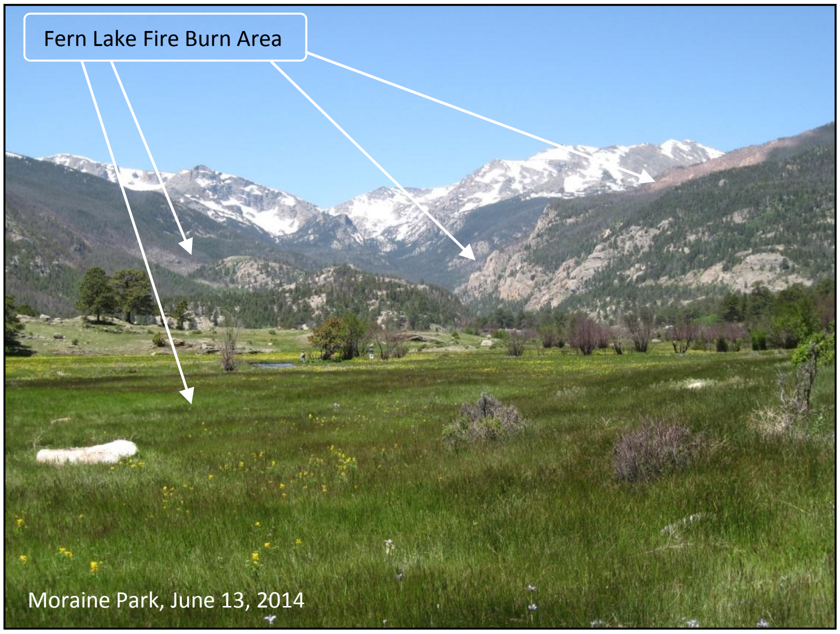
Fern Lake Fire Water Quality Study



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August 25, 2014

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Executive Summary

The Fern Lake Fire started on October 9, 2012 and burned approximately 3,500 acres in Rocky Mountain National Park (RMNP) before it was eventually extinguished by winter snows that began in early December, 2012. The fire occurred within the headwaters of the Big Thompson River in an area that had not burned in more than 800 years. The Big Thompson River flows into Lake Estes where it mixes with waters from the Upper Colorado River as part of the Colorado Big Thompson (CBT) Project. This water serves as a drinking water supply for drinking water treatment plants operated by over 15 entities in northern Colorado, making it particularly important to understand potential threats to source water quality and treatment, including the potential impact of wildfires.

Study Objective & Scope. The objective of this study was to characterize the impacts to upper Big Thompson River water quality due to snowmelt and rainfall runoff originating from the Fern Lake Fire burn area during the first spring/summer after the fire (sample collection April – November, 2013). This time period was selected for study since water quality impacts from wildfires are generally the most severe during the first year after a fire. The occurrence in September 2013 of a historic rainfall/flood event that impacted much of northeastern Colorado was also considered during the assessment of data collected in October and November.

The Fern Lake Fire was a high elevation fire near the Continental Divide, with the burn area occurring at elevations ranging from approximately 8,000 to 11,000 feet. Many of the recent wildfires in Colorado have been at lower elevations where post-fire water quality impacts of the snowmelt process may be less significant. Monitoring of the water quality impacts due to the spring snowmelt runoff and rainfall runoff from the Fern Lake Fire burn area provides information that may be transferable to future wildfires that occur within the higher elevation watersheds of the West and East Slope portions of the CBT Project.

The water quality impacts associated with the Fern Lake Fire were assessed from water samples collected by the U.S. Geological Survey (USGS) at three Big Thompson River monitoring stations (Figure ES-1): BT-MPU (located at the upstream end of Moraine Park), BT-MPD (located at the downstream end of Moraine Park), and BT-LEU (located just upstream of Lake Estes, approximately 5.2 river-miles downstream of Moraine Park and BT-MPD). Monitoring sites were selected at both the upstream and downstream ends of Moraine Park in order to assess the ability of this wide, low-gradient area to help mitigate the impacts of potential sediment loads originating from the upstream, steeper slopes within the burn area.

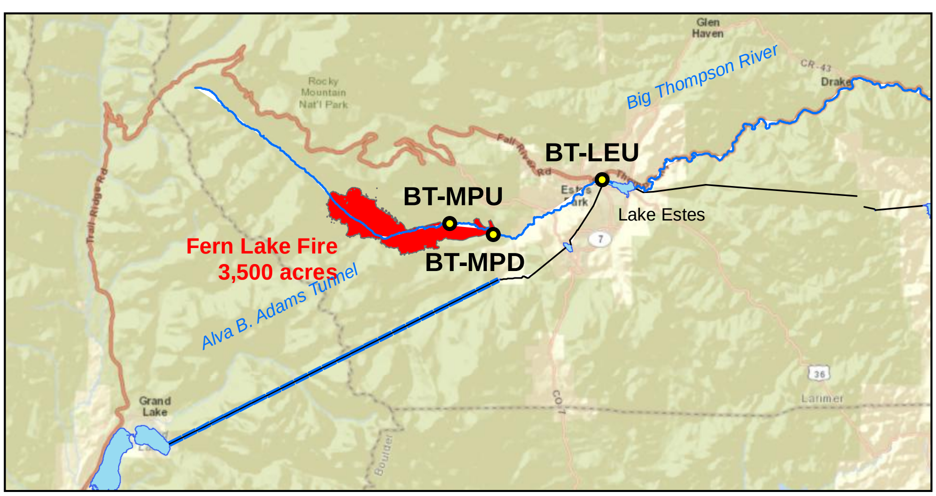

Figure ES-1. Fern Lake Fire Water Quality Study sampling sites.

Collaborative Effort. This project was a collaborative effort with costs shared by Northern Water, the Town of Estes Park, the cities of Loveland, Fort Collins, Greeley, and Boulder, and the USGS. In addition, the Big Thompson Watershed Forum (BTWF) long-term Cooperative Water Quality Monitoring Program provided pre-fire data at BT-MPD and BT-LEU that were used to compare pre- and post-fire conditions.

Results. Water quality data collected in 2013 downstream of the Fern Lake Fire burn scar indicate that runoff from the burn area resulted in some water quality changes in the Big Thompson River upstream and downstream of Moraine Park (at BT-MPU and BT-MPD, respectively). However, the measured impacts were generally short-lived, not significant enough to impact aquatic life and drinking water supplies, and/or occurred in parameters (major ions) that typically would not result in impacts to aquatic life or drinking water supplies. At the monitoring site just upstream of Lake Estes (BT-LEU), the collected samples showed minimal water quality changes. The water quality changes observed in 2013 at BT-MPD compared to pre-2013 data are qualitatively summarized in Table ES-1.

The size of the burn area, the burn severity, the presence of steep slopes, and the intensity of summer storm events all contribute to the severity of water quality impacts typically observed downstream of a burn area. The Fern Lake Fire burn area is relatively small compared to other recent, nearby fires. In addition, the burn area made up relatively small portions of the watershed areas draining to the sampling sites, such that dilution from unburned areas would be expected. However, visual observations made at BT-MPU and BT-MPD (the upstream and downstream ends of Moraine Park) during an intense, localized rainfall event on July 18, 2013 showed that significant amounts of sediment could be transported from the burn scar to the river under the right conditions. Water quality samples were not collected (due to scheduling and manpower constraints), so the impacts from this intense rainfall event were not characterized by water quality data. However, the impacts were short-lived.

Snowmelt Runoff Results. Several parameters typically exhibit a peak concentration during the spring snowmelt runoff including total organic carbon (TOC), dissolved organic carbon (DOC), total phosphorus (Total P), total Kjeldahl nitrogen (TKN), and turbidity. Higher peak spring runoff concentrations were observed in 2013 for Total P, TKN, and turbidity at Moraine Park compared to typical peak concentrations during the spring runoff. Total P at BT-MPD reached a concentration of 0.058 mg/L (about 3 times higher than typical spring runoff peaks), coincident with the peak total suspended solids (TSS) of 55 mg/L measured at BT-MPD. The 2013 spring runoff TKN peak at BT-MPD was 0.63 mg/L, compared to a range of 0.22 – 0.38 mg/L for pre-fire spring runoff peaks. The turbidity peak of 6 Nephelometric Turbidity Ratio Units (NTRU) at BT-MPD during the spring runoff was higher than normal (compared to approximately 4 NTRU), but would not be considered a high value under the circumstances. Peak TOC concentrations during the 2013 spring runoff (13.6 at BT-MPD, and 10.3 mg/L at BT-LEU) were not above the normal range as measured using Standard Method 5310C (UV-persulfate oxidation). The high-temperature combustion method yielded higher TOC concentrations (with peaks of 19.8 mg/L at BT-MPU, 19.9 mg/L at BT-MPD, and 15.1 at BT-LEU), likely due to the higher recovery of particulate organic carbon with this method.

Major ion concentrations in the upper Big Thompson River typically increase over the fall and winter, and peak at the onset of spring runoff before being diluted by runoff flows. The peak April/early May 2013 calcium, magnesium, sulfate and chloride concentrations at BT-MPU and BT-MPD were well above their typical peaks, and resulted in an elevated peak in the specific conductance at this time. An increase in major ions is often observed downstream of burn areas, particularly in streams with low pre-fire dissolved solids concentrations that drain granitic bedrock basins, such as that of the headwaters of the Big Thompson River. The collection of major ion data during this study provided evidence that the burn area was influencing general water chemistry.

The peak total recoverable aluminum concentration during the snowmelt runoff was 470 µg/L at BT-MPU, and 831 µg/L at BT-MPD, coincident with peaks in TSS. The peak dissolved aluminum concentration during the snowmelt runoff was 236 µg/L at BT-MPU, with a similar concentration at BT-MPD, exceeding the secondary (aesthetic-based) drinking water standard for dissolved aluminum of 50 µg/L. Pre-fire aluminum data and BT-LEU aluminum data are not available for comparison.

Summer Storm Event Results. Monitoring related to rainfall events (August 13 rain event, and the beginning of the September 9-15 rain/flood event) revealed increased concentrations at BT-MPU and BT-MPD of turbidity, TSS, major ions, specific conductance, Total P, TKN, and TOC (TOC values from high-temperature combustion method) compared to summer baseflow conditions (note that pre-fire monitoring did not target rainfall events so that concentrations that occurred during "typical" pre-fire summer storm events are not known). None of the increased concentrations related to 2013 storm events were extreme or exceptionally high. Peak turbidity during the August precipitation event was 26 NTRU at BT-MPU and 33 NTRU at BT-MPD, while peak TSS during this event was 65 mg/L at BT-MPU and 37 mg/L at BT-MPD. Total aluminum was higher than during the spring runoff. Dissolved manganese was elevated at the Moraine Park sites during the August and September precipitation events compared to baseline summer conditions, although all measured concentrations were below the 50 µg/L secondary drinking water standard.

Fall (October/November). By the October sampling event, Total P and TKN concentrations had dropped back to within normal ranges, coincident with a drop in TSS. Major ion concentrations and specific conductance at BT-MPU and BT-MPD were slightly elevated compared to pre-fire falls. TOC (using SM 5310C) at BT-MPD and DOC at BT-MPU and BT-MPD were also elevated compared to previous falls (TOC and DOC concentrations were within the range of 3.1 to 4 mg/L, compared to a more typical fall range of approximately 1.6 to 2.2 mg/L). It is likely that the significant amounts of rain that occurred in September flushed the watershed and resulted in subsurface flows that slowly carried increased concentrations of major ions, TOC, and DOC to the Big Thompson River well into the fall. However, it is not known the degree to which the burn area was influencing these increases compared to increases that might have occurred as a result of a similar flood prior to the Fern Lake Fire. Fall data collected at BT-LEU were not assessed with regard to impacts from the Fern Lake Fire due to the overwhelming impacts of the September flood and inputs from the other watersheds that drain to BT-LEU.

Other Data Observations. There were several constituents that notably did not increase in 2013 (above the typical pre-fire seasonal peaks and ranges), although data in the literature for other fires would suggest that increases might be expected. Downstream of the Fern Lake Fire burn area, no increases above normal ranges were observed in 2013 for ortho-phosphate, nitrate, and ammonia. Prior to the fall (Oct/Nov), TOC (analyzed using SM 5310C) and DOC concentrations at BT-MPD were not elevated above normal seasonal ranges.

Table ES-1. Qualitative changes in concentrations during 2013 compared to historic (pre-fire) concentrations at Big Thompson River at the downstream end of Moraine Park (BT-MPD).

Key to observed changes in concentrations during 2013 at BT-MPD: (qualitative, visual observations of time series & boxplots; not statistical assessment)	
	+ = observed increase above typical range; **- = decrease** **++ = significant increase** **(blank) = no change; values within historic ranges (annual and/or seasonal)**

Parameter		**Prior to Spring Runoff**	**Onset of Spring Runoff**	**Spring Runoff**	**Summer (July base-flow)**	**Aug 13 rain event (b)**	**Start of Sept Flood (Sept 10)**	**Fall, post-flood (Oct & Nov)**
General Parameters	pH (field)			-				
	Specific Conductance (field)		++	+		+	+	+
	Dissolved Organic Carbon (DOC)							+
	Total Organic Carbon (TOC) **(c)**							+
	Alkalinity							
	Total Suspended Solids (TSS) **(a)**			++		+	+	
	Turbidity			+		++	+	
Major Ions	Calcium		++	+		+	+	+
	Magnesium		+			+	+	+
	Potassium		+	+		+		
	Sodium							
	Chloride		++	+		+	+	+
	Sulfate		++	+		+		+
Nutrients	Ammonia							
	Nitrite + Nitrate			+				
	Ammonia + Organic Nitrogen (Total Kjeldahl Nitrogen, TKN)			++		+	+	
	Ortho-phosphate (Ortho-P)							
	Total Phosphorus (Total P)	+		++		++	++	
Metals	Aluminum, dissolved **(a)**			++		+		+
	Aluminum, total **(a)**			+		++	+	
	Arsenic, dissolved							
	Copper, dissolved							
	Iron, dissolved					+		
	Lead, dissolved							
	Manganese, dissolved		+	+		+	+	
	Mercury, low level total rec.					+	+	
	Nickel, dissolved							
	Silver, dissolved							

<u>Notes:</u>
(a) No data prior to 2013; comparison is made relative to low flow/baseflow conditions.
(b) Pre-fire (pre-2013) monitoring did not target rainfall events; comparison is made relative to baseflow summer conditions.
(c) TOC analysis by SM 5310C, UV-persulfate oxidation.

Comparison of Upstream & Downstream ends of Moraine Park. During the snowmelt runoff, TSS was higher at the downstream end of Moraine Park, likely due to the mobilization of finer sediments that do not have a chance to settle within Moraine Park. During the summer precipitation events, TSS was higher at BT-MPU (at the upstream end of Moraine Park) than at BT-MPD. Intense summer storm events likely mobilize coarser sediments from the areas upstream of BT-MPU that can settle within Moraine Park prior to reaching the downstream end of Moraine Park.

The chemical quality at BT-MPU and BT-MPD during 2013 was very similar. Exceptions to this were consistent with the differences observed in TSS between the two sites. During the spring runoff, when TSS was higher at BT-MPD, concentrations of Total P, TKN, and total aluminum were also higher at BT-MPD. During the August rain event, when TSS was higher at the upstream site, concentrations of Total P, TKN, TOC, and total aluminum were also higher at the upstream site. From the data collected in 2013, the broad, low-gradient area of Moraine Park provides for some attenuation of water quality impacts during summer storm events.

Future Monitoring. It is not known the degree to which runoff from the Fern Lake Fire burn area will continue to influence water quality in the upper Big Thompson River into the future. The Erosion Risk Management Tool modeling conducted by RMNP to evaluate sediment response from the burn area concluded that natural recovery of hill-slope stability is likely to occur within 3 to 5 years following the fire.

Monitoring stations BT-MPD and BT-LEU are both part of the long-term BTWF Cooperative Monitoring Program, while the USGS collects data at BT-MPU and BT-MPD for other projects. The persistence of the influence of the Fern Lake Fire burn scar on water quality in the upper Big Thompson River can be evaluated from the ongoing collection of data at these sites. The water quality impacts that were observed in 2013 are expected to be the most significant, with impacts decreasing over time as the vegetation recovers.

Pre- and post-fire water quality monitoring to assess the impacts of future wildfires within the C-BT system watersheds should include turbidity, TSS, TOC, DOC, major ions, nutrients, aluminum, manganese, and iron. Additional metals may be of interest post-fire depending on the site-specific baseline data. The assessment conducted for this study highlighted the importance of a pre-fire data set. The ongoing, long-term monitoring programs conducted by the BTWF, Northern Water, the City of Fort Collins, the USGS and other entities provide baseline data that are invaluable for assessing the impacts of future, potential adverse events, including wildfires, that may occur within the watersheds. The sampling locations included in these long-term programs provide broad spatial coverage within the C-BT watersheds such that data should be available to help assess the impacts of adverse events no matter where they occur within this region.

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1. Purpose & Overview of Study

The Fern Lake Fire started on October 9, 2012 and burned approximately 3,500 acres in Rocky Mountain National Park (RMNP). The fire occurred within the headwaters of the Big Thompson River in an area that had not burned in more than 800 years (RMNP, 2013). The Big Thompson River flows into Lake Estes where it mixes with waters from the Upper Colorado River as part of the Colorado Big Thompson (CBT) Project. This water serves as a water supply for drinking water treatment plants operated by over 15 entities in northern Colorado, making it particularly important to understand potential threats to source water quality and treatment, including the potential impact of wildfires.

The Fern Lake Fire was different from other recent Colorado Front Range wildfires (Figure 1) in that it was a high elevation fire near the Continental Divide, with the burn area occurring at elevations ranging from approximately 8,000 to 11,000 feet. In comparison, the High Park Fire burned an area generally characterized by elevations in the range of 6,500 to 9,500 feet. The higher elevation of the Fern Lake Fire burn area, with its higher snowpack and associated differences in vegetation and soils compared to lower elevations, may result in some differences in post-fire water quality impacts, although such differences may be difficult to discern since they are likely overshadowed by the influence of such factors as burn severity, size of the burn area, steepness of slopes, and post-fire storm events. However, general information gained about the water quality impacts of the Fern Lake Fire may be transferable to future wildfires that occur within the high elevation watersheds of the West and East Slope portions of the CBT Project.

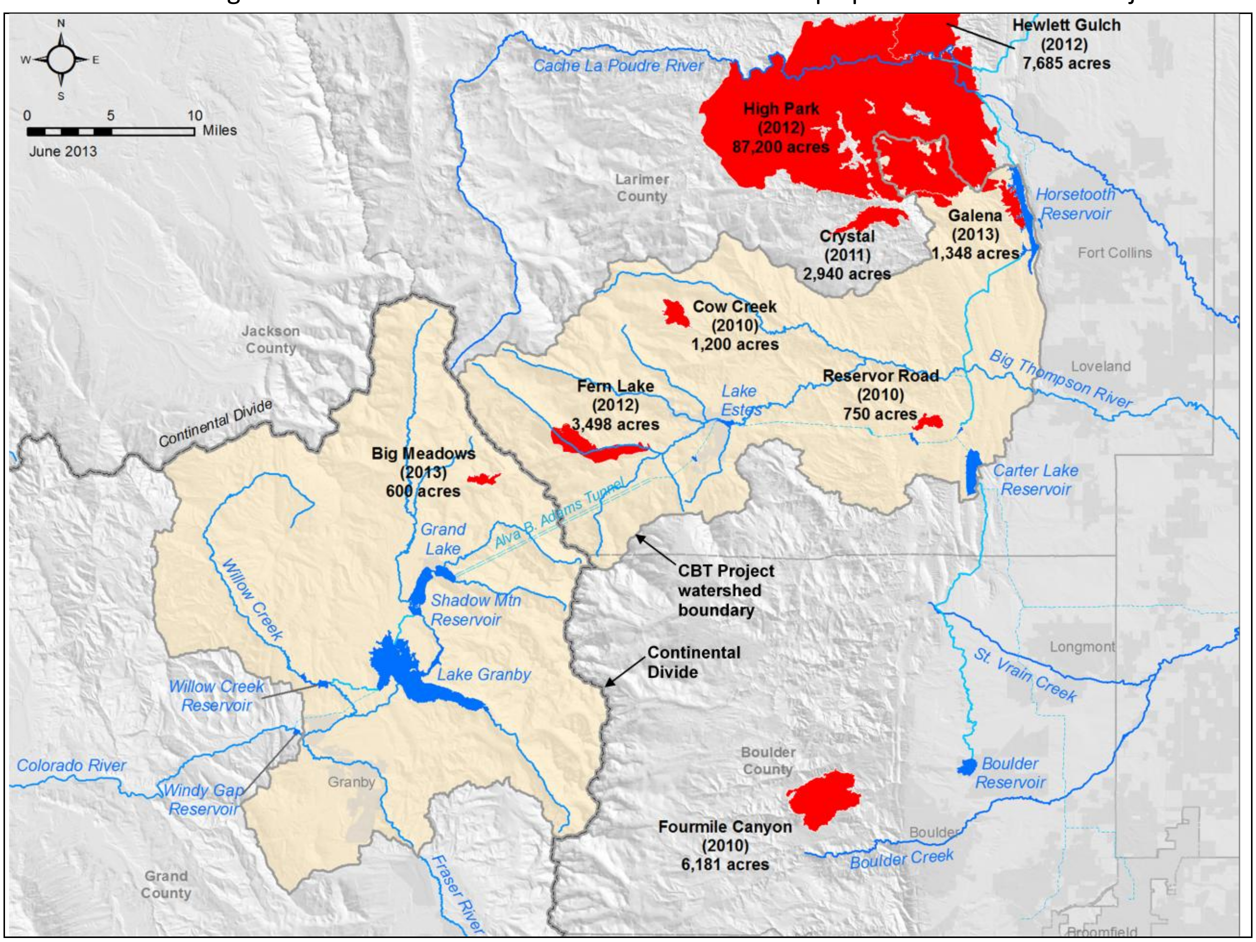

Figure 1. Recent wildfires in and near Colorado-Big Thompson (CBT) Project watersheds.

Study Objective. The objective of this study was to characterize the impacts to Big Thompson River water quality due to snowmelt and rainfall runoff originating from the Fern Lake Fire burn area during the first spring/summer after the fire (sample collection April – November, 2013). This time period was selected for study since water quality impacts from wildfires are generally the most severe during the first year after a fire.

Collaborative Study. This project was a collaborative effort with costs shared by Northern Water, the Town of Estes Park, the cities of Loveland, Fort Collins, Greeley, and Boulder, and the U.S. Geological Survey (USGS). In addition, the Big Thompson Watershed Forum (BTWF) covered a portion of this study since the long-term BTWF Cooperative Monitoring Program includes sites that are located within the study area and were used to compare pre- and post-fire conditions. The USGS collects and conducts the laboratory analyses for the long-term BTWF program samples and, for data consistency, the USGS also collected and analyzed the additional samples directly associated with the Fern Lake Fire Study.

Monitoring Locations. The water quality impacts associated with the Fern Lake Fire were assessed using data collected at the three monitoring stations listed in Table 1 and shown on Figure 2.

