessment of the state of the rivers, streams and canals in the Big Thompson watershed. This section also presents a description of the graphical and statistical methods applied to evaluate the data.

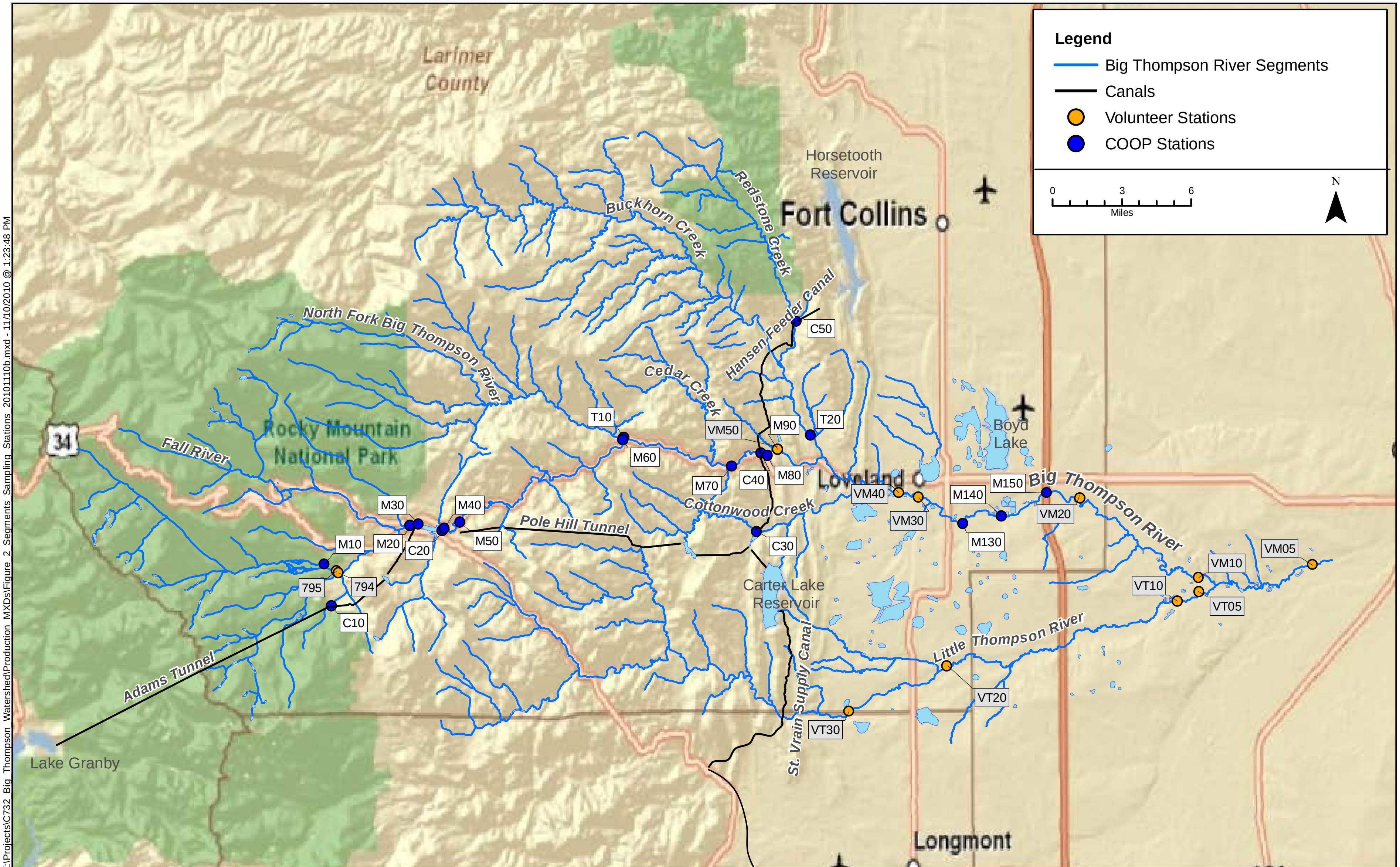
2.1 DATASET

This report reviews and evaluates the water quality and flow rate data from rivers, streams and canals in the Big Thompson watershed from WY 2000 through WY 2009. These data were retrieved from the Forum's recently developed NPSTORET database[12] and were collected as part of the U.S. Geological Survey (USGS) Cooperative (COOP) Program (August 2000-present) [13] and the U.S. Environmental Protection Agency (EPA) Volunteer Program (August 2001-Present)[14]. In total, 31 Volunteer and COOP sampling stations are included in this analysis. Figure 5 presents the location of each station on the watershed map. 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. In total, the final dataset contains over 78,000 records.

[12] NPSTORET v.1.81 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)

[13] The Forum's Cooperative Monitoring (COOP) Program is a Joint Funding Agreement (JFA) with its major funders (City of Loveland, City of Greeley, City of Fort Collins, Northern Colorado Water Conservancy District and Tri-Districts-Soldier Canyon Filter Plant) and the U.S. Geological Survey (USGS). For this program, USGS laboratory and staff are primarily utilized for laboratory analysis and the collection of water quality samples. A subset of the sample collected by the USGS are analyzed by Northern Water (*chlorophyll a* and nutrients for canal locations), the City of Fort Collins' laboratory (total organic carbon & chlorophyll *a),* and the City of Loveland's laboratory (E. Coli and total coliforms)). The COOP locations include 19 sites west of I-25 in the watershed.

[14] 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 12 volunteer sites are located both east and west of I-25 in the watershed.



X:\Projects\C732 Big Thompson Watershed\Production MXDs\Figure 2 Segments Sampling Stations 20101110b.mxd - 11/10/2010 @ 1:23:48 PM

Figure 7.
Big Thompson 2010 Report
Sampling Sites

Table 2. Volunteer and COOP Monitoring Stations.

Station ID	General Description	Station type	Stream Segment ID	Sampling purpose
M10	Moraine Park, Most Upstream Site- Mainstem Big Thompson	COOP	COSPBT01	Assess inputs from upstream Big Thompson River & Rocky Mountain National Park
795	Upstream Mainstem Big Thompson/ Almost Collocated with M10	Volunteer	COSPBT01	Assess inputs from upstream Big Thompson River before confluence with Glacier Creek
794	Glacier Creek -Tributary input	Volunteer	COSPBT02	Assess inputs from Glacier Creek
M20	Mainstem Big Thompson – Upstream of Estes Park Sanitation District	COOP	COSPBT02	Assess effects of runoff in Estes Park
C10	Adam's Tunnel – East Portal Canal Input	COOP	n/a	C-BT background water quality
M30	Mainstem Big Thompson – Downstream of Estes Park Sanitation District	COOP	COSPBT02	Assess effects of Estes Park Sanitation District Effluent
C20	Olympus Tunnel Canal -Flow Out of Lake Estes	COOP	n/a	Asses outflows to Olympus Canal
M40	Mainstem Big Thompson – Downstream of Olympus Dam/Upstream of Upper Thompson Sanitation District Outlet	COOP	COSPBT02	Assess baseline for Big Thompson River below Lake Estes
M50	Mainstem Big Thompson – Downstream of Upper Thompson Sanitation District	COOP	COSPBT02	Assess effects of Upper Thompson Sanitation District effluent
M60	Mainstem Big Thompson – Drake, Upstream of Confluence with North Fork of Big Thompson	COOP	COSPBT02	Assess effects of upper canyon businesses and residences
T10	North Fork Big Thompson - Tributary Input	COOP	COSPBT07	Assess inputs from North Fork tributary
M70	Mainstem Big Thompson – Upstream of Dille Diversion	COOP	COSPBT02	Assess effects of North Fork and lower-canyon
C30	Hansen Feeder Canal – Canal Outlet of Flatiron Reservoir	COOP	n/a	Assess baseline conditions for Hansen Feeder Canal (out of Flatiron Reservoir) upstream of Dille Tunnel diversions
C40	Hanson Feeder Canal – Canal Downstream of Trifurcation	COOP	n/a	Assess changes in Hansen Feeder Canal due to Dille Tunnel

Table 2. Volunteer and COOP Monitoring Stations.

Station ID	General Description	Station type	Stream Segment ID	Sampling purpose
C50	Hansen Feeder Canal – Canal Upstream of Horsetooth Reservoir Tunnel - Inlet	COOP	n/a	Assess changes due to in-Hansen Feeder Canal effects before emptying in Horsetooth Reservoir
M80	Mainstem Big Thompson – Downstream of Thompson Powerplant Outlet (Sylvan Dale Ranch)	COOP	COSPBT02	Assess effects of Hansen Feeder Canal Water and Sylvan Dale Ranch (Note: this station was discontinued in 2009 and will be added back in 2011))
M90	Mainstem Big Thompson – Upstream of Loveland Drinking Water Intake	COOP	COSPBT03	Assess Big Thompson water quality upstream of Loveland Drinking Water intake; QC cross sampling program comparison with volunteer site VM50
VM50	Mainstem Big Thompson – Upstream of Loveland Drinking Water Intake	Volunteer	COSPBT03	Assess Big Thompson water quality upstream of Loveland Drinking Water intake; QC cross sampling program comparison with coop site M90
T20	Buckhorn Creek - Tributary Input	COOP	COSPBT07	Assess inputs from Buckhorn Creek
VM40[a]	Mainstem Big Thompson/ At Wilson St Bridge - Above the Mariano Exchange Ditch	Volunteer	COSPBT04a	Assess baseline conditions on the Big Thompson River before Mariano Exchange Ditch
VM30[b]	Mainstem Big Thompson - Downstream of Mariano Exchange Ditch	Volunteer	COSPBT04a	Assess effects of Mariano exchange ditch
M130	Mainstem Big Thompson – Upstream of Loveland WWTP	COOP	COSPBT04b	Assess baseline conditions upstream of Loveland WWTP effluent
M140	Mainstem Big Thompson – Downstream of Loveland WWTP	COOP	COSPBT04c	Assess effects of Loveland WWTP effluent
M150	Mainstem Big Thompson/ at I-25	COOP	COSPBT05	Assess conditions at the end of the COOP-USGS measured system
VM20	Mainstem Big Thompson – East of I-25	Volunteer	COSPBT05	Assess baseline conditions upstream of proposed permitted WWTP
VM10	Mainstem Big Thompson – Outlet of Big Thompson before Confluence with Little Thompson.	Volunteer	COSPBT05	Assess baseline conditions for Big Thompson before confluence with Little Thompson

Table 2. Volunteer and COOP Monitoring Stations.

Station ID	General Description	Station type	Stream Segment ID	Sampling purpose
VT30	Little Thompson River – Upper Reach, Input to VT20	Volunteer	COSPBT09	Assess upper reach baseline conditions and for potential segment for new WWTP discharge
VT20	Little Thompson River – Middle Reach, Input to VT10	Volunteer	COSPBT09	Assess baseline conditions upstream of Berthoud WWTP; downstream paired station (VT15) initiated sampling in 2010, so no data available
VT10	Little Thompson River – Lower Reach, Input to VT05	Volunteer	COSPBT09	Assess baseline conditions upstream of Johnstown WWTP
VT05	Little Thompson River – Last Station on Little Thompson before Confluence with Big Thompson	Volunteer	COSPBT09	Assess effects of Johnstown and Berthoud WWTP; assess inputs from Little Thompson River to Big Thompson River
VM05	Mainstem Big Thompson – Last Station in Big Thompson before Confluence with South Platte	Volunteer	COSPBT05	Assess conditions at the end of the system and Town of Milliken WWTP

[a] All results for this station Include results from VM45, which was actually collected at Namaqua Park -in 2008 only.

[b] All 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.

Water quality and flow rate summary statistics are presented in Appendix A. These summary statistics are organized by parameter group, and present the following information for each parameter at each station:

- Location,
- Units,
- Number of samples/ measurements,
- Number detected[15],
- Percent detected,
- Sampling date range,
- Range of observed detection limits,
- Range of observed concentrations,
- Mean concentration,
- Median concentration, and
- Standard deviation.

The following subsections describe the parameter list included in this evaluation, the data pre-treatment conducted, and comments on the observed frequency of results below detection limits.

2.1.1 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), each of which is described below.

Flow Rate –- The Forum's database includes flow records for 19 of the 31 monitoring stations considered in this report. These 19 stations are the COOP monitoring stations. Measurement frequency varies from daily to monthly. Forum database flow rate information was supplemented with more complete daily flow records provided to the Forum by the Northern Colorado Water Conservancy District (Northern Water) for COOP stations C10, C20, C40, C40, and C50. The complete set of flow rate data was used to evaluate the site hydrology (natural and operational) and to estimate loading rates.

[15] 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.

<u>Metals</u> – The parameter list includes five metals:

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

All five of these metals are naturally occurring elements in the earth's crust. Copper, selenium, and zinc are essential elements for plants and animals (including humans); however, elevated concentrations can be toxic. Cadmium and mercury, however, are not essential elements for human health, and both have forms that EPA has classified as 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 released to the environment by natural processes; however, additional releases can occur through mining and burning of coal and waste. Additionally, copper-based algaecides (copper sulfate) were historically used in canals in the Big Thompson watershed. Application of copper sulfate was discontinued in April 2008 by Northern Water in favor of a slurry form of hydrogen peroxide. Copper sulfate is still being used by the U.S. Bureau of Reclamation at Pole Hill near Lake Estes.

These five metals are included in the parameter list for this report because they are currently on the 303d List for the Big Thompson watershed (WQCD, 2010a), as discussed in Section 1.1. The analysis and discussion focus total mercury and dissolved cadmium, copper, selenium, and zinc. Cadmium, copper, selenium, and zinc are all on the 303d List for various river segments shown on Figure 5. 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) have been placed on the 303d List for non-attainment of aquatic life use due to mercury fish consumption advisories (accumulation of mercury in fish tissues).

