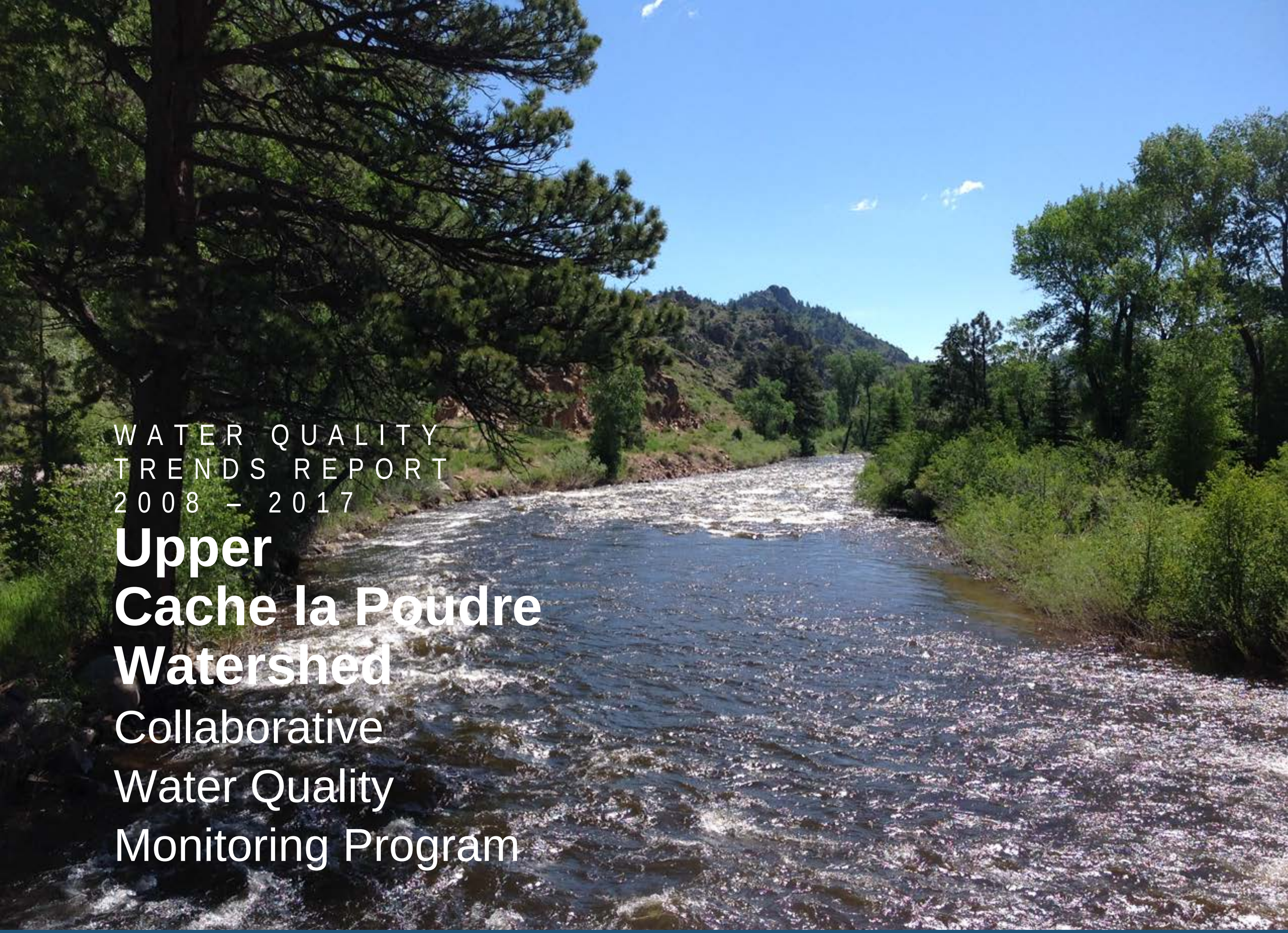

WATER QUALITY TRENDS REPORT 2008 – 2017

Upper Cache la Poudre Watershed

Collaborative Water Quality Monitoring Program

June 25, 2018

PREPARED FOR:
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EXECUTIVE SUMMARY

BACKGROUND

The Upper Cache la Poudre Collaborative Water Quality Monitoring Program (hereafter referred to as the Upper CLP monitoring program) is designed to assist the City of Fort Collins, the City of Greeley and the Soldier Canyon Water Treatment Authority (formerly Tri-Districts) in meeting current and future drinking water treatment goals by reporting current water quality conditions and trends within the Upper Cache La Poudre River (CLP) watershed and summarizing issues that potentially impact watershed health. Annual reports were published in 2008 through 2011 and 2013 through 2016. The last five-year report was published in 2012.