Table 1. Fern Lake Fire Study water quality monitoring sites.

Station	USGS Station No.	Description	Latitude	Longitude
BT-MPU (BTWF M-05)	402123105370401	Big Thompson River near Cub Lake Trailhead, upstream end of Moraine Park, RMNP	40.35645	-105.61765
BT-MPD (BTWF M-10)	402114105350101	Big Thompson River, downstream end of Moraine Park, RMNP	40.3539	-105.5841
BT-LEU (BTWF M-20)	06733000	Big Thompson River upstream of Lake Estes	40.3785	-105.5138

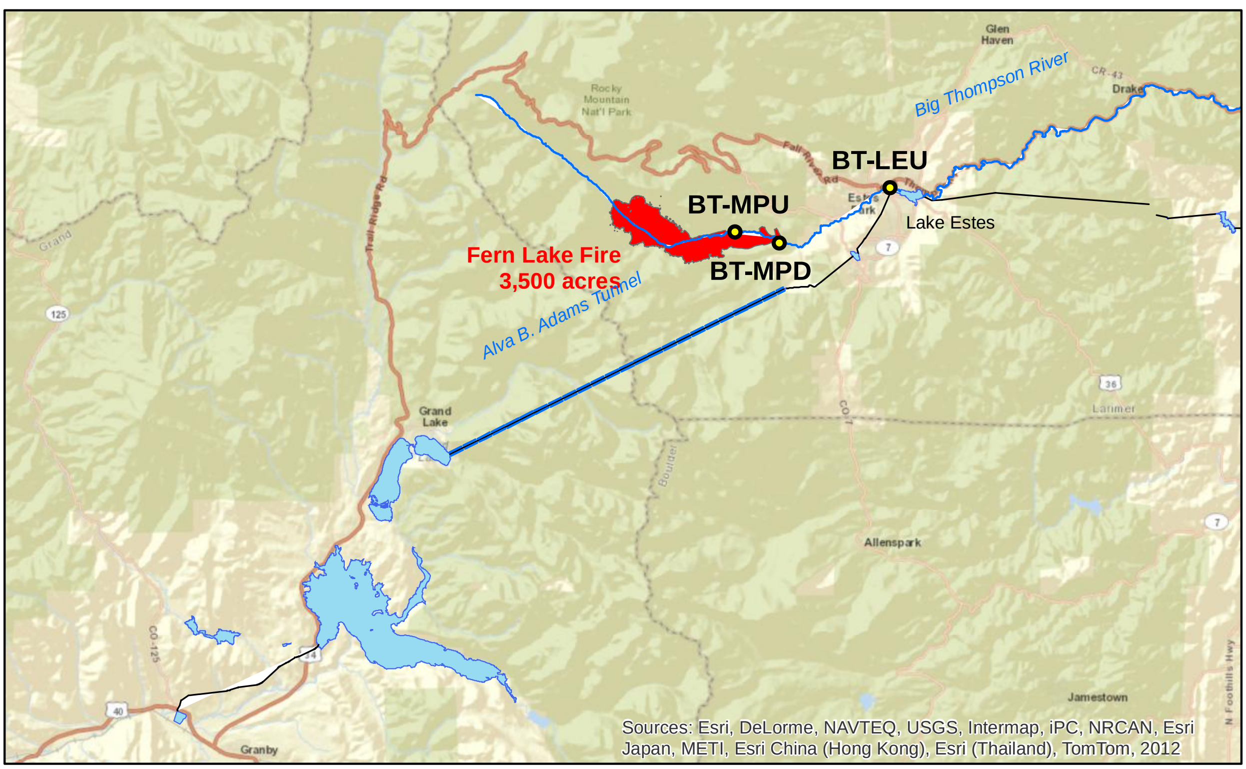

Figure 2. Fern Lake Fire Study water quality monitoring sites.

Station BT-MPU is located at the upstream end of Moraine Park and is relatively close to steep areas that were moderately or severely burned. BT-MPD is located at the downstream end of Moraine Park, and captures flows downstream of BT-MPU plus flows from the Cub Lake area. Monitoring sites were selected at both the upstream (BT-MPU) and downstream (BT-MPD) ends of Moraine Park in order to assess the ability of this wide, low-gradient area to help mitigate the impacts of potential sediment loads originating from the upstream, steeper slopes within the burn area. BT-LEU is on the Big Thompson River just upstream of Lake Estes (at the bridge at the Estes Park Visitor Center) and monitors the potential impacts approximately 5.2 river-miles downstream of BT-MPD, after dilution from the unburned areas that also drain to BT-LEU.

Two of the stations -- BT-MPD (or M-10, as designated by the BTWF) and BT-LEU (or M-20, as designated by the BTWF) -- are part of the long-term BTWF Cooperative Monitoring Program network and have pre-fire data dating back to 2001 for BT-MPD and 2000 for BT-LEU. BT-MPD is also a USGS Hydrologic Benchmark Network (HBN) site and has some additional data beyond what is collected for the BTWF. BT-MPU (M-05) is not part of the BTWF network, but the USGS established this as a monitoring site in April 2011 for a USGS program, so a limited pre-fire data set exists for this site.

Parameters. Monitoring for impacts of the Fern Lake Fire included analyses for physical parameters, total organic carbon (TOC), dissolved organic carbon (DOC), total suspended solids (TSS), total dissolved solids (TDS), turbidity, major ions, nutrients, and metals. The list of parameters is outlined in Table 2, and generally coincides with the BTWF Cooperative Monitoring Program parameter list except for the addition of DOC, TSS, and dissolved and total aluminum. Laboratory analysis was conducted at the USGS National Water Quality Laboratory except for TSS (Huffman Laboratories), mercury (USGS Mercury Research Laboratory), and routine BTWF TOC (City of Fort Collins Water Quality Lab).

Sampling Frequency. The Fern Lake Fire Study consisted of 13 sampling events in 2013, including eight routine monthly sampling events from April 2013 through November 2013. During spring runoff, there were four additional sampling events at BT-MPU and BT-MPD such that weekly samples were collected over a 6-week period, beginning the week of May 13 and ending the week of June 17. Finally, there was one sampling event at BT-MPU and BT-MPD on August 13 that was associated with a summer rainstorm runoff event. Note that it is very difficult to capture storm events, and the August 13 event was relatively minor compared to a missed rainfall event that occurred on July 18 and the historic September precipitation/flood event. The September routine sampling event was conducted September 9-10, before the flows began to significantly increase on September 11 in response to the historic precipitation event.

Routine sampling of the BTWF sites (BT-MPD and BT-LEU) by the USGS also occurred in 2013, including monthly events from February through November. The April through November monthly BTWF events coincided with the sampling conducted for the Fern Lake Fire Study, with the collected samples serving both the Fern Lake Fire Study and the BTWF Monitoring Program. BT-LEU also had three nutrient-only sampling events (one each in May, June and July) as part of the BTWF Program. All BTWF data collected at BT-MPD and BT-LEU were included in the assessment of impacts of the Fern Lake Fire.

Sampling Protocols. Sample collection utilized the protocols outlined by the USGS's "National Field Manual for the Collection of Water-Quality-Data" (U.S. Geological Survey, variously dated).

Table 2. Water quality monitoring parameters for Fern Lake Fire Study.

		Method (Lab analysis at USGS National Water Quality Lab except as noted)	Unit	Reporting Limit
FIELD PARAMETERS:				
	Water Temperature		C	
	Barometric Pressure		mm Hg	
	Specific Conductance		uS/cm	
	Dissolved Oxygen		mg/L	
	pH		units	
LAB PARAMETERS:				
	Alkalinity	Titration, Alkalinity as CaCO3, lab value, Filtered Water (fixed endpoint: pH 4.5)	mg/L	4.6
	Dissolved Organic Carbon (DOC)	Filtered, analyzed by persulfate oxidation & infrared spectrometry (USGS lab, Parameter Code 00681, OX008)	mg/L	0.23
	Total Organic Carbon (TOC)	Nonpurgeable, unfiltered recoverable, by high-temperature combustion (USGS lab, Parameter Code 00680, COMB9) OR persulfate-uv oxidation SM-5310C (City of Fort Collins Water Quality Lab for the BTWF)	mg/L	0.5
	Total Dissolved Solids (TDS)	Solids, Residue on Evaporation (ROE) at 180 deg C, dissolved, gravimetric (TDS)	mg/L	20
	Total Suspended Solids (TSS)	Solids, Residue at 105 deg C, Suspended, gravimetric (TSS); Analysis by Huffman Laboratories with Detection Limit = 1 mg/L	mg/L	5
	Turbidity	Broad band light (400-680 nm), detectors at angles including 90+/-30 degs, NTRU, USGS Parameter Code 63676	NTRU	2
	Major Ions			
	Calcium	Calcium, Water, Filtered, ICP-AES	mg/L	0.022
	Magnesium	Magnesium, Water, Filtered, ICP-AES	mg/L	0.011
	Potassium	Potassium, Water, Filtered, mg/L, ICP-AES	mg/L	0.03
	Sodium	Sodium, Water, Filtered, ICP-AES	mg/L	0.06
	Chloride	Chloride, Water, Filtered, IC	mg/L	0.06
	Sulfate	Sulfate, Water, Filtered, IC	mg/L	0.09
	Nutrients			
	Ammonia	Ammonia, as N, colorimetry, DA, salicylate-hypochlorite, Filtered	mg/L	0.01
	Nitrite + Nitrate nitrogen	Nitrate+nitrite, as N, low level, colorimetry, DA, enzyme reduction-diazotization, Filtered	mg/L	0.01
	Ammonia + Organic nitrogen	Colorimetry, ASF, microkjeldahl digestion, N, ammonia + organic nitrogen, WWR, acidified	mg/L	0.07
	Orthophosphate (Ortho-P)	Orthophosphate as P, colorimetry, DA, Phosphomolybdate, Filtered	mg/L	0.004
	Phosphorus	Low Level Total Phosphorus - Filtered	mg/L	0.003
	Phosphorus	Low Level Total Phosphorus - Whole Water Recoverable, Acidified	mg/L	0.004
	Metals			
	Aluminum, dissolved	Aluminum, Water, Filtered, ICP-MS	µg/L	2.2
	Aluminum, total	Aluminum, Water, Unfiltered, ICP-MS	µg/L	3.8
	Arsenic, dissolved	Arsenic, Water, Filtered, cICP-MS	µg/L	0.04
	Copper, dissolved	Copper, Water, Filtered, cICP-MS	µg/L	0.8
	Iron, dissolved	Iron, Water, Filtered, ICP-AES	µg/L	4
	Lead, dissolved	Lead, Water, Filtered, ICP-MS	µg/L	0.025
	Manganese, dissolved	Manganese, Water, Filtered, ICP-MS	µg/L	0.15
	Mercury, total, low level	Unfiltered total mercury; analysis at USGS Mercury Research Lab	ng/L	0.04
	Nickel, dissolved	Nickel, Water, Filtered, cICP-MS	µg/L	0.09
	Silver, dissolved	Silver, Water, Filtered, ICP-MS	µg/L	0.005

2. Literature Review: Water Quality Impacts of Wildfires

The impacts of wildfires on water quality are summarized in a number of literature reviews presented by others including Bitner et al (2001), Ranalli (2004), Neary et al (2005), and Sham et al (2013). Some of the main water quality impacts reported in these literature reviews include:

- **Suspended Solids & Turbidity:** High turbidity and high suspended solids concentrations in streamflow are the most obvious impacts of runoff from burn areas. Increased runoff and erosion rates across burn areas result in the transport of significant amounts of sediment and ash to receiving waters. Post-fire turbidity and suspended solids concentrations in streamflow are highly variable and can, at times, approach extreme values depending on the intensity of summer storm events, steepness of slopes, vegetation cover, fire severity (how much of the fuel is consumed), and the presence of a hydrophobic (water repellent) layer at the surface of burned soils.

- **Major Ions:** The inorganic component of ash produced by fire contains carbonates and oxides of calcium and magnesium, carbonates and chlorides of sodium and potassium, and polyphosphates of calcium and magnesium, with relative concentrations varying depending on plant species. Leaching of ash and partially burned forest floor litter results in the mobilization of calcium, magnesium, sodium, potassium and chloride, resulting in increased concentrations of these constituents in water. Sulfate concentrations may increase due to the oxidation of sulfur present in soil organic matter. Post-fire increases in major ion concentrations are more apparent in streams that drain granitic bedrock basins, such as that of the headwaters of the Big Thompson River, since the pre-fire ion concentrations are normally very low.

- **pH:** The leaching of the alkaline compounds in ash (the carbonates and oxides of calcium and magnesium) generally results in an increase in pH in the waters draining from burn areas.

- **Organic Carbon:** The grey or black ash produced in most wildfires contains a significant amount of organic matter by weight (30 to 90 percent). Because of this, streamflow concentrations of particulate organic carbon and dissolved organic carbon can both exhibit post-fire increases.

- **Metals:** Increases in total iron, total manganese, and total mercury have been observed in runoff from some burn areas. These increases are generally associated with the increased sediment and ash loads.

- **Nutrients:** Increases in concentrations of one or more nutrients (nitrate, ammonia, organic nitrogen, orthophosphate (ortho-P), and total phosphorus (Total P)) in streams downstream of burn areas have been reported by many. Ammonia concentrations may increase during and immediately following a fire due to the release of ammonia during the combustion of organic matter. Nitrate concentrations can initially increase due to the nitrification of the ammonia released from the combustion of organic matter, with later increases in streamflow nitrate due to reduced uptake by plants in the burn area. Ortho-P concentrations can increase as a result of the leaching of ash, although it may be subsequently immobilized by adsorption onto soil iron and aluminum oxide surfaces. Increases in Total P, with or without significant increases in ortho-P, occur as a result of increased sediment loading to streams.

Water quality impacts of wildfires along the Colorado Front Range have been the subject of several recent studies and reports. A brief summary of findings from water quality studies associated with the Hayman Fire, Fourmile Canyon Fire, and the High Park and Hewlett Gulch Fires is presented below to provide some context for the water quality findings from the Fern Lake Fire.

Hayman Fire. Rhoades et al (2011) report on the results of U.S. Forest Service pre-fire and post-fire water quality monitoring related to the 2002 Hayman Fire. The Hayman Fire burned 138,000 acres dominated by ponderosa pine and Douglas-fir in the headwaters of the South Platte River that serve as a drinking water supply for Denver Water. The post-fire monitoring summarized in the paper was conducted at monthly intervals for five years after the fire; storm event sampling was not conducted as part of the study due to personnel and budgetary constraints and remoteness of sites. They found that sub-basins that burned at high severity on 45% of their area had twice the streamwater nitrate and four times the turbidity as sub-basins burned to a lower extent. These elevated nitrate and turbidity levels persisted through the five years of post-fire monitoring. The highest nitrate concentrations occurred during the peak flows of the spring snowmelt runoff, with a seasonal peak concentration that averaged 1.5 mg/L (over the five-year study) in streamflow associated with areas that burned at high extent and severity. The highest nitrate concentration (2.3 mg/L) occurred during the third spring snowmelt after the fire. Peak streamwater turbidity exceeded 200 NTU on a number of occasions in sub-basins that burned at high severity on 45% of their area, with high values occurring both during the spring snowmelt and during the summer.

Stevens (2013) reported on the results of a five-year USGS study of the water quality impacts of the Hayman Fire. Streamflow and transport of water-quality constituents were significantly higher in the first year after the fire, and remained elevated (compared to the unburned reference stream) for five years. Nitrate plus nitrite and ortho-P stream concentrations were one order of magnitude higher the first year post-fire, while total nitrogen and total phosphorus stream concentrations were generally two or three orders of magnitude larger. TOC concentrations were also high, particularly during storm events, and the median TOC concentrations remained elevated over the five year study compared to the unburned reference stream. DOC concentrations did not show increases except during some storm events. Concentrations of dissolved iron and manganese were high the first year after the Hayman Fire but decreased in later years. Metals that exceeded acute or chronic aquatic life water quality standards at one or more sites during one or more sampling events included dissolved copper, dissolved manganese, total recoverable arsenic, total recoverable iron, and total recoverable mercury. Exceedances for total recoverable iron, arsenic, and mercury, which are commonly bound to soil and streambed sediments, generally occurred during periods of high suspended-sediment transport in the streams (Stevens, 2013, page 79). It was speculated that the dissolved manganese and copper were from weathering of geologic materials and release from burned vegetation.

Fourmile Canyon Fire. Writer and Murphy (2012) reported on the first-year findings of a USGS study to determine water quality impacts of the 2010 Fourmile Canyon Fire to Fourmile Creek (in Boulder County, CO; see fire location on Figure 1). They found that high-intensity summer thunderstorms resulted in large increases in turbidity, DOC, nitrate and some metals by 1 to 4 orders of magnitude. The results of the first year of monitoring also indicated that during spring snowmelt, nitrate concentrations increased downstream of the burned area, although not to the same degree as during the high-intensity summer storm events. DOC concentrations downstream of the burned area were similar to DOC concentrations downstream of the unburned area during the spring snowmelt period.

Hewlett Gulch and High Park Fires. Oropeza and Heath (2013) evaluated the effects of the 2012 Hewlett Gulch and High Park wildfires on Poudre River water quality (fire locations shown on Figure 1). Their analysis was based on 2008 to mid-May 2012 pre-fire routine sampling data and 2012 post-fire routine and storm event data, with storm sampling beginning shortly after fire containment. Post-fire summer storm events in 2012 produced elevated levels of many parameters including pH, conductivity, hardness, total dissolved solids, turbidity, TOC, ammonia, total Kjeldahl nitrogen (TKN), ortho-P, Total P, and dissolved aluminum. After storm events, concentrations generally returned to values within the range observed for the pre-fire data. Ortho-P was an exception to this, with elevated concentrations observed in the post-fire routine samples (non-storm event sampling) that were outside of the normal range for the pre-fire data. Unlike observations made by Writer and Murphy (2012) and Rhoades et al (2011) for other Colorado Front Range wildfires, nitrate concentrations in Poudre River samples did not change after the fire, and storm runoff events only produced small increases in nitrate concentrations. Also note that the post-fire sampling in 2012 started after the snowmelt runoff period, such that this report (which only covers data collected through 2012) does not include a comparison of pre-fire and post-fire concentrations that occur during the spring snowmelt runoff period.

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3. Burn Area Description & Assessment

The Fern Lake Fire started on October 9, 2012 in Forest Canyon, an area comprised of steep, rugged forested terrain where the Big Thompson River originates. The fire burned approximately 1,100 acres by November 9 (the area roughly outlined by the dashed line on Figure 3), with an additional 350 acres by November 28. High winds exceeding 70 miles/hr caused the fire to flare up on the night of Nov. 30 and early morning of Dec. 1 (RMNP, 2013), and triggered the rapid spread of the fire by an additional 2,000 acres, including east through the Cub Lake area and Moraine Park, and areas west and south of the 1,100 acre burn area. The total burn area covered 3,500 acres on Dec. 7, and was eventually extinguished by winter snows that began in early December. The fire was not officially declared "out" until June 25, 2013 after an infrared flight over Forest Canyon confirmed that there was no heat coming from the burn area.

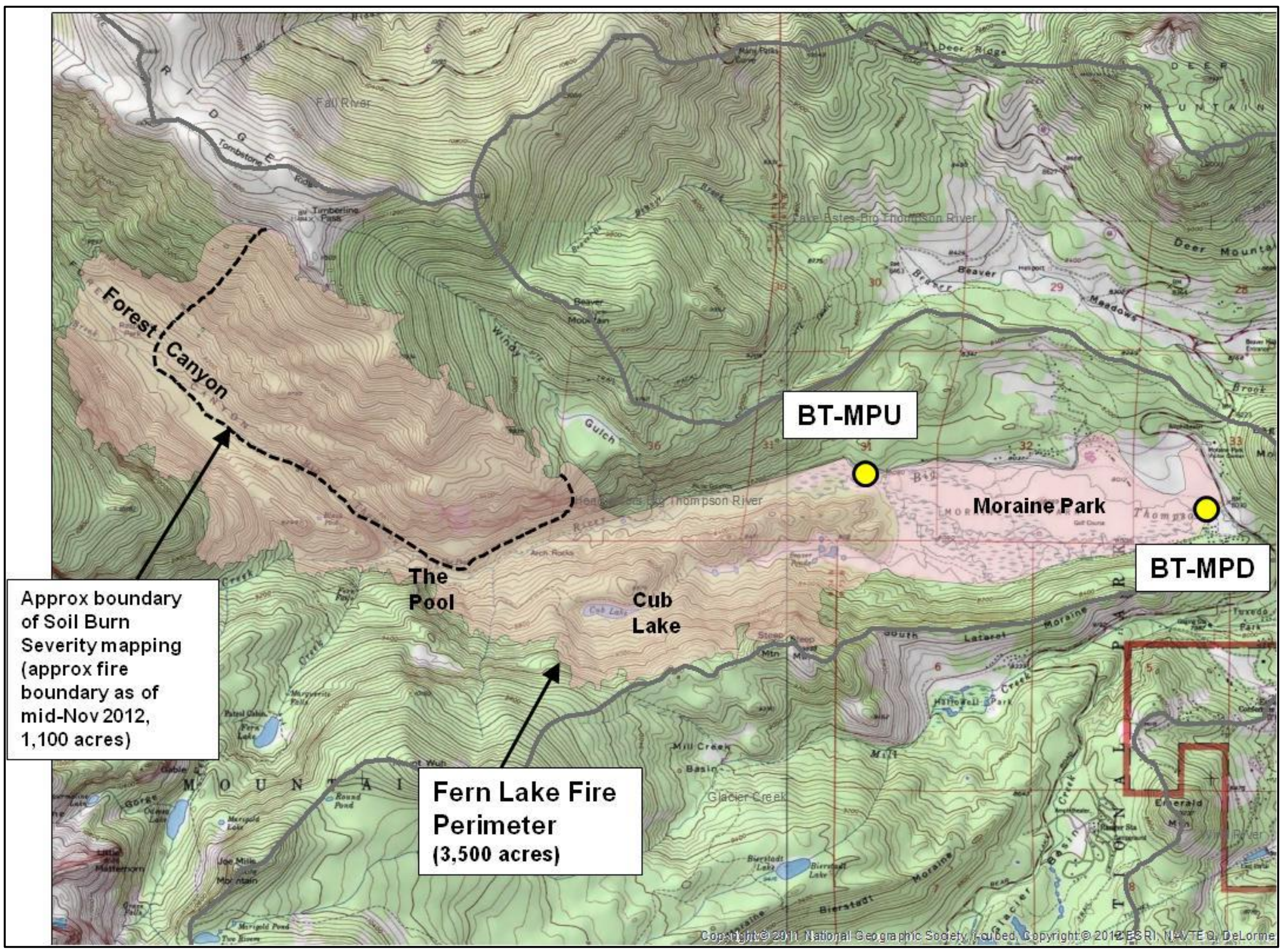


Figure 3. Map of Fern Lake Fire Perimeter

Within Forest Canyon, the fire burned through stands of spruce, fir, and lodgepole pine (RMNP, 2012). The lodgepole pine stands were impacted by the ongoing mountain pine beetle epidemic, and approximately 50% of these trees were in the "dead and grey" stage. Fire suppression activities included water drops and firefighters working on the ground. Much of the area that burned prior to the end of November was inaccessible to firefighters due to the steep slopes (as seen in the photo of Figure 4) and hazards posed by the presence of beetle-killed trees. The use of fire retardant was restricted because the burn area is part of a municipal water supply. One application of fire retardant was made in early December (RMNP, 2013, page 4) but was not effective and its use was not continued.