<u>General Parameters</u> – There are ten general parameters included in this assessment:

- Alkalinity (a measure of a waters buffering capacity against changes in pH),
- Chlorophyll *a* (a form of chlorophyll used in oxygenic photosynthesis; used as a measure of phytoplankton abundance),
- Dissolved oxygen,
- Temperature,
- 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 alkaline),
- Specific conductivity (a measure of the concentration of ions in solution),

- Total organic carbon (TOC; a bulk 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]),
- Turbidity (a measure of light refraction of solids in a water sample; is indicative of phytoplankton and suspended sediment), and
- Total suspended solids (TSS; a measure of mass of solids in a water sample).

These parameters are included in this report because they provide a wide-spectrum description of the overall physical, chemical and biological conditions present in the watershed. Additionally, alkalinity, chlorophyll a, dissolved oxygen, temperature, pH, and TOC are relevant to evaluation of the nutrient data[16]. Likewise, pH and hardness are directly relevant to evaluation of the toxicity of ammonia and metals, respectively.

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 carcinogens that are formed when TOC reacts with chlorine at the water treatment plants. Water treatment plants have regulatory requirements related to TOC removal and DBP concentrations in treated water. 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. Haby and Loftis (2007) documented a statistically significant increasing trend in TOC concentrations at many of the canal and river sites as well as in Horsetooth Reservoir. This report is available at: www.btwatershed.org.

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

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

- Phosphorus nutrient parameters:

[16] For over-fertilized systems, alkalinity is important because the water's buffering capacity controls the pH response to CO2 depletion, and the pH response controls the equilibrium concentrations of ammonia (NH3) and ammonium ion (NH4+); more of the toxic, un-ionized form (NH3) is present at higher pH. TOC, as it relates to BOD, is relevant to consideration of dissolved oxygen and nutrients.

- 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. The nitrogen and phosphorus parameters listed above are included in this report because the Forum has identified nutrients as the priority pollutants of concern for the watershed (Buirgy, 2007). The following paragraphs briefly describe relevant information about the various forms of nitrogen and phosphorus; however, additional material is provided in Section 3.4 to support discussions of observations from the data and calculations.

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) dominant at higher pH; and nitrate can be toxic to infants in drinking water). Nitrogen is an essential nutrient for plant growth; however, in excess it can over stimulate plant growth in aquatic systems leading to eutrophication. Ammonia can lead to oxygen depletion and increased nitrate concentrations through nitrification.

Phosphorus is naturally a fairly scarce resource; however, many human activities cause phosphorus loading to surface waters, with sources including human and animal wastes, fertilizer use, phosphate detergent use, and anthropogenic soil erosion. As noted for nitrogen, phosphorus is an essential nutrient for plant growth, but in excess it can over stimulate plant growth in aquatic systems leading to eutrophication. 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, also called soluble reactive phosphate (SRP), is the form that is most readily available to plants. Dissolved phosphorus includes both orthophosphate and non-particulate organic and inorganic phosphorus.

<u>Microbiological Parameters</u> – The parameter list includes two measures of bacteria:

- Total Coliforms, and
- Escherichia Coliforms (*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 (WQCD, 2010c); 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 fecal 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).

2.1.2 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 clean 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. Additionally, the specific queries used for dataset preparation were provided to the Forum for future use/modification.

Duplicates

For the parameters and stations evaluated, there were over 10,000 duplicate entries in the database, meaning over 10,000 cases of multiple results for a given station, sampling date, parameter, and sampling fraction. 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 not-detected.

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 make the most of the dataset, summing of analytical results was performed to fill in missing information 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.

Database Issues: The following paragraphs describe issues identified in the database and how each issue was handled.

1. Sample Fraction Designations:

   There are data entry issues in the database with the definition of "sample fraction". This category is meant to differentiate between filtered and unfiltered; however, from the database, it is apparent that it was sometimes misinterpreted in data entry. For example, analytes such as pH, alkalinity, hardness, specific conductivity, and nitrate plus nitrite were given designations in this category including dissolved, total, and N/A, including duplicate entries with different designations. Modifications to the database to recommend a setting for this variable for specific analytes may be warranted. Alternatively, the input fields/format could be modified to designate only three options – filtered, unfiltered, or N/A. The clean data were generated by applying the primary/secondary approach described above, and the final datasets were visually inspected relative to other concentrations for the given sampling location.

2. Nitrate + Nitrite/ Ammonia Parameter Designation:

   For a subset of the data (e.g., C30 in 2004 and others), nitrate plus nitrite concentrations were erroneously designated in the database as ammonia results. When missing data for nitrate plus nitrite were found to occur during the same time frame as unlikely concentrations for ammonia and several stations, the database was carefully reviewed. It was determined from the laboratory analysis that some nitrate plus nitrite samples were erroneously identified as ammonia samples. The database was corrected, and the clean dataset reflects this correction.

3. Suspect Data:

   The draft data plots and summary statistics were reviewed for suspect (non-sensical) data results. For mercury, it was determined that two sets of data were in the database.

One set had labels of ug/L, and one set had labels of ng/L. The ug/L data were not realistic values and are likely entry errors. The ng/L data were used in this analysis. For other analytes, if no correction could be applied, these data points (e.g., pH of 35) were removed from the clean dataset and documented. The list of these suspect data points is included as Table A-6 in Appendix A.

Additionally, in review of the draft report, the Forum Science and Monitoring Committee noted that flow records for the canal locations (C10, C20, C30, C40, and C50) obtained from the NP STORET database were inaccurate. For the analysis presented in this final draft, daily flow results for these locations were obtained from Northern Water. The origin of the error was not apparent in the database in this review. The flow data for these locations should be reloaded, using the dataset compiled by Northern Water. The upload error should be identified to prevent reoccurrence in future uploads.

2.1.3 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 quantified below the detection limit, the laboratory will report the result as non-detect, noting that the value is below the given detection limit. For many of the parameters of interest in this report, low concentrations are present in the system, often below typical detection limits. High detection limits and/or a high frequency of non-detect results can skew the findings of an analysis, particularly when trend analysis is performed. 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 A present the range of detection limits and the percent of detection for each station and analyte. 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:
    - Selenium, mercury, copper,
    - Ammonia, and orthophosphate.

- Very high percentages of non-detect results were observed for certain analytes at many stations:
    - Selenium, mercury, copper, cadmium,
    - Ammonia, orthophosphate, 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 a few 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. Next, non-detect results are not compared to compliance values. Finally, for ammonia and orthophosphate, loading estimates were generated in two ways: (1) setting non-detect results to half detection limits, and (2) setting non-detect results to zero. This approach allowed for an assessment of the effect of detection limits on the results. This approach is generally consistent with treatment of non-detect results in the previous watershed reports (Jassby and Goldman, 2003; Haby and Loftis, 2007).

2.2 STATISTICAL AND GRAPHICAL METHODS

This section presents the approaches and tools used to present the data, calculate loading, perform statistical trend testing, and evaluate compliance. This information supports the data analysis sections (Sections 3 and 4), which refer extensively to these calculations and graphical tools. This section also describes the geographic locations of all of these data products in the appendices.

2.2.1 Concentration Figures

A primary objective of this assessment is to review the temporal (including seasonality[17]) and spatial patterns in the water quality dataset. To support that review, 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 B1. The time series plots present the individual concentration results over the full 10 year period of record for a given station and parameter on a scatterplot. Additionally, these plots show seasonality through data point color and shape. 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 draft criteria value for nutrients) is also indicated on these plots (compliance values are discussed in greater detail in Section 2.2.5). 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

[17] 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). This seasonal definition varies slightly from that used in the previous Big Thompson Report (Haby and Loftis, 2007) by changing the seasonal assignment for the month of April from Winter to Summer.

findings from the trend tests (described in Section 2.2.4) will be discussed in the data analysis sections. An example time series concentration plot is shown below in Figure 6.

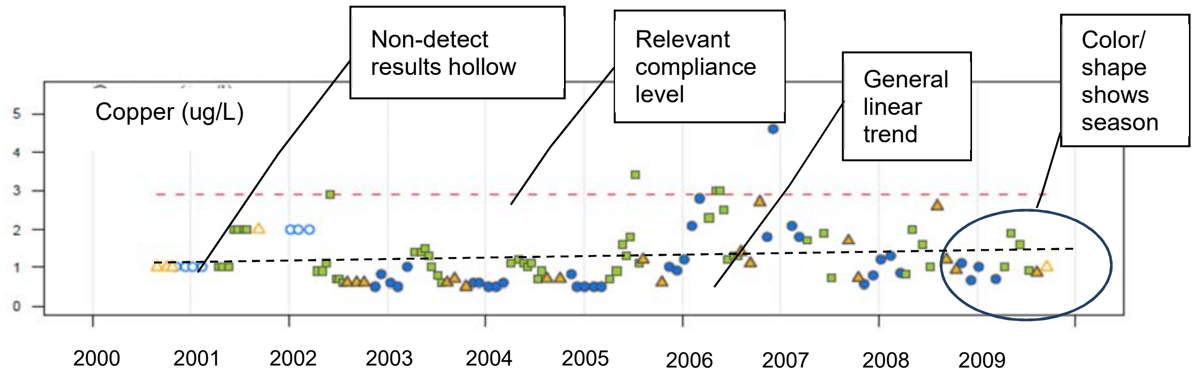


Figure 8. Example Concentration Time Series Plot.

The concentration box plots allow for visual review of the spatial trends in the dataset. These plots are presented in Appendix B3. The concentration box plots essentially present visual statistical summaries of the full ten year dataset for a given parameter across the watershed. For each station, the concentration results are presented with a box and whisker plot. These plots represent the range of observed concentrations with markers for the median, the interquartile range (IQR; the 25th percentile to the 75th percentile), and relatively high or low values (defined as values outside the limits of 1.5 times the IQR). An example box and whisker plot is shown below in Figure 7.

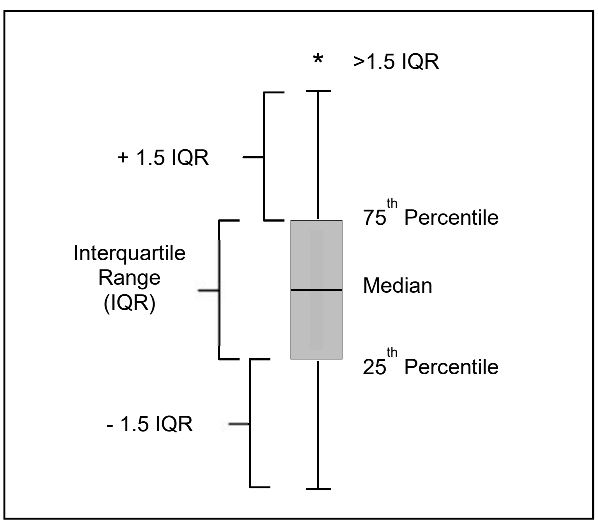


Figure 9. Example Box and Whisker Plot.

On the concentration box plots, the layout is intended to generally represent the relative upstream to downstream order of the stations from left to right. Stations on the mainstem of the Big Thompson River are designated with grey-filled boxes. Hollow boxes designate offchannel measurement points (inflows to or outflows from the river). The inflow/ outflow direction is designated with arrows over the station names on the axis. Additionally, two small subplots are included on each figure to show the C-BT canal system and the Little Thompson River stations.

2.2.2 Loading Calculations, Figures, and Tables

Load in a river system 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 total loads. As such, average monthly 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 to assess the effects of frequent non-detect results and variable detection limits on the patterns observed from the loading calculations.

To adequately assess the seasonal and annual loads, values for both flow rate and concentration were needed for each month. Missing average monthly flow rates for river and tributary locations were estimated by linear regression, applying the best relationship observed among proximal sampling stations. For the canal locations, flow rates could not be reliably predicted from other stations; therefore, missing average monthly flow rates were interpolated. Fortunately, the canal flow records were nearly complete, with only seven missing monthly values out of the 585 monthly values at the five canal locations. Missing monthly concentration data were also estimated for all stations. Concentrations were estimated by interpolation between the previous and subsequent concentrations at the given station.

Loading calculation results are presented in two ways that allow for both spatial and temporal (including seasonal) review. First, the annual loading results are presented in spatial box plot diagrams, with all loading stations presented on a single figure for a given parameter. These plots follow the general format described above (Section 2.2.1) for concentration box plots. The loading box plot figures are presented in Appendix C1. The second display of the loading calculation results also presents the annual loads by station, but also presents the seasonal breakdown for each year of data. These figures are called loading bar graphs and are presented in Appendix C2. These figures group canal and non-canal stations, for easier visual distinction of this information. An example of a partial (3-year) bar graph is shown below in Figure 8. In review of these figures, be aware that only a partial year of record was available for WY 2000; therefore, the magnitude of these loads do not compare directly with the other years, but are presented for completeness.

Annual loading estimates are also presented in tabular form in Appendix C, Table C-1. This table groups estimates by stations and analyte. The table also presents annual flow-weighted mean concentrations, which were estimated by dividing the total annual load by the annual flow volume.

