Effects of the 2012 Hewlett & High Park Wildfires on Water Quality of the Poudre River and Seaman Reservoir

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1.0 Introduction

The two largest wildfires in the history of the Cache la Poudre River Watershed occurred during the summer months of 2012, resulting in extensive loss of forest and shrub lands, altered hydrology and changes water quality.

This report provides a detailed discussion on the following topics:

- fire activity and affected areas,
- observed and anticipated impacts on watershed processes,
- key uncertainties related to water quality, and
- mitigation and emergency response measures.

Results of 2012 post-fire water quality monitoring on the Poudre River and Seaman Reservoir are presented Sections 2 and 3.

1.1 Fire Activity and Affected Areas

The Hewlett Fire started on May 14, 2012 and burned until May 22, after flames from a camping stove ignited dry grass in the Hewlett Gulch area. The fire burned 7,685 acres in dense Ponderosa Pine forest stands on the north-facing slopes, as well as shrub and grasslands that occupied much of the south-facing aspects. The burned area includes sub-watersheds that drain both to the Mainstem Poudre and into Seaman Reservoir on the North Fork Poudre River.

The High Park Fire was ignited by lightning strike on June 9th and declared contained on July 2nd. In total, the fire burned 87,415 acres of primarily forested landscape, characterized by Ponderosa and Lodgepole Pine at the lower elevations and mixed conifer species at the upper elevations. To a lesser degree, shrublands, grasslands and riparian areas were also impacted (Figure 1). The burned area includes numerous sub-drainages that are tributary to the Mainstem Poudre River and the South Fork of the Poudre River. The two fires were in close proximity to each other; the northeastern edge of the High Park Fire shares the southern boundary of the Hewlett Fire, creating a contiguous burned area approximately 95,000 acres in size (Figure 2). In total, the High Park Fire destroyed 259 homes and cabins.
No homes were damaged in the Hewlett Fire.

Figure 1. Hewlett Fire burning in the riparian zone of the Poudre River.

Approximately 400 acres along the eastern edge of the High Park Fire burned within a direct drainage area for Horsetooth Reservoir, the second of the two main sources of raw drinking water supplies for the City of Fort Collins and Greeley and the Tri-Districts. Impacts to that drainage area were relatively limited and will not be included in the discussion for the purposes of this report.

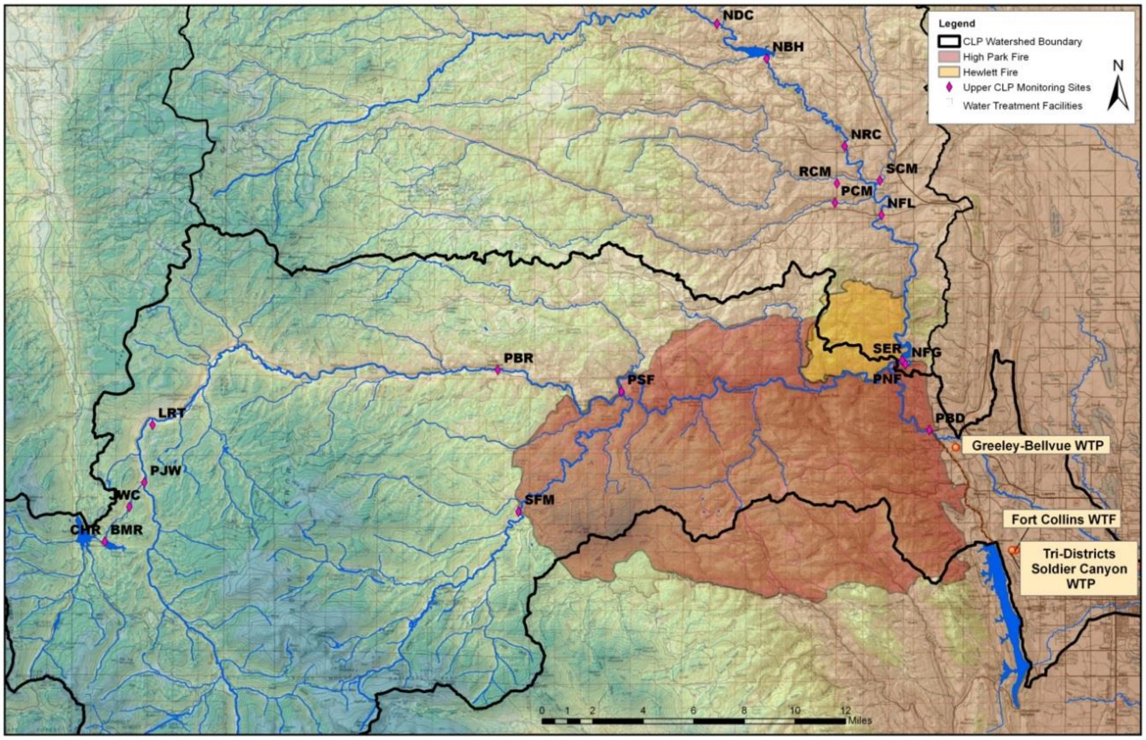


Figure 2. Map of the Upper CLP monitoring locations and the area affected by the Hewlett, High Park and Galena Fires.

1.2 Fire Effects on Forest Hydrology

The hydrology of forested ecosystems is largely controlled by the degree to which precipitation is intercepted by surface materials and the rate at which that precipitation infiltrates into the underlying soils. Tree canopy, surface vegetation and accumulated surface organic matter increase infiltration rates by slowing the velocity and dispersing the impact of water droplets, while the organic matter on the forest floor absorbs soil moisture and provides a physical barrier against erosion. As long as infiltration exceeds the rate of precipitation during snow or rain events, the hydrology will be dominated by subsurface flow.

When surface vegetation is removed, by fire or other disturbance, the capacity to intercept precipitation and retain moisture is significantly diminished. Under these conditions, the hydrology can quickly shift to overland versus subsurface flow pathways. The significance of a shift in forest hydrology from subsurface to overland flow is the tendency for overland flows to move quickly and consolidate along the paths of least resistance. The increase in flow volume and velocity dramatically increases the erosive capacity, which can quickly transform small ephemeral channels into active conduits for large sediment and debris flows following a fire (Moody and Martin, 2001).

A report issued by the Natural Resource Conservation Service (NRCS) on the increased flood potential in the High Park Fire burn area (Yochum, 2012) identified a substantial increase in the risks associated with flash flooding in several drainages in response to the shift to overland flow hydrology. The report outlines results of hydrologic model (HEC-HMS) simulations and predicts a much “flashier” system with substantial increases in peak flows and total flood flow volume, increased sediment transport, and channel destabilization in key drainages within the High Park Burn area. These hydrologic responses are expected to persist over the next several years.

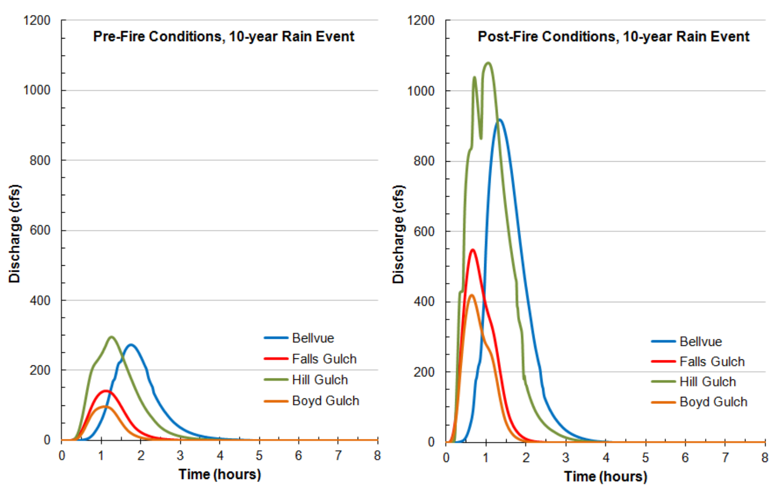


Figure 3. Pre-fire and post-fire discharge (cfs) in four key drainages in the High Park burn area under a simulated 10-yr rain event (Yochum, 2012).

A 2012 USGS analysis modeled the probabilities and volume of debris flows in all the identified drainages in the High Park Fire area under 2-yr, 10-yr, and 25-yr rain event scenarios (Verdin et al. 2012). Model results indicate that for the small and intermediate sized basins, the likelihood and size of debris flow increases with the size of the rain event. In contrast, the largest basins (Hewlett and South Fork) had low probabilities of producing debris flows even for large rain event scenarios. For example, results suggest that the South Fork of the Poudre is capable of producing debris flows of over 100,000 m^3, but the probability of such an event is only 4% and 6%, for 10-yr and 25-yr rain events, respectively.

Table 1 identifies the drainages that, according to the USGS analysis, have the highest likelihood (>50%) of delivering sediment and debris into the Mainstem Poudre River during a 10-yr-recurrence, 1-hour rain event.

Table 1. Drainages to the Mainstem Poudre River with estimated debris-flow volumes and probabilities >50% for a 10-year/1-hour precipitation event in the High Park Burn Area (USGS OFR 2012–1148).