A "Soil and Water Resources Damage Assessment Report/Burned Area Assessment" for the Fern Lake Fire was prepared by Rocky Mountain National Park (dated Nov. 26, 2012). Both the burn severity analysis (included here as Table 3 and Figure 5) and the report were completed before the fire spread on December 1 - 3, so the mapping only covers a portion of the total burn area (approximately 1,100 acres out of the total 3,500 acres, as delineated in Figure 3). Of this area, 53% had a moderate burn severity and 8% had a high burn severity. Note that the unburned (dark green) area at the southeast corner is an area consisting of steep rock outcrops.

Figure 4. Looking west across Moraine Park at the Fern Lake Fire Oct 12, 2012 (photo credit: Ann Schonlau, NPS)

Table 3. Post-Fire Soil Burn Severity Summary Table

(from RMNP, Nov. 2012, page 5; applies to mapping area shown on Figure 5 conducted prior to the spread of the fire in early December).

Soil Burn Severity (SBS)	Acres	Percent Area
Unburned	199	18%
Low	235	21%
Moderate	578	53%
High	85	8%
	1,096	100%

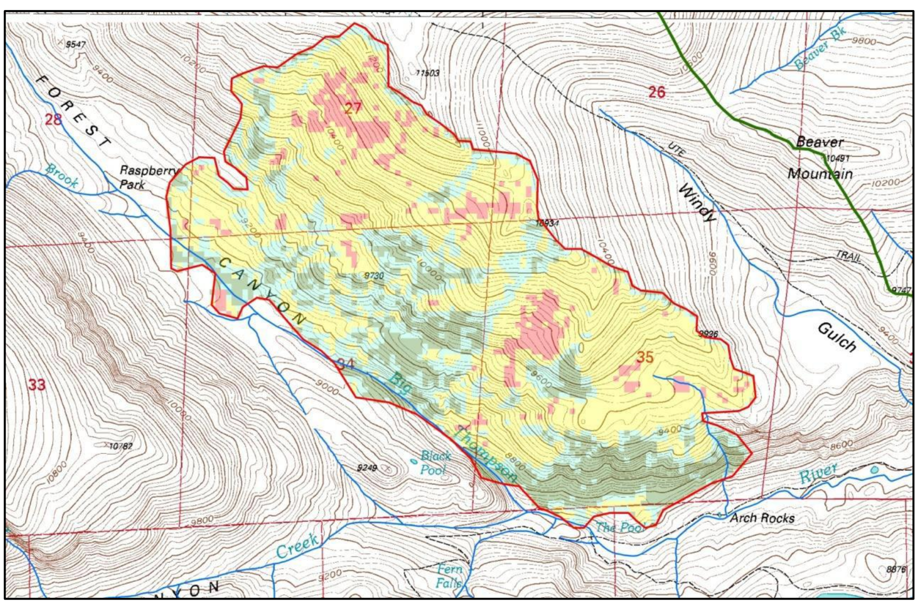


Figure 5. Fern Lake Fire Soil Burn Severity (SBS) Map

(only covers approx 1,100 acres of total burn area; see mapping location on Figure 3; Dark Green = unburned, Light Green = Low SBS, Yellow = Moderate SBS, Red = High SBS; figure from RMNP, 2012).

The burn area summarized on Table 3 and Figure 5 occurred in steep terrain in Forest Canyon (Figures 6 and 7) adjacent to the Big Thompson River. Increased erosion rates would be expected on slopes greater than 20% where soil burn severity is moderate or high (RMNP, 2012, page 5). Note that the yellow, orange and red areas shown on Figure 6 all represent slopes greater than 20% (i.e., most of the mapped area has slopes ≥20%). Erosion Risk Management Tool (ERMiT) modeling was used by RMNP to evaluate sediment response from the burned area of Figures 5 and 6 (RMNP, 2012, pg 6-7) with the following conclusions:

- Post-fire hill-slope erosion and sediment delivery rates are expected to be approximately 15 to 30 times pre-fire rates.
- Most soil erosion and sediment delivery to stream channels will be associated with precipitation events of high intensity likely to occur in any given year.
- Natural recovery of hill-slope stability is likely to occur within 3 to 5 years following the fire.

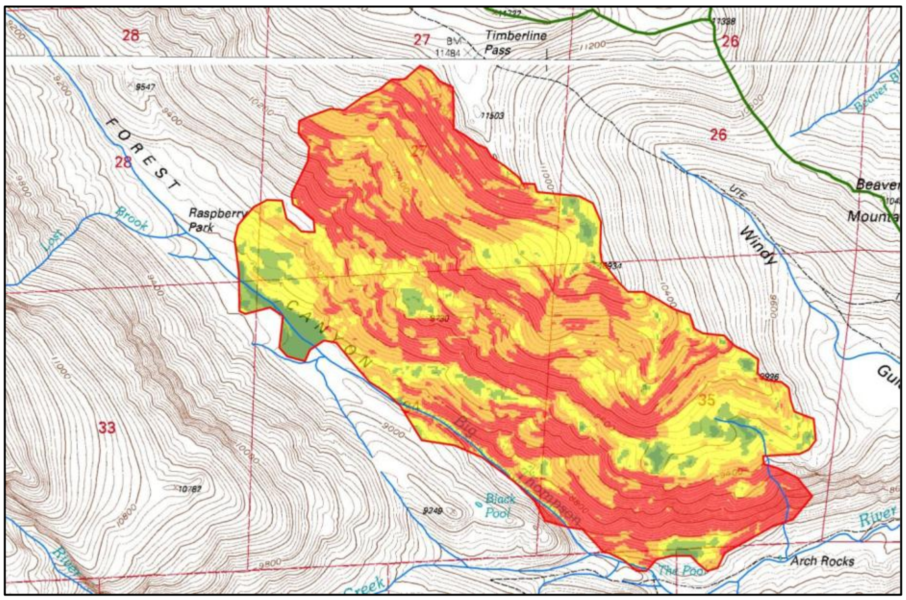


Figure 6. Fern Lake Fire Burned Area Slopes

(only covers approx 1,100 acres of total burn area; see mapping location on Figure 3; Green = less than 20% slopes, Yellow = 20-40% slopes, Orange = 40-60% slopes, Red = 60+% slopes; figure from RMNP, 2012).

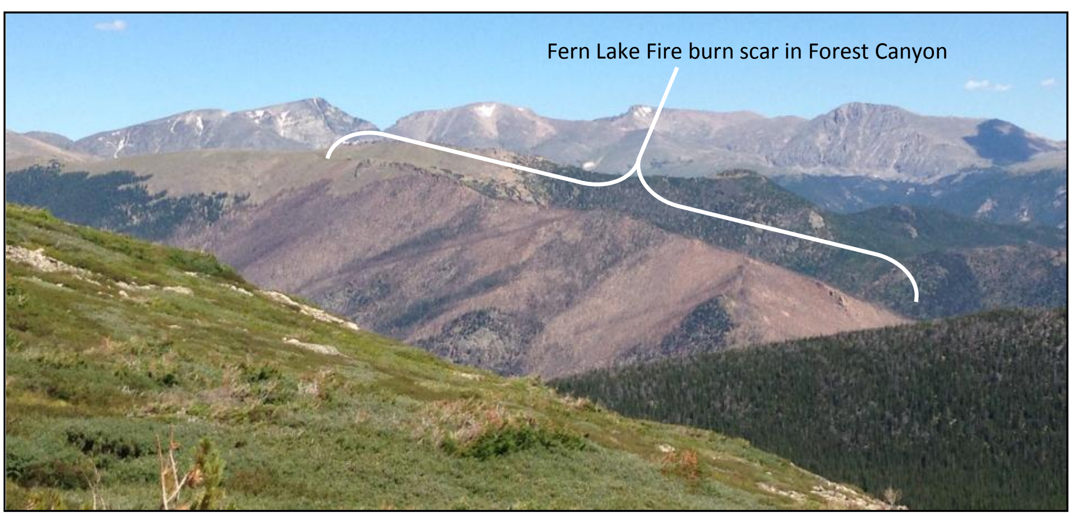


Figure 7. Fern Lake Fire burn scar in Forest Canyon, as seen looking north from the Flat Top Mountain Trail (photo taken Aug. 17, 2014).

The downstream (east) end of the ultimate Fern Lake Fire perimeter coincides with the downstream end of Moraine Park (Figure 3). Moraine Park is a wide, flat, glacier-carved valley (Figures 8 and 9). The Big Thompson River meanders through Moraine Park over a distance of approximately 2 miles. The low gradient, meandering and multi-channel characteristics of the Big Thompson River as it flows through Moraine Park provide multiple opportunities for sediment/debris deposition. Although Moraine Park burned during the Fern Lake Fire, the grasses that fill the valley have quickly recovered (Figure 10). It is expected that Moraine Park will help mitigate the impacts of soil erosion that may occur on the upstream, steeper slopes within the burn area.

Figure 8. A view of the Fern Lake Fire burn area at the downstream end of Moraine Park along the Big Thompson River at the BT-MPD (M-10) monitoring site (photo taken January 28, 2013).

Figure 9. A view of the Fern Lake Fire burn area at the upstream end of Moraine Park (photo taken May 7, 2013).

Figure 10. Recovery of grasses in Moraine Park along the Big Thompson River near BT-MPU (photos taken May/June, 2013).

The area that burned south of the Big Thompson River around Cub Lake at the end of November/beginning of December (see location on Figure 3) was not included in the Fern Lake Fire "Soil and Water Resources Damage Assessment Report/Burned Area Assessment". This area consists of relatively steep slopes as shown in the photos of Figures 11, 12 and 13. There is a mosaic of burned and unburned areas, and areas of bare ground mixed with areas where ground vegetation is recovering. The burn scar at the higher elevations on the north side of the Big Thompson River can be seen from the Cub Lake area (Figure 13).

Figure 11. Steep slopes in the Fern Lake Fire burn area south of the Big Thompson River, along the "The Pool – Cub Lake Trail" (photos taken June 13, 2014).

Figure 12. Fern Lake Fire burn area south of the Big Thompson River, as viewed from the Ute Trail (photo taken June 29, 2014).

Figure 13. Fern Lake Fire burn area along the "The Pool – Cub Lake Trail", looking northwest across the Big Thompson River to the burn scar at high elevation above Forest Canyon (photo taken June 13, 2014).

Drainage Areas

Downstream water quality impacts are related (among many other factors) to the size of the burn area compared to the unburned areas within a watershed. Water samples collected at monitoring sites BT-MPU, BT-MPD, and BT-LEU include a mixture of runoff originating from the burn scar as well as runoff from the unburned areas upstream of each monitoring site.

The Fern Lake Fire burn scar is located within the 25,602 acre sixth-level "Headwaters Big Thompson River" watershed (Figure 14) which includes Forest Canyon, Moraine Park, Spruce Canyon, and Fern Creek. The 3,500 acre Fern Lake Fire burn area makes up approximately 14% of the portion (25,400 acres) of the Headwaters Big Thompson River watershed that drains to BT-MPD (Table 4).

The upstream Moraine Park site, BT-MPU, drains approximately 23,529 acres of the Headwaters Big Thompson River watershed and 2,363 acres of the total burn area (Table 4). The burn area covers approximately 10% of the area that drains directly to BT-MPU.

The BT-LEU monitoring station is located on the Big Thompson River just upstream of Lake Estes. The sixth-level watersheds that drain to this site include Headwaters Big Thompson River, Fall River, Black Canyon Creek, Wind River, Glacier Creek, and a portion of the Lake Estes-Big Thompson River (Table 4 and Figure 14). The total area that drains directly to BT-LEU is approximately 88,100 acres. The 3,500 acre Fern Lake Fire burn area makes up approximately 4% of the total area that drains to BT-LEU. It would be expected that water quality impacts from the Fern Lake Fire that may be observed at BT-MPD would be significantly diluted by the time this flow reaches BT-LEU.

Table 4. Watershed areas draining to Fern Lake Fire monitoring sites BT-MPU, BT-MPD, and BT-LEU.

Monitoring Station	Watersheds draining to monitoring station	Watershed Area above monitoring station (acres)	Fern Lake Fire Burn Area above monitoring station (acres)	Fern Lake Fire Burn Area as a percent of watershed area
BT-MPU	Headwaters Big Thompson River watershed, area upstream of BT-MPU	23,529	2,363	10 %
BT-MPD	Headwaters Big Thompson River watershed, area upstream of BT-MPD	25,400	3,500	14 %
BT-LEU	Black Canyon Creek watershed	6,410		
	Fall River watershed	25,504		
	Headwaters Big Thompson River watershed	25,602		
	Glacier Creek watershed	16,117		
	Wind River watershed	6,532		
	Lake Estes-Big Thompson River watershed, area upstream of BT-LEU	7,946		
	Total watershed area above BT-LEU	88,111	3,500	4 %

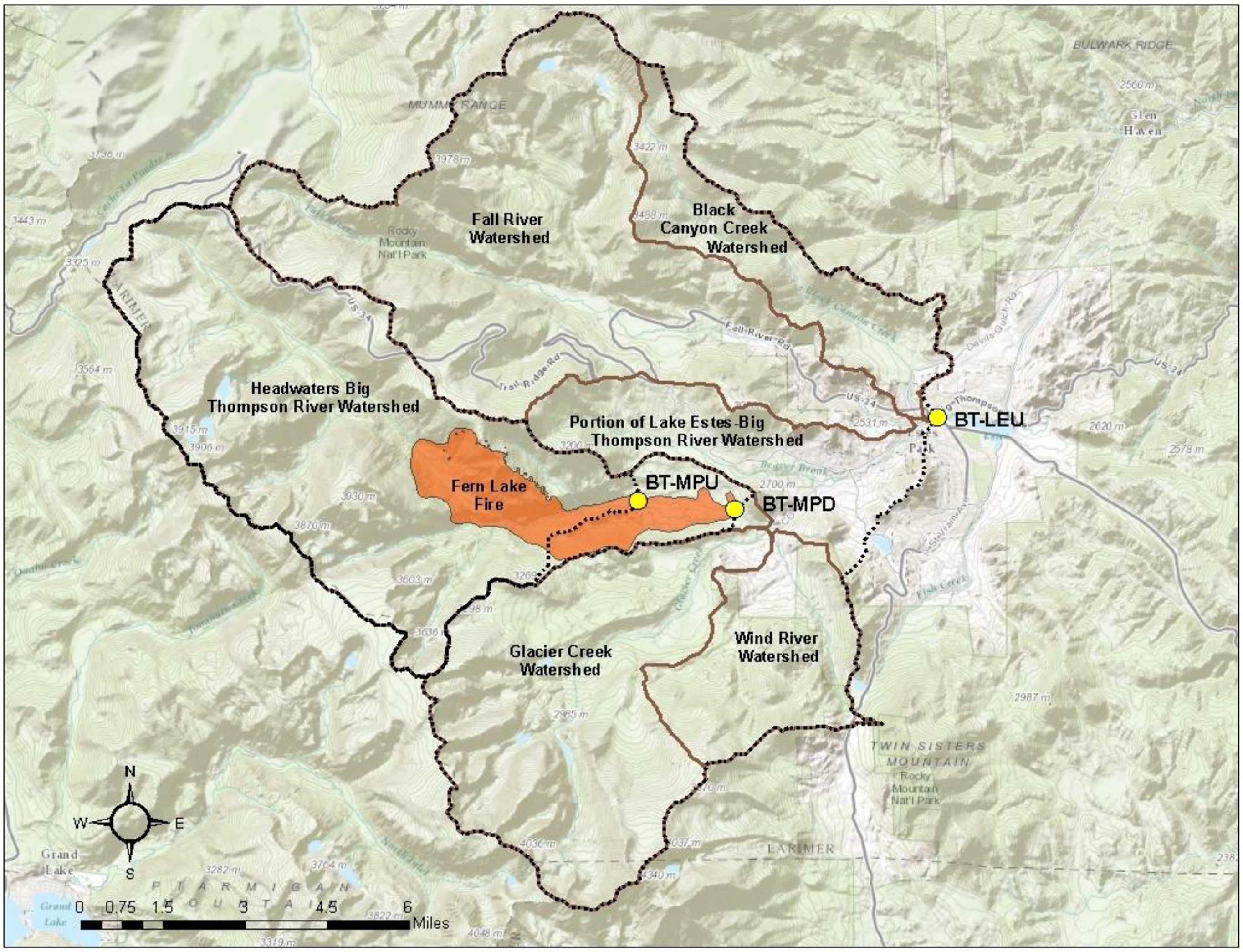


Figure 14. Sixth-level watersheds draining to Fern Lake Fire monitoring sites BT-MPU, BT-MPD, BT-LEU.

4. 2013 Hydrology Summary

The 2013 flow measurements at BT-MPU, BT-MPD, and BT-LEU are shown on Figures 15 and 16. The sampling dates are also shown on these figures (red diamonds) to show how they relate to the seasonal hydrology. Figure 17 is a plot of the 2012 and 2013 flows at the USGS gaging station at the Big Thompson River below Moraine Park site (BT-MPD) along with the medians of the daily average flows for the period of record (POR, 1996-2013) for that site; data from http://waterdata.usgs.gov/nwis/uv?402114105350101.

During the 2013 snowmelt runoff period, Figures 15, 16 and 17 indicate that the snowmelt runoff was characterized by three "peaks". Multiple peaks are typical during the snowmelt runoff period due to changes in the daily weather, from warm days of melting snow to cold days where snowmelt is reduced or where additional snowfall occurs. At the USGS gaging station at BT-MPD, the 2013 peaks included daily average flows of 226 cubic feet per second (cfs) on May 17, 272 cfs on May 25, and 396 cfs on June 10, and 15-minute peak flows of 276 cfs on May 17, 330 cfs on May 26, and 537 cfs on June 10. Figure 17 shows that the 2013 spring snowmelt runoff flow at BT-MTD was above the POR medians of the daily averages. Samples were collected weekly at BT-MPU and BT-MPD for six weeks during the snowmelt runoff period, with the first sample collected on May 15 (on the rising limb of the first "peak") and the last sample collected on June 18 (a week after the third peak). At the BT-LEU site (above Lake Estes), four samples were collected during the snowmelt runoff period on May 13, May 29, June 10, and June 25.

After the snowmelt runoff, the 2013 June through mid-September flows at BT-MPD are slightly lower than, but generally align with, the POR medians of the daily flows (Figure 17). In mid-September, the flow deviates as a result of the historic rainfall/flood event, with a peak 15-minute flow of 1,130 cfs on September 12 at BT-MPD, and a peak daily average flow of 763 cfs on September 13 at BT-MPD, as a result of rainfall that began on September 9 and intensified from the afternoon of September 11 through the morning of September 13. However, until the September 2013 flood, the 2013 summer hydrology was fairly typical with the occasional thunderstorm. The summer routine water samples were collected July 9 and August 12 at BT-MPU and BT-MPD.

One of the goals of the 2013 monitoring was to sample the Big Thompson River during one high intensity summer rainfall event that produced runoff from the burn scar. This is not an easy task because it is nearly impossible to predict and plan for these short duration, often localized events.

A significant rainfall event occurred on July 18 that resulted in a debris flow (consisting of mud, rocks and trees) originating from the Fern Lake Fire burn scar that covered approximately 150 yards of the Fern Lake Trail in the Arch Rock Area (http://www.eptrail.com/ci_23692774/wednesday-thunderstorm-damages-trail-rocky-mountain-national-park). Big Thompson River flow at BT-MPD increased from 78 cfs to 207 cfs in 1.25 hours (an increase in flow of 129 cfs) in response to the July 18 precipitation event. The USGS was not able to sample during this event. However, visual observation by Northern staff on July 18 showed that summer rainstorm events on the burn scar can result in the delivery of significant amounts of sediment to the Big Thompson River (Figures 18 and 19), with high suspended solids observed in the Big Thompson River both upstream and downstream of Moraine Park.

The USGS sampled the Big Thompson River on August 13 during an assumed less significant rainfall event (based on the flows at BT-MPU and BT-MPD). Big Thompson River flow measured at BT-MPU and BT-MPD increased from approximately 30 cfs to approximately 40 cfs (an increase in flow of about 10 cfs) in response to rainfall occurring on August 13.

The September sampling event at BT-MPU and BT-MPD was intended to be a “routine” summer event. However, these samples were collected on September 10 as flows were just beginning to rise in response to the September 9-15 precipitation event. On September 10, the gaging station at BT-MPD indicated a flow of approximately 40 cfs, compared to flows that had been averaging approximately 27 cfs in the days before September 10.

Site-specific details about the rainfall events on July 18, August 13, and September 9-15 are not available (i.e., rainfall total, intensity, and duration at the Fern Lake Fire burn scar). For the July 18, 2013 precipitation event, COCORaHS data (http://www.cocorahs.org/ViewData/ListDailyPrecipReports.aspx) for station CO-LR-767 just east of Mary’s Lake indicates a 24-hr total (ending 7:00 am 7/19/13) of only 0.31 inches, which does not appear representative of conditions that likely existed at the Fern Lake burn scar. For the August 13, 2013 rainfall event, the COCORaHS data for station CO-LR-767 indicates a 24-hr total (ending 7:00 am 8/14/13) of 0.16 inches. For the September 2013 rain event, the COCORaHS data for station CO-LR-767 indicates that a total of 10.41 inches fell during the period of September 9 - 15.