SCOPE OF THE 2017 WATER QUALITY TRENDS REPORT

This water quality trends report analyzes the hydrology, climate, and water quality in the Upper CLP watershed over the last decade. Water quality data collected throughout the Upper CLP watershed were analyzed for long-term trends to determine if concentrations increased, decreased or stayed the same over the ten-year period of record from 2008 to 2017. This report documents 1) watershed impacts and issues of concern; 2) significant trends in climate, hydrology, and water quality in the Upper CLP watershed; 3) potential sources of pollution and/or watershed disturbances influencing water quality trends; and 4) a summary of significant findings and implications to water treatment.

STATE OF UPPER CACHE LA POUDRE WATERSHED

Watershed Impacts & Issues of Concern

Over the past ten years the Upper CLP watershed has experienced periods of wet and dry water years influencing both streamflow and water quality conditions in the CLP watershed. Exceptionally hot and dry conditions in 2012 led to extreme drought and two major wildfires in the watershed. In the following year, a long-duration, high intensity rainfall event brought severe flooding in streams and rivers throughout the Upper CLP watershed. These two events signify the extreme variability in the hydrology, and weather of the Upper CLP watershed and highlight potential future climate driven events that may impact water quality.

Forest insects and diseases have impacted the Upper CLP watershed over the past two decades. Although, recent surveys show the mountain pine beetle epidemic is declining, expanding outbreaks in Engelmann spruce forests suggests that forested watershed continue to be susceptible to forest insects and disease.

Watershed impacts caused by climate change and atmospheric deposition are less clear, but remain a major threat to future watershed processes and water quality. Unlike extreme-weather driven disturbances, the watershed response from climate change and atmospheric deposition impacts may be subtle emphasizing the importance of continued monitoring through the Upper CLP watershed.

Climate & Hydrology Trends

Air temperature increased at higher elevations in the Upper CLP watershed over the last decade. Precipitation volume did not change, but the maximum amount of water contained within the snowpack decreased over the past decade suggesting higher elevations of the Upper CLP watershed may receive less snowfall in the future. In addition, snowpack and precipitation data imply that precipitation patterns may be shifting in the upper CLP watershed. No trends were measured in the magnitude or timing of streamflow, but streamflow volume increased over the long-term period of record specifically during the winter months. This trend may be driven by the recent flood event in 2013 and elevated baseflows for several years following the flood.

Trends in Water Quality

Two types of trends were identified in the Upper CLP watershed. In general, step trends (an abrupt shift in data) were measured for most water quality parameters at monitoring sites from the South Fork CLP river (PSF) downstream to the Mainstem CLP river below the confluence with the North Fork (PBD). These trends occurred in response to the dramatic landcover change in the Mainstem CLP watershed caused by wildfire that burned in 2012. Monotonic trends, or gradual, continuous changes (increasing or decreasing) in the data over time, were measured in pH, total organic carbon, total dissolved solids, and ammonia.

Trends were detected at varying scales. Both site-specific and watershed-wide trends were detected in the Upper CLP watershed. Site-specific trends capture impacts to a specific site, while watershed-wide trends imply a large disturbance that impacted the entire basin or large areas of basin impacting multiple monitoring locations.

Implications to Water Treatment

Long-term trends in certain water quality parameters may pose issues to water treatment processes in the future. It is anticipated that water quality impacts caused by recent wildfire and flooding will recover with time. Wildfire impacted water quality parameters are trending toward baseline conditions in recent years implying watershed recovery. However, climate change projections for Colorado point to a warmer climate and unpredictable precipitation patterns that will likely increase the frequency and severity of drought and wildfires, and other extreme-weather events that can impact water quality.