Drainage	Area (km^2)	Probability (%)	Volume (m^3)
Skin Gulch	15.5	53	>100,000
Falls Gulch	3.5	62	32,000
Watha/Hill Gulch	14.4	57	>100,000
Boyd Gulch	3.2	75	32,000
Unnamed Creek near Hwy 14, west of mm 119	1.7	55	14,000
Unnamed Creek near Hwy 14, northwest of mm 119	3.0	69	25,000
Unnamed Creek near Hwy 14, northwest of mm 118	0.7	95	8,600
Unnamed Creek near Hwy 14, northwest of mm 118	0.5	92	6,200
Unnamed Creek near Hwy 14, between mm 115-116	0.7	86	8,100

These reports provide some spatially explicit information as to the predicted nature of stream flows and the estimated probabilities and size of debris flows out of key drainages in the burn area. Such information can be useful in the development of post-fire treatments to minimize the risk of post-fire erosion and sedimentation to human, cultural, and natural resources in the watershed. However, actual conditions will depend to a great extent on localized precipitation patterns and timing following the fire.

1.3 Burn Severity

Burn severity is a qualitative term that is used to characterize the energy that is released by a fire and the resulting impact on soils and water resources. Traditionally, fire severity for a given area is classified as low, moderate or high and depends on the amount, type and condition of fuels, the degree to which they are consumed by the fire and the amount of heat transferred into the soil profile during the fire (DeBano and Neary, 2005).

Both the High Park and Hewlett Fires burned as a mosaic of mixed burn severities according to the respective Burned Area Emergency Response (BAER) evaluations (Table 2 and Figure 4). Maps of fire extent and severity show approximately 41,113 acres (47%) of the High Park burn area 2,152 acres (28%) of the Hewlett Fire area burned at the moderate or high severity level (Table 2).

Burn severity can affect infiltration rates by altering the physical characteristics of soils, such as porosity and bulk density, and by producing hydrophobic, or water repellant soils. Hydrophobic soils occur following moderate to high-severity wildfires where soil particles have become coated with the organic waxes and other hydrocarbons from plant materials, causing water to bead-up on the surface (DeBano and Neary, 2005). Hydrophobic soils, which further promote overland flow development and increase recovery time have been identified the burn areas of the Upper Poudre watershed.

High Park Fire		
Burn Severity	**Acres**	**Percent of Burned Area**
Unburned	14,000	16%
Low	32,302	37%
Moderate	35,399	40%
High	5,714	7%
Total	**87,415**	
Hewlett Fire		
Burn Severity	**Acres**	**Percent of Burned Area**
Unburned	67	1%
Low	5,466	71%
Moderate	639	8%
High	1,513	20%
Total	**7,685**	

Table 2. Burn severity and acreage for High Park and Hewlett Fires.

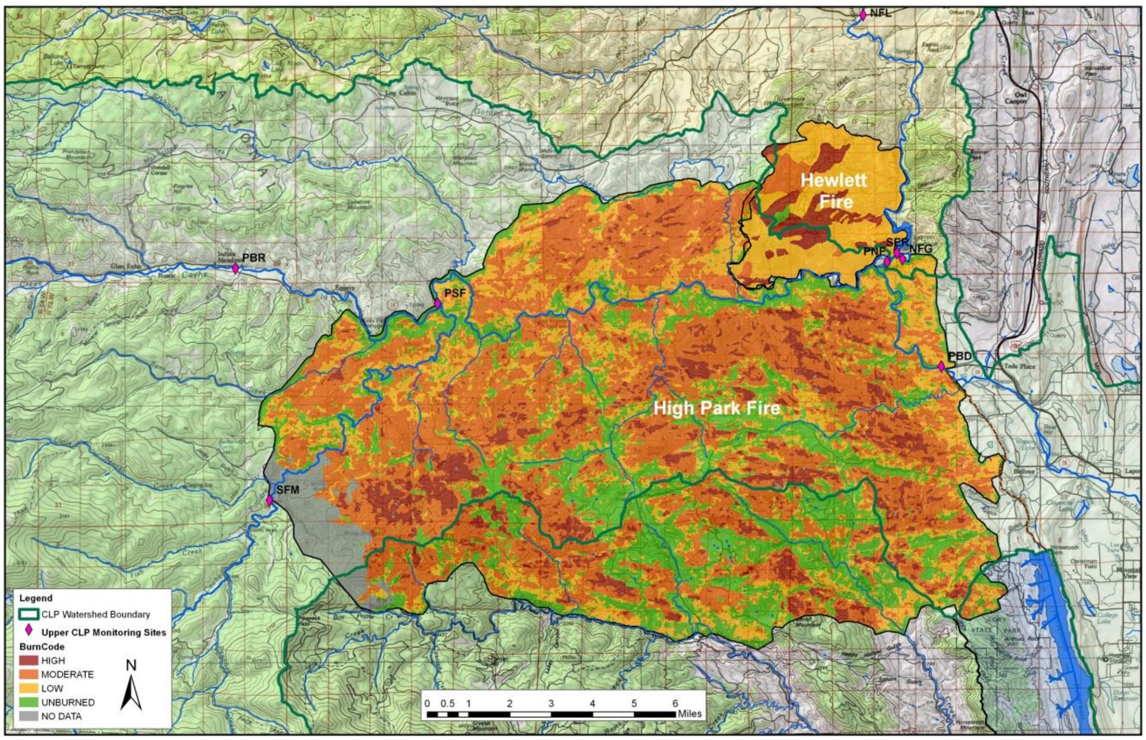


Figure 4. Soil burn severity map of 2012 High Park and Hewlett Fires in the Upper Cache la Poudre watershed.

1.4 Effects of Sediment Loading on Poudre River Water Quality

Ultimately, it was not until precipitation fell on the burned landscape that the effects of the fires on vegetation and soils translated to changes in hydrology and water quality. Immediately following the containment of the 2012 fires, convective summertime thunderstorm activity began to occur over the burn area. These thunderstorms can be extremely localized and intense, as demonstrated by the July 7th storm event which delivered 1-2 inches of rain in some areas of the burn scar, over a short amount of time (CoCoRaHS). Consistent with predictions, mudslides and debris flows occurred in many burned drainages during this rain event and others throughout the summer, delivering massive quantities of ash and sediment into the South Fork and Mainstem of the Poudre River (Figure 5) as well as into Seaman Reservoir. Notably, during the first season following the fire, even small, localized precipitation events proved sufficient to cause dramatic changes in water quality and streamflow as shown by the numerous turbidity spikes shown in Figure 6.

Figure 5. Highly turbid Poudre River during the July 7 rain event.

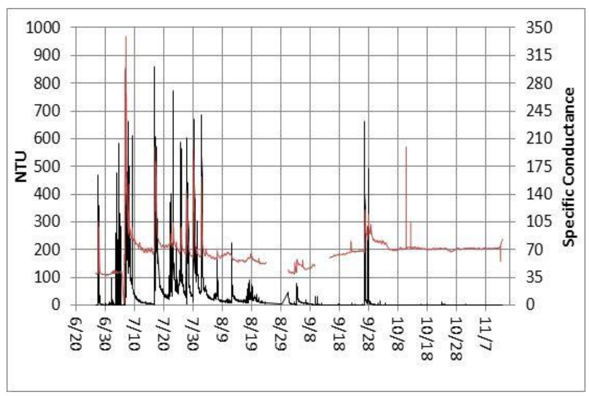


Figure 6. Turbidity (black solid line) and conductivity (red solid line) record from early warning system sonde located approximately four miles above the Fort Collins water supply intake facility.

Notably, the spike observed on September 28, 2012 occurred not as a result of precipitation event, but as a result of a water release from an upstream reservoir. The release of water effectively elevated the river level and resulted in a re-suspension of fire sediments that had settled on the river banks during earlier summer storms. This event illustrates the extreme sensitivity of river water quality immediately following the fires.

The numerous alluvial fans that are evident along the Hwy 14 indicate actively eroding channels that will continue to provide sediment and debris to the river until vegetation recovers sufficiently to stabilize the hillslopes higher in the drainage areas. The rate of vegetation establishment will vary by location and aspect, as it depends on the remaining seed bank, the available soil nutrients and condition as well as how much precipitation the area receives in the coming year. In some areas where the soil seed bank remained, new grass and forb cover established by the end of the summer; many other areas remained bare (Figures 7, 8 and 9).

Water quality samples were collected for three storm events during the summer of 2012 in order to gain an understanding of the dissolved and particulate constituents in runoff from these fires. This sampling was beyond the scope of routine monthly sampling conducted as part of the cooperative Upper Cache la Poudre Monitoring Program, which is not designed to capture the impacts of short duration events. Storm samples were collected on June 26th (Hewlett Fire runoff), July 7th, and July 25th and were analyzed for metals, nutrients, major ions, turbidity, total dissolved solids (TDS), pH and conductivity. The results of the 2012 storm sampling are discussed in Section 2.0.

Figure 7. Post-fire vegetation recovery in meadows areas of the South Fork Poudre basin, August 2012.