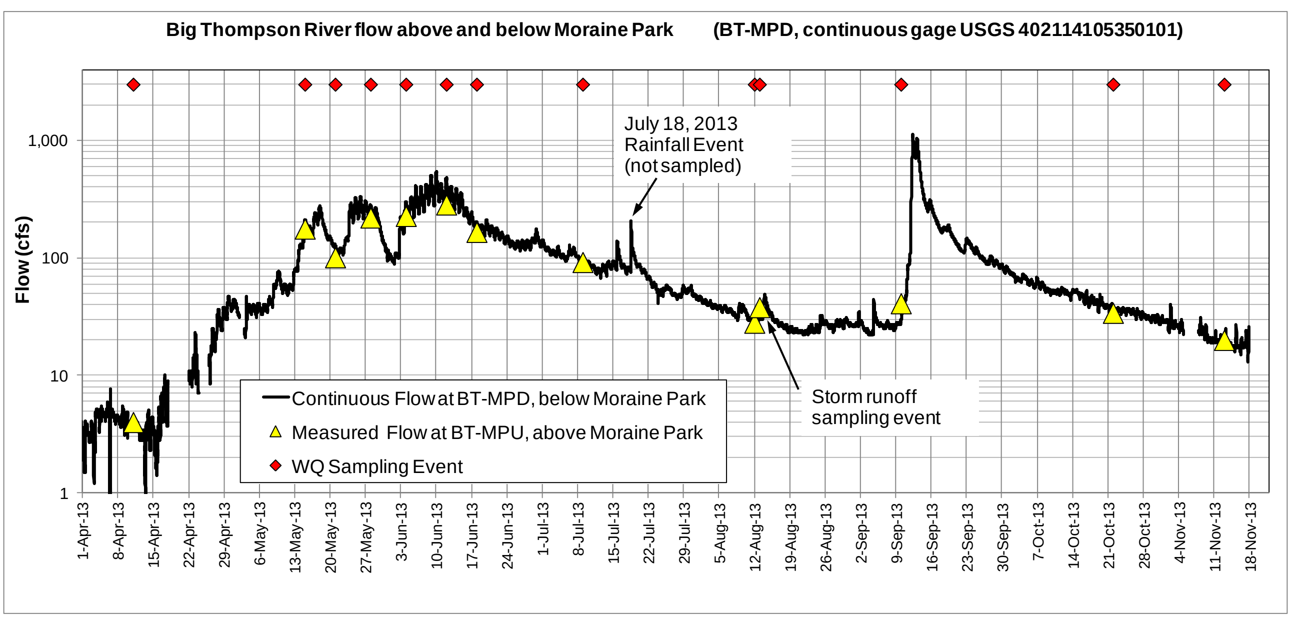


Figure 15. April-November, 2013 Big Thompson River flows at BT-MPU and BT-MPD, above and below Moraine Park; also shown are the dates of the 2013 sampling events (red diamonds).

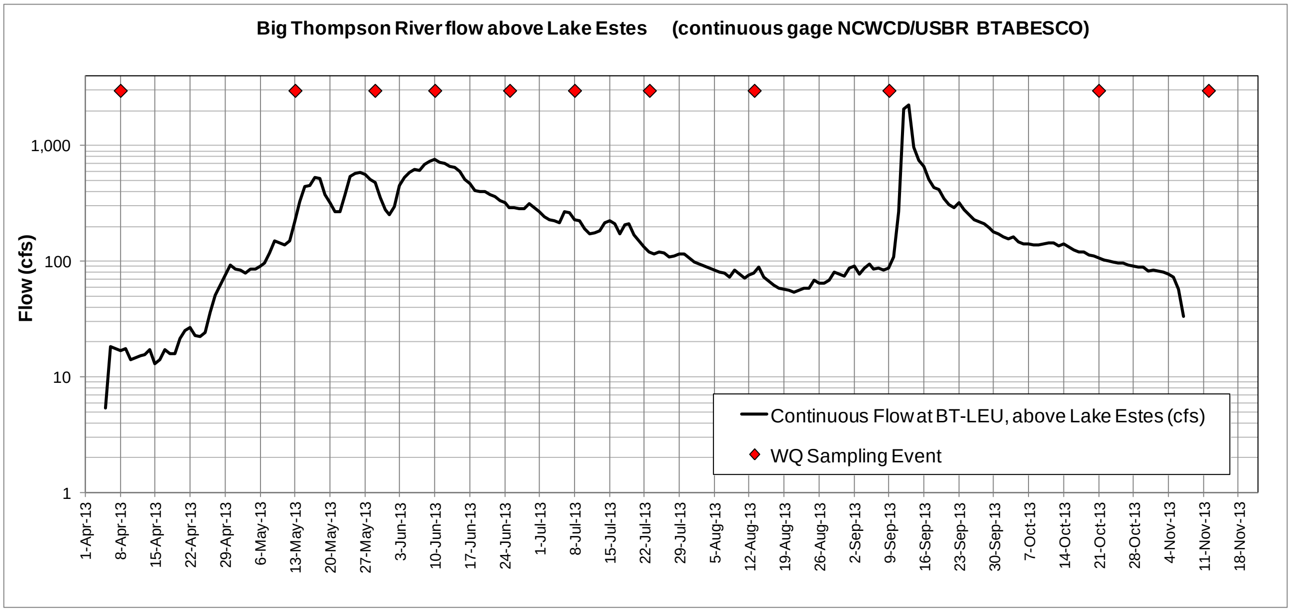


Figure 16. April-November, 2013 Big Thompson River flows at BT-LEU, upstream of Lake Estes; also shown are the dates of the 2013 sampling events (red diamonds).

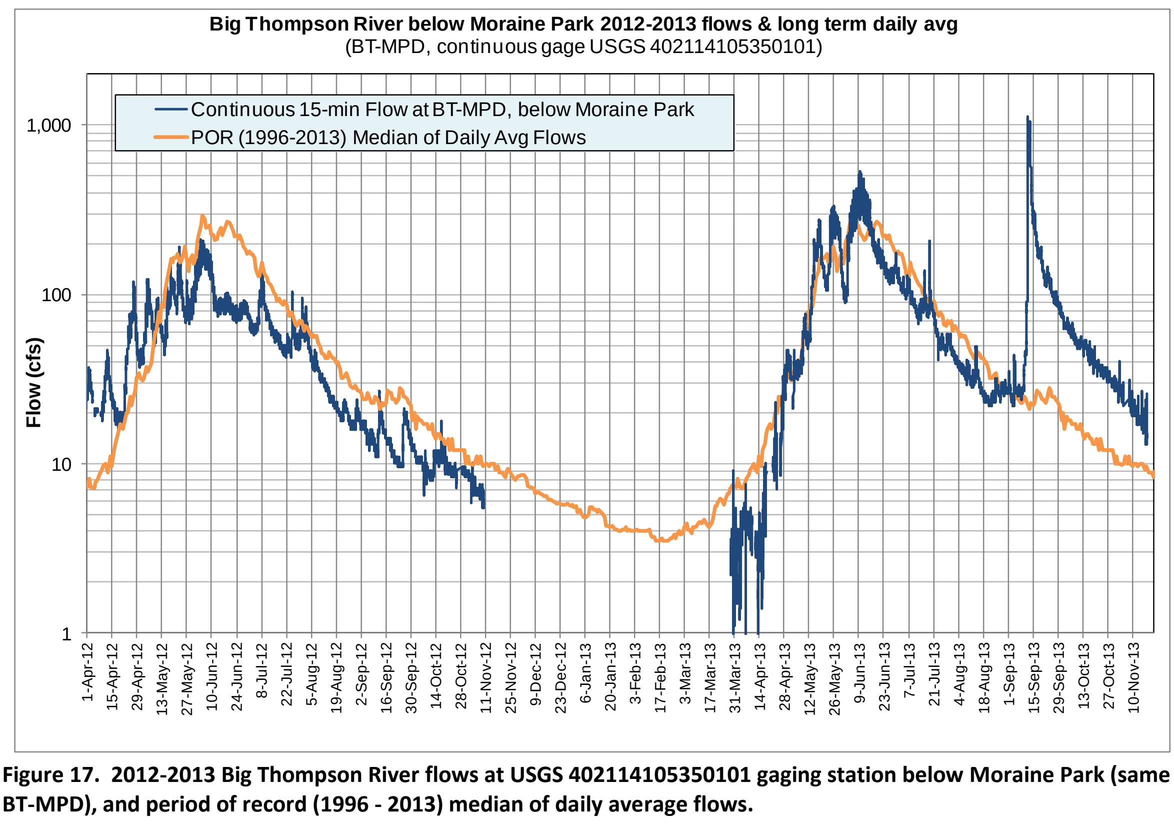


Figure 17. 2012-2013 Big Thompson River flows at USGS 402114105350101 gaging station below Moraine Park (same location as BT-MPD), and period of record (1996 - 2013) median of daily average flows.

Figure 18. Water from the Big Thompson River at the upstream end of Moraine Park (near BT-MPU) on July 18, 2013 after a significant summer precipitation event on the Fern Lake Burn scar.

Figure 19. High turbidity, sediment laden waters of the Big Thompson River in Moraine Park after the July 18, 2013 rainstorm event.

5. Water Quality Data Summary

The water quality data collected in 2013 are compared to pre-fire data that have been collected for the BTWF and/or USGS programs. BT-MPD and BT-LEU are part of the long-term BTWF monitoring network and have pre-fire data dating back to 2001 for BT-MPD and 2000 for BT-LEU (although note that the period of record is shorter at both sites for some parameters). BT-MPD is also a USGS Hydrologic Benchmark Network (HBN) site and has some additional data beyond what is collected for the BTWF. BT-MPU is not part of the BTWF network, but the USGS established this as a monitoring site in April 2011 for a USGS program, so a limited pre-fire data set exists for this site for some parameters. All data are available for independent review at http://www.northernwater.org/DynData/WQDataMain.aspx.

The water quality data collected in 2013 are discussed in relation to the following distinct hydrologic seasons and events:

- **Winter & early spring**: baseline flows occurring prior to spring snowmelt runoff, with samples collected on April 11 at BT-MPU, on Jan 21, Feb 11, March 11 and April 11 at BT-MPD, and on Feb 12, March 12, and April 8 at BT-LEU.
- **Snowmelt Runoff**: flows began increasing mid-April and peaked June 10, with six weekly samples collected at BT-MPU and BT-MPD on May 15, May 21, May 28, June 4, June 12, and June 18; four runoff samples were collected at BT-LEU including May 13, May 29, June 10 and June 25.
- **Summer**: BT-MPU & BT-MPD samples collected July 9 and August 12; BT-LEU samples collected July 8 and July 23.
- **Summer Rainstorm Event**: August 13
- **Beginning of September flood**: Samples were collected at the beginning of the September 9-15 rainfall event, September 9 at BT-LEU and on September 10 at BT-MPU and BT-MPD.
- **Fall, post-flood**: BT-MPU and BT-MPD samples collected Oct 22 and Nov 13; BT-LEU samples collected Oct 21 and Nov 12.

The discussion below is divided into sub-sections to summarize the findings related to the following water quality categories: turbidity and TSS; major ions and specific conductance; total and dissolved organic carbon; nutrients; and metals. The findings from all categories are summarized together in Section 5.6. The data were assessed by visual inspection of time series plots and monthly box-and-whisker plots (boxplots) to reveal pre- and post-fire differences. The boxplot "boxes" correspond to the middle 50 percent of the data in that group, the bottom of the box represents the 25th percentile, the horizontal line within the box indicates the median, and the top of the box represents the 75th percentile (Figure 20).

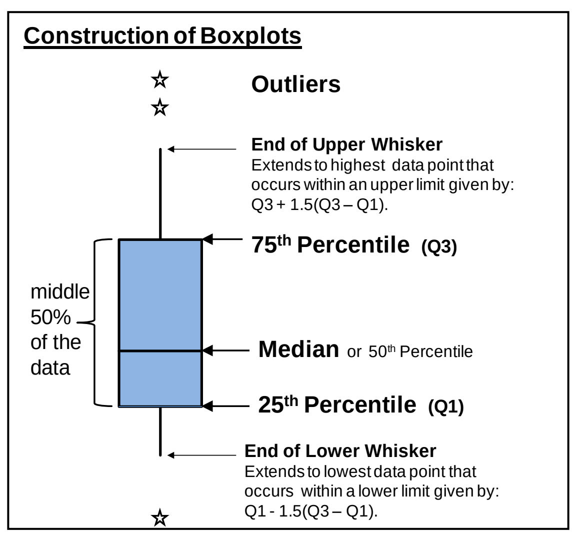


Figure 20. Construction of boxplots.

5.1 Turbidity & Total Suspended Solids (TSS)

Large increases in TSS and turbidity are the most obvious impacts to water quality downstream of burn areas. For example, post-High Park Fire turbidity in the Poudre River during summer storm events increased in excess of 500 NTU as measured by a continuous sonde, and a laboratory value of over 4,000 NTU was measured for one storm event a few weeks after the fire was out (Oropeza and Heath, 2013). For the Hayman Fire, Rhoades et al reported streamwater turbidity peaks that exceeded 200 NTU on a number of occasions in sub-basins that burned at high severity on 45% of their area, with high values occurring both during the snowmelt and during the summer. For the Fern Lake Fire, turbidity increases were observed in the Big Thompson River downstream of the burn area, but the measured values did not approach the extreme values seen in other fire-impacted rivers.

The Erosion Risk Management Tool modeling conducted by RMNP (RMNP, 2012) to evaluate sediment response from the Fern Lake Fire burn area concluded that post-fire hill-slope erosion and sediment delivery rates should be expected to be approximately 15 to 30 times pre-fire rates. In addition, they predicted that most soil erosion and sediment delivery to stream channels would be associated with precipitation events of high intensity likely to occur in any given year.

Turbidity is a measure of the amount of light that is scattered in water due to the presence of suspended and dissolved substances. Turbidity values depend on the instrument design, including the light source, wavelength, and detector geometry. The USGS uses different units for turbidity measurements to reflect the design of the instrument/sensor. The traditional Nephelometric Turbidity Units (NTU) is reserved for instruments that strictly conform to EPA Method 180.1 where the detector angle is 90° to the incident light beam and there is one detector (http://water.usgs.gov/admin/memo/QW/attach_techmemo04.03.pdf). EPA Method 180.1 is primarily for drinking water applications or low turbidity situations. The pre- and post-fire turbidity measurements presented in this report were all made with an instrument that has a 90° detection angle with multiple detectors. The turbidity unit used by the USGS with this method is **Nephelometric Turbidity Ratio Unit (NTRU)**. This method is compliant with EPA Method 180.1 for turbidities < 40 NTRU (such that turbidity values < 40 NTRU should be similar to NTU values).

Turbidity values collected in 2013 prior to the snowmelt runoff were low at BT-MPU, BT-MPD, and BT-LEU, below the 2 NTRU detection limit. During the 2013 spring snowmelt runoff, the peak turbidity measured at BT-MPD, at the downstream end of Moraine Park, was 6.2 NTRU, compared to peak turbidities of about 4 NTRU during pre-fire spring runoffs (Figure 21). The peak turbidity of 5.6 NTRU at BT-LEU, upstream of Lake Estes, during the 2013 spring runoff was within the normal range for this site. After the snowmelt runoff, turbidity values at all sites were again low, below the 2 NTRU detection limit.

Turbidity increased to 26 NTRU at BT-MPU and 33 NTRU at BT-MPD on August 13 in response to the precipitation event (Figure 22). Turbidity measured at BT-LEU on August 13 remained low at 2.8 NTRU. Note that turbidity and TSS measurements were not made for the July 18 precipitation event (Figures 18 and 19), although it was expected that both measurements would have been very high. The higher turbidity values measured for the August rain event compared to the turbidity values obtained during the spring runoff are consistent with the RMNP conclusions that precipitation events would be responsible for most sediment delivery to the stream channel.

Turbidity measurements made on September 10 at BT-MPU and BT-MPD showed turbidity values of approximately 8 NTRU (and likely rising) at the beginning of the September 9-15 rainfall event. BT-LEU was sampled on September 9 and, as of that date, had not shown a response to the precipitation event. By the October sampling event, turbidity values at all three sites were at or below the 2 NTRU detection limit.

TSS data were collected specifically for this study and are only available for 2013 at the three sites. Similar to the turbidity data, increases are observed in TSS at all three sites during the snowmelt runoff period (Figure 23). Increases in TSS were also measured at BT-MPU and BT-MPD in response to the August 13 and September 9-15 precipitation events. The maximum TSS measured in 2013 was 65 mg/L at BT-MPU on August 13.

Monitoring sites were selected at both the upstream (BT-MPU) and downstream (BT-MPD) ends of Moraine Park in order to evaluate the ability of the flat area of Moraine Park to help mitigate the impacts of potential sediment loads originating from the upstream, steeper slopes within the burn area. The TSS data indicate that during the snowmelt runoff, the TSS is higher at BT-MPD (at the downstream end) than at BT-MPU. It could be that the sediments mobilized by the snowmelt runoff are relatively fine and do not have a chance to settle within Moraine Park. Additional fine sediments were likely picked up within Moraine Park due to the high flows of the Big Thompson River during this time. Flows coming from the Cub Lake area (that do not drain to BT-MPU) could have also contributed to the additional sediment load at BT-MPD.

During the summer precipitation events, TSS is higher at BT-MPU (at the upstream end of Moraine Park) than at BT-MPD (Figure 23). For example, on August 13 the TSS at the upstream end of Moraine Park was 65 mg/L while at the downstream end of Moraine Park it was 37 mg/L. Intense summer storm events likely mobilize coarser sediments from the areas upstream of BT-MPU that can settle within Moraine Park prior to reaching the downstream end of Moraine Park.

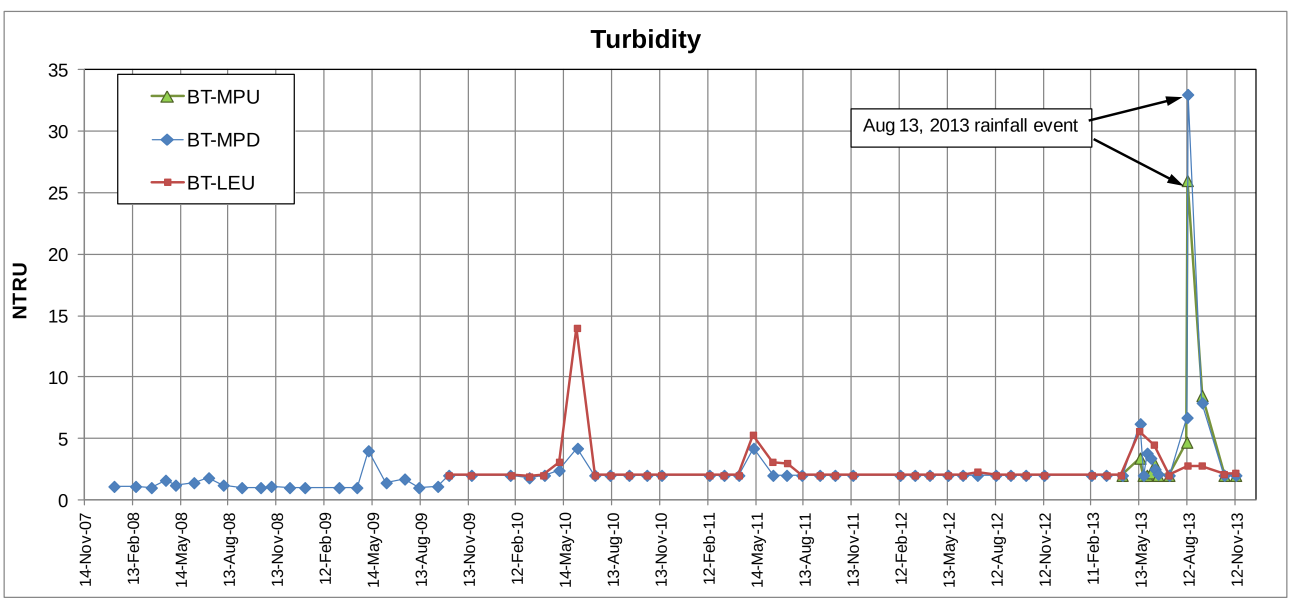


Figure 21. Turbidity time series for BT-MPU, BT-MPD, and BT-LEU.

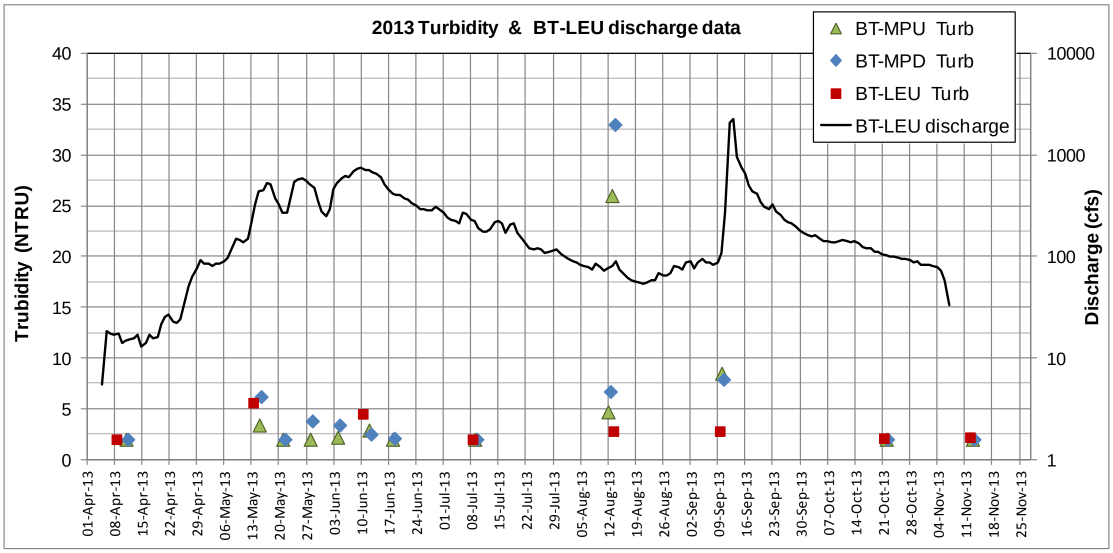


Figure 22. 2013 Turbidity and discharge.

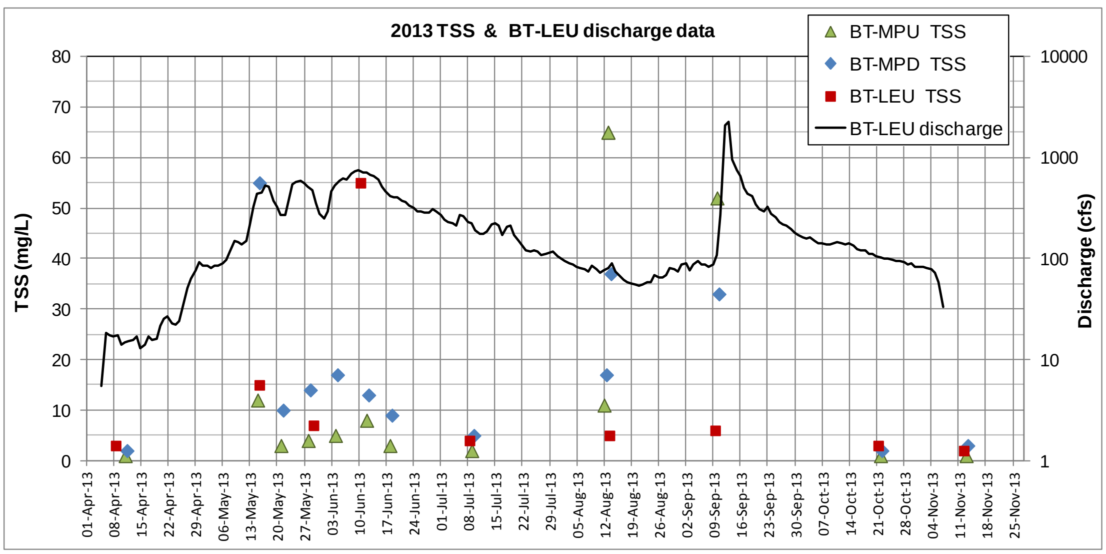


Figure 23. 2013 TSS and discharge.

5.2 Major Ions, Specific Conductance & pH

Major ion concentrations in the upper Big Thompson River typically increase over the fall and winter, and peak at the onset of spring runoff before being diluted by runoff flows. Downstream of burn areas, an increase in major ion concentrations is often observed as a result of the leaching of ash and partially burned forest floor litter.