Water quality changes were detected for the following parameters near the City of Fort Collins', City of Greeley's and Soldier Canyon Water Authority's raw water intakes:

- Alkalinity and hardness
- pH
- Total dissolved solids
- Total organic carbon
- Nutrients
- Total coliforms

In general, the water treatment facilities should continue to closely monitor key water quality parameters and may be required to adjust blending ratios and chemical additions to meet current water treatment goals. Routine water quality monitoring throughout the Upper CLP watershed will allow the Upper CLP Collaborative Monitoring Program to continue to sustain a long-term data record providing program partners with valuable information on short and long-term trends that may arise in the future.

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LIST OF ABBREVIATIONS & ACRONYMS

%	percent
BMR	Barnes Meadow Reservoir Outflow (routine monitoring site)
Ca	Calcium
CO_3^-	Carbonates
cfs	cubic feet per second
CHR	Chambers Lake Outflow (routine monitoring site)
CLAFTCCO	Cache la Poudre at Canyon Mouth Near Fort Collins Stream gage
CLP	Cache la Poudre River
cfu/100 mL	colony forming units per 100 milliliters
DBP	Disinfection By-Product
EPA	Environmental Protection Agency
FCWQL	Fort Collins Water Quality Lab
FCWTF	Fort Collins Water Treatment Facility
H^+	Hydrogen ion
JWC	Joe Wright Creek above the Poudre River (routine monitoring site)
K	Potassium
LRT	Laramie River Tunnel (routine monitoring site)
m	meter
Mg	Magnesium
mg/L	milligrams per liter
Na	Sodium
NADP	National Atmospheric Deposition Program
NBH	North Fork of the Poudre River below Halligan Reservoir (routine monitoring site)
NDC	North Fork of the Poudre River above Dale Creek Confluence (routine monitoring site)
NFG	North Fork of the Poudre River below Seaman Reservoir (routine monitoring site)
NFL	North Fork of the Poudre River at Livermore (routine monitoring site)
ng/L	nanograms per liter
NH_3-N	Ammonia as nitrogen
NO_2-N	Nitrite as nitrogen
NO_3-N	Nitrate as nitrogen
NTU	Nephelometric Turbidity Units
OH^-	Hydroxide ion
^oC	degrees Celsius

PBD	Poudre River at the Bellvue Diversion (routine monitoring site)
PBR	Poudre River below Rustic (routine monitoring site)
PCM	Pine Creek Mouth (routine monitoring site)
PJW	Poudre River above the confluence with Joe Wright Creek
PNF	Poudre River above the North Fork (routine monitoring site)
PO_4	ortho-phosphate
ppt	parts per trillion
RCM	Rabbit Creek Mouth (routine monitoring site)
SCFP	Soldier Canyon Filter Plant
SCWTA	Soldier Canyon Water Treatment Authority
SCM	Stonewall Creek Mouth (routine monitoring site)
SFC	South Fork above confluence with the Mainstem (routine monitoring site)
SFM	South Fork of the Poudre River above the Mainstem (routine monitoring site)
SMKT	Seasonal Mann-Kendall Test
SNOTEL	Snow telemetry network
SWE	Snow water equivalent
T&O	Taste & Odor
TKN	Total Kjeldahl Nitrogen
TN	Total Nitrogen
TOC	Total Organic Carbon
TP	Total Phosphorus
µg/L	micrograms per liter
µS/cm	microSeimens per centimeter
USGS	United States Geological Survey
WTP	Water Treatment Plant

1.0 INTRODUCTION

1.1 BACKGROUND

The Upper Cache la Poudre (CLP) River is an important source of high-quality drinking water supplies for communities served by the City of Fort Collins Water Treatment Facility (FCWTF), the City of Greeley-Bellvue Water Treatment Plant (WTP), and the Soldier Canyon Water Treatment Authority's (SCWTA) Soldier Canyon Filter Plant (SCFP). In the shared interest of sustaining this high-quality water supply, the City of Fort Collins, the City of Greeley, and the SCWTA partnered in 2007 to design the Upper CLP Collaborative Water Quality Monitoring Program. The Program was subsequently implemented in spring 2008. The goal of this collaborative monitoring program is to assist the participants in meeting current and future drinking water treatment goals by providing up-to-date information about water quality and trends within the Upper CLP watershed.