To help ensure the safety of field personnel and improve the likelihood of capturing storm events, an automatic sampler was installed at the Fort Collins intake facility in 2013. The auto-sampler can be triggered remotely from the Fort Collins Water Treatment Facility and capture samples from the Poudre River during storm events.

Figure 8. Debris flow across Highway 14in the High Park burn area following a rain event during summer of 2012.

Figure 9. Woody debris accumulation in the lower segment of the South Fork above the confluence with the Mainstem Poudre September 2012.

1.5 Sediment Deposition

As water levels receded following the 2012 storm events, the water quality recovered fairly quickly. However, fine mineral sediments and ash settled along the depositional reaches of the river, creating significant banks of stored black fine sediment along the river channel (Figure 10).

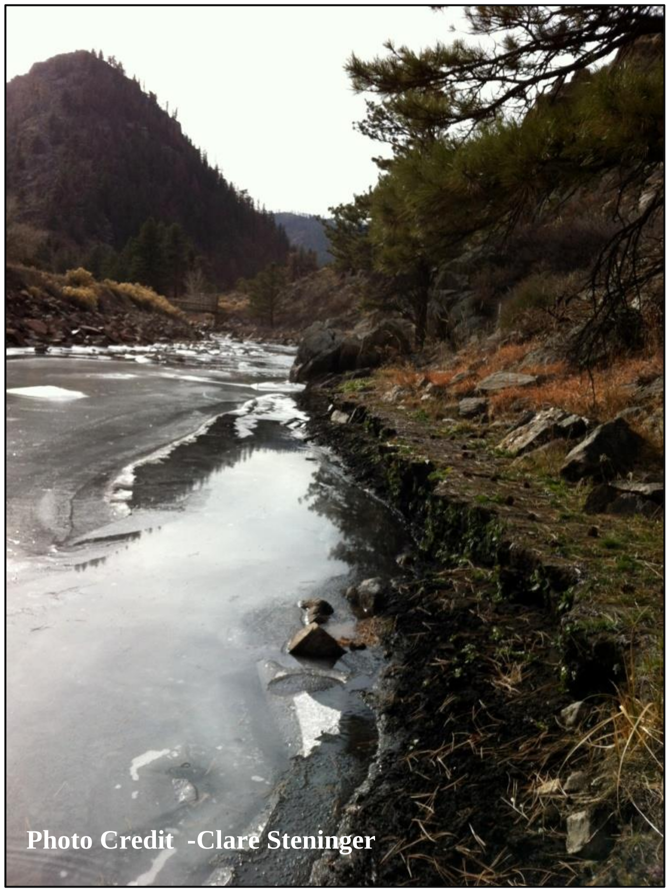


Figure 10. Riverbank deposits of sediment and ash from the High Park and Hewlett Fires on the Mainstem Poudre River.

It is expected that these stored riverbank sediments will persist until flows are sufficient to flush them downstream past water supply intake structures. However, even if flows from spring snowmelt runoff flows are sufficient to scour the riverbanks of these sediments, additional loading will likely occur during future rain events. The acute negative effects of these sediment deposits on water quality, as described above, occur any time water levels rise and stored sediments are re-suspended (e.g. spring runoff, upstream water releases). The chronic water quality effects of theses sediments are largely unknown, but this and other questions are being addressed through collaborations with University of Colorado, Colorado State University, USGS, City of Greeley, Colorado Parks and Wildlife, Denver Water, Aurora Water, and Northern Water (See Table 3).

Despite the remaining uncertainties, it is well understood that the Poudre River water quality, which was once considered stable and reliable, is now less predictable and highly sensitive to even small precipitation events or changes in flows. These changes are expected to persist as long as sediments are present in the stream channel and hillslopes remain exposed. Continued reliance on the Poudre River as a source of drinking water supply under post-fire conditions demands increased responsiveness and planning on the part of water treatment operations and water resource managers.

1.6 Early Warning System

An early warning alert system is key to being able to respond quickly to rapid changes in Poudre River water quality. To this end, a multi-parameter water quality sonde was installed in the river approximately four miles upstream of the Fort Collins water supply intake facility, immediately following the Hewlett Fire (Figure 11).

Figure 11. A multi-parameter water quality sonde provides real-time turbidity, conductivity and temperature measurements of the river as part of City of Fort Collins early-warning system.

The purpose of this installation is to provide the Cities of Fort Collins and Greeley and the Tri-Districts water treatment operations adequate warning time to bypass ash- and sediment-laden water at the intake facility in the event of a storm. The instrument provides real-time measurements of turbidity, specific conductance and temperature and has been programmed to send alerts when significant deviations from background levels are detected (See Figure 6 for example of graphical record). The turbidity and conductivity data generated from the sonde also serve as a proxy record of storms and other events that affect the water level in the river.

1.7 Pleasant Valley Pre-sedimentation Basin

To address the water quality issues from the 2012 wildfires, Fort Collins Utilities began a fast-tracked design and construction project of improvements to the turnout structure for the Pleasant Valley Pipeline (PVP). The PVP is located adjacent to the Munroe Canal, due north of the mouth of the Poudre Canyon. The resulting project consists of a new presedimentation basin located on property owned by the Northern Colorado Water Conservancy District (NCWCD). The Tri-Districts and the City share the capacity in the PVP during the summer months. The project took 4-1/2 months from design to construction completion.

This project was necessary to address the removal of sediment in the Poudre River that resulted from the High Park and Hewlett Fires during the summer of 2012. While the intake structure for the pipeline currently is equipped with mechanical screening equipment, the screen will not function properly when faced with the large amount of sediment that is expected in the raw river water.

The presedimentation basin will reduce the variability of the Poudre River water quality prior to arriving at the water treatment facility, thereby increasing the efficiency of the treatment process. The basin will also aid in the removal of debris during normal spring snowmelt runoff, when pine needles and other debris move quickly in the river.

1.8 Fire Effects Mitigation

In the aftermath of each of the 2012 fires, an interagency Burned Area Emergency Response (BAER) Team was assembled, with resource specialists from the Natural Resources Conservation Service (NRCS), Larimer County, Colorado Department of Transportation (CDOT) and the U.S. Forest Service (USFS). This team evaluated the risks to life, property, natural and cultural resources resulting from the post-fire effects and identifies treatment options for mitigating those risks. In this process, the USFS assumes responsibility for mitigating fire effects on USFS lands, while the NRCS worked with private landowners and other local participants, including the City of Fort Collins, City of Greeley, and Larimer County to identify treatment priorities. Funding provided by the participants is eligible for a federal match through the NRCS Emergency Watershed Protection (EWP) Program.

Following a fire, debris flow originates from channel scour; however, the majority of the water originates from hillslope runoff. Therefore, first focus of post-fire mitigation is often to control hillslope runoff, with in-channel controls as secondary efforts. Accordingly, the primary treatment identified through the High Park Fire BAER process was the aerial application of certified weed-free agricultural straw mulch to erosion prone hillslopes. Wood shred mulch was also identified as a treatment for high severity burn areas on steep slopes where the lighter agricultural straw was especially susceptible to being moved around by winds. The intent of both straw and wood mulch is to lend stability to fire-affected soils by reducing the impact of precipitation and helps retain soil moisture which facilitates seed establishment. Through the BAER process, the USFS identified 5,581 acres of federal land for mulching. In 2012, 881 acres of wood-shred mulch was applied, and an additional 4,700 additional acres of aerial straw mulching was completed in 2013. In addition, the NRCS identified 5,600 acres of private land for treatment – approximately 3,000 acres of which was treated with aerial application of straw mulch in 2012. Additional wood shred mulching and hillslope treatments are planned on private lands in 2013.

1.9 Key Uncertainties

In effect, the fire was a major destabilizing force within the watershed. How quickly the system will recover remains uncertain. As the recovery process continues, the Cities of Fort Collins and Greeley and the Tri-Districts must continue to rely on the Poudre River as an important municipal water supply. To understand future challenges related to water quality as well as cost-effectiveness of post-fire treatment options, water providers have worked closely with researchers from University of Colorado, Colorado State University, US Geological Survey as well as private consultants to investigate specific issues of concern. In 2012, the City of Fort Collins and/or City of Greeley contributed funding toward several post fire-related investigations, as outlined below in Table 3.

Table 3. Fire-related studies sponsored or co-sponsored by the City of Fort Collins and City of Greeley.