Calcium, magnesium, sulfate and chloride concentrations all sharply peaked at the onset of 2013 spring snowmelt at both BT-MPU and BT-MPD (Figures 24 - 28). These peak concentrations were well above those typically observed, and resulted in a peak in the specific conductance (Figure 29). Major ion concentrations remained elevated above normal values through the runoff in May 2013. Note that BT-MPU was sampled three additional times (compared to BT-MPD) between April 11 - May 15 as part of a USGS study. The peak major ion concentrations at BT-MPU occurred within this time. Because of this, it appears that concentrations were higher at BT-MPU than at BT-MPD, although samples collected at both BT-MPU and BT-MPD on the same dates had very similar concentrations. It is likely that the peaks at BT-MPD would have been higher if that site had been sampled on all of the dates that BT-MPU was sampled.

The lowest 2013 major ion concentrations were measured during the July sampling event, similar to pre-fire concentrations observed in the month of July (Figure 30). During and after the August and September precipitation events, major ion concentrations at BT-MPU and BT-MPD were slightly elevated compared to pre-fire concentrations observed during those months.

From a practical (water treatment, aquatic life) standpoint, none of the increases in major ion concentrations is significant and the increases appear to have been short-lived. However, monitoring for major ions provides evidence that a burn area is impacting the general chemistry of a receiving stream.

Major ion concentrations just upstream of Lake Estes (at BT-LEU) are typically two to three times higher than at BT-MPD (see for example the plot for calcium on Figure 24), with the exception of sulfate which is about the same at both locations (Figure 27), and chloride, which is about 10 times higher at BT-LEU. Because of the higher concentrations at BT-LEU compared to BT-MPD, the BT-LEU data are not included on the magnesium, chloride and specific conductance plots shown here.

The post-fire increases in major ion concentrations seen at BT-MPD at the onset of the 2013 spring runoff did not cause concentrations at BT-LEU to fall outside of their normal ranges. The exception to this is sulfate, where the similar pre-fire concentrations typically observed at BT-MPD and BT-LEU mean that a concentration increase at BT-MPD can be transmitted and observed downstream at BT-LEU (Figure 27), with some dilution at BT-LEU by the other watersheds that contribute to flow at BT-LEU. Sulfate concentrations at BT-LEU increased during the 2013 post-fire spring runoff as a result of the increase at BT-MPD. However, sulfate concentrations quickly fell back to more typical values and the peak sulfate concentration of 7.3 mg/L at BT-LEU was well below the secondary drinking water maximum contaminant level of 250 mg/L.

pH. Field measurements of pH at BT-MPD in 2013 generally ranged from 6.7 to 7.6, which is within the normal pH range for this site. However, a low value of 6.4 was measured on 6/12/13 which is the lowest pH measured at BT-MPD over the period of record (dating back to Feb. 2001). A pH lower than normal was not expected since the literature reports that the pH in waters that percolate through burn areas show an increase compared to pre-fire or unburned conditions (Ranalli, 2004).

At BT-LEU, field pH in 2013 ranged from 7.2 to 8.0, well within the typical range for this site.

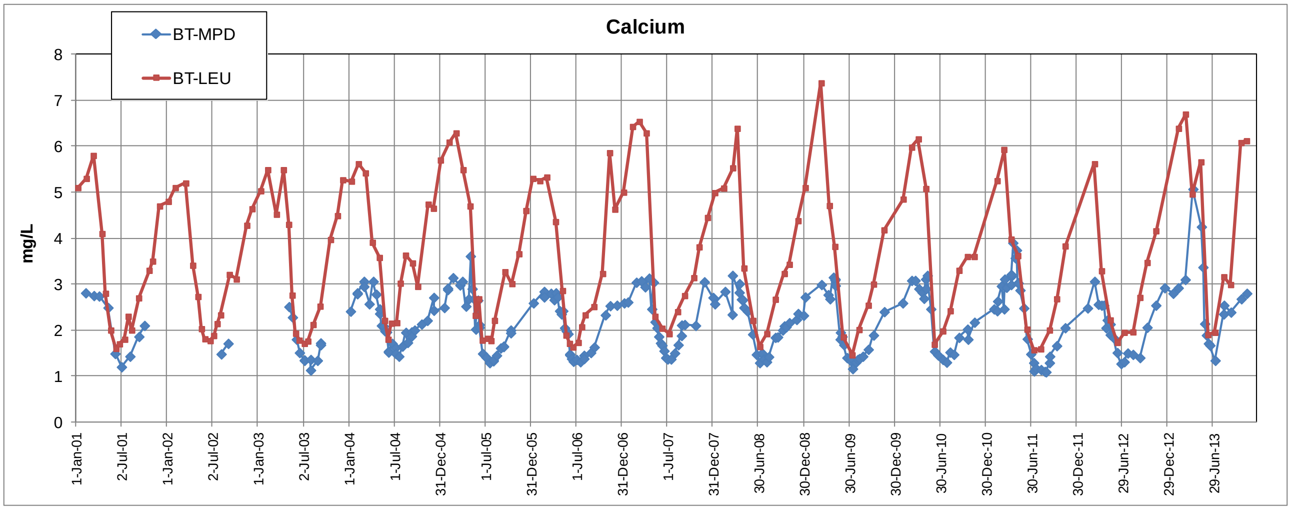


Figure 24. 2001 – 2013 Calcium times series for BT-MPD and BT-LEU.

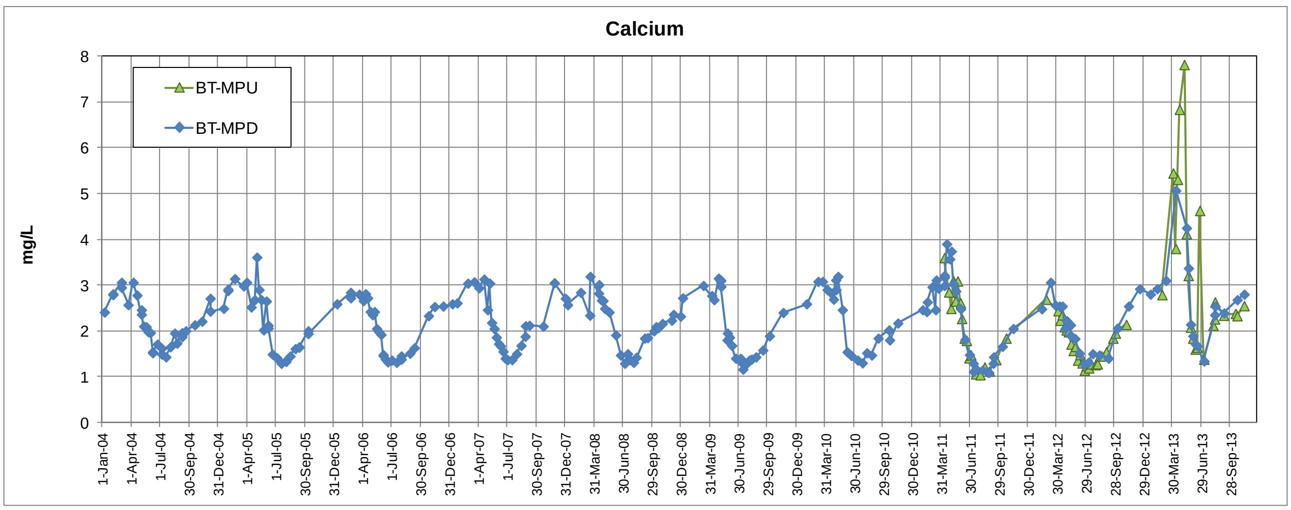


Figure 25. Calcium time series for BT-MPU and BT-MPD.

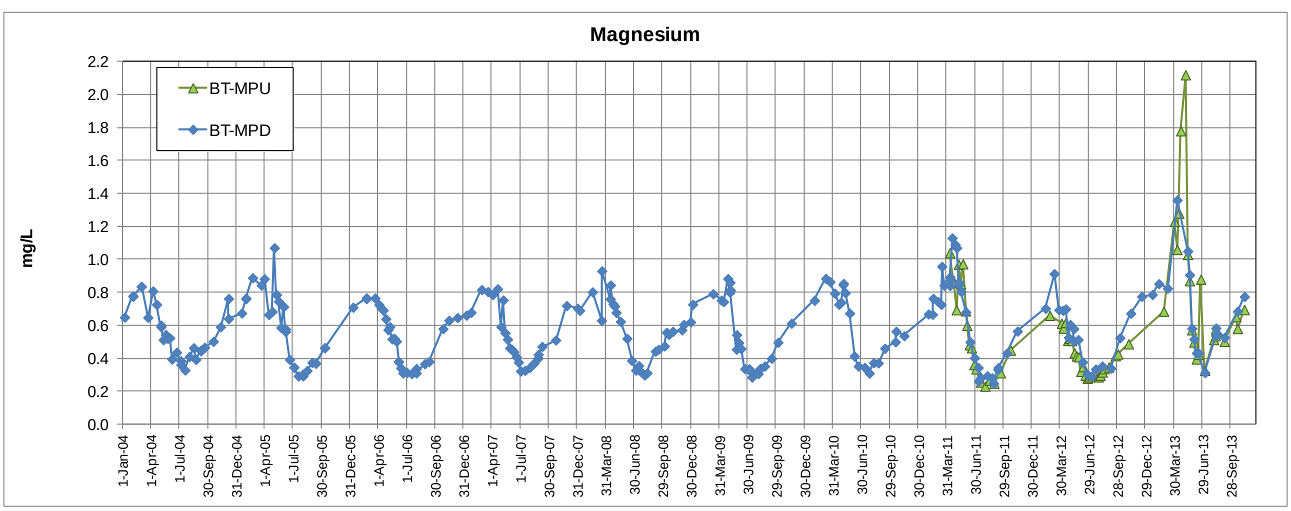


Figure 26. Magnesium time series for BT-MPU and BT-MPD.

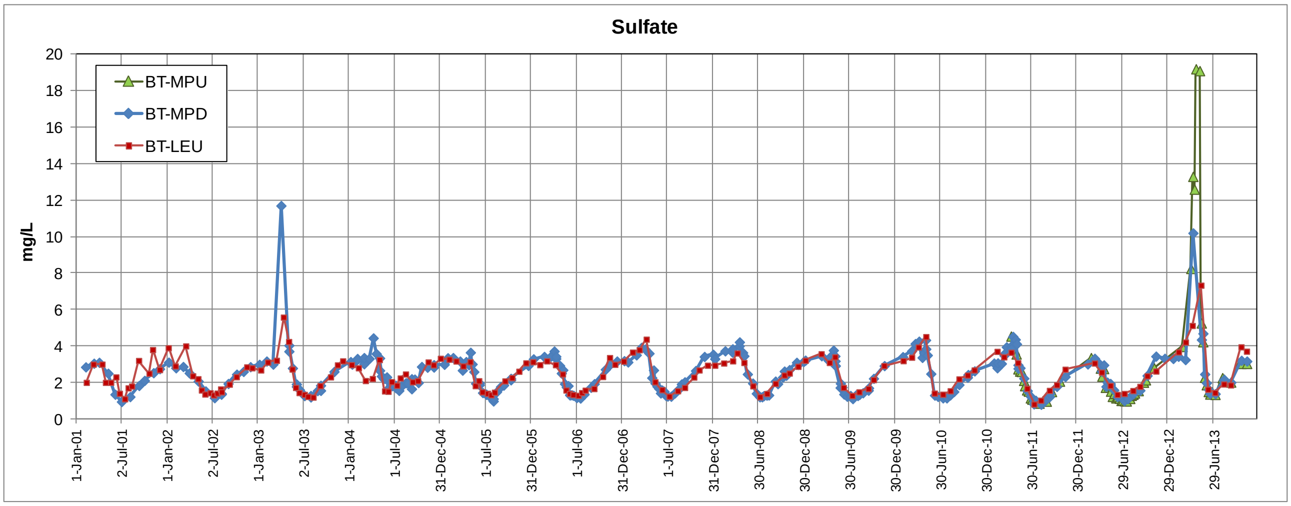


Figure 27. Sulfate time series for BT-MPU, BT-MPD and BT-LEU.

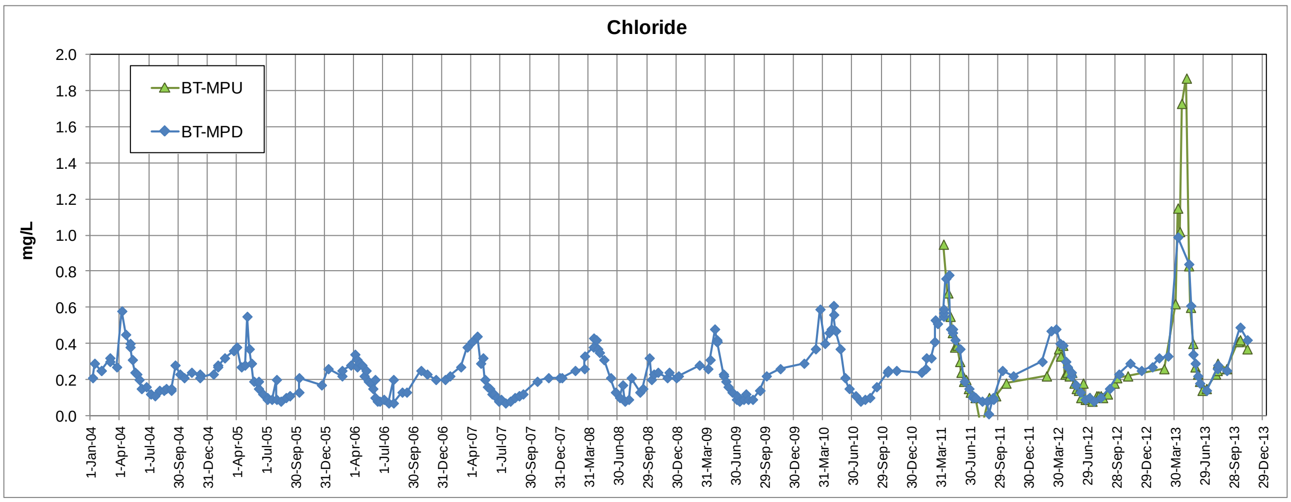


Figure 28. Chloride time series for BT-MPU and BT-MPD.

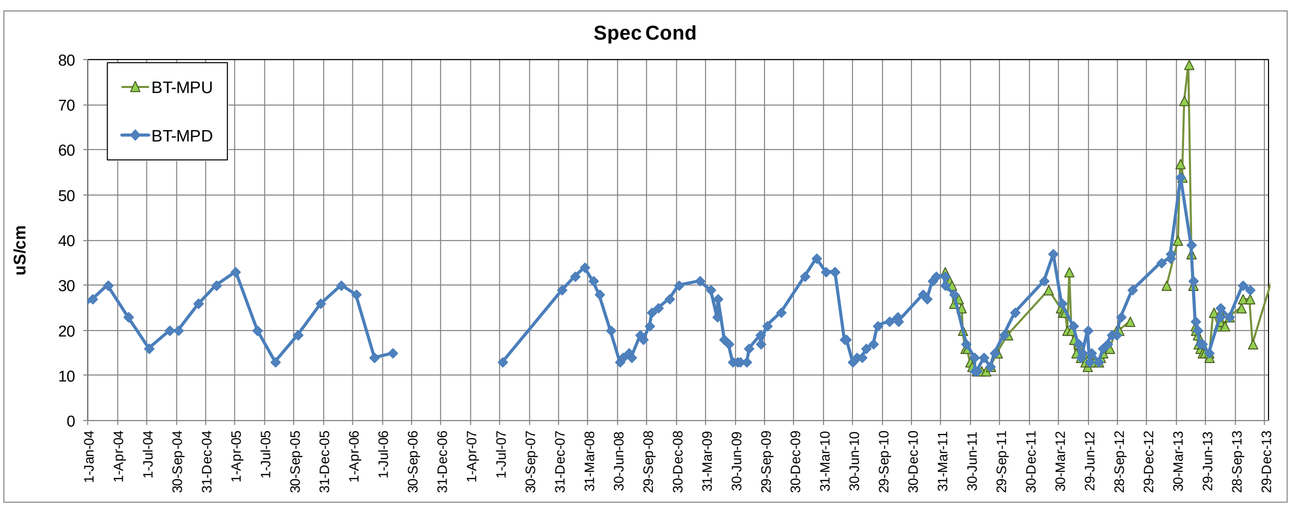
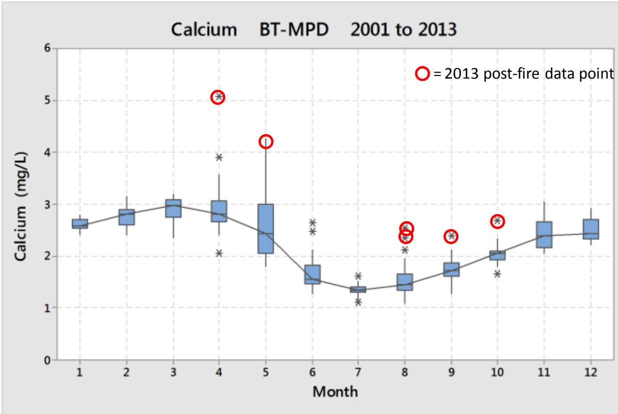
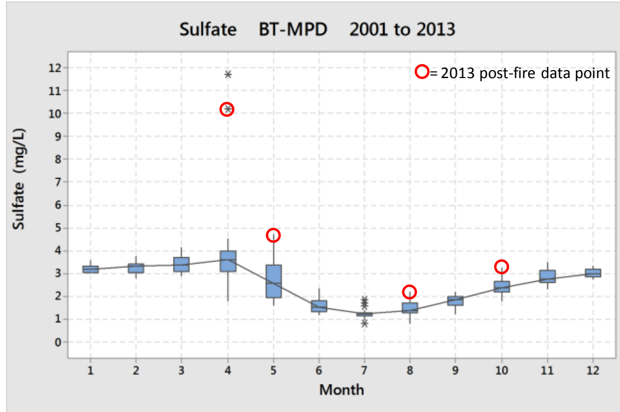
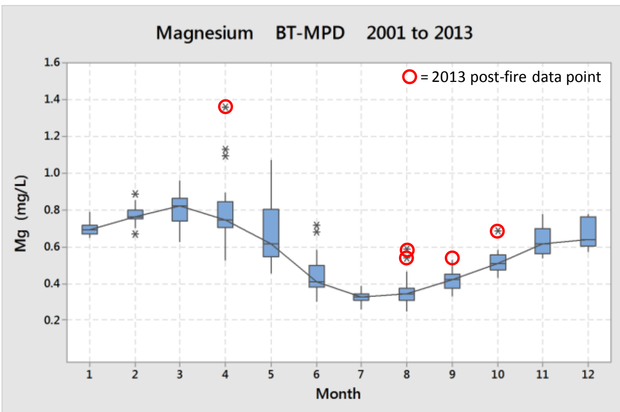
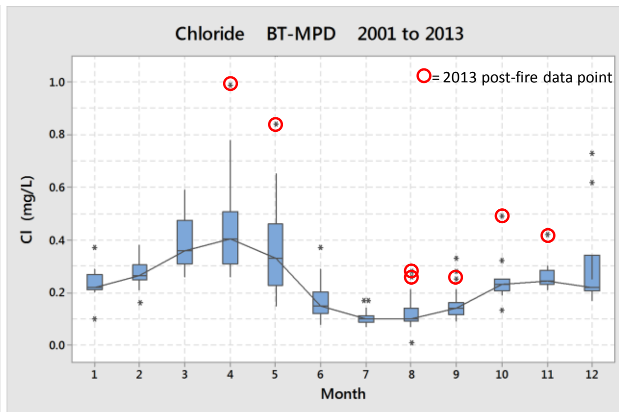


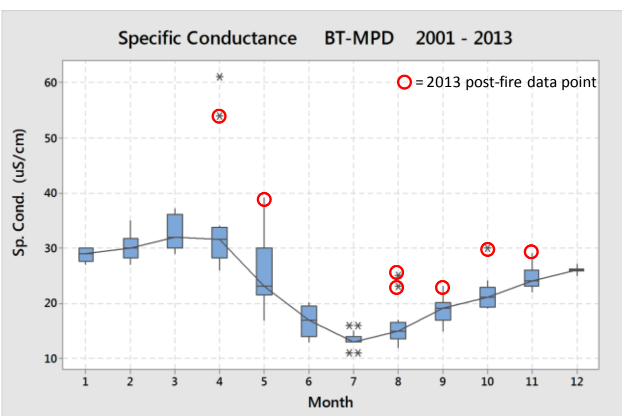
Figure 29. Specific conductance time series for BT-MPU and BT-MPD.











Red circles indicate 2013 (post-fire) data points that are outliers or on the upper end of the range for the period of record.

Figure 30. BT-MPD monthly boxplots of calcium, magnesium, sulfate, chloride and specific conductance data.

5.3 Total Organic Carbon (TOC) & Dissolved Organic Carbon (DOC)

TOC data assessed in this report have been analyzed by two different methods. The BTWF routine TOC samples collected at BT-MPD (M-10) and BT-LEU (M-20) are analyzed by the City of Fort Collins Water Quality Lab using Standard Method 5310C (SM 5310C), with UV-persulfate oxidation. Additional TOC samples collected for the 2013 Fern Lake Fire Study (including some samples at BT-MPD and BT-LEU, and all TOC samples collected at BT-MPU) were analyzed by the USGS using a method (USGS COMB9) essentially equivalent to SM 5310B, where oxidation of the organic compounds is accomplished using high-temperature combustion. The 2013 TOC data obtained using the combustion method yielded significantly higher TOC values, especially at the higher TOC levels, likely due to the higher recovery of particulate organic carbon with the combustion method. Because of this, the 2013 USGS TOC data are not combined with the long term BTWF TOC data set. The USGS conducted the analysis for the DOC samples using persulfate oxidation and infrared spectrometry.

Naturally occurring organic matter, measured as TOC and DOC, typically peaks in the Big Thompson River on the rising limb of the spring snowmelt hydrograph as the melting snow mobilizes organic matter contained in the forest litter and soils. Peak TOC concentrations of 13.6 mg/L and 10.3 mg/L at BT-MPD and BT-LEU, respectively, were measured during the post-fire 2013 spring runoff (as analyzed using SM 5310C). These peak values fall within the historic range for these sites (Figure 31). TOC concentrations decreased as is typical after the spring runoff period.

TOC concentrations measured during the 2013 spring runoff using the high-temperature combustion method were significantly higher than the concentrations obtained using SM 5310C (note that pre-fire TOC values obtained using the high-temperature combustion method are not available). Peak TOC measured during the spring snowmelt was 19.8 mg/L at the upstream end of Moraine Park (BT-MPU), 19.9 mg/L at the downstream end of Moraine Park (BT-MPD), and 15.1 mg/L just above Lake Estes (BT-LEU); Figure 32.