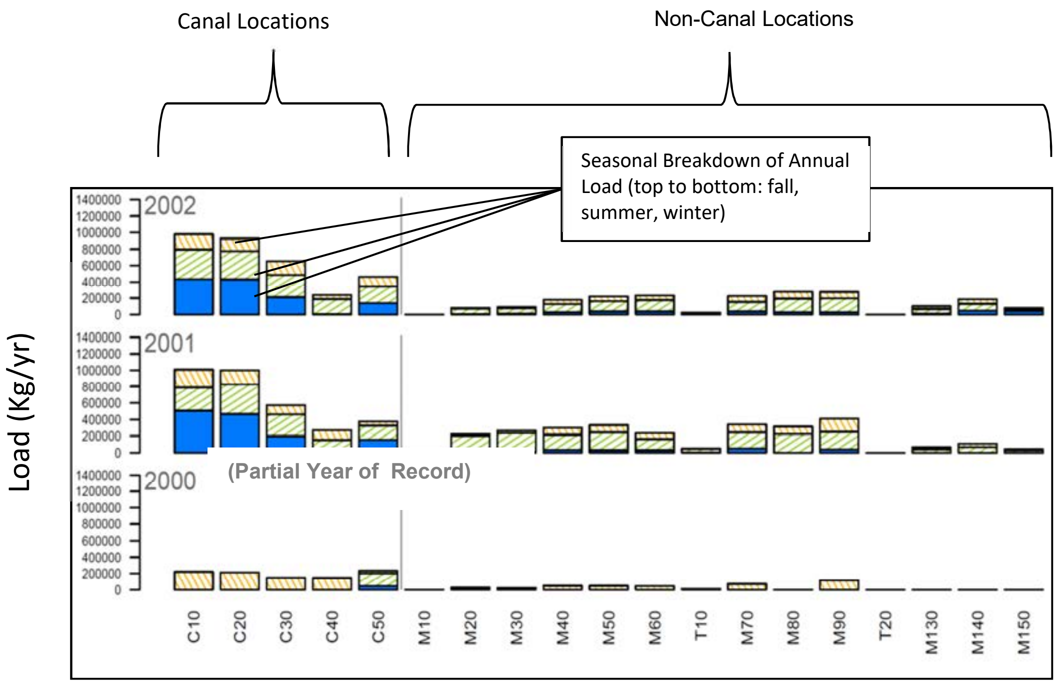


Figure 10. Example Loading Bar Graph.

2.2.3 Hydrology Figures

To support review of the hydrology, flow rate records were plotted in several ways to allow for visual identification of temporal (including seasonal) and spatial patterns. First, instantaneous flow rates were plotted for each station for the period of record (WY2000- WY2009). These plots are presented in Appendix B2 with the concentration time series plots. Next, flow records were plotted using the same tools used to present loads, as described in Section 2.2.2. Box plots were generated using the annual flow volume totals for each station (presented in Appendix C1). Seasonal flow volume totals were plotted for each year in bar graphs (presented in Appendix C2). To generate these figures, the average monthly flow rate results from the loading analysis were used, including the estimates for missing values (see discussion in Section 2.2.2).

2.2.4 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, a Seasonal Mann-Kendall trend test was applied. This test 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[18]) and magnitude (Sen slope[19]) 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. Final 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 Seasonal Mann Kendall testing results is presented in Appendix D. This table presents, for each station/parameter, the number of samples, the percent detection, the p-values, 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 B1). Note: The Sen slopes are presented on the plots regardless of the findings or interpretations of significance of the trend.

2.2.5 Compliance Analysis and Summary Tables

The water quality data were assessed relative to Colorado's applicable numeric water quality standards, in accordance with State Regulation 38 (WQCD, 2010b) and State Regulation 31 (WQCD, 2010c). It should be noted that all ten years of record were evaluated against the most recently published Colorado water quality regulations, effective as of November 30, 2010. Standards have changed over time, and this analysis is not intended to assess compliance during each year of record. The information provided does not constitute a legal interpretation of current or historical compliance. Instead, this analysis assesses patterns in the dataset relative to the most recent water quality standards for system informational purposes only.

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[18] 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.

[19] 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.

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 (aquatic life standards),
- Dissolved Oxygen (aquatic life standards),
- pH (recreational, aquatic life, and domestic water supply standards),
- *E. Coli* (primary contact recreational use standards),
- Ammonia (acute and chronic[20] aquatic life standards),
- Cadmium (dissolved, acute and chronic aquatic life standards),
- Copper (dissolved, acute and chronic aquatic life standards),
- Mercury (total, chronic aquatic life standards),
- Selenium (dissolved, acute and chronic aquatic life standards), and
- Zinc (dissolved, acute and chronic aquatic life standards).

Additionally, total nitrogen and total phosphorus concentrations were compared to the most recent draft proposed Colorado WQCD numeric nutrient criteria[11] at the time of publication of this report. These draft values (0.4 mg/L for total nitrogen and 0.11 mg/L for total phosphorus assessed as an annual median with an allowable exceedance frequency over a five year period still to be determined) are not adopted standards, but were assessed here for informational purposes.

Standards are assigned by stream segment definition; therefore, standards are specific to each sampling station. Some standards are set numeric values (pH [range], *E. Coli*, mercury, and selenium), some are assessed seasonally (temperature and dissolved oxygen), and some are station- and sample-specific calculated values (ammonia [pH and temperature dependent], cadmium [hardness dependent], copper [hardness dependent], and zinc [hardness dependent]). These standards that are not set numeric values vary over time, seasonally, and/or by sample.

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 approach has potential flaws; however, it was assumed that it is more appropriate than alternatives of ignoring non-detect results or designating high detection limit non-detect results as out of compliance.

For hardness-based standards (cadmium, copper, and zinc), the hardness value for each station was set as the 85th percentile result for the dataset for the most recent five years of record (October 1, 2004 through September 30, 2009). As such, the resulting standard values for these

[20] Acute standards are assessed against a one-day average sample result. Chronic standards are assessed against 30-day moving averages of sampling results. Both acute and chronic standards are not to be exceeded more than three times per year on average.

metals were constants for each station. This approach was recommended by the Forum Science and Monitoring Committee.

In stream Segment 2 on the Big Thompson River, the Wapiti Meadow wetlands located at the toe of the Lake Estes Dam is designated with a temporary standards modification. Station M40 is located in this area. This temporary modification sets the standard at "current conditions" for dissolved oxygen, *E. Coli*, ammonia, cadmium, copper, mercury, selenium, and zinc. Current condition concentrations for station M40 were calculated from the most recent five years of data (October 1, 2004 through September 30, 2009), using the 85^{th} percentile (metals, ammonia, E. Coli), 15^{th} percentile (dissolved oxygen), or geometric mean (*E. Coli*). Station M40 results were also compared against the basic Segment 2 standards to allow for comparison to other stations.

A table summarizing the standards by sampling station is presented in Appendix E (Table E-1). The compliance assessment results for each station are also presented in Appendix E as exceedance counts and percent exceedances for each parameter for the complete data set (Table E-2). For analytes with exceedances, results are summarized for each year of record in Table E-3. Additionally, compliance levels are presented on time series concentration plots in Appendix B1.

3 DATA ANALYSIS

This section presents discussions of the data time series plots, concentration box plots, loading analysis, trend testing, and compliance analysis. The discussions are organized by parameter group (flow rate, metals, nutrients, general parameters, and microbiological parameters), and all supporting figures and tables are presented in Appendices A through E:

Appendix A. Summary Statistics Tables
Appendix B. Flow Rate and Concentration Figures
    Appendix B1. Time Series Concentrations and Flow Rate Plots
    Appendix B2. Concentration Box Plots
Appendix C. Loading Box Plots and Bar Graphs
    Appendix C1. Loading and Flow Volume Box Plots
    Appendix C2. Loading Bar Graphs
    Appendix C3. Annual Loading Tables
Appendix D. Seasonal Mann-Kendall Statistical Analysis of Long Term Concentration Trends
Appendix E. Compliance Assessment Summary Tables

3.1 FLOW RATES

The Forum database includes flow records for the 19 COOP monitoring stations[21] shown in Figure 5. The frequency of flow rate measurements varies from monthly to daily, with daily records available for seven stations (M20, M40, C10, C20, C30, C40 and C50)[22]. Time series plots of flow rates are presented in Appendix B1 (Figure B1-156 through B1-159). Box plot showing the range of observed annual flow volumes across the system is shown in Appendix C1 (Figure C1-12). Bar graphs of seasonal and annual flow volumes across the system are presented in Appendix C2 (Figure C2-12). Observed flow rates at river locations range from one cfs (at M150) to 1,291 cfs at M20. Observed flow rates in canal locations range from zero cfs (at all C-stations) to 717 cfs at C30.

Figures B2-1 through B2-4 illustrate how flow rates across the system vary seasonally and spatially. At the canal locations, there are no clear seasonal patterns in the dataset, reflecting the water management control of this system. At river locations, a clear seasonal pattern is apparent, with the highest flow volumes observed each year during the spring snowmelt runoff period, typically in May and June (note that these months are included in the summer season

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[21] As shown in the Summary Statistics (Table A-5), five flow rate measurements are also in the database for a twentieth station, volunteer monitoring station VM40; however, these measurements cover only a 1 month period and are not discussed here.

[22] The Forum database flow rate information was replaced with more complete daily flow records that were provided by Northern Colorado Water Conservancy District (NCWCD) for COOP stations C10, C20, C30, C40, and C50.

for seasonality analysis). Relative peak flows are highest above Lake Estes; below Lake Estes, system flows are more regulated by dams, canal inputs, and diversions. At the end of the flow-monitored system (M150) flow peaks are significantly reduced

As seen in Figure C1-12, annual flow volumes at C10 (Adams Tunnel) and C20 (to Olympus Canal) are the highest in the system. 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 (Figure C2-12). Below M10, annual flow volumes are fairly consistent across the mainstem until M130, with increases apparent below the North Fork (T10) and below the trifurcation (see M80).

Volumes drop off significantly within the City of Loveland, as seen in M130, M140, and M150, due to various diversions, including the City of Loveland drinking water treatment plant intake (below M90).

3.2 METALS

This section describes the findings of concentration plotting, the trend analysis, and the compliance analysis for metals. As described in Section 2.1.1, the metals considered in this assessment are:

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

3.2.1 Metals Concentrations

Concentration trends for metals across the watershed for the full period of record are shown on box plot Figures B3-1 through B3-5. Time series plots of the metals data at each station are presented in Figures B1-1 through B1-31.

Figure B3-1 presents the box plot summary of dissolved cadmium concentration data across the watershed; however, a review of the scatter plots (Figures B1-1 through B1-31) reveals that these boxes reflect largely non-detect results. In fact, less than 5% of the dissolved cadmium results across the watershed are above detection limits. The highest observed detection was 0.38 ug/L at VM30. Dissolved cadmium was only detected at VM30 (six times between 2004 and 2008), and at the canal sites C10 (two times), C20 (four times), C30 (once), and C40 (once).

Figure B3-2 presents the box plot summary of dissolved copper concentration data across the watershed; however, as noted for cadmium, patterns in this figure should be carefully considered for the effects of detection limits. Specifically, volunteer monitoring stations exhibit relatively high detection limits for copper (typically 10 ug/L), which explains the median value of 10 ug/L on the box plots for all of the volunteer locations. The highest detected copper concentrations were observed at M90, with a maximum value of 110 ug/L in 2003; but the average detected value across the watershed was well below 10 ug/L, at 2.5 ug/L. Dissolved copper concentrations in the mainstem from above Lake Estes at Adam's Tunnel (C10) to below the Hansen Feeder Canal at M80 exhibit a period of relative increased concentrations. These higher concentrations start in 2005 and generally peak in 2006 or 2007, showing lower concentrations in the recent year or two of data. This pattern is also observed at C20; however, the pattern does not emerge in the lower portion of the canal system (C30, C40, and C50). Likewise, the pattern is not apparent in the watershed below M80 or on the Little Thompson.

Detected total mercury concentrations vary from 0.26 ng/L to 26 ng/L (ignoring suspect high values of 100 ng/L and one high value of 1,700 ng/L at C50). Mercury was only measured at volunteer monitoring stations in 2006; therefore, the dataset is limited over much of the watershed. Additionally, there is a high frequency of non-detect results and high detection limits (up to 1,000 ng/L). There are a large number (120) of results at 100 ng/L, which is a common detection limit level suggesting that these values may be erroneously reported as detected in the database. As such, the results should be carefully reviewed and interpreted. Considering these limitations in the dataset, there are no clear temporal (B1-1 through B1-31) or spatial (Figure B3-3) patterns that emerge in the dataset.

Figure B3-4 shows a clear pattern in dissolved selenium concentrations across the watershed. Selenium concentrations are low in the upper watershed and C-BT system (note: box plots for stations 795 and 794 represent mostly non-detect results), and selenium concentrations begin to increase around VM40 in the lower foothills. Selenium concentrations continue to increase downstream. This pattern is also apparent on the Little Thompson. As seen in B1-1 through B1-31, in the lower half of the watershed, selenium concentrations are generally higher in the winter, with some high points also observed in summer months. This pattern is expected considering the probable source of the selenium – naturally occurring selenium-rich shale. Groundwater contributions to base flow are likely to have high concentrations of selenium, and selenium loading may be exacerbated in this area by agricultural irrigation and/or wastewater return flows.

There are relatively few dissolved zinc samples across the dataset (not a parameter in the COOP sampling program for the mainstem locations), and the detection frequency is fairly low (~40%). As such, any patterns shown on Figure B3-5 need careful scrutiny. For example, there appears to be an increase in dissolved zinc concentration at C30; however, review of the time series concentration plots (B1-1 through B1-31) shows C30 results are almost entirely below detection limits. In general there are no clear patterns of increasing concentration across the watershed or seasonality apparent in the dissolved zinc concentration dataset.

3.2.2 Metals Concentration Trends

Concentration time series data for metals were evaluated for statistically significant trends applying the Seasonal Mann-Kendall approach, as described in Section 2.2.4. Using the fairly relaxed criteria of p-values less than or equal to 0.10(90% confidence level), statistically significant trends were identified for dissolved copper and selenium at some but not all stations, as listed in Appendix D, Table D-1. The trends were further assessed with a review of the time-series plots, and no clear trends from 2000 to 2009 were identified.