Study Description	Key Questions Addressed
Effectiveness of Aerial Mulching at Controlling Sediment Movement in the South Fork drainage of the Poudre River P.I. Sara Rathburn, Colorado State University Contributors: US Forest Service, City of Greeley, City of Fort Collins	Is mulching an effective treatment for reducing hillslope erosion and water quality impacts at the basin-scale? **Status:** started Spring 2013
Effects of Fire on TOC Character and Treatability P.I. – Fernando Rosario-Ortiz, University of Colorado Contributors: City of Fort Collins Utilities, CDPHE, Denver Water, Aurora Water, Northern Water, Water Research Foundation	How has Total Organic Carbon (TOC) character and Disinfection By-Product formation-potential changed post-fire and during recovery? Do those changes affect treatability? **Status**: ongoing
Leaching Study on the Effects of Stored Riverbank Fire Sediments on Poudre River Water Quality P.I. Clare Steninger, Colorado State University. Advisor: Pinar Omur-Ozbek Contributor: City of Fort Collins Utilities	How do the stored sediments affect background river water quality? **Status:** Completed
Leaching Study on the Effects of Stored Riverbank Fire Sediments on Poudre River Water Quality P.I. Clare Steninger, Colorado State University. Advisor: Pinar Omur-Ozbek Contributor: City of Fort Collins Utilities	How do the stored sediments affect background river water quality? **Status:** Completed
Cache La Poudre River Post-Fire Sediment & Aquatic Insect Monitoring Contributors: Fort Collins Natural Areas, Fort Collins Utilities, Colorado Division of Parks and Wildlife, Colorado State University	What are the effects of fine fire sediment deposition on aquatic macroinvertebrate communities in the Poudre River? **Status:** Ongoing

2.0 Results of Storm Event and Routine River Water Quality Sampling

Improvements in water quality are expected to follow the process of watershed recovery, although there is no certainty as to how long recovery will take, what specific changes in water quality can be expected along the way or if it will even return to pre-fire condition. The availability of baseline water quality data collected as part of the Upper CLP Cooperative Monitoring Program from 2008-2012 has allowed a quantitative comparison of pre- and post-fire water quality. Moving forward, routine and targeted monitoring will be essential to understanding the types of changes that have occurred and will continue to occur as watershed recovery proceeds.

In addition to routine water quality sampling, there was a focused effort on monitoring water quality during storm events, as storm samples indicate the progress of future watershed recovery (e.g. hillslope stability, hydrology, forest nutrient cycling). As previously mentioned, summertime convective thunderstorm activity began immediately following the containment of the 2012 wildfires and storm samples were collected on three occasions: June 27, July 6 and July 25.

The graphical presentations of pre- and post-fire data include routine monitoring data from the Poudre above the the North Fork (PNF), situated at the Fort Collins water supply intake. The results of the storm samples collected in 2012 near PNF are also included. Samples were analyzed by the Fort Collins WQL for nutrients, metals, hardness, and Total Dissolved Solids (TDS). The Fort Collins Water Treatment Facility Process Control Lab provided measurements for pH, Conductivity and Turbidity and Total Organic Carbon (TOC) data were provided by the US Geological Survey.

2.1 Conductivity, Alkalinity, Hardness and pH

Conductivity is an index of dissolved ionic solids in the water and hardness is an index of the total calcium and magnesium in the water. Alkalinity is a measure of the effective acid buffering capacity of the water, and is derived, in large part, from the dissociation of mineral carbonates (CO_3^-), bicarbonates (HCO_3^-) and hydroxides (OH^-). Conductivity, hardness and alkalinity are influenced by the local geology as well as the dissolved constituents derived from other watershed activities. Across the watershed, these three parameters along with pH generally track closely, with minimum values occurring during peak run-off when the concentrations of all dissolved constituents are diluted by large volume streamflows, with higher values occurring at times of low streamflow (Figures 12.a -12.d).

Late summer values for all four parameters were slightly elevated following the fires in background, non-storm event samples, but were within the range of annual variability observed from 2008 – 2012 (Figures 12.a & 12.b). Following storm events, hardness, conductivity, and pH values were substantially higher than in post-fire background samples, but concentrations returned to background levels following storm events.

Elevated hardness, conductivity, and pH following wildfires is well documented (DeBano et al, 1998; Marion et al, 1991) and is likely due to the concentration of elements such as calcium and magnesium in the surface ash and sediments that were initially washed into the river.

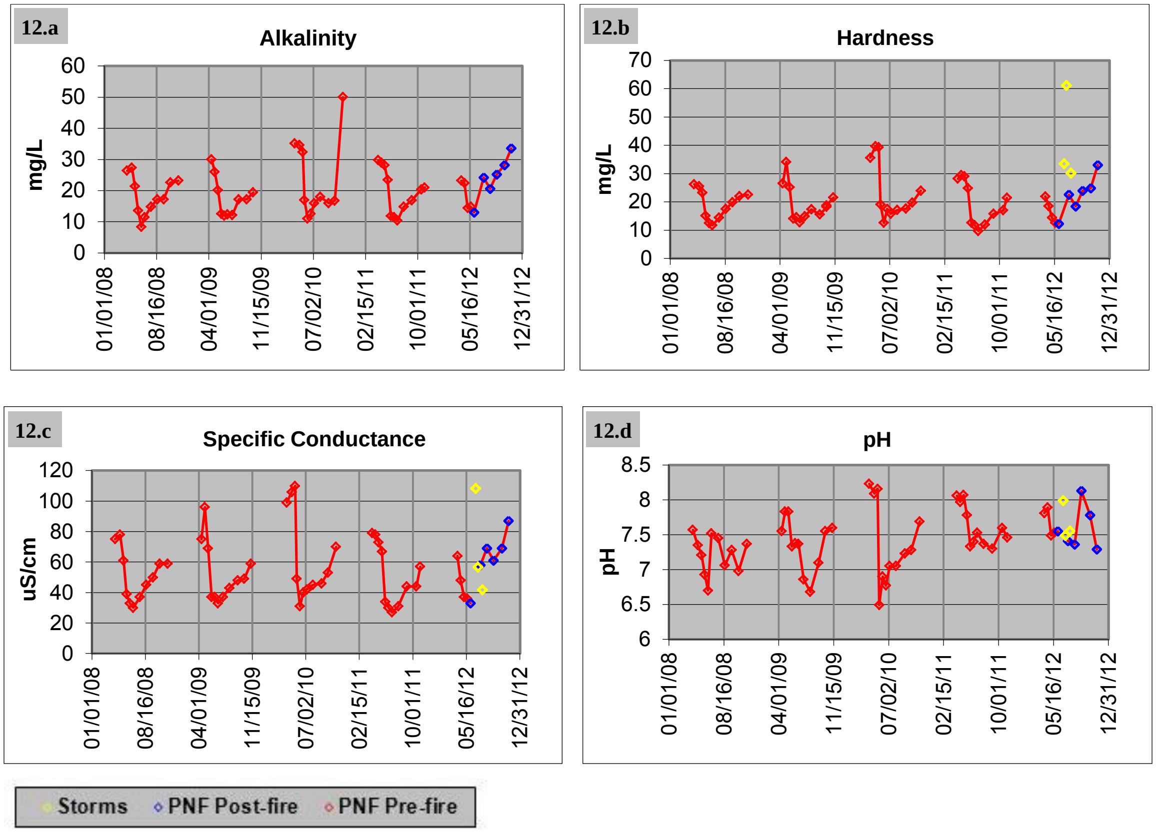


Figure 12(a-d). Pre- and post-fire alkalinity (a), hardness (b), conductance (c) and pH (d) values at PNF with storm event concentrations.

2.2 Total Dissolved Solids & Turbidity

The concentrations of total dissolved solids (TDS) in the Poudre River (PNF) range from near 20 to 80 mg/L during the years 2008-2012 (Figure 13 and closely follow the hydrograph. Peak concentrations occur during spring snowmelt runoff, followed by a steep decline during the summer months and a slight increase in concentrations again during late fall. Following the fire, concentrations spiked during storm events, but background concentrations do not indicate any sustained post-fire impact on TDS concentrations in the Poudre River (Figure 13).

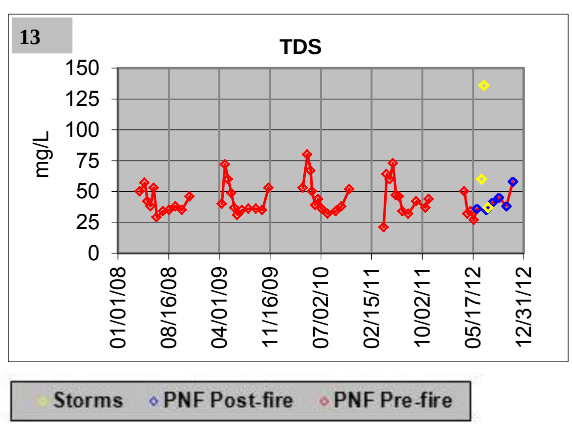


Figure 13. Pre- and post-fire Total Dissolved Solids (TDS) values at PNF with storm event concentrations.

Turbidity is a measure of the ability for light to penetrate the water column, and is influenced by the amount of suspended material in the water. Like TDS, turbidity also increases during the spring snowmelt runoff and quickly falls to low concentrations (typically below 3 Nephelometric Turbidity Units (NTU)) during the summer. Turbidity levels remained somewhat elevated (3.38 NTU) in July following the fires and were exceptionally high (14.6 NTU) during the August sampling event. Figure 14.a and 14.b illustrate the dramatic changes in turbidity that occurred during post-fire flash flooding events. Like other parameters, the concentrations seen during storm events were not sustained.