A significant increase in TOC was observed at BT-MPU during the August 13, 2013 storm event (Figure 32). The TOC concentration at BT-MPU increased from 3.9 mg/L on August 12 to 18.8 mg/L on August 13 (both values from high-temperature combustion method). TOC concentrations at BT-MPD did not increase from August 12 to August 13, with a TOC concentration of about 5 mg/L on both days. TOC samples collected on August 13 were outside of the routine BTWF sampling, so data from SM 5310C analysis are not available for this date (the August 12 value for BT-MPD was 2.4 mg/L).

After the September flood, TOC concentrations at BT-MPD and BT-LEU were elevated through the fall, at concentrations between 3.5 to 4.0 mg/L, compared to the typical fall range of 1.7 to 2.2 mg/L (Figure 31). The significant amounts of rain that occurred in September likely flushed the watershed and resulted in subsurface flows that slowly carried increased concentrations of TOC (and DOC) to the Big Thompson River well into the fall. However, it is not known the degree to which the burn area was influencing the post-flood increases compared to increases that might have occurred if there had been a similar flood prior to the fire.

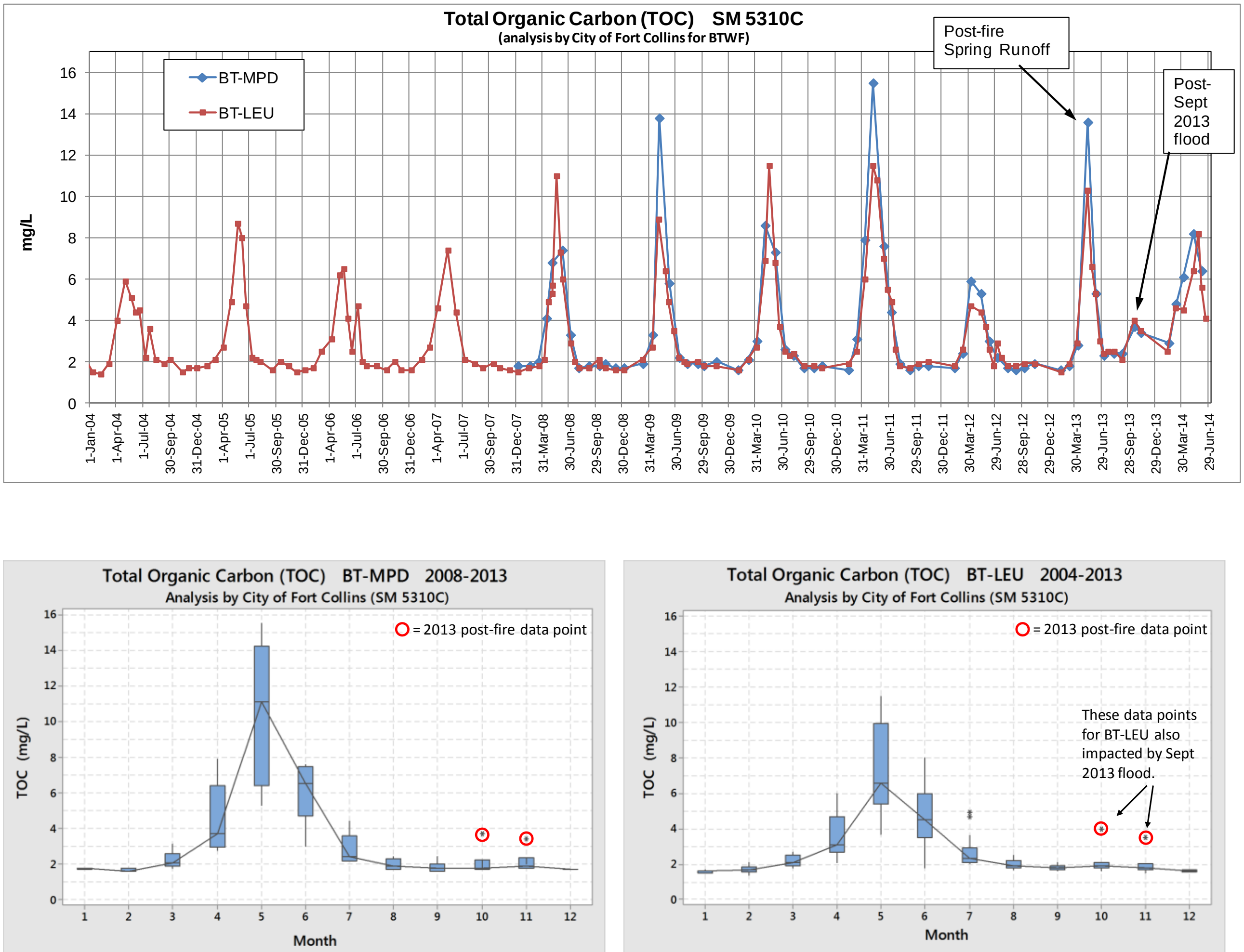


Figure 31. BT-MPD and BT-LEU TOC time series plots & monthly boxplots (analysis using SM 5310C UV-persulfate oxidation).

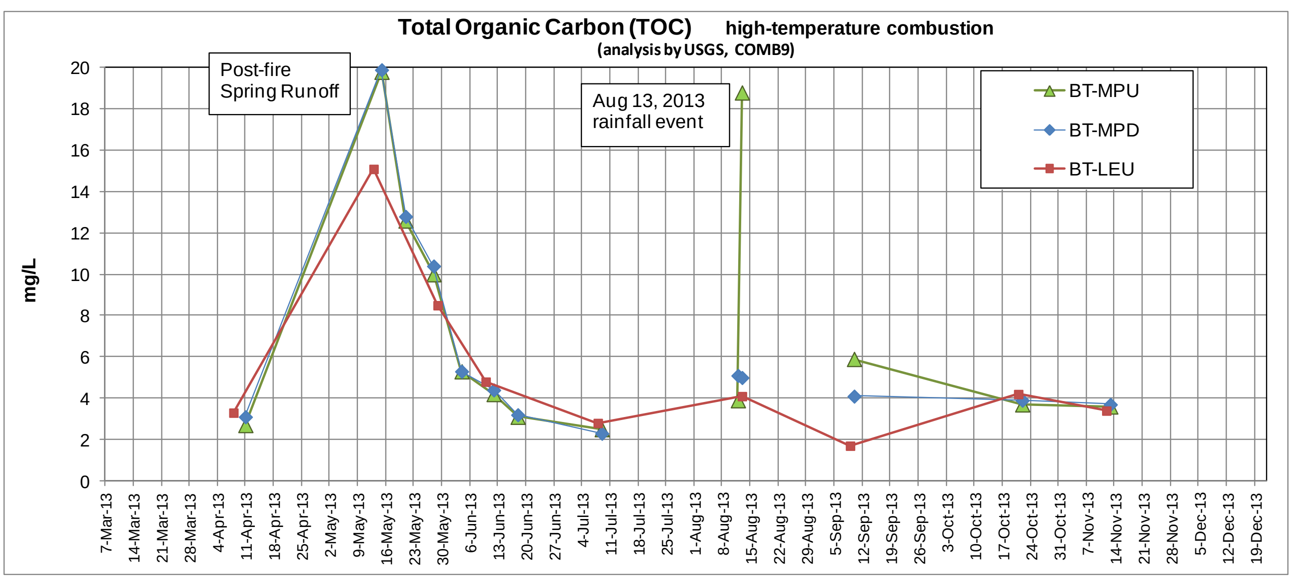


Figure 32. 2013 TOC data at BT-MPU, BT-MPD, and BT-LEU (analysis using high-temperature combustion).

DOC concentrations are important since it is this fraction of the TOC that is available to react with disinfectants (chlorine) at water treatment plants to form regulated disinfection byproducts. DOC concentrations at BT-MPU and BT-MPD increased as is typical during the spring runoff, but the peak DOC concentrations were within the range observed during previous spring runoffs as seen on Figure 33 (note that BT-LEU does not have DOC data). During the August 13 rainfall event, the DOC at BT-MPU increased by 1 mg/L (from 2 mg/L to 3 mg/L), while the DOC concentration at BT-MPD remained essentially unchanged. Similar to TOC, the DOC concentrations were elevated through the fall, after the September flood (elevated by 1 to 2 mg/L compared to previous fall concentrations).

The post-fire DOC concentrations at both BT-MPU and BT-MPD were significantly lower than their respective TOC concentrations during the spring snowmelt runoff (as measured using the high-temperature combustion method; Figures 34 and 35) and also during the August and September rainfall events. This indicates that a significant portion of the high TOC that was mobilized in 2013 was in the particulate form.

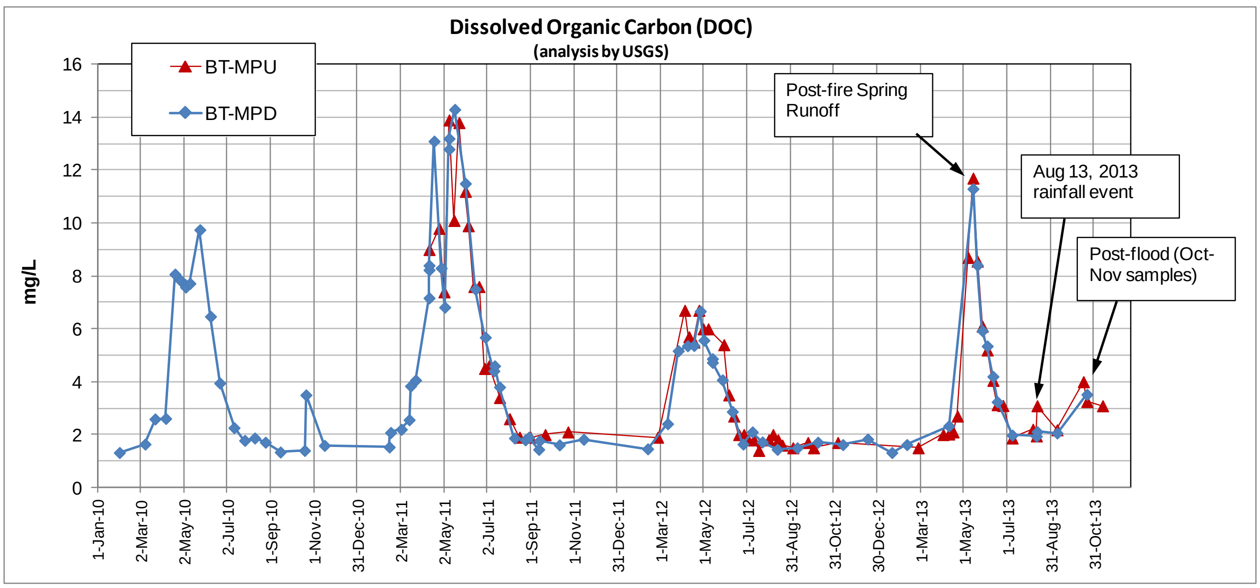


Figure 33. Dissolved organic carbon time series for BT-MPU and BT-MPD.

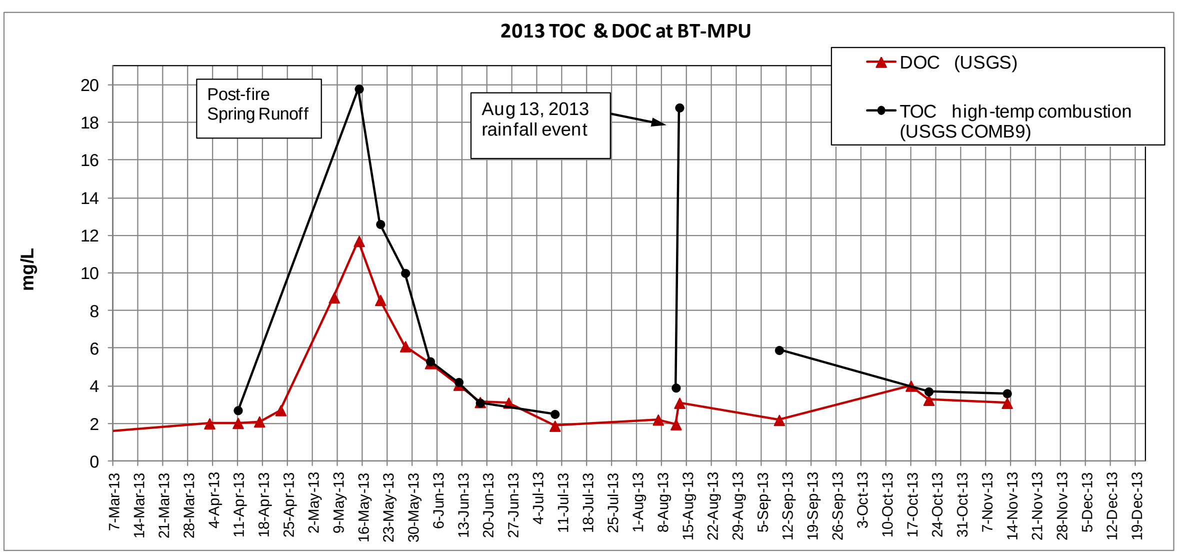


Figure 34. 2013 TOC and DOC at BT-MPU.

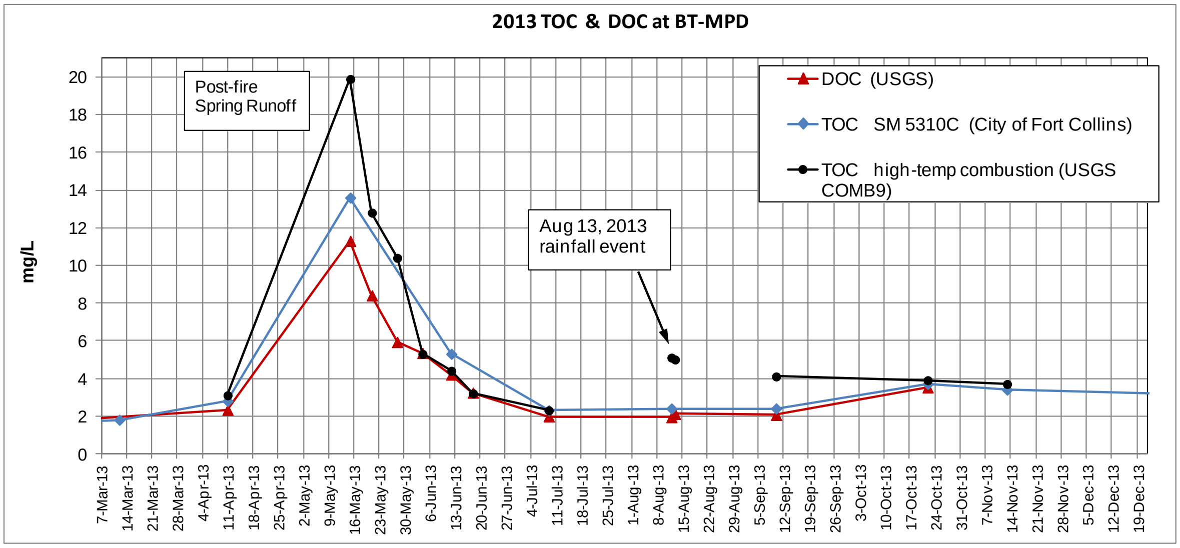


Figure 35. 2013 TOC and DOC at BT-MPD.

5.4 Nutrients

One of the important impacts of wildfires is an increase in nutrient concentrations and loads to downstream water bodies. An increase in nutrients is of concern because it can lead to increases in algal growth in the receiving water bodies. Data collected upstream and downstream of Moraine Park (BT-MPU and BT-MPD) indicate that total phosphorus (Total P) and total Kjeldahl nitrogen (TKN, which measures organic plus ammonia nitrogen) had the largest post-fire increases compared to pre-fire concentrations (Figures 36, 37 and 40), while ortho-P, nitrate and ammonia concentrations exhibited minor or no impact from the Fern Lake Fire (Figures 38, 39 and 41). Nutrient increases outside of normal ranges were not observed at the BT-LEU site upstream of Lake Estes.

Total P typically peaks during the spring snowmelt runoff and precipitation events due to the mobilization of sediments. Total P at BT-MPD was significantly higher during the 2013 snowmelt runoff than in previous runoffs, with a peak concentration of 0.058 mg/L (about 3 times higher than typical spring runoff peaks), coincident with the peak TSS of 55 mg/L measured at BT-MPD. Total P was elevated again at BT-MPD during the August 13 storm event (Total P = 0.067 mg/L, with TSS = 37 mg/L) and was also high on September 10 (Total P = 0.069 mg/L, with TSS = 33 mg/L) as seen on Figures 37 and 42. The highest Total P concentration was measured at BT-MPU during the August 13 storm event (0.11 mg/L). By the October sampling event, all Total P concentrations had dropped back to within the normal ranges, coincident with the drop in TSS. An increase in ortho-P at BT-MPD outside of normal ranges was not observed, and the increase in Total P reflects the increase in the particulate P associated with increased sediment loads.

TKN also typically peaks during the spring snowmelt runoff. TKN at BT-MPD was significantly higher during the 2013 snowmelt runoff than in previous runoffs. The 2013 spring runoff TKN peak was 0.63 mg/L, compared to a general range of 0.22 – 0.38 mg/L for pre-fire spring runoff peaks (Figures 40 and 42). TKN was elevated again in 2013 during the August 13 storm event and also on September 10. By the October sampling event, TKN concentrations had dropped back to within normal ranges.

Nitrate concentrations at BT-MPD typically peak during the winter (Dec –Feb) and are generally lowest during the spring and summer before increasing again in the fall (Figures 39 and 42). After the Fern Lake Fire, nitrate concentrations showed a small, atypical peak on the rising limb of the snowmelt hydrograph (a concentration of 0.16 mg/L, compared to values typically in the range of 0.07 to 0.10 mg/L in May), but otherwise fell within normal ranges.

The Colorado Water Quality Control Commission adopted interim numerical values for Total P and Total Nitrogen to protect designated uses of Colorado waters. For cold water rivers and streams, the Total P value is 0.110 mg/L and the Total Nitrogen value is 1.25 mg/L, both to be assessed as an annual median with an allowable exceedance frequency of 1-in-5 years. The Total P and Total Nitrogen (= TKN + nitrate + nitrite) post-fire concentrations did not exceed their respective interim values. Note that these nutrient values have not yet been adopted as standards for the Big Thompson River.

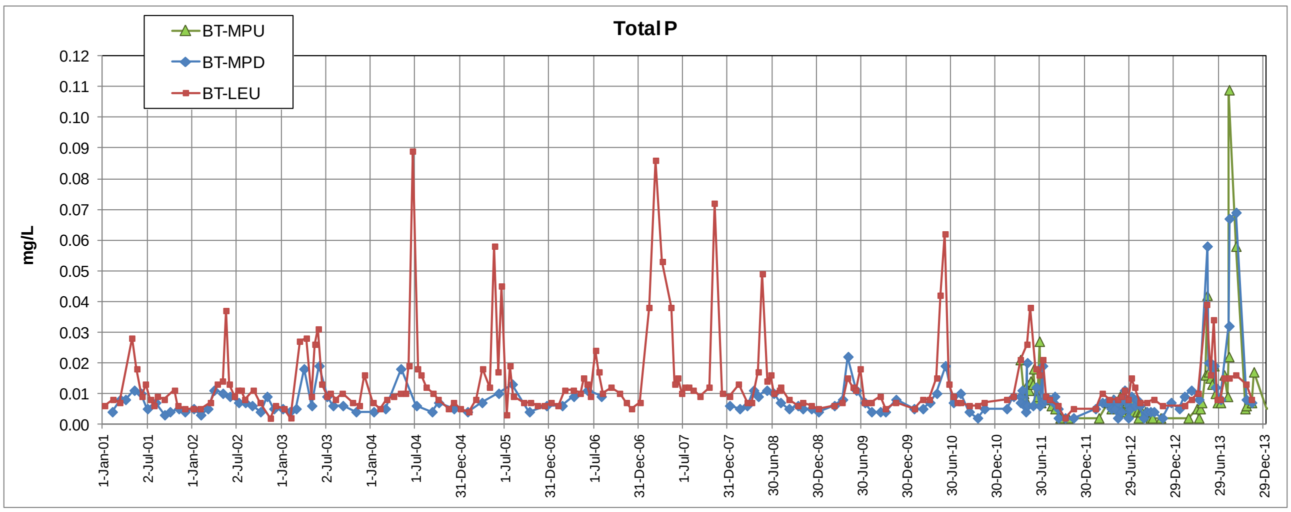


Figure 36. Total P time series for BT-MPU, BT-MPD, and BT-LEU.

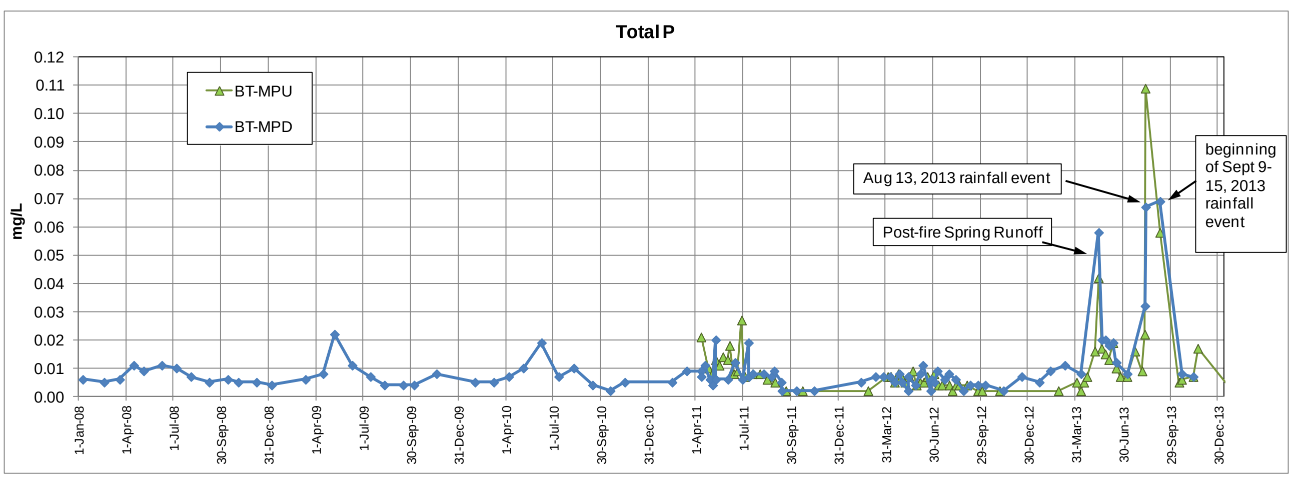


Figure 37. BT-MPU and BT-MPD Total P data.