There were, however, some noteworthy patterns in the copper dataset. Specifically, as described in Section 3.2.1, dissolved copper concentrations in the mainstem from above Lake Estes at Adam's Tunnel (C10) to below the Hansen Feeder Canal at M80 exhibit a period of relative increased concentrations. These higher concentrations start in 2005 and generally peak in 2006 or 2007, showing lower concentrations in the recent year or two of data. This pattern is also observed at C20; however, the pattern does not emerge in the lower portion of the canal system (C30, C40, and C50). Likewise, the pattern is not apparent in the watershed below M80 or on the Little Thompson. Copper sulfate has been used in the watershed as an algaecide by Northern Water and the U.S. Bureau of Reclamation. Northern Water copper sulfate applications occurred in the C-BT system in the area of the trifurcation, and would not have affected the upstream areas noted here. Further, applications by Northern Water were discontinued by 2008. The U.S. Bureau of Reclamation; however, is still using copper sulfate in the siphon near Lake Estes. Information about any reduced or modified usage in the recent year of record was not available to help further investigate these observations.

3.2.3 Metals Compliance

Compliance with current applicable standards was assessed for the full dataset for all five of the metals. The percent exceedances for all years of data are summarized in Appendix E, Table E-2 (acute) and Table E-3 (chronic). Percent acute exceedances for each year at each station are summarized in Tables E-8 and E-9 for dissolved copper and selenium, respectively. Percent chronic exceedances for total mercury are presented in Table E-11.

No acute or chronic exceedances were observed for cadmium or zinc across the watershed. Cadmium and zinc are currently on the 303d list for Segment 2 (see Table 1 and Figure 5); however, the basis for those listings is not apparent in this dataset.

Acute and chronic copper exceedances are routinely observed in the upper watershed at station M10, where copper standards are lower due to low hardness[23]. This is included in the large area

[23] As a reminder, for hardness-based standards (cadmium, copper, and zinc), the hardness value for each station was set as the 85th percentile result for the dataset for the most recent five years of record (October 1, 2004 through September 30, 2009). As such, the resulting standard values for these metals were constants for each station.

303d listed for copper (see Table 1 and Figure 5). Farther downstream along the mainstem, fairly routine periodic acute and chronic exceedances were observed at M80 and M90. Routine exceendances were also observed at the North Fork (T10) in 2006 and 2007; however, there have been no exceedances at M80, M90, or T10 since 2008. Exceedances even farther downstream are not seen due to relatively high hardness values resulting in much higher standard concentrations.

As discussed in Section 3.2.1, the mercury dataset contains suspect results and is limited by low detection frequencies and high detection limits. The compliance analysis indicated chronic exceedances (Hg is only evaluated for chronic exceedances) at M10, and historically at M20 and M40. Rejecting the likely non-detect result for M10 in 2001, there are only three exceedances of the chronic standard across the watershed over the 10 year period. As such, there are no clear patterns in these results or indications of point or non-point sources.

In accordance with the observed patterns in selenium concentration and load, the compliance results show acute compliance issues for selenium in the lower half of the watershed, generally downstream from VM40 and in the lower portion of the Little Thompson. On the Little Thompson, acute selenium standards are exceeded in 100% of samples at VT20. Chronic standards are also violated for selenium at the lower end of the Big Thompson (esp. VM10) and the Little Thompson (esp. VT20). These patterns are in general agreement with the location of the 303d listings for selenium (Figure 5).

3.3 GENERAL PARAMETERS

This section describes the findings of the time series concentration plots, trend analysis, loading calculations, and the compliance analysis for the general parameters. As described in Section 2.1.1, the general parameters considered in this assessment are:

- Alkalinity (a measure of a waters buffering capacity against changes in pH),
- Chlorophyll *a* (form of chlorophyll used in oxygenic photosynthesis; used as a measure of phytoplankton abundance),
- Dissolved oxygen,
- Temperature,
- Hardness (a measure of the mineral content of water, usually dominated by calcium [Ca^{2+}], and magnesium [Mg^{2+}]),
- pH (a measure hydrogen ion activity in water; pH< 7 is acidic, pH>7 is basic),
- Specific conductivity (generally a measure of concentration of ions in solution),
- Total organic carbon (TOC; a bulk 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]),

- Turbidity (a measure of light refraction of solids in a water sample; indicative of phytoplankton and suspended sediment), and
- Total suspended solids (TSS; a measure of mass of solids in a water sample).

3.3.1 General Parameters Concentrations

Concentration trends for general parameters across the watershed for the full period of record are shown on box plot Figures B3-15 through B3-25. Time series plots of the general parameters are presented in two groups, with alkalinity, dissolved oxygen, hardness, pH, and specific conductivity presented in Figures B1-94 through B1-124 and TDS, temperature, TOC, TSS, and turbidity in Figures B1-125 through B1-155. Chlorophyll *a* is presented on Figures B1-63 through B1-93.

Temperature and dissolved oxygen generally show expected patterns across the watershed. Temperature shows a general increasing trend from upstream to downstream (Figure B3-22). Observed temperatures range from 0 to 28 degrees Celsius, with the highest value observed at C50. Dissolved oxygen does not show a clear pattern across the watershed (B3-17), though dissolved oxygen in the C-BT canal system shows a general increase from upstream to downstream, reflecting slightly depressed dissolved oxygen concentration (relative to M20) upon entry to the watershed (C10). Figure B3-17 suggests lower median dissolved oxygen at VM50, VM20, VM10, and VT05; however, review of the concentration time series plots for these locations (Figures B1-94 through B1-124) clarifies that these stations have only short periods of record for dissolved oxygen and very few samples in the winter when concentrations tend to be higher. Further, the paired COOP location for VM50 (M90) shows no indication of depressed oxygen concentrations. Temperature and dissolved oxygen also generally follow the expected natural seasonal patterns across the watershed. Temperatures are highest in the summer and lowest in the winter. Dissolved oxygen saturation is a function of temperature (higher at lower temperatures), salinity (higher at lower salinity), and altitude (higher at lower altitude, reflecting partial pressures in the atmosphere). Dissolved oxygen seasonal patterns across the watershed generally show the opposite pattern to temperature, with the highest dissolved oxygen concentrations observed in the winter.

TDS, specific conductivity, hardness, and alkalinity are all different measures of dissolved species in solution. These parameters show similar relative patterns across the watershed (Figures B2-16, B2-18, B2-20, and B2-21), with increasing values moving downstream, and a large increase at VM40, which includes high concentrations from the tributary Buckhorn Creek (T20). 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 in particular is a common evaporate mineral and is easily dissolved, indicating the presence of a geology in this drainage that would lead to elevated dissolved mineral species. In the Little Thompson, a large increase in concentrations is apparent at VT20. Seasonally, Figures B1-94 through B1-155 show a consistent pattern of higher

TDS, specific conductivity, hardness, and alkalinity in winter and early spring (included as "summer" in the seasonal definitions). The concentrations of these parameters drop in the late spring and early summer due to dilution by the snowmelt runoff waters. The pattern is not as clear on the Little Thompson River or below the confluence with the Little Thompson River; however, this may be attributable to the relatively short periods of record for these stations and less frequent sampling.

pH shows a generally increasing trend from upstream to downstream (Figure B3-19). The lowest median value (7.0) was observed at the most upstream station, M10; and the highest median value (8.2) was observed near the end of the Big Thompson watershed at VM10. Seasonality is more variable across the system (Figures B1-94 through B1-124)

TSS and turbidity are generally measures of solids in suspension; and given the very limited dataset for TSS, these parameters were considered together. Figures B2-24 and B2-25 show a few patterns across the watershed. First, turbidity is 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 the median value and range observed. The limited TSS record also shows high values at VT10 along the Little Thompson River, which are higher than any values observed on the Big Thompson. Urban, suburban, and agricultural runoff are possible sources.

Chlorophyll *a* concentrations show some interesting patterns in Figure B2-15; however, these results should be evaluated recognizing that the volunteer monitoring stations have only a partial year of record for chlorophyll *a*. First, it is clear that the upper watershed (M20 and above) show generally low chlorophyll *a* concentrations. The tributary locations (T10 and T20) also have relatively low chlorophyll *a* concentrations. The CB-T system carries relatively high chlorophyll *a* concentrations into the system at C10 (Adams Tunnel), as compared to M20. Below the City of Loveland, there is a general trend of increasing chlorophyll *a* concentrations, possibly reflecting the input of nutrients discussed in Section 3.4. Likewise, chlorophyll *a* concentrations increase sharply at VT20 on the Little Thompson, also possibly reflecting inputs of nutrients discussed in Section 3.4. Patterns in seasonality are not as consistently observed across the watershed (Figures B1-63 through B1-93). It should also be mentioned that chlorophyll *a* concentrations come from three different laboratories (Fort Collins for COOP locations, USEPA8 for Volunteer locations, and Northern Water for canal locations). However, a simple comparison of chlorophyll *a* concentrations at collocated COOP and Volunteer stations, presented in Section 3.6, suggests results from the Fort Collins and USEPA8 labs compare well.

TOC concentrations in the watershed are strongly influenced by both the spring snowmelt runoff and by inputs from the C-BT west slope reservoirs via the Adams Tunnel (C10). Upstream of Lake Estes, the median TOC concentrations in the Big Thompson River are relatively low (≤ 2 mg/L) while the range is large (see Figure B3-23) due to the influence of the high TOC concentrations (> 8 mg/L) that occur during the spring snowmelt runoff period (May and June). Downstream of Lake Estes (below M30), both the river and canal sites are significantly influenced by flow from the Adams Tunnel (C10). The relative volume of west slope (C10) water that mixes with the native Big Thompson River water in Lake Estes controls the median and peak TOC concentrations downstream of Lake Estes. TOC concentrations at C10 fall into a relatively narrow range (2.0 to 5.4 mg/L) reflective of the blending and storage effects of the west slope C-BT reservoirs, with a median concentration of 3.5 mg/L. The median TOC concentrations downstream of Lake Estes (both river and canal sites) are similar to the C10 median (Figure B3-23). TOC concentrations in the canal and river sites downstream of Lake Estes generally exhibit peaks during the spring snowmelt runoff period, although they can be muted compared to the upstream sites depending on the blend in Lake Estes blend. Further down the river, TOC concentrations increase at M140 (downstream of the Loveland WWTP), likely reflecting the influence of runoff and WWTP effluent. Concentrations of TOC also increase from upstream to downstream on the Little Thompson, again likely reflecting runoff and WWTP effluent and possibly agricultural runoff.

3.3.2 General Parameter Concentration Trends

Concentration time series data for general parameters were evaluated for statistically significant trends applying the Seasonal Mann-Kendall approach, as described in Section 2.2.4. Using the fairly relaxed criteria of p-values less than or equal to 0.10 (90% confidence level), statistically significant trends were identified for all general parameters except dissolved oxygen and hardness, as listed in Appendix D, Table D-1. The trends were further assessed with a review of the time-series plots (considering date ranges and non-detect patterns), and only trends for TOC and minor trends for alkalinity and pH were interpreted as likely trends.

Similar to the findings of Haby and Loftis (2007), increasing trends in TOC concentrations were noted across the canal system from C10 through C40. The strongest trend (in terms of slope and confidence level) was observed at C10 (p-value of 4×10^{-7}, slope of 0.11 mg/L-yr). At C50 (flowing to Horsetooth Reservoir), there was no statistically significant trend in TOC concentrations. A review of the flow-weighted mean annual concentrations at C50 (annual load divided by annual flow volume), further supports the statistical finding that on an annual basis, there is no clear increasing trend in TOC concentration (see Figure 11). However, a visual pattern of slightly increasing concentrations in winter and fall months (<0.05 mg/L TOC per year) over the period of record is apparent in the time-series graph for C50 (Figure B1-139). Similar patterns were also observed along the mainstem of the Big Thompson from M40 (below Lake Estes) through M90, though on an annual basis, there was no statistically significant trend at these locations either.

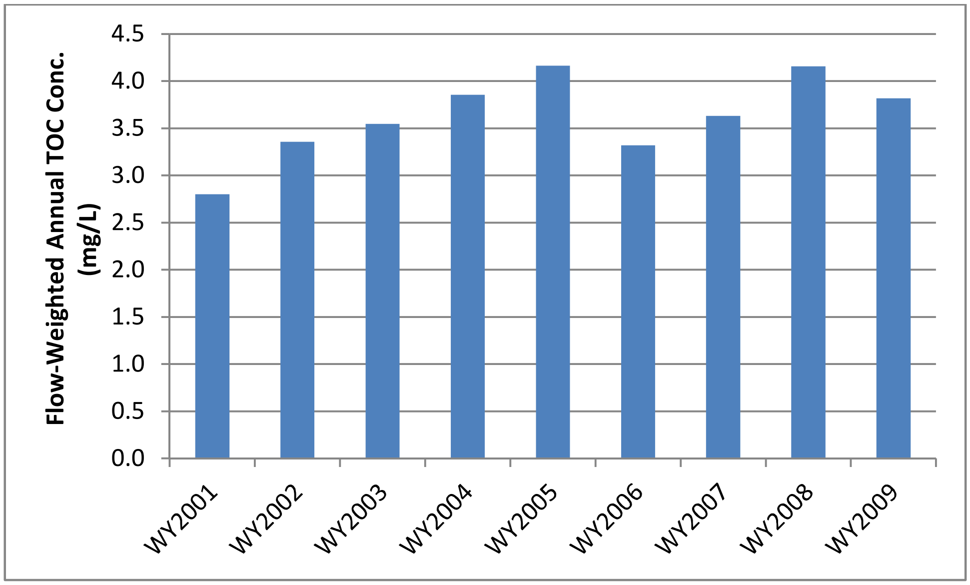

Figure 11. Flow-Weighted TOC Concentrations at C50.