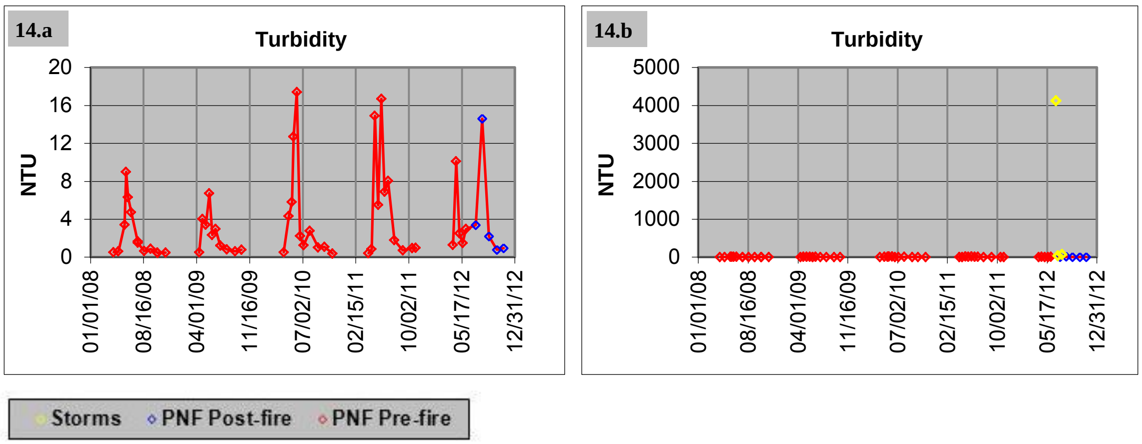


Figure 14(a-b). Pre- and post-fire Turbidity (a) values at PNF with storm event concentrations (b).

2.3 Total Organic Carbon (TOC)

Total organic carbon (TOC) is the combined dissolved and particulate carbon that originates from the watershed soils and biological material in the river. TOC is of concern for water treatment due to its tendency to react with chlorine during the disinfection process and produce regulated disinfection by-products, or DBPs. Peak Total Organic Carbon (TOC) concentrations are also closely associated with the timing and magnitude of spring snowmelt runoff. The relatively low 2012 peak flows resulted in a lower than usual peak TOC concentration of 6.8 mg/L, compared to previous years (9.5-11mg/L; Figure 15). Background (non-event) TOC concentrations did not appear to be affected by post-fire conditions. Storm events did mobilize organic carbon and resulted in elevated concentrations (3.7-13.7 mg/L); however the response was small and did not present conditions that pose concerns for water treatment.

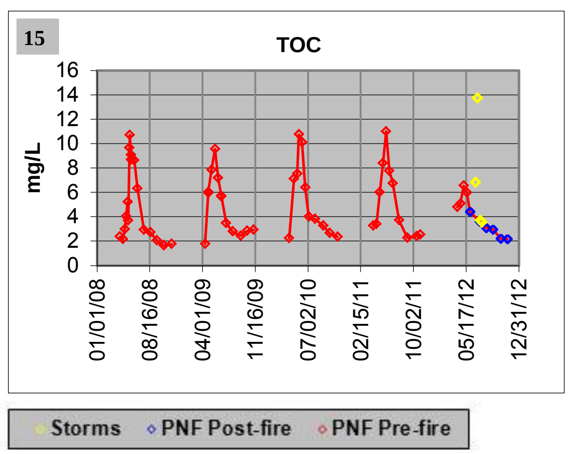
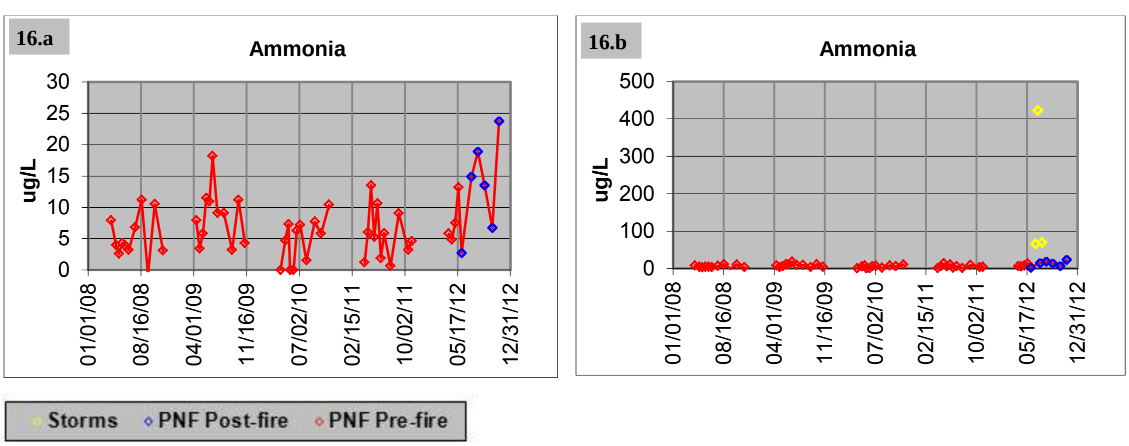


Figure 15. Pre- and post-fire Total Organic Carbon (TOC) concentrations.

2.4 Nutrients

In an unburned forested system, nutrients are made available to plants via microbial and physical decomposition of soil organic matter. In effect, the C, N, and P bound within the organic matter is slowly liberated and transformed into biologically available forms that subsequently can become dissolved in subsurface water (soil solution). Fire results in instantaneous decomposition of forest floor organic matter, where during combustion, N and C are lost to the atmosphere by volatilization, primarily as N_2, CO_2 and other volatile organic compounds (Debano et al, 1998, Debano 1991). At high combustion temperatures nearly all N is lost as N_2, whereas at lower burning temperatures, some of the N remains on the soil surface as partially consumed organic matter or is converted to NH_4 (Neary et al., 2005). Typically, less phosphorus is volatilized during a fire compared to nitrogen (Raison et al, 1985), resulting in more available P in the ash. If left undisturbed, these transformed nutrients will eventually become available for new plant growth; however, if these surface materials and the underlying mineral soils are subject to erosion, as they were following the 2012 fires in the Upper CLP watershed, the associated nutrients are transferred to the aquatic system in both dissolved and particulate forms.

Following the 2012 wildfires, the largest post-fire responses were observed for ammonia (NH_3) (indicative of NH_4 concentrations), Total Kjeldahl Nitrogen (TKN), ortho-P and Total P (Figures 16-20). Concentrations of these nutrients remained elevated in post-fire background samples to different degrees, with exceptionally high concentrations observed during and following storm events. It is expected that the higher than normal background concentrations and strong pulses following runoff events are due to the movement hillslope materials into the river. It is notable that background nitrate (NO_3) concentrations in the water did not change following the fire and that runoff events produced only very small changes in concentrations. Nitrate is a highly mobile, dissolved form of nitrogen which in an intact forested system is found primarily in the soil solution and is made available to aquatic systems through subsurface flow pathways. The lack of nitrate response immediately following the fires is possibly due to the cessation of nitrate production in the soils (Neary et al., 2005) as well as a switch from subsurface flow pathways to predominantly overland flow (Bladon et al, 2008).



Figures 16 (a-b). Pre- and post-fire values (a) with storm event concentrations (b) at PNF for ammonia.