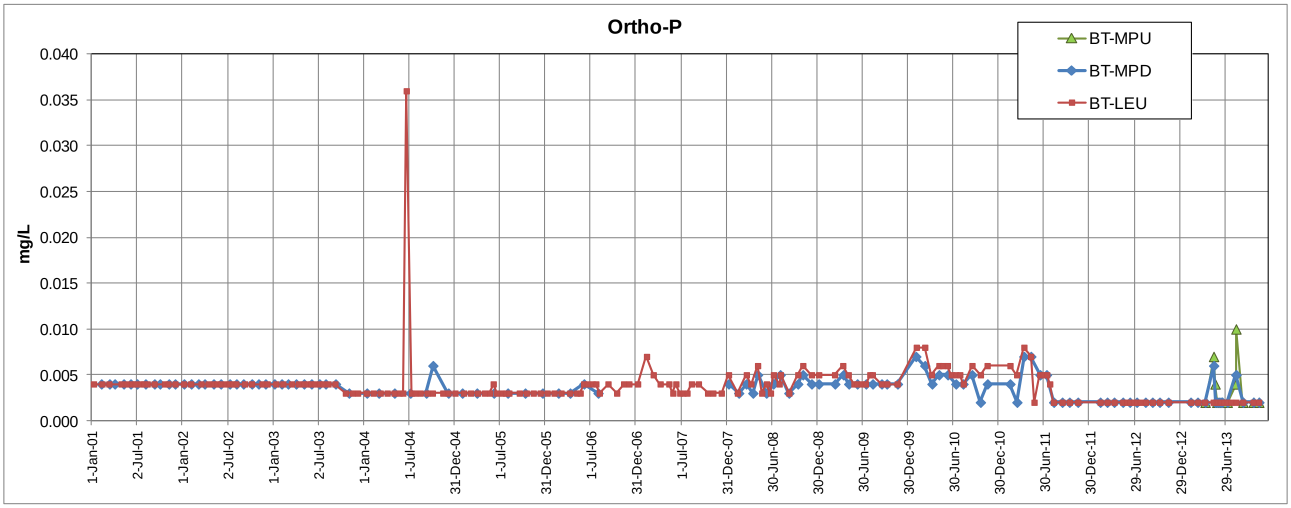


Figure 38. Ortho-P time series for BT-MPU, BT-MPD, and BT-LEU.

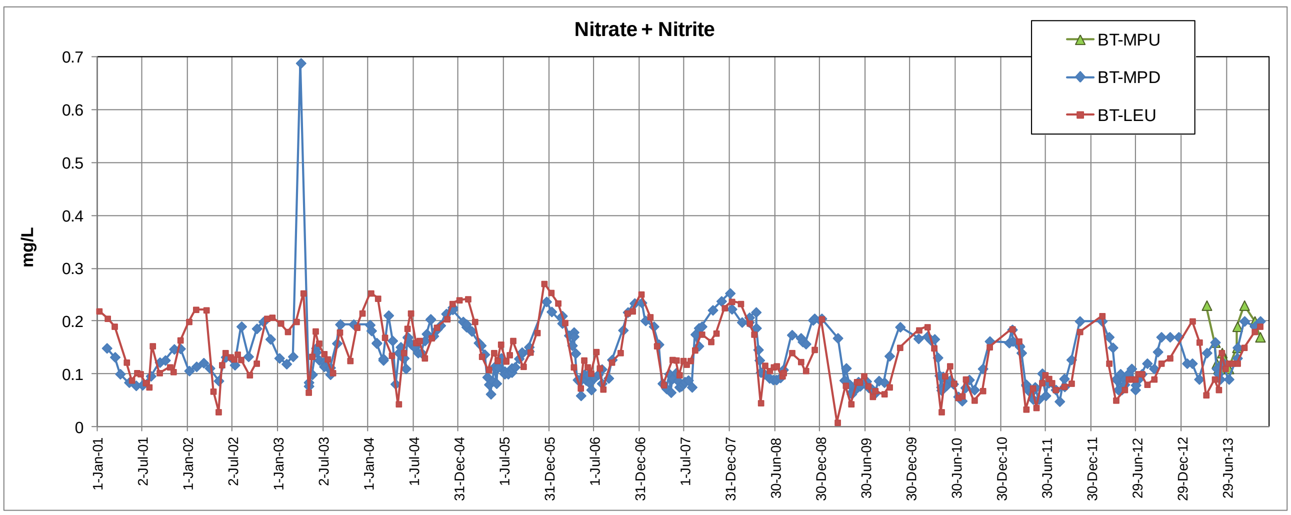


Figure 39. Nitrate + nitrite time series for BT-MPU, BT-MPD, and BT-LEU.

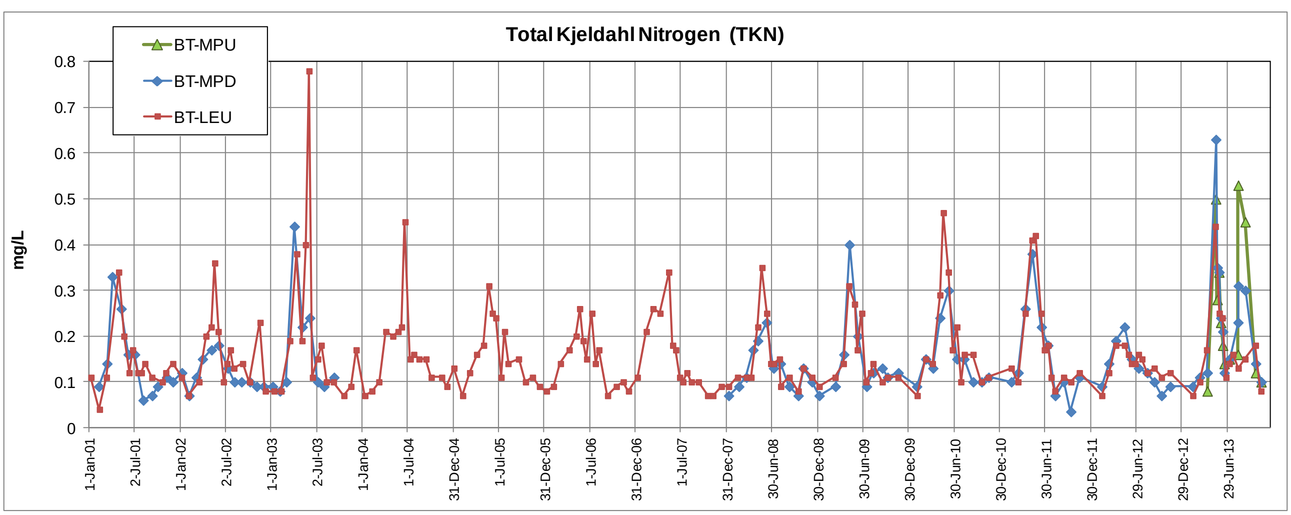


Figure 40. TKN time series for BT-MPU, BT-MPD, and BT-LEU.

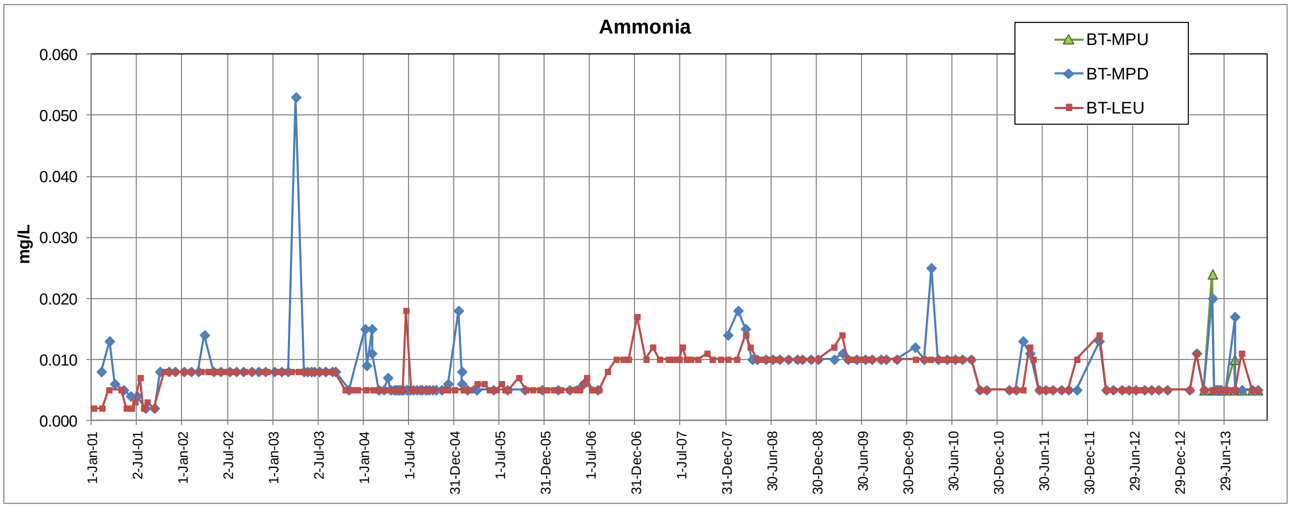


Figure 41. Ammonia time series for BT-MPU, BT-MPD, and BT-LEU.

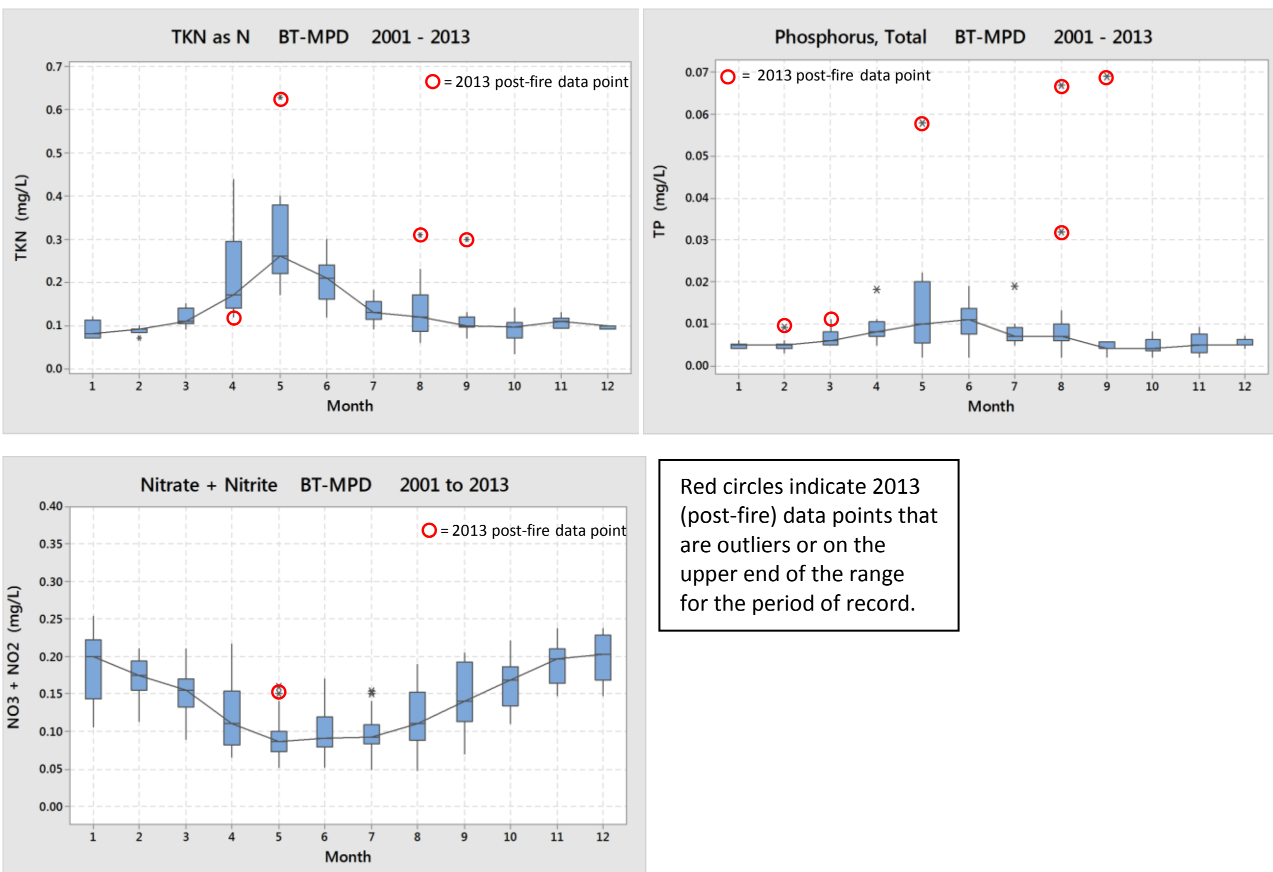


Figure 42. Monthly boxplots of TKN, nitrate plus nitrite, and Total P for 2001-2013 at BT-MPD, Big Thompson River at downstream end of Moraine Park.

5.5 Metals

Metals analyzed during this study include dissolved and total recoverable aluminum, low level total mercury, and dissolved arsenic, copper, iron, lead, manganese, nickel and silver. In most cases, a response was observed during the spring runoff and August precipitation event, but concentrations were not outside of normal ranges. Post-fire concentrations of dissolved arsenic, dissolved copper, dissolved lead, and dissolved nickel were unremarkable and are not discussed further in this document. Some additional observations about the aluminum, iron, manganese, mercury and silver data are discussed below.

Aluminum. Data were collected in 2013 at BT-MPU and BT-MPD for dissolved and total recoverable aluminum. Aluminum was added to the parameter list because of high aluminum concentrations that had been observed in the Poudre River by the City of Fort Collins after the High Park Fire. Aluminum data were not collected at BT-LEU.

Aluminum data are plotted on Figure 43. The peak total recoverable aluminum concentration during the snowmelt runoff was 470 µg/L at BT-MPU, and 831 µg/L at BT-MPD. Peaks in total recoverable aluminum are coincident with the peaks in TSS. During the spring snowmelt runoff, the TSS and total recoverable aluminum concentrations are both higher at the downstream end of Moraine Park, BT-MPD, compared to the upstream end of Moraine Park. During the precipitation events of August and September, the total aluminum and TSS concentrations were both higher at the upstream end of Moraine Park, BT-MPU. On September 10, total recoverable aluminum concentrations of 2,070 µg/L and 620 µg/L were measured at BT-MPU and BT-MPD, respectively.

Colorado has an acute and chronic aquatic life standard for total recoverable aluminum that is based on hardness. However, an aluminum standard is not routinely applied to stream segments in Colorado and has not been adopted for any segment of the Big Thompson River.

Dissolved aluminum concentrations were similar at BT-MPU and BT-MPD (Figure 43). The peak dissolved aluminum concentration during the snowmelt runoff was 236 µg/L at BT-MPU, with a similar concentration at BT-MPD. Dissolved aluminum concentrations increased during the August 13 precipitation event, but an increase was not observed during the beginning of the September precipitation event. The secondary (aesthetic-based) drinking water standard for dissolved aluminum (50 µg/L) was exceeded at BT-MPU and BT-MPD during the spring snowmelt runoff, during the August 13 precipitation event, and in the fall.

It is difficult to put the aluminum concentrations into perspective since pre-fire data are not available. Post-High Park Fire sampling of the Poudre River by the City of Fort Collins showed concentrations of total aluminum ranging from approximately 10,000 µg/L to approximately 90,000 µg/L, and dissolved aluminum ranging from approximately 60 µg/L to 150 µg/L during three storm events in June-July 2012 (Oropeza and Heath, 2013). Daily grabs samples collected from July 30 – September 17, 2012 showed dissolved aluminum concentrations up to nearly 400 µg/L during storm events, but rapidly dropping to low values (below 50 µg/L) following rain events.

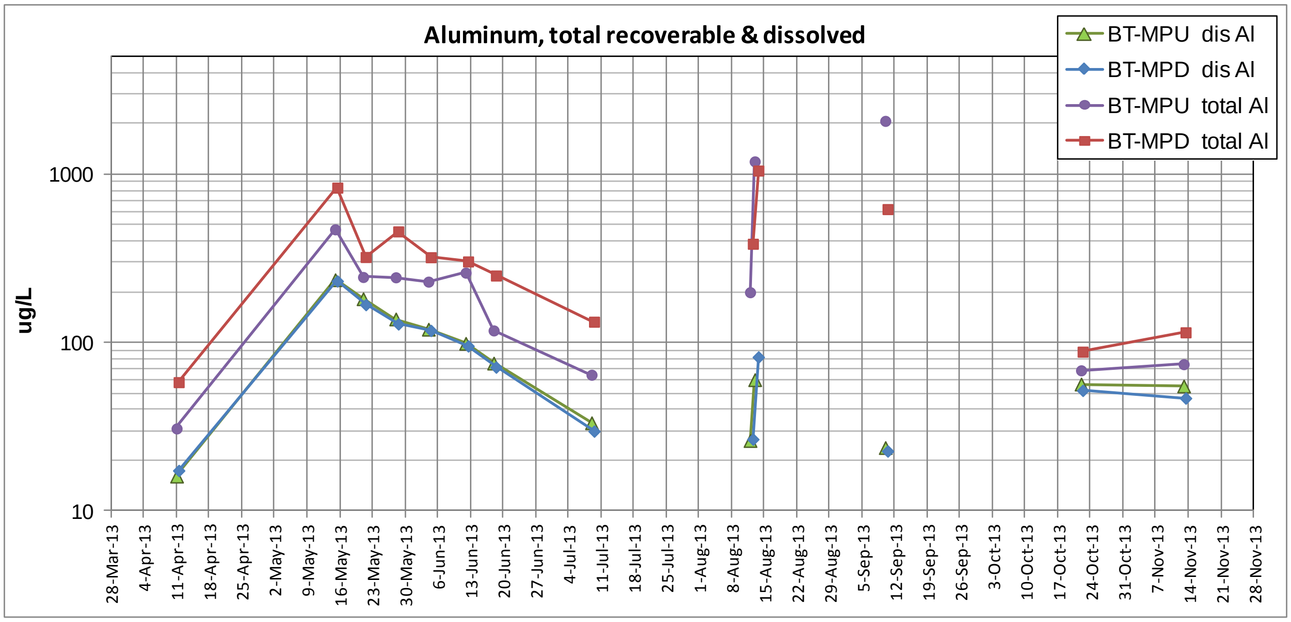


Figure 43. 2013 Aluminum (total recoverable and dissolved) at BT-MPU and BT-MPD.

<u>**Manganese**</u>. Dissolved manganese at BT-MPD and BT-LEU typically peaks prior to the beginning of the spring snowmelt runoff, and this was the case during 2013. The pre-runoff dissolved manganese peaks at BT-MPD (29 µg/L) and at BT-LEU (12 µg/L) were both within normal ranges observed for these sites (Figure 44). During the spring runoff, dissolved manganese concentrations dropped, but concentrations at BT-MPD were elevated compared to pre-2013 runoff concentrations (Figure 45, month of May). Dissolved manganese was also elevated at BT-MPD during the August and September precipitation events (Figure 45). All measured concentrations were below the 50 µg/L secondary drinking water standard for dissolved manganese, and well below the acute and chronic aquatic life standards (for a hardness of 15 mg/L, the acute and chronic aquatic life standards for dissolved manganese are 1,587 µg/L and 877 µg/L, respectively).

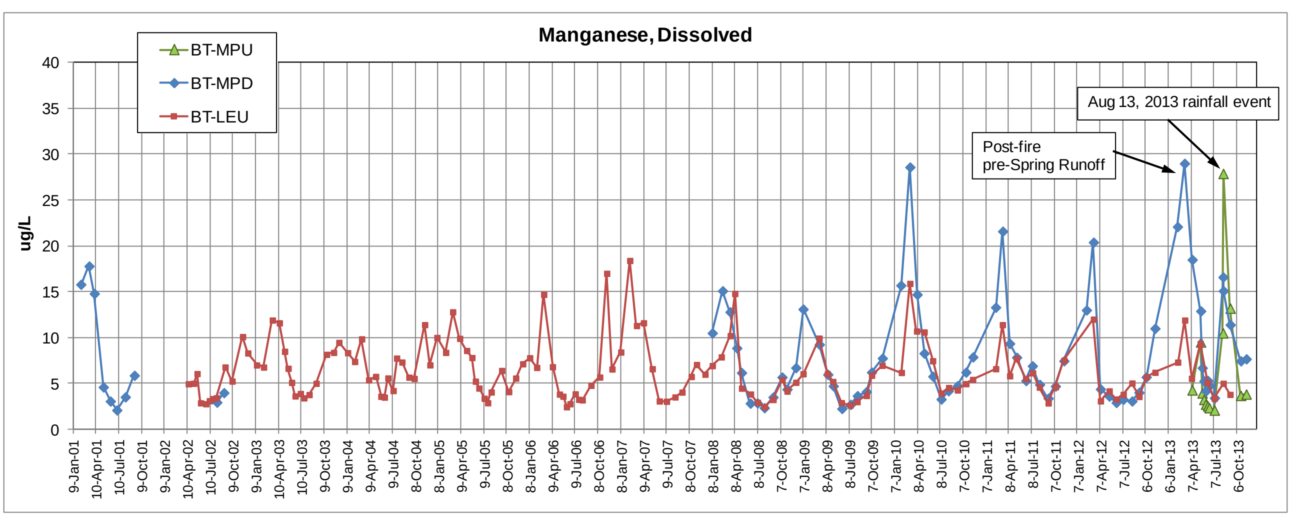


Figure 44. Manganese (dissolved) time series for BT-MPU, BT-MPD, and BT-LEU.

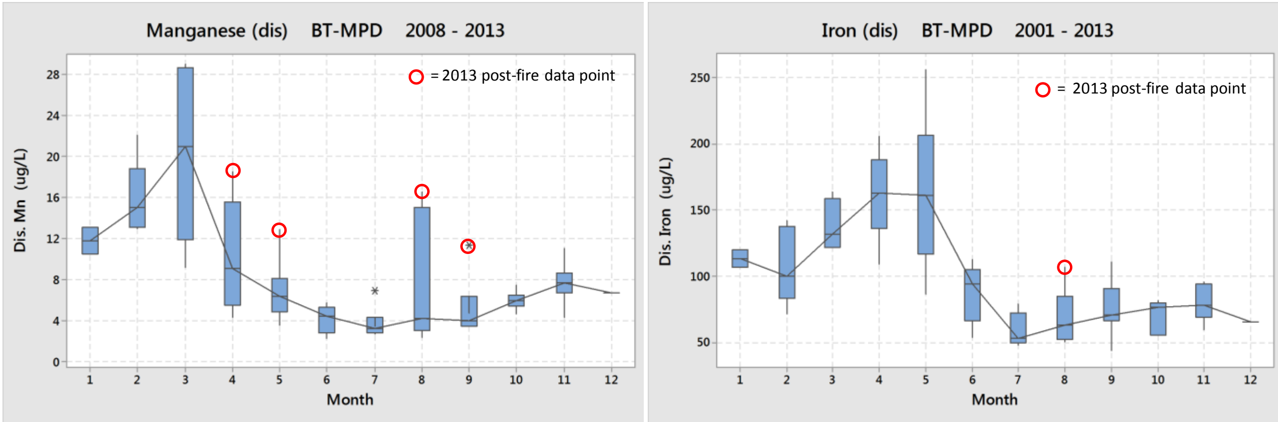


Figure 45. Monthly boxplots for dissolved manganese and iron at BT-MPD.

<u>Iron</u>. Dissolved iron typically peaks during the spring runoff at BT-MPD (Figures 45 and 46), and concentrations during the 2013 runoff were well within the typical range. Dissolved iron concentrations increased during the August precipitation event, but again were within normal ranges. All measured concentrations were below the 300 µg/L secondary drinking water standard for dissolved iron. The aquatic life standard of 1,000 µg/L for iron is based on the total recoverable concentration, which has not been measured at the sites in this study.