C10 also exhibited a slight increasing trend for alkalinity, but otherwise there were no clear and strong trends that passed the visual data inspection. Low slope trends for pH at a few stations exist, however the rate of change is slow, and these trends should be reassessed in the next watershed evaluation. Also a number of trends appeared to be related to early conditions (2000 and 2001), but have been fairly stable for five or more years (e.g., specific conductivity at C10).

3.3.3 TOC Loading

Of the general parameters, loading was only assessed for TOC. Figures C1-1 and C2-1 present the loading analysis results for TOC. The TOC loads closely track annual and seasonal discharge in the canals and river, as can be seen by comparing the patterns on Figure C2-1 for TOC with Figure C2-12 for discharge. 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. From Figure C1-1, it is apparent that TOC loads decrease dramatically below M90 due to diversions, including the City of Loveland drinking water treatment plant intake. Station M140 shows a relative increase in mean TOC load compared to the upstream station, corresponding to the increased TOC concentrations (Figure B3-23) and flow (Figure C1-12) from the Loveland WWTP effluent.

3.3.4 General Parameter Compliance

Of the general parameters, compliance was assessed for pH, temperature, and dissolved oxygen. The percent exceedances for all years of data are summarized in Appendix E, Table E-2. Percent exceedances for each year at each station are summarized in Tables E-6, E-7, and E-8 for pH, temperature, and dissolved oxygen, respectively.

For pH, exceedances are occasionally observed in the uppermost watershed at stations 794 and 795, where low alkalinity is also observed. At these locations the exceedances tend to be values below pH of 6 (as opposed to above pH 9). Exceedances of pH standards are also occasionally observed at M50, below the Upper Thompson Sanitation District effluent. Exceedances are also observed across the Little Thompson and at volunteer monitoring stations from VM50 downstream, though no exceedances were observed at these locations in 2009. Further, the average number of exceedances per year is less than one at all of these locations across the watershed. Finally, the Forum does not have a monitoring station on the short segment listed for pH in the upper watershed (see Figure 6), so no comment on that listing can be made here.

The temperature compliance evaluation should be cautiously interpreted. Continuous temperature record is needed to appropriately evaluate the river conditions relative to the standards, and 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 in 2002 at VM40 and VM30. The basis for the 303d listing of temperature in the upper half of the watershed (see Figure 6 and Table 1) is not apparent from this dataset; however, as noted, a continuous dataset would be needed to appropriately evaluate the system against the standards. Overall, as evaluated, the average number of exceedances per year is 1.1 or less at each of the noted locations; and there were no exceedances in 2009.

Dissolved oxygen compliance findings show occasional exceedances at M40 (representing flow out of Lake Estes) and further downstream at volunteer monitoring stations VM40, VM30, and VM10. Dissolved oxygen is 303d listed for the upper portion of the Little Thompson (see Figure 6 and Table 1); however, the volunteer monitoring stations in the Little Thompson, which are downstream of the listing, do not show dissolved oxygen exceedances. The average number of exceedances per year is one or less at each station with exceedances.

3.4 NUTRIENTS

This section describes the findings of concentration plotting, the trend analysis, loading calculations, and the compliance analysis for nutrients. As described in Section 2.1.1, the nutrients considered in this assessment are:

- Nitrogen parameters:

  - Total nitrogen,
  - Ammonia nitrogen,
  - Total Kjeldahl nitrogen (TKN; organic plus ammonia nitrogen), and
  - Nitrate + nitrite.

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

3.4.1 Nutrient Concentrations

Nutrient concentrations are presented on time-series concentration plots (Appendix B, Figure B1-63 through B1-93 for nitrogen and Figures B1-32 through B1-62 for phosphorus) and concentration box plots (Appendix B, Figure B3-11 through B3-14 for nitrogen and Figure B3-8 through B3-10 for phosphorus). The following subsections describe and discuss patterns observed in the concentrations dataset for nitrogen and phosphorus nutrients.

3.4.1.1 Nitrogen Concentrations

The concentrations and seasonality of total nitrogen and its components vary widely across the watershed. Observed total nitrogen concentrations vary almost three orders of magnitude, with the lowest concentrations typically observed at the upstream end of the watershed, and the maximum concentration (11 mg/L) observed at M140 and M150. The maximum concentrations of ammonia, nitrate plus nitrite, and TKN were also observed at M140, which is located below the outfall for the Loveland WWTP.

As shown on Figure B3-14, total nitrogen 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), significantly at M140 (below the Loveland WWTP effluent), at VT20 on the Little Thompson (below Berthoud Estates WWTP and two minor WWTPs [Ranches/Vaquero Estates and River Glenn HOA]), and at VT10 (below the Berthoud WWTP). Total nitrogen concentrations in the C-BT canal stations remain fairly consistent across the watershed, showing only a slight increase moving downstream, with concentrations similar to those observed in the upper mainstem stations.

The relative contribution of ammonia, nitrate plus nitrite, and TKN to the observed increases in total nitrogen concentration below the WWTPs is apparent in Figures B2-11 through B2-13. At M30 (below the Estes Park Sanitation District effluent), ammonia is the primary fraction that is increased, which is also apparent in the TKN values. At M50 (below the Upper Thompson Sanitation District effluent), nitrate plus nitrite contributes more to the increase in total nitrogen, as compared to ammonia and TKN. A similar pattern is seen at M140 (below the Loveland

WWTP effluent) and at VT20 (below Berthoud Estates WWTP and two minor WWTPs [Ranches/Vaquero Estates and River Glenn HOA]), where nitrate plus nitrite increases explain most of the observed total nitrogen concentration increases. Finally, at VT10 (below the Berthoud WWTP), ammonia is the component that is largely responsible for the observed increase in total nitrogen, though increases in nitrite plus nitrate are also observed. The relative fractions of total nitrogen are discussed further in the loading analysis in Section 3.4.3.1.

Nitrogen coming in from the major tributaries of North Fork and Buckhorn Creek shows different patterns. The North Fork (T10) shows lower total nitrogen, ammonia, nitrate plus nitrite, and TKN, as compared to the upstream mainstem location, M60. In contrast, Buckhorn Creek has comparable or higher median total nitrogen and nitrate plus nitrite values as compared to the upstream mainstem location VM50.

Seasonal patterns in nitrogen compound composition vary across the system as shown in Figures B1-63 through B1-93. At the upstream end of the system (M10 and M20) and in the major tributaries (T10 and T20), TKN values are highest in the summer, possibly reflecting the organic matter contribution to TKN, while nitrate plus nitrite is highest in the winter, possibly reflecting baseflow sources. A similar but more drawn out pattern is observed at C10 (Adams Tunnel), with the highest values for TKN observed in fall and summer, and the highest values of nitrate plus nitrite observed in winter and spring (early 'summer' per the seasonal definitions used here). Total nitrogen and ammonia do not show clear seasonality at C10. Through the rest of the canal system, ammonia and TKN are generally highest in the fall and summer, and total nitrogen shows little clear pattern. Down the mainstem of the Big Thompson, nitrate plus nitrite and total nitrogen are generally higher in the winter down to M140, where the pattern breaks down due to large WWTP nutrient contributions.

3.4.1.2 Phosphorus Concentrations

The concentrations and seasonality of total phosphorus and its components vary across the watershed. Median total phosphorus concentrations vary almost three orders of magnitude across the watershed. The lowest concentrations are generally observed at the upstream ends of the system, in the canal system, and in the major tributaries (North Fork [T10] and Buckhorn Creek [T20]). The highest concentration (2.82 mg/L) was observed at M140 (below the Loveland WWTP effluent). This is also the location of the highest observed concentrations of dissolved phosphorus (2.67 mg/L) and orthophosphate (2.42 mg/L).

Figures B3-10 shows total phosphorus concentrations increasing below each of the major WWTP outfalls within 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), VT20 on the Little Thompson (below Berthoud Estates WWTP and two minor WWTPs [Ranches/Vaquero Estates and River Glenn HOA]), and at VT10 on the

Little Thompson (below the Berthoud WWTP effluent). Total phosphorus concentrations at the canal locations are generally lower than those observed along the mainstem.

The relative contribution of the dissolved phosphorus and orthophosphate to the observed increases in total phosphorus below the WWTPs is apparent in Figures B3-8 and B3-9. Generally, orthophosphates account for most of the increased dissolved phosphorus and total phosphorus at these locations (M30, M50, M140, VT20, and VT10). The relative fractions of total phosphorus are discussed further in the loading analysis in Section 3.4.3.2.

Seasonal patterns in phosphorus concentrations varied across the system as shown in Figures B1-32 through B1-62. At the upstream end of the system (M10 and M20) and from the major tributaries (T10 and T20), phosphorus concentrations follow a similar pattern, showing higher concentrations in the summer and fall, possibly reflecting overland runoff inputs of natural organic material. This pattern changes between M30 and M90, with higher phosphorus concentrations observed during the winter and fall, possibly reflecting less available dilution of treatment plant effluent. This pattern is broken at station M130, but reappears at M140, below the Loveland WWTP.

3.4.2 Nutrient Concentration Trends

Concentration time series data for nutrients were evaluated for statistically significant trends applying the Seasonal Mann-Kendall approach, as described in Section 2.2.4. Using the fairly relaxed criteria of p-values less than or equal to 0.10 (90% confidence level), statistically significant trends were identified for all of the analytes at various locations across the system, as listed in Appendix D, Table D-1. The trends were further assessed with a review of the time-series plots to generate the following findings.

For total nitrogen, slightly decreasing trends in concentration were observed in the mainstem at M20, M30, M50, and M70 through M90. Decreasing trends in ammonia and TKN were also observed at M30, possibly reflecting improvements to the Estes Park Sanitation District processes for managing nitrogen based nutrients since 2005 (though there are apparent increases in total and dissolved phosphorus in the recent years of record [not observed in the 10 year trend testing]).]). Decreases in ammonia and TKN concentrations in recent years are also apparent at M50 and M140 (and M150) in Figure B1-71 and B1-85 (and B1-86), though they were not identified as significant in this 10 year period. These observations may also reflect upgrades to the Upper Thompson Sanitation District WWTP in 2007 and upgrades to the Loveland WWTP in 2004.

For total phosphorus, small but statistically significant increasing trends were observed at C10, C20, and C40. Visual review of time series plots for C40 also indicate higher ranges of observed dissolved phosphorus and orthophosphate in recent years (Figure B1-45). WWTP upgrades noted above do not appear to have reduced phosphorus concentrations.

3.4.3 Nutrient Loading

Nutrient loading analysis results are summarized in Appendix C Figures C1-2 through C1-11 (box plot figures) and C2-2 through C2-11 (bar graph figures). Nitrogen and phosphorus loading are discussed in the following two subsections.

3.4.3.1 Nitrogen Loading

TKN comprises the majority of the Total N load across the system. There are some interesting patterns in this dataset. First, the TKN loading pattern across the system (Figure C1-7 and C2-7) shows some similarities to the TOC loading (Figure C1-1 and C2-1), reflecting the dominant role of discharge in controlling the loads of these parameters. Specifically, TKN shows the highest loads carried in the canal stations, with winter month loads being distinctly higher in the canal stations. One noteworthy difference between TOC and TKN loading patterns is that TKN loads increase more significantly at M140, reflecting a higher input of TKN by the Loveland WWTP (Figures C1-3 and C2-3).

While this 10-year dataset shows an historical average increase in ammonia loads below the Loveland WWTP, the effect has been greatly reduced in the most recent five years of record. Ammonia loading plots (Figures C1-3/ C1-4 and C2-3/ C2-4) show fairly consistent load increases (compared to the corresponding upstream station) below the other major WWTP effluents within the COOP monitored area: M30 (below Estes Park Sanitation District) and M50 (below Upper Thompson Sanitation District effluent). These loads also show relatively higher winter loads, reflecting the year-round nature of the effluents. A similar WWTP effect is also apparent on nitrate plus nitrite loads (Figures C1-6 and C2-6), though it is less apparent for M30 (below Estes Park Sanitation District) and more pronounced and consistent into recent years for M140 (Loveland WWTP).

The total nitrogen loading picture (Figures C1-2 and C2-2) reflects the combination of effects of the components. Total nitrogen loads are relatively high in the upper canal locations (C10 - Adam's tunnel and C20 – Olympus Canal), reflecting elevated organic nitrogen and the high flow volumes. Total nitrogen load increases along the mainstem at M30 (below Estes Park Sanitation District) and at M50 (below Upper Thompson Sanitation District), largely reflecting increases in ammonia, and to a lesser degree increases in nitrate plus nitrite. Finally, the large total nitrogen load at M140 (compared to the upstream station) reflects a large nitrate plus nitrite load from the Loveland WWTP. These observations are apparent in Figure 12, Figure 13, and Figure 14, below, which present the average percent contribution of ammonia, TKN, and nitrate plus nitrite, respectively, to the total nitrogen load across the COOP monitored system for the full period of record.

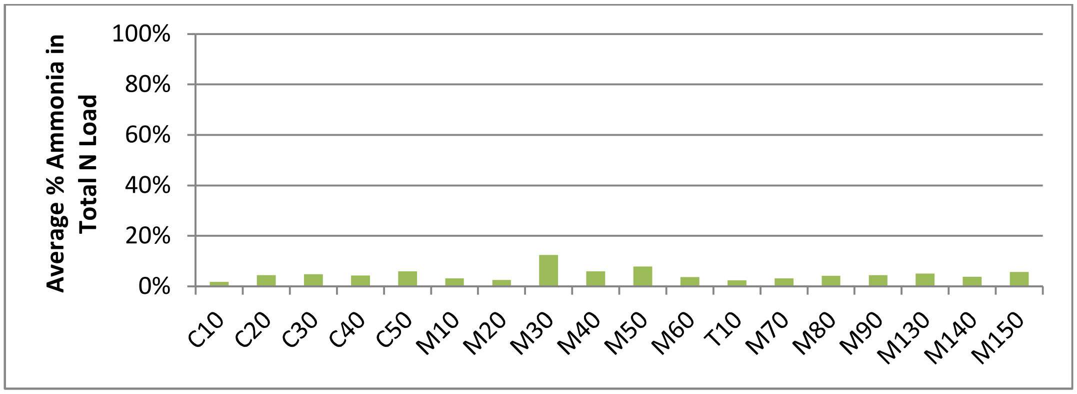

Figure 12. Average Ammonia Fraction in Total Nitrogen Load.