Raw CLP River water quality parameters that have historically had the most impact on treatment at the three treatment plants include:

- turbidity
- total organic carbon (TOC)
- pH
- alkalinity
- temperature
- pathogens (*Giardia* and *Cryptosporidium*),
- taste and odor (T&O) compounds

Seasonal updates, annual water quality reports, and five-year reports for the collaborative program are prepared by City of Fort Collins' Source Watershed Program staff to keep participants informed of current issues and trends in water quality of the Upper CLP. Seasonal updates are provided throughout the monitoring season in the Spring, Summer, and Fall. These updates include a summary of precipitation, streamflow, and water quality conditions. The purpose of annual reports is to summarize hydrologic and water quality information for the current year, provide a comparison with water quality from the preceding three years, describe notable events and issues, and summarize the results of special studies. The five-year report provides a more in-depth analysis of long-term trends in watershed hydrology, climate and water quality. Upper CLP updates and reports are available on the City of Fort Collins Utilities' Source Water Monitoring website:

(www.fcgov.com/ source-water-monitoring).

1.2 WATERSHED DESCRIPTION AND SAMPLING LOCATIONS

Sampling efforts are divided between the Mainstem (including the Little South Fork Cache la Poudre River) and North Fork Cache la Poudre River watersheds. Collectively these drainages encompass approximately 645,500 acres of forest, other natural land types, and agricultural land. An additional 4,700 acres, representing less than 1% of land surface, is developed for commercial, industrial, utility, urban or residential purposes.

The original monitoring network, established in 2008, consisted of 20 water quality monitoring locations selected to characterize the headwaters, major tributaries and downstream locations of the Upper CLP River near the City of Fort Collins, SCWTA, and City of Greeley raw water intake structures. In 2014, an additional monitoring location was included on the South Fork (SFC) approximately 500 feet upstream of the confluence with the Mainstem Poudre River. This monitoring location was added to the monitoring network to capture the full extent of the South Fork drainage following the 2012 High Park Fire. The South Fork above Mainstem (SFM) site was discontinued in 2015 because analyses between SFC and SFM revealed similar water quality conditions. The Seaman Reservoir (SER) monitoring locations were also discontinued from the Upper CLP monitoring program in 2015.

The current monitoring network consists of 18 monitoring locations (Figure 1.1). A description and rationale for each site is provided in Attachment 2.

1.3 SAMPLING PLAN AND PARAMETERS

The sampling frequency for the Upper CLP monitoring program was determined based on both statistical performance and cost considerations. Parameters included