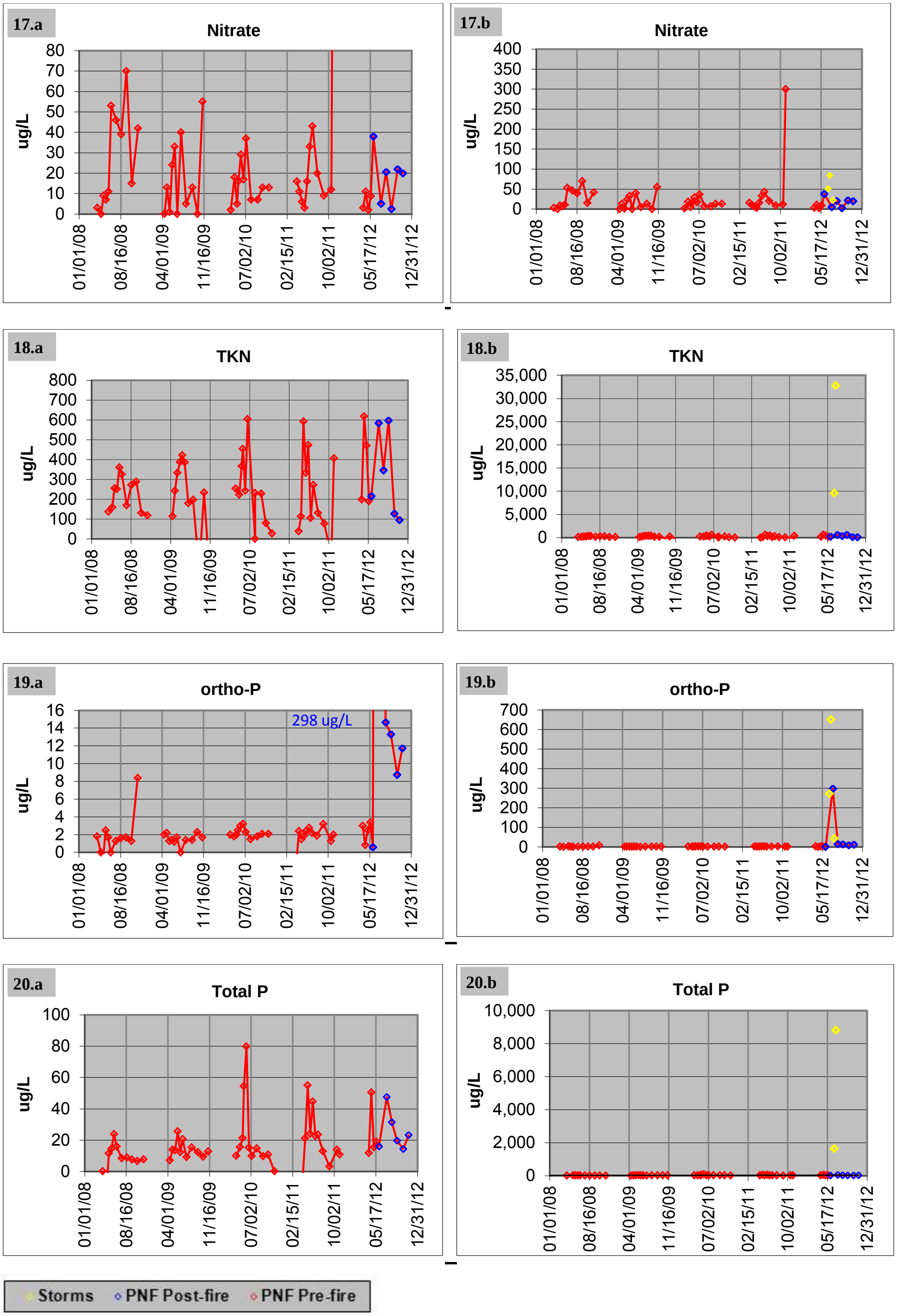


Figure 17-20 (a-b). Pre- and post-fire values (a) with storm event concentrations (b) at PNF for nitrate (Fig.17), Total Kjeldahl Nitrogen (Fig.18), ortho-phosphate (Fig.19) and Total P (Fig.20).

2.5 Metals

The high temperatures necessary to volatilize heavy metals are not typically experienced during wildfires (Knoepp et al., 2005). Like other elements, metals are liberated from soils and organic matter during combustion and find their way into surface waters during storms and runoff events. Figures 21 and 22 show total and dissolved concentrations, respectively, of heavy metals that were observed in the three storm event water samples in 2012. The observed concentrations for total metals were two to three orders of magnitude greater than dissolved concentrations. Most national drinking water standards are based on dissolved fractions and relate to finished treated drinking water; however, it is helpful to understand what concentrations are present in the source waters in order to address potential problems before the treatment phase. Assessment of total concentrations provides an approximation of how much can potentially be released given the appropriate time and conditions.

For the post-fire storm samples, only aluminum (Al) exceeded drinking water standards (Table 4). Aluminum is subject to secondary drinking water standards, which are non-enforceable guidelines for contaminants that may have cosmetic (i.e. color) or aesthetic (i.e. taste) effects, but do not pose public health concerns. The secondary standard for dissolved Al is 50 ug/L, and observed concentrations reached approximately 150 ug/L (Figure 22).

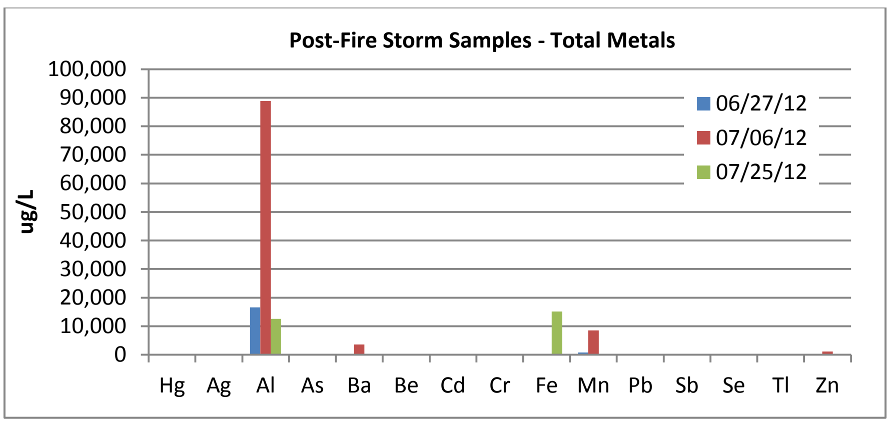


Figure 21. Concentrations of heavy metals (total) in post-fire storm samples.

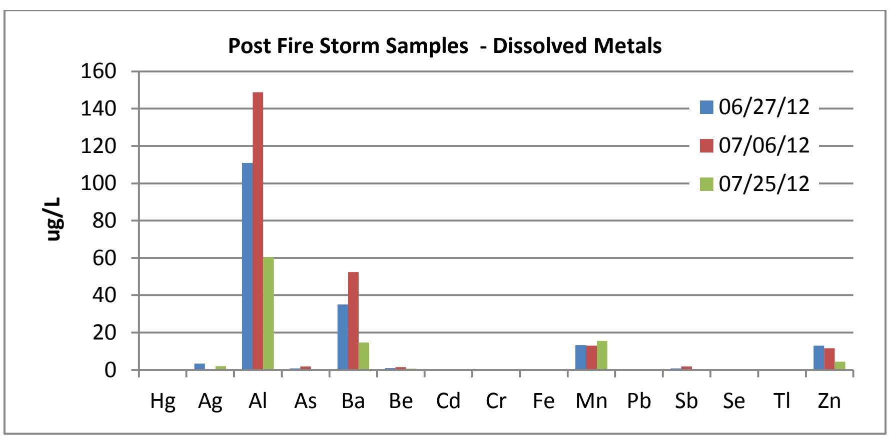


Figure 22. Concentrations of heavy metals (dissolved) in post-fire storm samples.

Table 4. National Primary and Secondary Drinking Water Standards for select heavy metals.

Metal	EPA Maximum Contaminant Level (MCL) or Treatment Technique Standard (TT)	Secondary Standard
Mercury (Hg)	2 ug/L	
Silver (Ag)	100 ug/L	
Aluminum (Al)		50 ug/L
Arsenic (As)	10 ug/L	
Barium (Ba)	2,000 ug/L	
Beryllium (Be)	4 ug/L	
Cadmium (Cd)	5 ug/L	
Chromium (Cr) - Total	100 ug/L	
Iron (Fe)		300 ug/L
Manganese (Mn)		50 ug/L
Lead (Pb)	15 ug/L	
Antimony (Sb)	6 ug/L	
Selenium (Se)	50 ug/L	
Thallium (Tl)	2 ug/L	
Zinc (Zn)		5,000 ug/L

In addition, daily grab samples were collected from the river from July 30 until September 17, while the Poudre River supply was off-line due to impaired water quality and loss of power and access at the intake facility. During this time, daily grab samples were analyzed for dissolved aluminum and manganese (Figures 23.a and 23.b). Like the storm event samples, the daily grab samples results indicated that storm events produce high concentrations of these metals, but concentrations decreased rapidly to low levels following rain events.

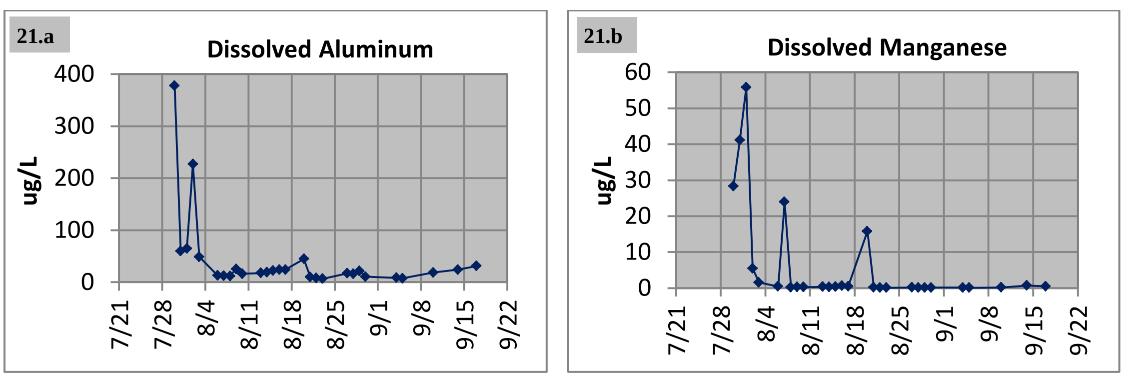


Figure 23(a-b). Concentrations of dissolved aluminum (a) and manganese (b) in daily grab samples from Poudre River (July 30 to September 17), following High Park and Hewlett Fires.