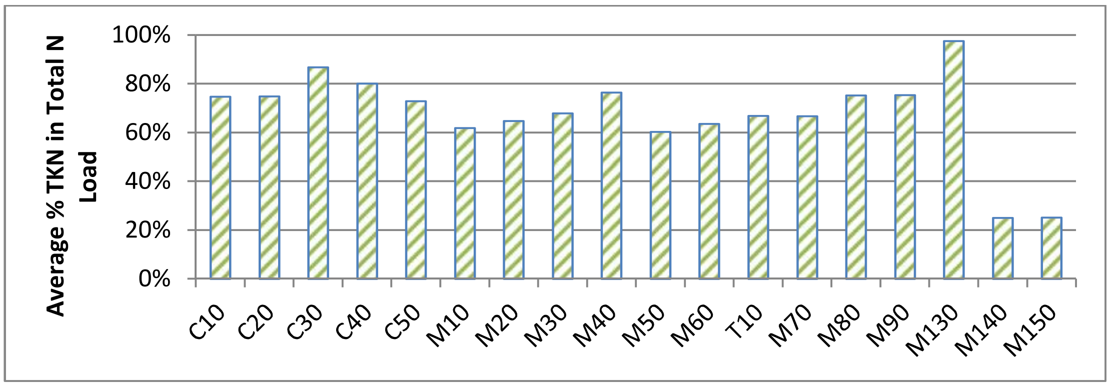

Figure 13. Average TKN Fraction in Total Nitrogen Load.

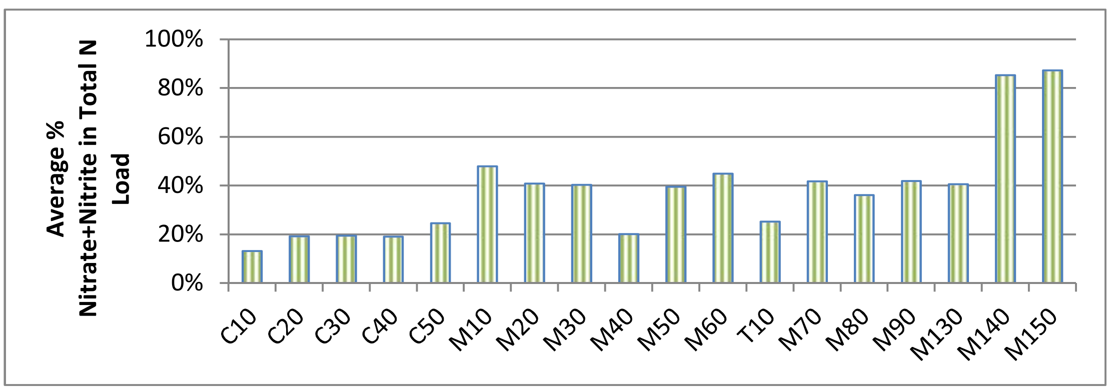

Figure 14. Average Nitrate plus Nitrite Fraction in Total Nitrogen Load.

3.4.3.2 Phosphorus Loading

As shown in Appendix C Figures C1-5 and C1-9 through C1-11, total phosphorus, orthophosphate, and dissolved phosphorus show the same general loading pattern across the sites. Generally small loads are apparent in the upstream reaches (M10 to M20) as well as the tributaries (T10 and T20), and increases in load are observed along the mainstem below the major WWTP outfalls (M30, M50, and M140), with the largest increases observed at M140, located below the Loveland WWTP outfall. The significance of the increase in load at M140 is even more apparent in the loading bar graphs (Appendix C Figures C2-5 and C2-9 through C2-11), which do not have a logarithmic y-axis. These figures also show that the increase in load is present in all seasons.

The loading bar graphs also show that the C-BT canal system caries 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 10% of the load observed at M140 and M150. In fact, as shown below in Figure 15, the relative decrease in 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. Figure 16 shows that the fraction of orthophosphate in the dissolved phosphorus also increases at M140. Orthophosphate is the form most readily available to aquatic plants/algae, and is an important parameter in assessment of eutrophication.

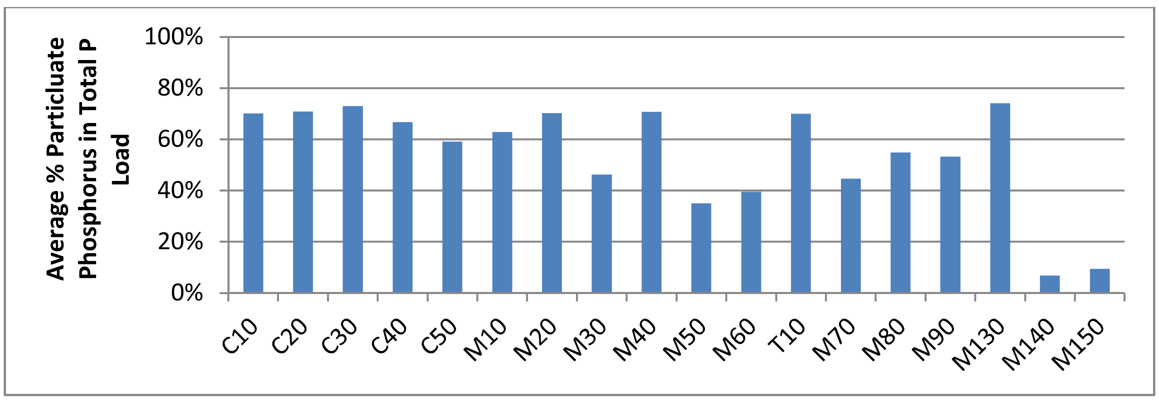

Figure 15. Average Particulate Fraction in Total Phosphorus Load.

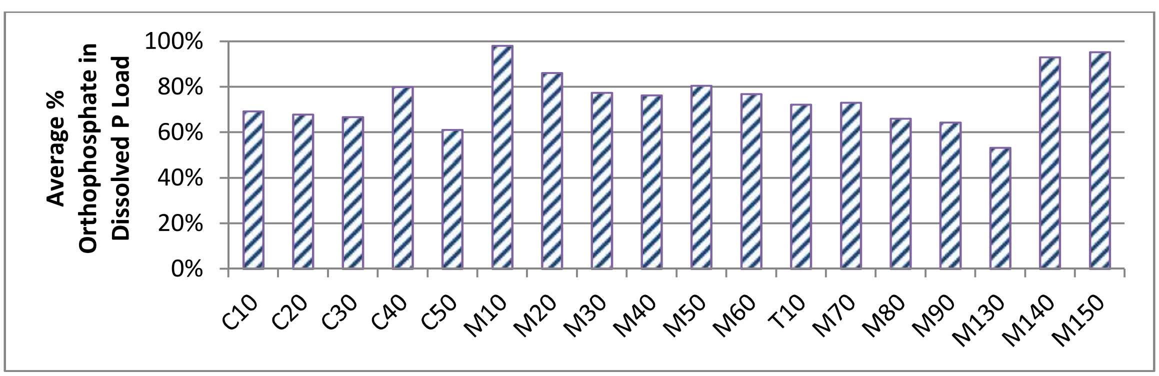

Figure 16. Average Fraction of Orthophosphate in Dissolved Phosphorus Load.

3.4.4 Nutrient Compliance

As described in Section 2.2.5, ammonia was compared to applicable acute and chronic aquatic life Colorado WQCD water quality standards. Total nitrogen and total phosphorus concentrations were compared to the current draft Colorado WQCD numeric nutrient criteria for cold water rivers and streams. These draft numeric values (0.4 mg/L for total nitrogen and 0.11 mg/L for total phosphorus) were developed by the WQCD for the nutrient rulemaking hearing now scheduled for March 2012. They are not adopted standards but were assessed solely here for informational purposes. Assessments against standards and draft criteria are summarized in Appendix E tables E-2 and E-3. Results for acute comparisons are assessed annually for ammonia, nitrogen, and phosphorus in Tables E-4, E-12, and E-13, respectively.

For ammonia, the standard varies as a function of pH (and in some cases temperature). The calculated variable standard is presented in Appendix B1, Figures B1-63 through B1-93. Both acute and chronic evaluations of ammonia show frequent and widespread exceedances of current standards on the Big Thompson mainstem (from M30 through M140) and on the Little Thompson (starting at VT10). Buckhorn Creek (T20) has also shown frequent exceedances in the most recent two years of record.

The draft numeric criteria for total nitrogen and total phosphorus are shown on concentration time series plots in Appendix B1 (Figures B1-32 through B1-62 for TP, and Figures B1-63 through B1-93 for TN); however, a review of the concentration box plots (Figure B2-14 and Figure B2-10) shows the general pattern. For total nitrogen, the median observed concentrations exceed 0.4 mg/L at M50 and most stations further downstream, excluding canal locations and the North Fork tributary. Station M140 (below the Loveland WWTP effluent) to the end of the system, as well as little Thompson stations VT20, VT10, and VT05 show 100% exceedance of the 0.4 mg/L draft criteria level for all years of record.

For total phosphorus, a review of Figure B2-10 reveals that, with the exception of M30, M50, and M60, generally infrequent exceedances of the draft criteria level are observed for stations upstream of M130, including canal locations. At M140 and farther downstream, the majority of results exceed the 0.11 mg/L value. Likewise, on the Little Thompson, concentrations frequently exceed the 0.11mg/L draft criteria value for total phosphorus at VT10 and downstream.

In evaluation of these comparisons to draft nutrient criteria values, it is important to note that WWTPs are only currently regulated for ammonia (not total nitrogen or total phosphorus). As such, these informational comparisons or river water quality are not indications of WWTP system discharge permit compliance issues. For instance, the Loveland WWTP has been operating well under its permit limits, and upgraded its treatment in 2004 to meet changing permit requirements for ammonia and *E. Coli.* Implementation of phosphorous and nitrogen nutrient criteria would likely require many WWTPs to modify their treatment processes to target nitrogen and phosphorus removal.

3.5 MICROBIOLOGICAL PARAMETERS

This section describes the findings of concentration plotting, the trend analysis, and the compliance analysis for microbiological parameters. As described in Section 2.1.1, the parameter list includes two measures of bacteria:

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

3.5.1 Microbiological Parameter Concentrations

Figures B2-6 and B2-7 show generally similar patterns in concentrations for total coliforms and *E. Coli* across the watershed. Concentrations generally increase from upstream to downstream on both the Big Thompson and Little Thompson Rivers. 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 (Figures B1-32 through B1-62). The highest concentration results for both total coliforms and *E. Coli* were observed on the Little Thompson at VT20 (242,000 CFU/100mL and 16,000 CFU/100mL, respectively). 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.

3.5.2 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 2.2.4. Using the fairly relaxed 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 D, Table D-1. The trends were further assessed with a review of the time-series plots. From that review, trends of increasing total coliforms were observed at C40, T10, M140, and M150. At T10, M130, M140, and M150, there was an observed increase in *E. Coli*, particularly in recent years. Higher concentrations of E. Coli have also been observed in recent years at T10 and T20 (though these were not statistically significant trends for the 10 year record).

3.5.3 Microbiological Parameter Compliance

Of the microbiological parameters evaluated, compliance values 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 126/100 mL. For stations downstream of M90, the data were assessed on a seasonal basis with a standard of 126/100 mL for May 1 through October 15, and a standard of 630/100 mL for October 16 through April 30. The percent exceedances for all years of data are summarized in Appendix E, Table E-2. Percent exceedances for each year at each station are summarized in Table E-10. From Table E-2, it is apparent that exceedances have occurred at most locations across the watershed, though exceedances are infrequent in the upper reaches and in the central mainstem between M50 and M90. Beginning with T20 (Buckhorn Creek), the frequency of exceedances generally increases downstream, with the most frequent exceedances on the mainstem observed at M140 (below the Loveland WWTP outfall). On the Little Thompson, the frequency of exceedances increases sharply at VT20, where the exceedance frequency has increased from 60% in 2001 to 100% in 2008 and 2009. 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.

3.6 COMPARISON OF COOP AND VOLUNTEER SAMPLING RESULTS

A simple comparison of COOP and Volunteer sampling results was made for the two sets of collocated (or nearly collocated) stations (M10/795 and M90/VM50). This comparison was made to support a non-statistical assessment of systematic differences in results by program. The two programs differ in sampler training, analytical laboratories, and even analytical method, depending on the analyte. 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, with the exception of total organic carbon, chlorophyll a, *E. Coli*, and total coliforms. These samples are analyzed by Northern Water (chlorophyll *a* and nutrients at the canal sites), the City of Fort Collins' laboratory (TOC & chlorophyll *a*) and the City of Loveland's laboratory (*E. Coli* and total coliforms). A recent article in Environmental Science and Technology (Loperfido et al., 2010) observed systematic differences in results generated by volunteer groups in Iowa, though the situation was not completely analogous to the Forum's situation because the Iowa volunteer groups were also performing their own laboratory analyses for nutrients.

A subset of the full parameter list was identified by the Forum for this evaluation. This list included the following laboratory and field parameters: TOC, chlorophyll *a*, copper, *E. Coli*, total phosphorus, specific conductivity, and dissolved oxygen. Sampling at the paired stations was targeted for the same week but infrequently occurred on the same day; therefore, datasets were compared by simply plotting the full set of results from each program at the paired station set, for each parameters evaluated, on a single plot.