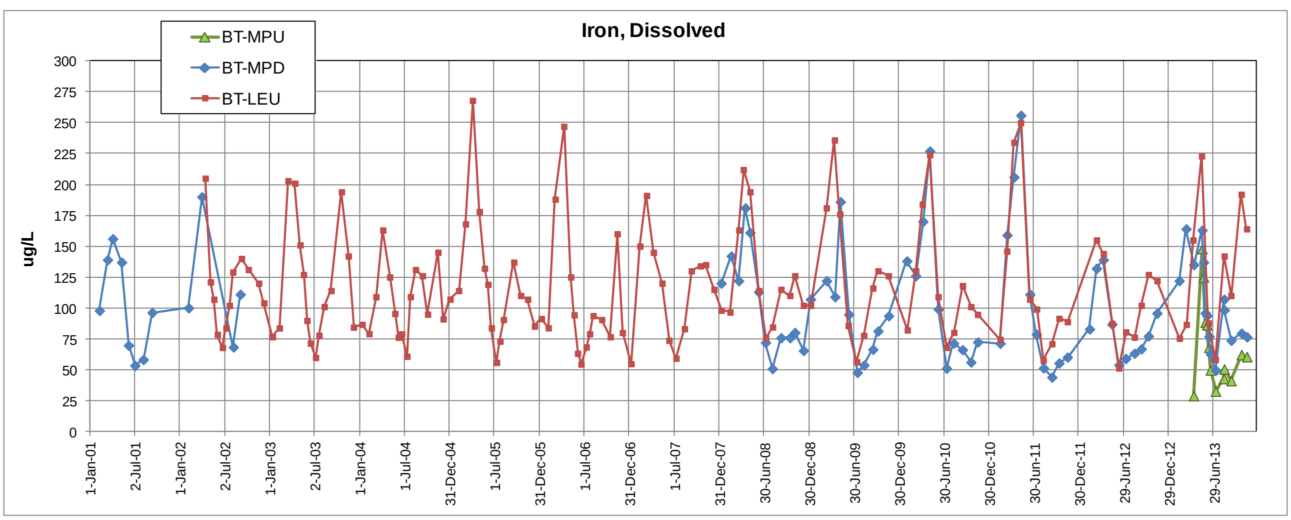


Figure 46. Iron (dissolved) time series for BT-MPU, BT-MPD, and BT-LEU.

<u>Mercury</u>. Mercury accumulates in forest ecosystems through atmospheric deposition. During wildfires, the mercury stored in vegetation, forest litter and soils is released back to the atmosphere during combustion (Biswas et al, 2007). Post-fire erosion can result in the mobilization of mercury that remains bound to the ash and soil, with an increase in total mercury concentrations in receiving streams. The presence of mercury in surface waters is of significant concern because microorganisms can convert inorganic mercury into methyl mercury, a highly toxic form of mercury that bioaccumulates in fish and animals that eat fish (including humans). The chronic aquatic life standard for total mercury is 0.01 µg/L (10 nanograms/L), while the primary drinking water standard is 2 µg/L.

At the BT-MPU, BT-MPD and BT-LEU monitoring sites, total recoverable mercury typically peaks during the spring runoff (Figure 47) as melting snow flushes particulate-bound and organic-bound mercury that has accumulated over time in the forest soils due to atmospheric deposition. The seasonal pattern is very similar to that exhibited by TOC, DOC and TSS since mercury is typically associated with organic carbon and suspended sediment.

The total recoverable mercury concentrations at BT-MPU, BT-MPD and BT-LEU during the 2013 spring runoff period were within the range that has been observed during previous runoffs (Figure 47). The concentrations measured at BT-MPD in August and September were slightly elevated compared to previous August/September values, but the values were low at less than 4 nanograms/L.

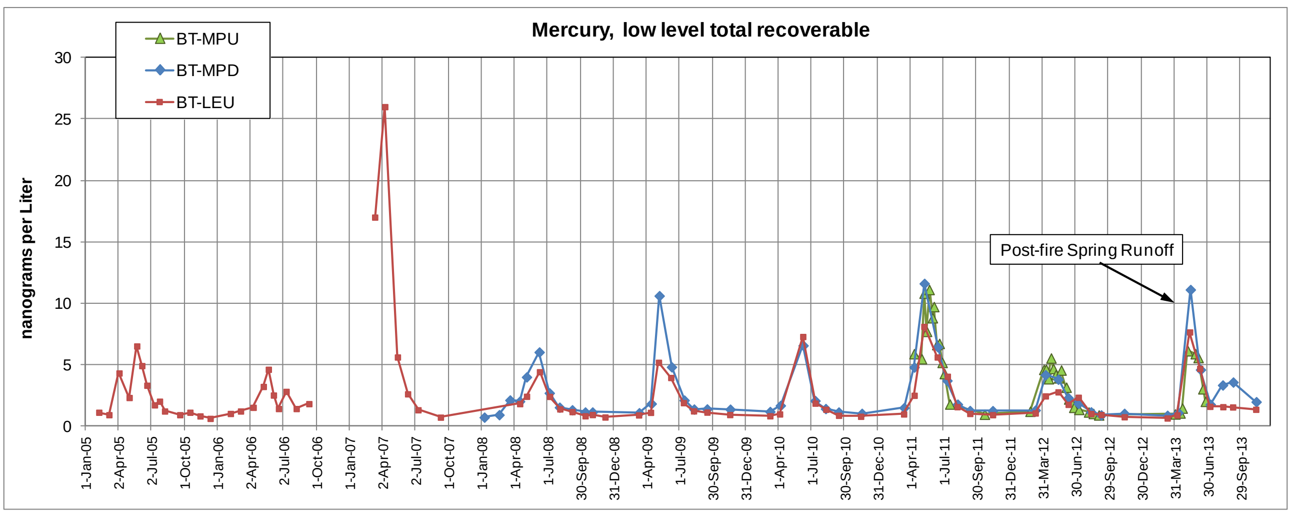


Figure 47. Mercury (low-level total recoverable) time series for BT-MPU, BT-MPD, and BT-LEU.

<u>Silver</u>. Dissolved silver is not typically detected at the Big Thompson River monitoring sites, but was detected during the 2013 snowmelt runoff at BT-MPD at a concentration of 0.009 µg/L on May 28 and 0.007 µg/L on June 12. Silver was not detected in 2013 at BT-MPU or BT-LEU at concentrations above the reporting limit. Colorado has an acute and chronic aquatic life standard for dissolved silver that is based on hardness. For a hardness of 8 mg/L (the hardness value at BT-MPD on May 28), the acute and chronic (trout) dissolved silver standards are 0.03 µg/L and 0.001 µg/L, respectively. The May 28 and Jun 12 values are both below the acute standard, but above the chronic standard. Note that the very low hardness results in very low standards, with the chronic standard of 0.001 µg/L below the detection limit of 0.003 µg/L. Silver was not detected at BT-MPD after June, and it is unknown if the Fern Lake Fire burn area was the cause of the two Spring 2013 detections.

5.6 Summary of water quality impacts due to Fern Lake Fire

Water quality data collected in 2013 downstream of the Fern Lake Fire burn scar indicate that runoff from the burn area resulted in some water quality changes in the Big Thompson River upstream and downstream of Moraine Park (at BT-MPU and BT-MPD, respectively). However, the measured impacts were relatively minor. At the monitoring site just upstream of Lake Estes (BT-LEU), very few water quality changes were observed.

The size of the burn area, the burn severity, the presence of steep slopes, and the intensity of summer storm events all contribute to the severity of water quality impacts typically observed downstream of a burn area. The Fern Lake Fire burned approximately 3,500 acres and is relatively small compared to other recent, nearby fires. In addition, the burn area made up relatively small portions of the watershed areas draining to the sampling sites, such that dilution from unburned areas would be expected. However, visual observations made at BT-MPU and BT-MPD during an intense, localized rainfall event on July 18, 2013 showed that significant amounts of sediment could be transported to the river under the right conditions (Figures 18 and 19). Water quality samples were not collected during this event (due to scheduling/manpower constraints) so the impacts from this event could not be characterized by water quality data. Data were collected during an August 13 rain event (assumed to be of a lesser intensity than the July 18 event) to characterize impacts from a typical summer storm.

A qualitative summary of the water quality changes observed at BT-MPD in 2013 are summarized in Table 5. The observed changes in concentrations indicated in Table 5 were made based on the review of time series plots and monthly boxplots conducted for this report (a rigorous statistical analysis was not conducted). The seasonal water quality observations made from the data collected at BT-MPU, BT-MPD and BT-LEU is summarized in the discussion below:

- **Prior to spring runoff**: Nitrate concentrations at BT-MPD typically peak during the winter (Dec – Feb). The 2013 nitrate concentrations at BT-MPD were within normal ranges during this time.

  Dissolved manganese at BT-MPD and BT-LEU typically peaks in March prior to the beginning of the spring snowmelt runoff, and this was the case during 2013. The March 2013 peaks in dissolved manganese at BT-MPD (29 µg/L) and at BT-LEU (12 µg/L) were both within normal ranges observed for these sites, and below the 50 µg/L secondary (aesthetic-based) drinking water standard for dissolved manganese.

- **Spring Snowmelt Runoff**: Total P, TKN and turbidity normally increase during the spring snowmelt runoff period due to the mobilization of particulate matter. Higher peak concentrations were observed in 2013 for Total P, TKN, and turbidity at Moraine Park compared to typical peak concentrations during the spring runoff. Total P at BT-MPD reached a concentration of 0.058 mg/L (about 3 times higher than typical spring runoff peaks), coincident with the peak TSS of 55 mg/L measured at BT-MPD. The 2013 spring runoff TKN peak at BT-MPD was 0.63 mg/L, compared to a range of 0.22 – 0.38 mg/L for pre-fire spring runoff peaks. The turbidity peak of 6 NTRU at BT-MPD during the spring runoff was higher than normal (approximately 4 NTRU), but would not be considered a high value under the circumstances.

Ortho-P and ammonia concentrations during the 2013 runoff were within normal ranges and did not exhibit impacts from the Fern Lake Fire. Nitrate concentrations at BT-MPD showed a very small, atypical peak on the rising limb of the snowmelt hydrograph (a concentration of 0.16 mg/L, compared to values typically in the range of 0.07 to 0.10 mg/L in May). Nutrient increases outside of normal ranges were not observed during the spring runoff at the BT-LEU site upstream of Lake Estes.

TOC and DOC concentrations also typically peak during the spring snowmelt runoff as the melting snow flushes organic matter from the forest litter and soils. Peak TOC concentrations during the 2013 spring runoff (13.6 at BT-MPD, and 10.3 mg/L at BT-LEU) were not above the normal range as measured using SM 5310C (UV-persulfate oxidation). The high-temperature combustion method yielded higher TOC concentrations (with peaks of 19.8 mg/L at BT-MPU, 19.9 mg/L at BT-MPD, and 15.1 at BT-LEU), likely due to the higher recovery of particulate organic carbon.

DOC concentrations at BT-MPU and BT-MPD did not rise above typical peaks during the spring runoff. The DOC concentrations at both BT-MPU and BT-MPD were significantly lower than their respective TOC concentrations (as measured using the high-temperature combustion method), indicating that a significant portion of the high TOC that was mobilized during the 2013 runoff was in the particulate form.

Major ion concentrations typically increase over the fall and winter, and peak at the onset of spring runoff before being diluted by runoff flows. The peak April/early May 2013 calcium, magnesium, sulfate and chloride concentrations at BT-MPU and BT-MPD were well above their typical peaks, and resulted in an elevated peak in the specific conductance at this time. An increase in major ions is often observed downstream of burn areas (particularly in streams with low pre-fire dissolved solids concentrations that drain granitic bedrock basins, such as that of the headwaters of the Big Thompson River), and the collection of major ion data during this study provided an indication that the burn area was influencing general water chemistry. Major ion concentrations remained elevated above normal values during the spring runoff after peaking just prior to the start of runoff.

Major ion concentrations at BT-LEU are normally much higher than at BT-MPU and BT-MPD, so that the increases in major ions observed at BT-MPU and BT-MPD were not observed at BT-LEU. The exception to this was sulfate, where concentrations at BT-LEU are typically similar to those at BT-MPD, and the sulfate increase observed at Moraine Park resulted in a higher concentration than normal at BT-LEU during spring runoff.

The peak total recoverable aluminum concentration during the snowmelt runoff was 470 µg/L at BT-MPU, and 831 µg/L at BT-MPD, coincident with peaks in TSS. The peak dissolved aluminum concentration during the snowmelt runoff was 236 µg/L at BT-MPU, with a similar concentration at BT-MPD, exceeding the secondary (aesthetic-based) drinking water standard for dissolved aluminum of 50 µg/L. Pre-fire aluminum data and BT-LEU aluminum data are not available for comparison.

Table 5. Qualitative changes in concentrations during 2013 compared to historic (pre-fire) concentrations at Big Thompson River at the downstream end of Moraine Park (BT-MPD).

Key to observed changes in concentrations during 2013 at BT-MPD: (qualitative, visual observations of time series & boxplots; not statistical assessment)

- **+** = **observed increase above typical range**
- **-** = **decrease**
- **++** = **significant increase**
- (blank) = **no change; values within historic ranges (annual and/or seasonal)**

Parameter		**Prior to Spring Runoff**	**Onset of Spring Runoff**	**Spring Runoff**	**Summer (July base-flow)**	**Aug 13 rain event (b)**	**Start of Sept Flood (Sept 10)**	**Fall, post-flood (Oct & Nov)**
General Parameters	pH (field)			-				
	Specific Conductance (field)		++	+		+	+	+
	Dissolved Organic Carbon (DOC)							+
	Total Organic Carbon (TOC) **(c)**							+
	Alkalinity							
	Total Suspended Solids (TSS) **(a)**			++		+	+	
	Turbidity			+		++	+	
Major Ions	Calcium		++	+		+	+	+
	Magnesium		+			+	+	+
	Potassium		+	+		+		
	Sodium							
	Chloride		++	+		+	+	+
	Sulfate		++	+		+		+
Nutrients	Ammonia							
	Nitrite + Nitrate			+				
	Ammonia + Organic Nitrogen (Total Kjeldahl Nitrogen, TKN)			++		+	+	
	Ortho-phosphate (Ortho-P)							
	Total Phosphorus (Total P)	+		++		++	++	
Metals	Aluminum, dissolved **(a)**			++		+		+
	Aluminum, total **(a)**			+		++	+	
	Arsenic, dissolved							
	Copper, dissolved							
	Iron, dissolved					+		
	Lead, dissolved							
	Manganese, dissolved		+	+		+	+	
	Mercury, low level total rec.					+	+	
	Nickel, dissolved							
	Silver, dissolved							

Notes:

(a) No data prior to 2013; comparison is made relative to low flow/baseflow conditions.

(b) Pre-fire (pre-2013) monitoring did not target rainfall events; comparison is made relative to baseflow summer conditions.

(c) TOC analysis by SM 5310C, UV-persulfate oxidation.

- **August & September rainfall events**: Monitoring related to rainfall events (August 13 rain event, and the beginning of the September 9-15 rain/flood event) revealed increased concentrations at BT-MPU and BT-MPD of turbidity, TSS, major ions, specific conductance, Total P, TKN, and TOC (TOC values from high-temperature combustion method) compared to summer baseflow conditions. Comparisons are made to summer baseflow conditions since pre-fire monitoring did not target rainfall events and concentrations that occurred during "typical" pre-fire summer storm events are not known. None of the increased concentrations measured during the 2013 storm-related events were extreme or exceptionally high. Peak turbidity during the August precipitation event was 26 NTRU at BT-MPU and 33 NTRU at BT-MPD, while peak TSS during this event was 65 mg/L at BT-MPU and 37 mg/L at BT-MPD. Total aluminum was higher during the August event than during the spring runoff, and dissolved aluminum concentrations exceeded the secondary drinking water standard (50 µg/L) at BT-MPU and BT-MPD. Dissolved manganese was elevated at the Moraine Park sites during the August and September precipitation events compared to baseline summer conditions, although all measured concentrations were below the 50 µg/L secondary drinking water standard. The total recoverable mercury concentrations measured at BT-MPD in August and September were slightly elevated compared to previous August/September values, but the values were low at less than 4 nanograms/L.

  The DOC concentrations at both BT-MPU and BT-MPD were significantly lower than their respective TOC concentrations during the August and September rainfall events (as measured using the high-temperature combustion method), again indicating that a significant portion of the high TOC that was mobilized in 2013 was in the particulate form.

- **Fall (October/November):** By the October sampling event, Total P and TKN concentrations had dropped back to within normal ranges, coincident with a drop in TSS. Major ion concentrations and specific conductance at BT-MPU and BT-MPD were slightly elevated compared to pre-fire falls. TOC (using SM 5310C) at BT-MPD and DOC at BT-MPU and BT-MPD were also elevated compared to previous falls (TOC and DOC concentrations were within the range of 3.1 to 4 mg/L, compared to a more typical fall range of approximately 1.6 to 2.2 mg/L). It is likely that the significant amounts of rain that occurred in September flushed the watershed and resulted in subsurface flows that slowly carried increased concentrations of major ions and TOC (and DOC) to the Big Thompson River well into the fall. However, it is not known the degree to which the burn area was influencing these increases, compared to increases that might have occurred as a result of a similar flood prior to the Fern Lake Fire.

  Fall data collected at BT-LEU were not assessed with regard to impacts from the Fern Lake Fire due to the overwhelming impacts of the September flood and inputs from the other watersheds that drain to BT-LEU.

Other Observations. There were several constituents that notably did not increase in 2013 (above the typical pre-fire seasonal peaks and ranges), although data in the literature for other fires would suggest that increases might be expected. Downstream of the Fern Lake Fire burn area, no increases above normal ranges were observed in 2013 for ortho-P, nitrate, and ammonia. Prior to the fall (Oct/Nov), TOC (analyzed using SM 5310C) and DOC concentrations at BT-MPD were not elevated above normal seasonal ranges.

Comparison of BT-MPU and BT-MPD. Monitoring sites were selected at both the upstream (BT-MPU) and downstream (BT-MPD) ends of Moraine Park in order to assess the ability of the flat area of Moraine Park to help mitigate the impacts of potential sediment loads originating from the upstream, steeper slopes within the burn area. During the snowmelt runoff, the TSS was higher at BT-MPD (at the downstream end) than at BT-MPU, likely due to the mobilization of finer sediments that do not have a chance to settle within Moraine Park. During the summer precipitation events, TSS was higher at BT-MPU (at the upstream end of Moraine Park) than at BT-MPD. Intense summer storm events likely mobilize coarser sediments from the areas upstream of BT-MPU that can settle within Moraine Park prior to reaching the downstream end of Moraine Park.

The chemical quality at BT-MPU and BT-MPD during 2013 was very similar. Exceptions to this were consistent with the differences observed in TSS between the two sites. During the spring runoff, when TSS was higher at BT-MPD, concentrations of Total P, TKN, and total aluminum were also higher at BT-MPD. During the August rain event, when TSS was higher at the upstream site, concentrations of Total P, TKN, TOC, and total aluminum were also higher at the upstream site. Other observed differences between the two sites include generally lower dissolved iron concentrations at BT-MPU.

Future Monitoring. It is not known the degree to which runoff from the Fern Lake Fire burn area will continue to influence water quality in the upper Big Thompson River into the future. The Erosion Risk Management Tool modeling conducted by RMNP to evaluate sediment response from the burned area concluded that natural recovery of hill-slope stability is likely to occur within 3 to 5 years following the fire. Evidence of the burn scar, however, will likely be visible from vantage points within Rocky Mountain National Park for a number of years (Figure 48).

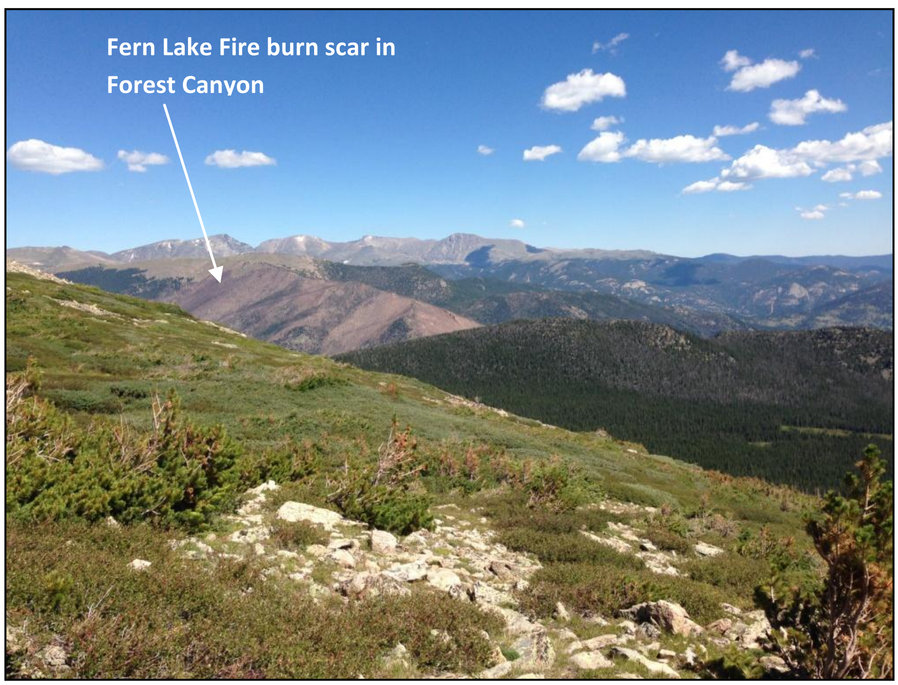


Figure 48. Fern Lake Fire burn scar in the Forest Canyon area of Rocky Mountain National Park, as seen looking north from the Flat Top Mountain Trail (Aug. 17, 2014).

Monitoring stations BT-MPD and BT-LEU are both part of the long-term BTWF Cooperative Monitoring Program, while the USGS collects data at BT-MPU and BT-MPD for other projects. The persistence of the influence of the Fern Lake Fire burn scar on water quality in the upper Big Thompson River can be evaluated from the ongoing collection of data at these sites. The water quality impacts that were observed in 2013 are expected to be the most significant, with impacts decreasing over time as the vegetation recovers.

Pre- and post-fire water quality monitoring to assess the impacts of future wildfires within the C-BT system watersheds should include turbidity, TSS, TOC, DOC, major ions, nutrients, aluminum, manganese, and iron. Additional metals may be of interest post-fire depending on the site-specific baseline data. The assessment conducted for this study highlighted the importance of a pre-fire data set. The ongoing, long-term monitoring programs conducted by the BTWF, Northern Water, the City of Fort Collins, the USGS and other entities provide baseline data that are invaluable for assessing the impacts of future, potential adverse events, including wildfires, that may occur within the watersheds. The sampling locations included in these long-term programs provide broad spatial coverage within the C-BT watersheds such that data should be available to help assess the impacts of adverse events no matter where they occur within this region.

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