3.0 Fire Effects on Water Quality in Seaman Reservoir

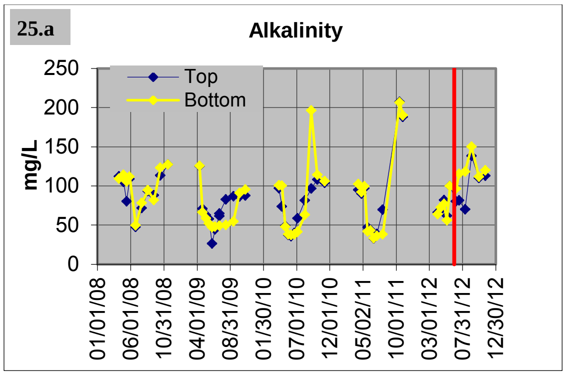
The Hewlett Fire burned an extensive area surrounding Seaman Reservoir, which is a major component of the City of Greeley's water supplies (See Figure 5). As on the Mainstem Poudre River, summer thunderstorm activity delivered a substantial amount of ash and sediment into Seaman Reservoir from some of the moderately and severely burned basins that drain directly into the upper reaches of the reservoir. This section will document the pre- and post-fire water quality collected near the spillway at the top and bottom of the reservoir.

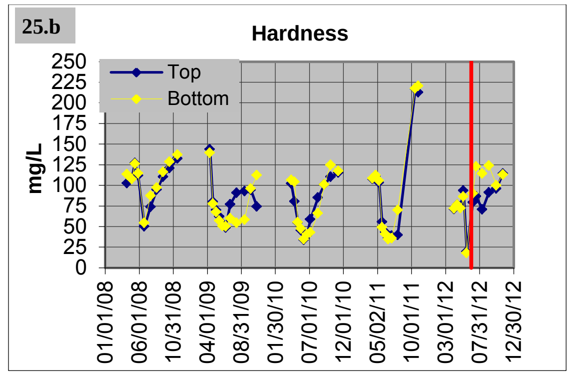
In addition to fire-sediment loading, there were additional factors that likely affected the water quality, including drought and other limitations on reservoir operations that resulted in very little water being released from the reservoir during the 2012. The lack of fresh water circulation within the reservoir and above average temperatures in 2012 contributed to prolonged periods of low dissolved oxygen and algal blooms (indicated by chlorophyll-*a* concentrations) (Figure 24). It should be noted that based on available data, the observed water quality impacts cannot be attributed solely to wildfire impacts, or any other single factor.

Figure 24. An aerial view of Seaman Reservoir captures the high chlorophyll-a concentrations that resulted from the 2012 mid-summer algal bloom.

3.1 Alkalinity and Hardness

Post-fire concentrations of alkalinity and hardness were within the range of the mid- to late-summer concentrations seen in previous years (Figures 25.a and 25.b).

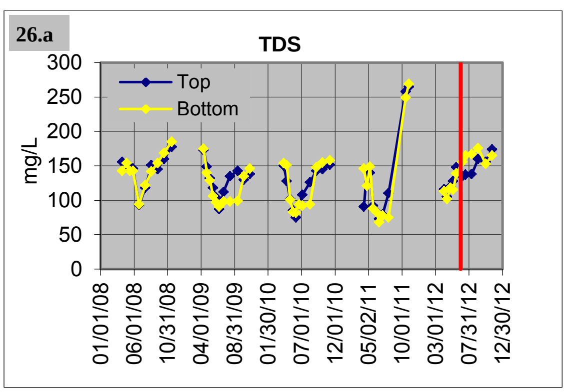


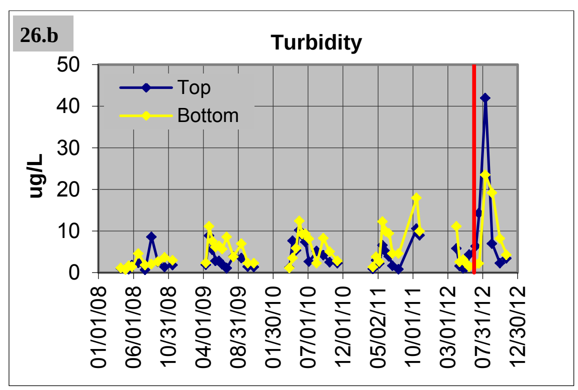


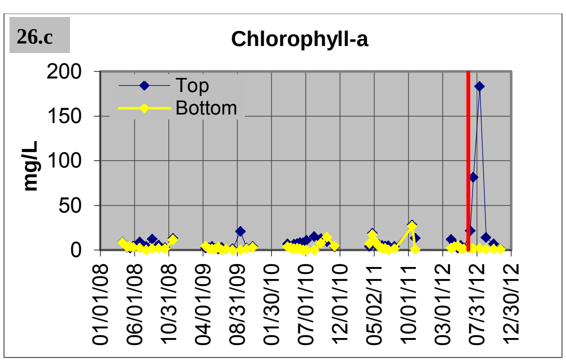
Figures 25 (a-b). Pre- and post-fire values for alkalinity (a), hardness (b) in Seaman Reservoir.

3.2 Total Dissolved Solids (TDS), Turbidity and Chlorophyll-a

TDS concentrations did not follow the typical seasonal pattern of spring dilution followed by late summer increases, most likely due to limited through-flow of water. However, all observed concentrations were within the range of values seen in previous years. In contrast, chlorophyll-a and turbidity exhibit exceptionally high concentrations at the top of the reservoir on the August 13th sample date.







Figures 26 (a-c). Pre- and post-fire values for Total Dissolved Solids (a), turbidity (b) and chlorophyll-a (c) in Seaman Reservoir.

These spikes in surface concentrations of chlorophyll-a and turbidity coincide with exceptionally high concentrations of dissolved oxygen (12.28 mg/L) at the surface of the reservoir (Figure 27). Together, these events suggest high rates of photosynthesis during this period, and provide evidence that the high turbidity values are due to algal production rather than an influx of inorganic fire sediments. Furthermore, the abrupt decreases in chlorophyll-a and dissolved oxygen concentrations indicate a subsequent period of algae die-off and/or consumption by zooplankton.

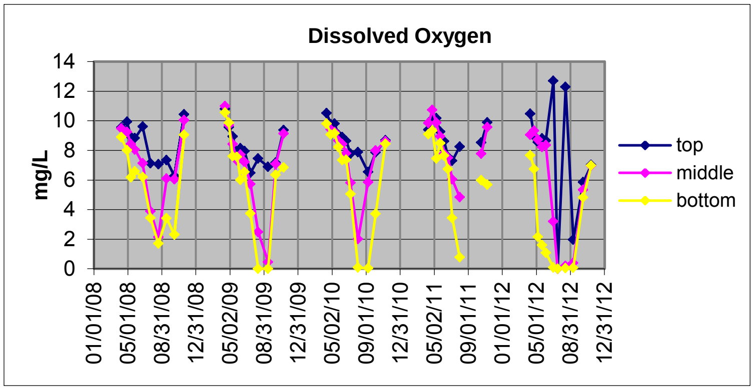


Figure 27. Dissolved oxygen concentrations at the top, middle and bottom of Seaman Reservoir for 2008- 2012.

3.3 Total Organic Carbon (TOC)

Concentrations of TOC do not appear to be affected by fire (Figure 28). Like other parameters, the timing of high concentrations of TOC at the top of the reservoir suggests that much of the available organic carbon may be derived from both dissolved and particulate matter from algal production and decomposition.