The full set of comparison plots are presented in Appendix F. For the field collected parameters evaluated, dissolved oxygen and specific conductivity, results compared very well. A plot of the specific conductivity results for stations 795 and M10 is shown below in Figure 17. For the laboratory-analyzed parameters (TOC, chlorophyll *a*, copper, *E. Coli*, and total phosphorus), results also compared very well, and shown in Figure 18, for TOC at M90 and VM50.

There was one exception. Copper results compare well in the early part of the record when Volunteer monitoring detection limits were lower; however, in 2006, Volunteer detection limits increased making comparison to USGS results impossible (Figure 19). More importantly, these detection limits, as noted in Section 3.2.3, are also too high to support compliance analysis in the upper portions of the watershed where hardness values are lower. Similar issues with detection limits were also identified for total mercury, as discussed in Section 3.2.3.

Overall, results compared well across the sampling programs, and continue combined interpretation of data appears appropriate.

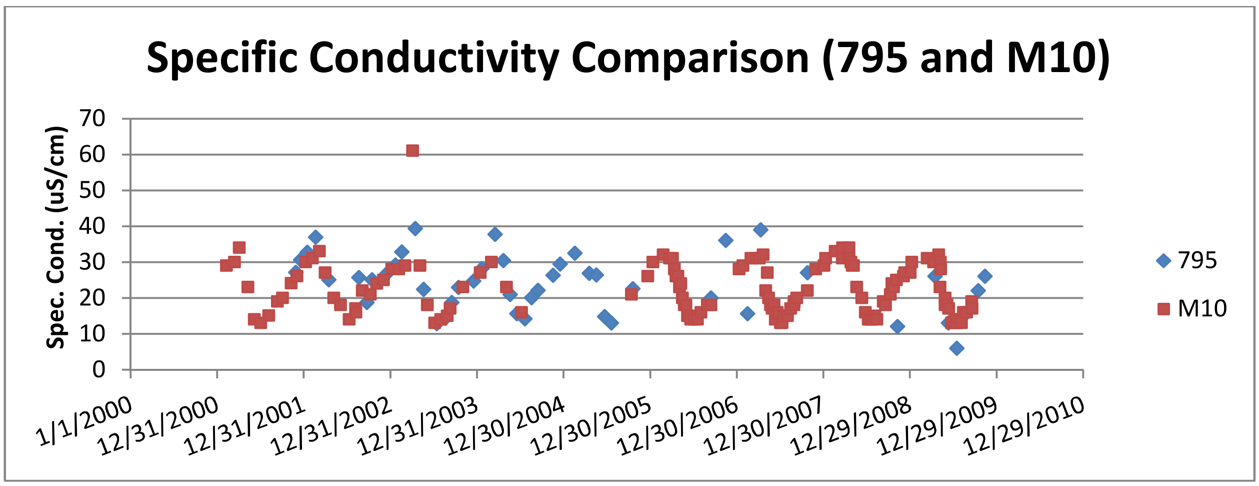

Figure 17. Specific Conductivity Results at 795 and M10.

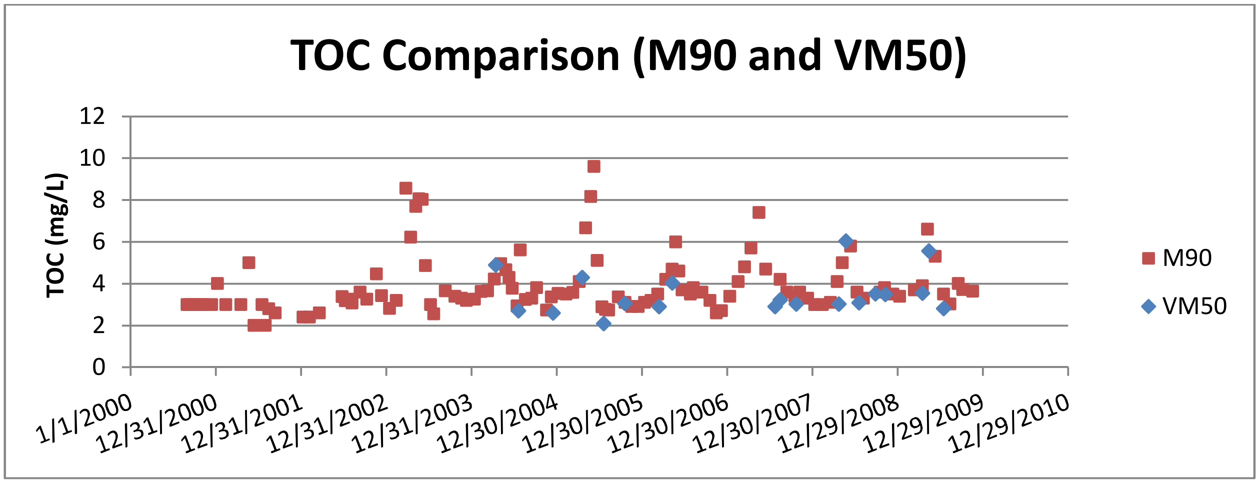

Figure 18. TOC Results at M90 and VM50.

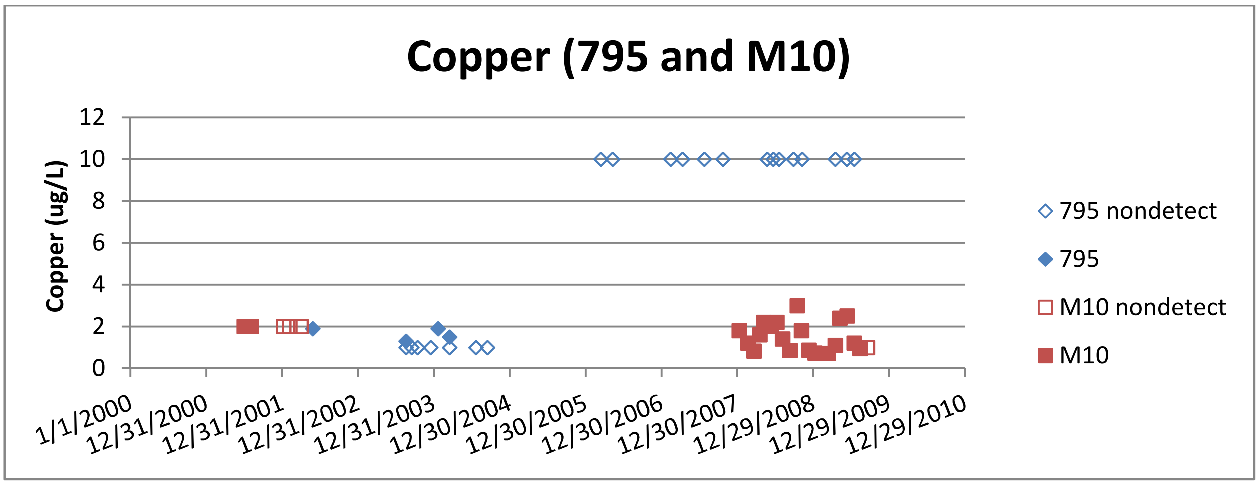

Figure 19. Copper Results at 795 and M10.

4 FINDINGS AND RECOMMENDATIONS

This section presents a summary of the findings and recommendations generated from the analysis described in Sections 2 and 3.

4.1 DATA ANALYSIS FINDINGS

The Forum's NPSTORET database was applied to generate a dataset of 25 selected parameters, including flow, metals, general parameters, nutrients, and microbiological parameters, for the last ten full years of record (WY 2000 through WY 2009). These data were plotted on time-series figures, applied to loading calculations, testing for temporal trends, and compared to current water quality standards. The results of this assessment are presented in Section 3 and summarized below for each parameter group.

4.1.1 Metals

Of the five metals evaluated, only copper and selenium show any clear spatial and seasonal patterns. Cadmium and zinc showed frequent results below detection limits and exhibited no standards exceedances. The basis for listing cadmium and zinc as high priority parameters on the 303d List for a segment of the watershed (Table 1 and Figure 5) is not clear from the Forum's dataset. As for mercury, the dataset is limited by high detection limits and frequent non-detect results, and some suspect data; however, the available data show no clear temporal or spatial patterns in concentrations or exceedances that would suggest significant point or non-point sources.

Periodic exceedances of copper standards continue to be observed in the uppermost watershed at M10, where relatively lower copper standards exist due to the lower hardness in this part of the basin. No dissolved copper exceedances were observed in the lower watershed (VM40 and below and the Little Thompson) due to higher hardness values increasing the standard for copper.

Dissolved copper concentrations in the mainstem from above Lake Estes at Adam's Tunnel (C10) to below the Hansen Feeder Canal at M80, exhibit a period of relative increased concentrations (exceedances of current estimated standards in some cases). These higher concentrations start in 2005 and generally peak in 2006 or 2007, showing lower concentrations in the recent year or two of data. This pattern is also observed at C20; however, the pattern does not emerge in the lower portion of the canal system (C30, C40, and C50). Likewise, the pattern is not apparent in the watershed below M80 or on the Little Thompson. Copper sulfate has been used in the watershed as an algaecide by Northern Water and the U.S. Bureau of Reclamation. Northern Water copper sulfate applications occurred in the C-BT system in the area of the trifurcation, and would not have affected the upstream areas noted here. Further, applications by Northern Water were discontinued by 2008. The U.S. Bureau of Reclamation; however, is still using copper sulfate in the siphon near Lake Estes. Information about any reduced or modified usage in the recent year of record was not available to help further investigate these observations.

For selenium, concentrations clearly increase in the lower foothills on the Big and Little Thompson Rivers, likely reflecting the presence of naturally-occurring selenium-rich shale. This pattern is clearly reflected in the routine exceedance of acute selenium standards in these reaches and exceedances of chronic standards toward the end of each reach. This source naturally contributes load to baseflows, and loading can be increased anthropogenically through agricultural irrigation and wastewater return flows[24].

4.1.2 General Parameters

Temperature, dissolved oxygen, and pH generally exhibit expected natural patterns across the watershed. There are no major compliance issues for pH, temperature, or dissolved oxygen in this dataset, though occasional acute exceedances (averaging one or fewer per year) continue to occur for pH and dissolved oxygen at a few locations.

Chlorophyll *a* concentrations are generally low in the upper watershed (M20 and above). The tributary locations (T10 and T20) also have relatively low chlorophyll *a* concentrations. The CB-T system carries relatively high chlorophyll *a* concentrations into the system at C10 (Adams Tunnel), as compared to M20. Below the City of Loveland, there is a general trend of increasing chlorophyll *a* concentrations, possibly reflecting the input of nutrients.

TOC concentrations in the watershed are strongly influenced by both the spring snowmelt runoff and by inputs from the C-BT west slope reservoirs via the Adams Tunnel (C10). TOC concentrations at C10 (Adams Tunnel), C20, C30, and C40 show statistically significant increases in concentration, decreasing along the system from 0.11 mg/L-yr at C10 to 0.07 mg/L-yr at C40. Statistically significant increases in TOC concentrations were also reported by Haby and Loftis (2007) in their review of the watershed.

TDS, specific conductivity, alkalinity, and hardness exhibit similar relative patterns across the watershed, with increasing values moving downstream, and a large increase at VM40, at least partially due to high values from the Buckhorn Creek tributary (T20). High values from Buckhorn Creek may be related to multiple quarry operations in that drainage, as well as the natural geology of the drainage. In the Little Thompson, a large increase in dissolved species

[24] The term "wastewater return flows", as used here, refers to treated drinking water released outside of the sewer system (via septic systems, lawn watering, etc.) which returns to the river via shallow groundwater flow.

concentrations is apparent at VT20. These increases in dissolved constituents may reflect a combination of treated wastewater, runoff, and irrigation return flows.

4.1.3 Nutrients

The effects of the major WWTPs are apparent in nutrient concentrations and loads across the watershed, with the most significant being loads to the Big Thompsons River from the Loveland WWTP at M140, followed closely in magnitude by loads to the Little Thompson River. At M30 (below the Estes Park Sanitation District effluent), contributions of ammonia and dissolved phosphorus, primarily orthophosphates, result in increased concentrations and loads of total nitrogen and total phosphorus. At M50 (below the Upper Thompson Sanitation District effluent), contributions of ammonia, nitrate plus nitrite, and dissolved phosphorus, primarily orthophosphates, result in increased concentrations and loads of total nitrogen and total phosphorus. A similar pattern is seen at M140 (below the Loveland WWTP effluent) and at VT20 (below Berthoud Estates WWTP and two minor WWTPs [Ranches/Vaquero Estates and River Glenn HOA]), where increases in nitrate plus nitrite and orthophosphate explain most of the observed increases in total nitrogen and total phosphorus concentration and load. Finally, at VT10 (below the Berthoud WWTP), ammonia is the component that is largely responsible for the observed increase in total nitrogen, while orthophosphates are again the main contribution to increases in total phosphorus. Effects of upgrades to the WWTPs (Estes Park Sanitation District in 2005, Upper Thompson Sanitation District in 2007, and Loveland WWTP in 2004) are apparent in decreasing ammonia and TKN concentrations.

Nutrient concentrations in the C-BT canal stations tend to be relatively low, though the loads are significant due to the high flow volume. Total nitrogen in the canals is primarily organic nitrogen, while phosphorus is primarily particulate.

The compliance review revealed frequent and widespread exceedances of both acute and chronic ammonia water quality standards on the Big Thompson mainstem (from M30 through M140) and on the Little Thompson (starting at VT10). Buckhorn Creek (T20) has also shown frequent exceedances in the most recent two years of record. A comparison of total nitrogen and total phosphorus data to the draft nutrient criteria indicates similarly widespread results above the total nitrogen value. For phosphorus, frequent exceedances are more focused on the downstream end of the system, below M130 on the Big Thompson and below VT10 on the Little Thompson.