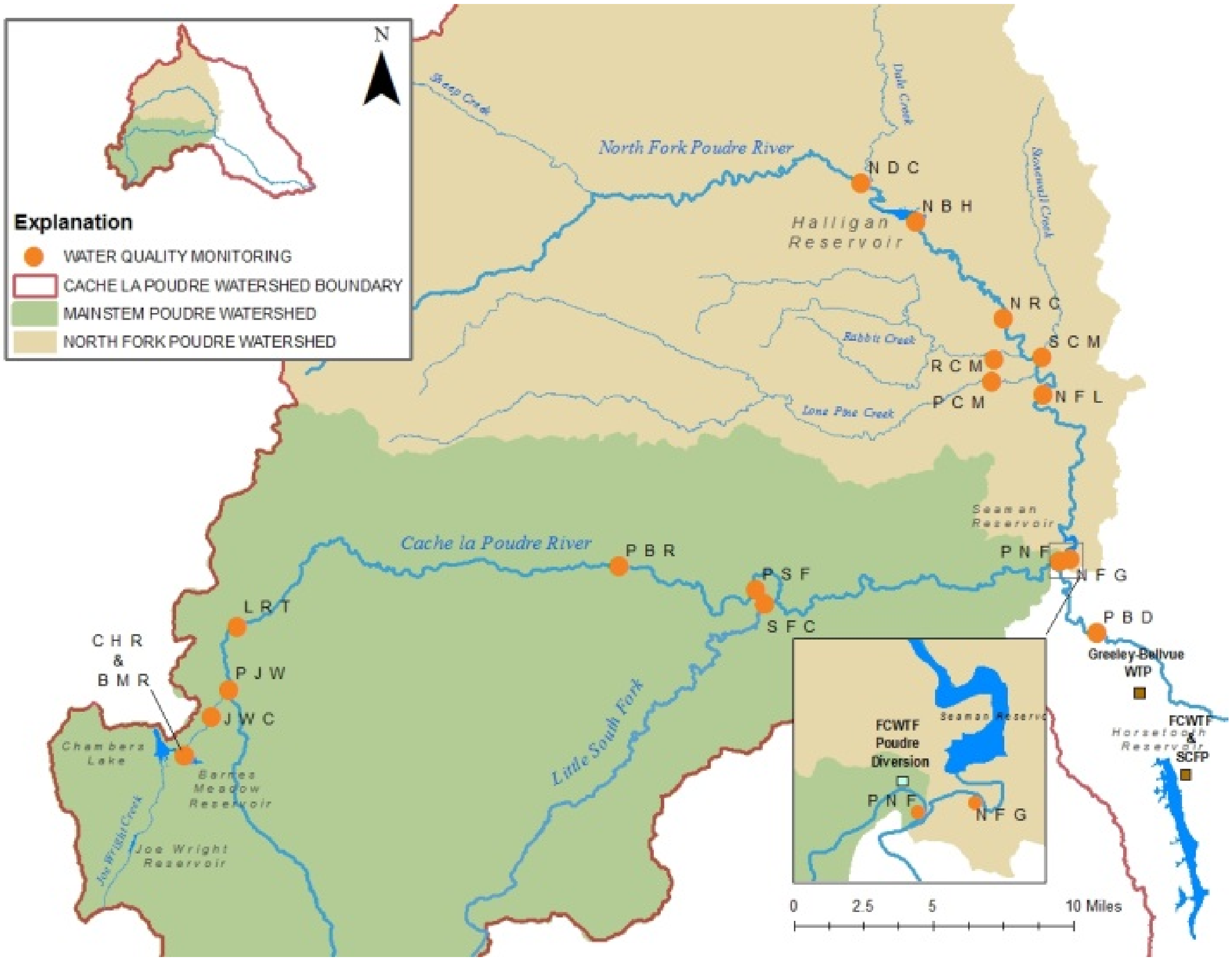


Figure 1.1 – Map of the Upper CLP collaborative water quality monitoring network.

in the monitoring program were selected based on analysis of historical data and aim to provide the best information possible within current budgetary constraints. A list of parameters is included in Attachment 3. Complete discussions of parameter selection and sampling frequency are provided in Sections 5.3 and 5.4, respectively, of the program design document by Billica, Loftis and Moore (2008). Previous year's sampling plans are provided in their corresponding annual reports. The 2017 sampling plan is provided in Attachment 4 of this report.

1.4 SAMPLE COLLECTION AND ANALYSIS

Dr. William Lewis, from the University of Colorado Boulder, was contracted from 2008 through 2013 to perform sampling activities for the Upper CLP monitoring program at 17 of the 19 Mainstem and North Fork CLP sites. Staff from the City of Fort Collins collected samples at the remaining two locations: North Fork Poudre above the confluence with Dale Creek (NDC) and North Fork Poudre below Halligan Reservoir (NBH). Sampling methods, including those for the collection of physical field measurements for temperature, pH, conductivity, and dissolved oxygen are documented in Section 5.5 of Billica, Loftis and Moore (2008).

The City of Fort Collins Watershed Program coordinated and lead all Upper CLP monitoring activities from 2013 through 2017. Sampling methods, including those for the collection of physical field measurements for temperature, pH, conductivity, and dissolved oxygen are documented in the Upper Cache la Poudre Watershed Monitoring Standard Operating Procedure (Heath 2015).

All bulk water samples were analyzed by the City of Fort Collins Water Quality Lab (FCWQL), except for *Cryptosporidium* and *Giardia* filter samples, which were delivered to CH Diagnostic and Consulting, Inc., in Berthoud, CO for analysis. The analytical methods and detection limits for the FCWQL parameters are included in Attachment 5.

Consistent with the quality assurance guidelines outlined in Section 5.5 of Billica, Loftis and Moore (2008), at least ten percent of environmental samples consist of field blanks and field duplicate samples, which are identified in the sampling plan (Attachment 4). Quality assurance and quality control of field blanks and field duplicates is discussed further in Chapter 6 of this document.