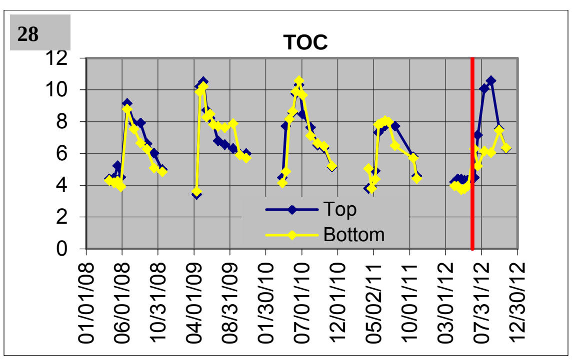
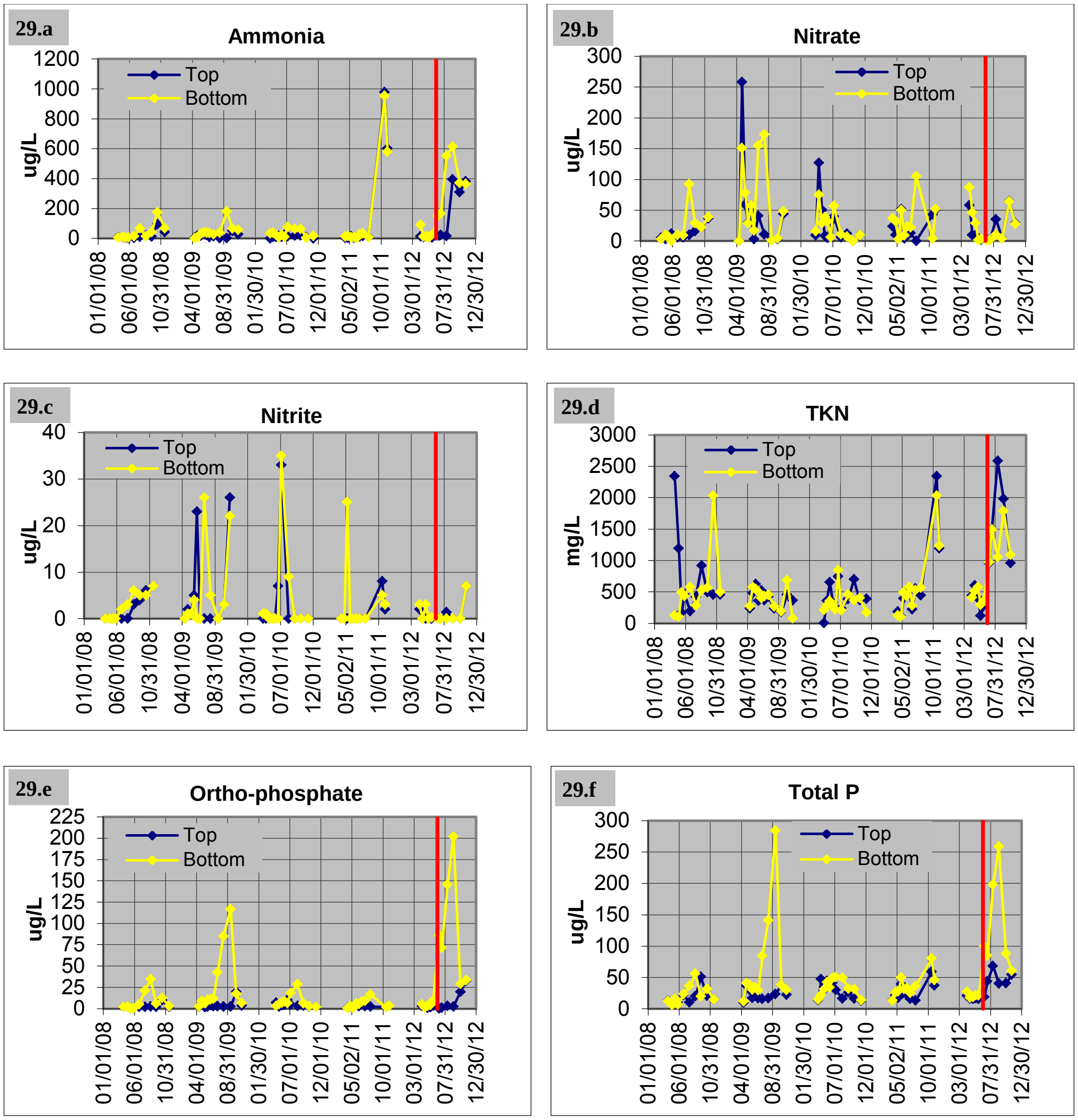


Figure 28. Pre- and post-fire concentrations of Total Organic Carbon (TOC) in Seaman Reservoir.

3.4 Nutrients

High concentrations of ammonia, Total Kjeldahl Nitrogen (TKN), ortho-phosphate and total phosphorus were observed during the summer following the fire (Figure 29.a, 29.e and 29.f). However, the timing of the 2012 spikes in concentrations were similar to previous years, and like other parameters, coincide with the seasonal period of low dissolved oxygen at the bottom of the reservoir. The magnitude of the spikes may be attributed to the particularly prolonged period of hypoxia, during which time nutrients are released from the sediments.



Figures 29(a-f). Pre- and post-fire values for ammonia (a), nitrate (b) and nitrite (c), Total Kjeldahl Nitrogen (TKN) (d), ortho-phosphate (e) and Total phosphorus (f) in Seaman Reservoir.

In general, it appears that the influx of sediments from the surrounding burned hillslopes is not significantly affecting water quality at the outlet of the reservoir at this time. The apparent lack of response may be being masked by the larger influence of seasonal reservoir dynamics. It is also possible that the location of the sediment deposition is far enough away from the reservoir outlet, that in a year with little through-flow, the impacts on downstream water quality are not yet detectable. Because fire sediments can carry high concentrations of nutrients, metals and organic matter, it is expected that they will have a detectable impact on water quality in the reservoir. The timing of when those impacts become noticeable will depend upon the reservoir dynamics in the coming years.

3.5 Post-fire changes in monitoring

The availability of baseline data obtained from the Upper CLP water quality monitoring program from 2008-2012 provides an excellent opportunity to monitor changes in river and reservoir conditions following large scale events like the wildfires of 2012. Minor changes in the monitoring plan were made in 2012 to ensure that the effects of the fires were captured. These changes include increased frequency and locations at which metals are sampled, as well as an increase in the number of metals monitored at each site. The new metals monitoring is outlined in Table 5 below.

Table 5. Sampling locations and frequencies for metals sampling as part of Upper CLP Monitoring Program.

	NFL	SER-Top	SER-Bottom	NFG	PBR	PSF	PNF	PBD
Al[1]	3x/yr[2]	3x/yr	3x/yr	3x/yr	3x/yr	3x/yr	3x/yr	3x/yr
As		3x/yr	3x/yr	3x/yr			3x/yr	3x/yr
Cd		3x/yr	3x/yr	3x/yr			3x/yr	3x/yr
Cr		3x/yr	3x/yr	3x/yr			3x/yr	3x/yr
Cu		3x/yr	3x/yr	3x/yr			3x/yr	3x/yr
Fe[1]	3x/yr	3x/yr	3x/yr	3x/yr	3x/yr	3x/yr	3x/yr	3x/yr
Hg		3x/yr	3x/yr	3x/yr			3x/yr	3x/yr
Mn[1]	3x/yr	3x/yr	3x/yr	3x/yr	3x/yr	3x/yr	3x/yr	3x/yr
Pb		3x/yr	3x/yr	3x/yr			3x/yr	3x/yr
Se		3x/yr	3x/yr	3x/yr			3x/yr	3x/yr
Ag		3x/yr	3x/yr	3x/yr			3x/yr	3x/yr
Ni		3x/yr	3x/yr	3x/yr			3x/yr	3x/yr
Zn		3x/yr	3x/yr	3x/yr			3x/yr	3x/yr

[1]All metals analyzed for dissolved fractions; Al, Mn and Fe also analyzed for Total Digested fractions
[2] 3x/yr = samples to be collected in May, August, and October

4.0 References

Bladon, K.D., Silins, U., Wagner, M.J., Stone, M., Emelko, M.B., Devito, K.J., Mendoza, C.A. & Boon, S. (2008). Wildfire impacts on nitrogen export and production from headwater streams in southern Alberta's Rocky Mountains. Can. J. For. Res. 38, 2359–2371.

Brooks, K.N, Ffolliott, P.F., Gregersen, H.M., Debano, L.F.2003. Hydrology and the management of watersheds. 3rd Edition. Ames: Iowa State Press. 704p.

DeBano, L.F., neary, D.G, Ffolliott, P.F.1998. Fire's effects on ecosystems. New York; John Wiley & Sons, Inc. 333p.

Debano 1991. The effect of fire on soil. In: Harvey, A.E., Nueunschwander, L.F.(eds.) Management and productivity of western-montane forest soils. General Technical Report INT-280. Ogden, UT: U.S. Dept. of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station: 32-50.

DeBano, L.F., Neary, D.G. 2005. Chapter 1: Introduction: Part A – The Soil Resource: Its Importance, Characteristics, and General Responses to Fire. In: Neary, D.G., Ryan, K.C., DeBano, L.F., (eds). Wildland Fire in Ecosystems: Effects of Fire on Soil and Water. General Technical Report-42-vol.4. U.S. Dept. of Agriculture, Forest Service, Rocky Mountain Research Station.

Knoepp, J.D., DeBano, L.F., and Neary, D.G., 2005. Chapter 3: Soil Chemistry. In: Neary, D.G., Ryan, K.C., DeBano, L.F., (eds). Wildland Fire in Ecosystems: Effects of Fire on Soil and Water. General Technical Report-42-vol.4. U.S. Dept. of Agriculture, Forest Service, Rocky Mountain Research Station.

Marion, G.M; Morena, J.m, Oechel, W.C.1991. Fire severity, ash deposition, and clipping effects on soil nutrients in chaparral. Soil Science Society of America Journal 55: 235-240.

Moody, J.A., Martin, D.A. 2001. Post-fire, rainfall intensity-peak discharge relations for three mountainous watersheds in the western USA. Hydrological Processes 14: 2981-2993.

Neary, D. G., Landsberg, J.D., Tiedemann, A.R., Ffolliott, P.F. 2005. Chapter 6: Water Quality. In: Neary, D.G., Ryan, K.C., DeBano, L.F., (eds). Wildland Fire in Ecosystems: Effects of Fire on Soil and Water. General Technical Report-42-vol.4. U.S. Dept. of Agriculture, Forest Service, Rocky Mountain Research Station.

Oropeza, J. 2013. The 2012 5-yr synthesis report for the Collaborative Upper Cache la Poudre River Water Quality Monitoring Program. City of Fort Collins (*forthcoming*).

Raison, R.J., Khanna, P.K., Woods, P.V. 1985. Mechanisms of element transfer to the atmosphere during vegetation fires. Canadian journal of Forest Research. 15: 132-140.