It should be noted that these observations of increased nutrient loads below WWTPs contribute important understanding to the health of the system and sources of nutrients to the rivers and reservoirs; however, WWTPs are only currently regulated for ammonia (not total nitrogen, nitrate plus nitrite, or total phosphorus). As such, these observations and comparisons to the draft nutrient criteria are not indications of WWTP system discharge permit compliance issues. These finding do indicate that implementation of phosphorous and nitrogen nutrient criteria would likely require many WWTPs to modify their treatment processes to target nitrogen and phosphorus removal.

4.1.4 Microbiological Parameters

Concentrations of total coliforms and *E. Coli* generally increase from upstream to downstream along the watershed. The concentrations from the Adams Tunnel (C10) are much lower than concentrations observed elsewhere in the watershed, as expected, given the open water origin of those flows. The reach of the Little Thompson River between VT30 and VT20 shows the greatest increase in concentrations and the highest observed concentrations for *E. Coli,* possibly reflecting major and minor WWTP outfalls and/or livestock sources. In accordance with the generally increasing concentrations from upstream to downstream, compliance issues for *E. Coli* (exceedances of primary contact recreational use standards) increase from upstream to downstream, with frequent compliance issues occurring generally below M130 on the Big Thompson (as well as T20- Buckhorn Creek) and below VT20 on the Little Thompson.

4.2 SUMMARY

Based on the results of calculations, statistical testing, and data products developed for this assessment, the key findings are summarized as follows:

- **WWTPs** – The effects of the major WWTPs in the watershed are apparent in both nitrogen and phosphorus concentration observations below each major outfall. The largest concentration and load increases are observed below the Loveland WWTP (M140) on the mainstem of the Big Thompson River and below the Berthoud (VT10) and Berthoud Estates (VT20) WWTPs on the Little Thompson River. Effects of upgrades to the WWTPs (Estes Park Sanitation District in 2005, Upper Thompson Sanitation District in 2007, and Loveland WWTP in 2004) are apparent in decreasing ammonia and Total Kjeldahl Nitrogen (TKN) concentrations in the river[25]. It should be noted that these observations of increased nutrient concentrations and loads below WWTPs contribute important information to understanding the system and sources of nutrients to the rivers and reservoirs; however, WWTPs are only currently regulated for ammonia (not total nitrogen, nitrate plus nitrite, or total phosphorus). As such, these observations and comparisons to the draft nutrient criteria are not indications of WWTP system discharge permit compliance issues.
- **C-BT System** – The water introduced to the Big Thompson watershed by the C-BT system (via the Adams Tunnel, C10) has generally similar or lower concentrations for

[25] Neither phosphorus nor total nitrogen is currently regulated in WWTP discharge permits. Improvements to the Loveland WWTP targeted ammonia and *E. Coli*. Evaluation of WWTP effluent data and specific loads were beyond the scope of this assessment, but may be useful for future assessments.

most parameters, as compared to the water quality in the upper-most portion of the Big Thompson watershed. Two noteworthy exceptions are total organic carbon (TOC) and chlorophyll *a*.

- TOC concentrations continue to show a statistically significant increase over the last ten years in portions of the east slope C-BT system assessed in this report (C10, C20, C30, and C40). Haby and Loftis also noted an increasing trend in TOC concentrations in their review of the watershed in 2007 (Haby and Loftis, 2007). The increasing trend, on the order of 0.1 mg/L-yr at C10 through C40, was not observed at C50, which flows to Horsetooth Reservoir. 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.
- The CB-T system carries relatively high chlorophyll *a* concentrations into the system at C10 (Adams Tunnel), as compared to M20. Chlorophyll *a* is a form of chlorophyll used in oxygenic photosynthesis that is used as a measure of phytoplankton abundance and an indicator of water quality.

- **Major Tributaries –**
  - Buckhorn Creek – The Big Thompson tributary, Buckhorn Creek (T20), exhibits relatively poor water quality and possible trends of concern. High concentrations of Total Dissolved Solids (TDS), specific conductivity, alkalinity, and hardness are observed, which may be related to multiple quarry operations in the drainage as well as the general geology of the drainage. Buckhorn Creek only contributes an average of 5% of the flow observed at M130, but the effects of the higher concentrations of these parameters are apparent at VM40. Additionally, *E. Coli* and ammonia concentrations are high relative to the upstream concentrations on the Big Thompson River, contributing to frequent exceedances of water quality standards for these parameters at T20. Further, *E. Coli* concentrations show higher values in recent years, though no statistically significant trend was identified.
  - North Fork of the Big Thompson River (T10) – The North Fork flows are roughly 25% of the flows observed at the upstream mainstem station M60, and the water quality is generally good. Nitrogen, phosphorus, and TOC concentrations from the North Fork are generally low, as are Chlorophyll *a* concentrations, as compared to the mainstem upstream station, M60. There are, however, observations of increased *E. Coli* concentrations in recent years, and a trend of increasing total coliforms.
  - Little Thompson – The Little Thompson water quality at VT05, where it joins the mainstem, is similar to the mainstem water quality in the lower watershed, with elevated concentrations of nutrients, TOC, chlorophyll a, selenium, and coliforms. Concentrations of these parameters generally increase from upstream

to downstream on the Little Thompson. Of these parameters, phosphorus concentrations are lower than upstream mainstem concentrations (at VM10), but still higher than watershed values upstream of Loveland. Ammonia, nitrate, and total nitrogen concentrations are even higher than those in the immediately upstream mainstem location (VM10). The Little Thompson also contributes elevated values of alkalinity, specific conductivity, hardness, and temperature to the mainstem, relative to VM10 observations.

- **Compliance** –The compliance analysis indicated issues with dissolved copper, selenium, *E. Coli*, and ammonia.
  - Acute and chronic copper exceedances are routinely observed in the upper watershed at station M10, where copper standards are lower due to low hardness[26]. This is included in the large area 303d listed for copper (see Table 1 and Figure 5). Farther downstream along the mainstem, fairly routine periodic acute and chronic exceedances were observed at M80 and M90. Routine exceendances were also observed at the North Fork (T10) in 2006 and 2007; however, there have been no exceedances at M80, M90, or T10 since 2008. Exceedances even farther downstream are not seen due to relatively high hardness values resulting in much higher calculated standards. Copper sulfate has been used in the watershed as an algaecide by Northern Water and the U.S. Bureau of Reclamation. Northern Water copper sulfate applications occurred in the C-BT system in the area of the trifurcation, and would not have affected the upstream areas noted here. Further, applications by Northern Water were discontinued by 2008 in favor of a slurry form of hydrogen peroxide. Copper sulfate is still being used by the U.S. Bureau of Reclamation at Pole Hill near Lake Estes.
  - Dissolved selenium concentrations increase sharply in the lower foothills on the Big and Little Thompson Rivers, below which frequent exceedances are observed for both acute and chronic aquatic life standards. The selenium likely originates from naturally-occurring selenium-rich shale. This source naturally contributes loads to baseflows, and loading can be increased anthropogenically through agricultural irrigation and wastewater return flows[27].
  - Compliance issues for *E. Coli* (exceedances of standards to protect recreational use) increase from upstream to downstream, with frequent compliance issues

[26] As a reminder, for hardness-based standards (cadmium, copper, and zinc), the hardness value for each station was set as the 85th percentile result for the dataset for the most recent five years of record (October 1, 2004 through September 30, 2009). As such, the resulting standard values for these metals were constants for each station.
[27] The term "wastewater return flows", as used here, refers to treated drinking water released outside of the sewer system (via septic systems, lawn watering, etc.) which returns to the river via shallow groundwater flow.

occurring generally below M130 on the Big Thompson River and below VT20 on the Little Thompson River.

- Frequent and widespread exceedances of both acute and chronic aquatic life standards for ammonia were noted on the Big Thompson River mainstem (from M30 through M140) and on the Little Thompson River (starting at VT10).

- **Draft Nutrient Criteria** - A comparison of total nitrogen and total phosphorus data to the 2010 draft nutrient criteria indicates widespread results above the total nitrogen value. For phosphorus, values above the draft criteria are more prevalent in the downstream end of the system, below M140 on the Big Thompson River and below VT10 on the Little Thompson River. These findings indicate that implementation of phosphorous and nitrogen nutrient criteria, if set at draft values from 10/13/2010, would likely require many of the system WWTPs to modify their treatment processes to target nitrogen and phosphorus removal; however, direct WWTP effluent concentration and loading analysis was outside of the scope of this assessment.

- **Monitoring Program Comparability** – A simple comparison of results of the two sets of paired COOP and Volunteer monitoring stations revealed good comparability of results between the two sampling programs. The only exception was inconsistency in detection limits for dissolved copper and total mercury. The Volunteer monitoring program detection limits for those analytes are too high to allow for comparison of results and to fully assess compliance. Reduction of the Volunteer program detection limits for dissolved copper and total mercury is included in the program recommendations.

4.3 DATABASE

This report is the first major application of the Forum's newly developed NPSTORET database. In spite of the previously-unapplied condition of the database, the database was in very good condition. As expected, some errors were found, and some recommendations were generated. These items are all discussed in Section 2.1.2 and summarized below:

- Sample Fraction Designations – The current database should be cleaned up to accurately present sample fractions as filtered versus unfiltered. Following that cleanup, if possible, the data entry tools should change the terminology associated with this field to filtered, unfiltered, or N/A. Further, if possible, the data entry tools should be designed to limit options for specification of sample fraction to only meaningful options for each parameter (e.g., pH should only have an option of N/A, while metals could have filtered, not filtered).

- Nitrate + Nitrite/ Ammonia Parameter Designation – An error was found in the parameter designations for ammonia. It was determined from the laboratory analysis field that some nitrate plus nitrite samples were erroneously identified as ammonia samples. The copied database was corrected for this effort, and that correction should be extended to the primary database.

- Mercury Units Error - For mercury, it was determined that two sets of data were in the database. One set had labels of ug/L, and one set had labels of ng/L. The ug/L data were not realistic values and are likely entry errors. The ng/L data were used in this analysis. These erroneous duplicated data should be removed from the primary database.

- Suspect Data – In the course of reviewing all of the data, clearly questionable data points were identified and excluded from this analysis (e.g., pH values of 35). The list of these data points is included as Table A-6 in Appendix A. To minimize such entry errors in the future, a routine could be developed that assesses the input dataset relative to the existing dataset, providing a warning if values were included that were more than a factor (say 1000) greater than the existing mean. These data would not necessarily be excluded, but the routine could serve as an input check of units and bad laboratory results.

- Flow records for the canal locations (C10, C20, C30, C40, and C50) were found to be inaccurate in the NP STORET database. For this analysis, daily flow results for these locations were obtained from Northern Water. The origin of the error was not apparent in the database in this review. The flow data for these locations should be reloaded, using the dataset compiled by Northern Water. The upload error should be identified to prevent reoccurrence in future uploads.

4.4 PROGRAM RECOMMENDATIONS

Several program improvements and special studies are recommended related to operation of the monitoring program and additional data evaluation for the next State of the Watershed Report.

- For the next State of the Watershed report, consider adding the assessment of parameters on Colorado's Monitoring and Evaluation List[28] (WQCD, 2010a) for the Big

[28] "Colorado's Monitoring and Evaluation List identifies water bodies where there is reason to suspect water quality problems, but there is also uncertainty regarding one or more factors, such as the representative nature of the data. Water bodies that are impaired, but it is unclear whether the cause of impairment is attributable to pollutants as opposed to pollution, are also placed on the Monitoring and Evaluation List. This Monitoring and Evaluation list is a state-only document that is not subject to EPA approval." (WQCD, 2010a)

Thompson River segments. These currently include arsenic, lead, and sulfide (sulfide as un-dissociated H_2S [hydrogen sulfide]).

- Reduce copper detection limits for volunteer monitoring program sites, particularly upstream (794, 794, and VM50) where lower hardness results in standards that are well below the current detection limits. A detection limit of 1 ug/L or less is recommended.

- Either reduce detection limits on total mercury in the volunteer monitoring program or discontinue sampling for this parameter. The current detection limit is 100 ng/L, and the standard is 10 ng/L. Studies using 'clean' sampling techniques and low level analysis found total mercury concentrations in the water in Rocky Mountain National Park to be between 0.8 to 12 ng/L (Mast et al., 2005).

- Add collection of TSS or turbidity to the volunteer monitoring program. Turbidity would be preferable to match current data collection in the COOP program. Currently, there is a large information gap regarding transport of solids due to this difference in the COOP and volunteer programs.

- Consider alternative approaches to trend testing that test more specific hypotheses, as needed. The trend testing approach used in this report was a broad-based test for trends across the current 10-year dataset. This is a reasonable approach to screen for long-term trends; however, as the dataset grows, there are likely to be more short term trends of interest. For instance, in this assessment, the effects of recent changes to WWTP systems were apparent, but often not identified in long-term trending. As the understanding of the system grows, the ability to develop specific questions about specific reaches/stations over specific time-periods improves. This kind of hypothesis testing approach to trend testing could provide a more powerful and specific assessment of more focused questions.
- It would be useful to consistently upload any available USGS and U.S. Bureau of Reclamation flow records for the system into the Forum's NP STORET database. The less frequent flow measurements in the current database limit the accuracy of loading analyses.
- A focused study should be considered to determine whether other sources of water quality data in the watershed could add critical information to support future State of the Watershed assessments. This study should consider, at a minimum, data from the Colorado Water Quality Control Division, the City of Fort Collins, the City of Greeley, and Northern Water. Such a review could simultaneously allow for independent assessment of the 303d listings in the watershed.
- Flow monitoring at VT05 would be useful to assess the load from the Little Thompson River. Water from the Little Thompson River is of poorer quality than the Big Thompson River for some parameters (e.g., ammonia and nitrate plus nitrite), and flow

records would allow for better quantification of the significance of this for the Big Thompson River.

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