1.5 SCOPE OF FIVE YEAR REPORT

Annual and five-year reports for the Upper CLP Collaborative Water Quality Monitoring Program are prepared by the City of Fort Collins' Watershed Program to keep participants informed about current issues and trends in water quality of the Upper CLP. The purpose of annual reports is to summarize hydrologic and water quality information for the current year. Annual reports highlight significant events, issues of concern, the results of special studies, and provide a comparison with water quality from the preceding three years. Annual reports are available for the years 2008-2011 and 2013-2016.

Five-year reports provide an in-depth analysis of long-term trends in the climate, hydrology and water quality of the Upper CLP watershed. Water quality data collected throughout the Upper CLP watershed were analyzed for long-term trends to determine if concentrations increased, decreased or stayed the same over the ten-year period of record from 2008 to 2017. This report documents 1) watershed impacts and issues of concern; 2) significant trends in climate, hydrology, and water quality in the Upper CLP watershed; 3) potential sources of pollution and/or watershed disturbances influencing water quality trends; and 4) a summary of significant findings and implications to water treatment. The last five-year report was published in 2013, which reviewed trends over the five-year period of record from 2008 to 2012 (Oropeza and Heath, 2013).

2.0 WATERSHED IMPACTS & ISSUES OF CONCERN

2.1 CLIMATE CHANGE

Climate change is one of the most critical issues related to watersheds and water supplies of the Colorado Front Range. It is predicted that warmer temperatures will result in changes to the water cycle, which will influence the watersheds that collect, store, and deliver clean water for consumptive and non-consumptive uses. The most serious consequences of climate change on Colorado watersheds include:

- Changes in precipitation patterns, timing and type;
- Shifts in timing and intensity of runoff and streamflow;
- Increases in severity and frequency of droughts and wildfires;
- Increases in frequency and intensity of forest insect infestations.

Colorado is already limited on its water resources and extremely vulnerable to increasing extremes due to climate change. Many of the consequences of climate change will directly impact drinking water supplies. Precipitation patterns in Colorado vary over space and time. Changes in precipitation patterns, timing, and type may result in periods of extended drought, as well as periods of intense precipitation events. These patterns result in extreme variability from year to year. Most of Colorado's precipitation occurs during the winter months. Shifts in the timing of precipitation, in addition to more precipitation falling as rain than snow, will add to the uncertainty in the timing and intensity of runoff and streamflow. The onset of streamflow from melting snow is projected to shift earlier in the spring resulting in reduced runoff in the late summer. These climate-driven changes to the water cycle present many challenges to water managers making it difficult to estimate the quantity and quality of water available to meet current and future water needs.

In combination with changes to water quantity, changes to water quality may also occur because of climate change-driven impacts to Colorado watersheds. The increase in the severity, frequency, and intensity of droughts, wildfires, and insect infestations can result in dramatic changes to the land cover of Colorado's watersheds, directly impacting water quality. Droughts are the leading cause of wildfires and therefore, with the occurrence of more prolonged droughts come increased frequency of wildfires. Wildfires impact watershed hydrology by changing ecosystem resources such as vegetation and soils resulting in increased pollution to drinking water supply.

2.2 DROUGHT AND WILDFIRE

Extreme drought conditions were observed throughout the State of Colorado and the Upper CLP watershed in 2012. The maximum amount of water stored in the snowpack (snow water equivalent) in 2012 at the Joe Wright Snow Telemetry station near Cameron Pass was 57% of normal and occurred nearly two months earlier than expected. Colorado experienced its warmest March on record and abnormally hot and dry conditions persisted throughout the summer and fall. The summer of 2012 (June-August) was the warmest summer on record with statewide temperatures greater than 4°F (2.2°C) warmer than the long-term average temperature. Peak streamflow in June of 2012 was less than 40% of the historical average because of the low snowpack and hot, dry conditions

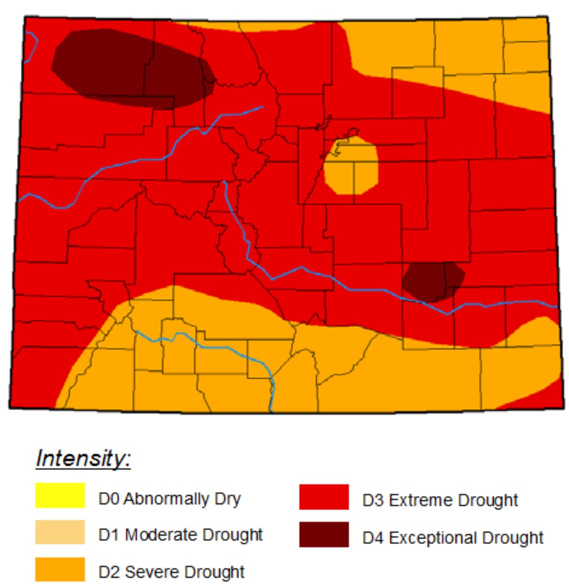


Figure 2.1 – Drought conditions in Colorado on July 3, 2012. Source: www.droughtmonitor.unl.edu

in the Upper CLP watershed. Potential impacts of drought on raw and treated water quality are summarized in Table 2.1.

Table 2.1 – Potential raw and finished water quality impacts related to drought. Adopted from Water Research Foundation Web Report #4324.

Raw Water Quality	Finished Water Quality
Increased nutrients, algae, cyanobacteria, MIB, geosmin	Taste and odor Potential for cyanotoxins
Increased water temperature	Increased water temperatures in distribution system
Color and turbidity	Color and turbidity
Increased microbial contamination	*Cryptosporidium* and giardia in treated water
Iron and manganese	Manganese, color
Increased TOC	DBPs (THMs and HAAs)
Decreased DO	
Increased hardness	
Low alkalinity	Corroded pipes
Increased concentrations of contaminants	Higher risk to public health

The exceptionally hot and dry conditions in 2012 (**Figure 2.1**) lead to extreme wildfire conditions throughout Colorado. The Upper CLP watershed was impacted by two major wildfires in 2012. The Hewlett Gulch Fire (May 14-22) 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 and into Seaman Reservoir on the North Fork.

The High Park Fire (June 9 - July 2) 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. The burned area includes numerous sub-drainages that are tributaries to the Mainstem and the South Fork.

The 2012 wildfires caused dramatic changes to land cover within the Upper CLP watershed that had an immediate effect on watershed hydrology and water quality within and downstream of the burn scars. The disturbance caused an increase in streamflow and sediment erosion into streams draining burned sub-basins specifically during and following high-intensity storm events. The loss of vegetative cover altered the cycling of water, carbon, nutrients and other elements, directly influencing water quality in the Poudre River. Potential impacts on raw and treated water quality from wildfires are summarized in Table 2.2.

Upper CLP monitoring sites that were impacted by the wildfires were limited to the middle to lower elevations of the watershed and included the South Fork above the Mainstem Confluence, SFC, the Poudre below the South Fork (PSF), PNF, the North Fork below Seaman Reservoir (NFG), and the Poudre at the Bellvue Diversion (PBD) (Figure 1.1). Routine data collected from these monitoring locations (pre- (2008 to 2012) and post-wildfire (2012-2017)) are valuable for evaluating the impacts of wildfire on CLP water quality (non-event based) and watershed recovery.

Table 2.2 – Potential raw and finished water quality impacts related to wildfire. Adopted from Water Research Foundation Web Report #4324.

Raw Water Quality	Finished Water Quality
Increased nutrients, algae, cyanobacteria, MIB, geosmin	Taste and odor Potential for cyanotoxins
Color and turbidity	Color and turbidity
Increased metals	Manganese, color
Increased TOC	DBPs (THMs and HAAs)
Decreased DO	
Increased hardness	
Increased alkalinity	DBPs (THMs and HAAs)

2.3 FLOODING

In September of 2013, the Colorado Front Range and adjacent foothills experienced a period of intense rainfall leading to severe flooding in streams and rivers throughout much of the South Platte and Arkansas River Basins. Intense rainfall was observed over a 7-day period from September 9th to September 16th with some areas receiving up to 18 inches of water (**Figure 2.2**). Several impacted areas measured record rainfall amounts that were greater than average annual perception totals.

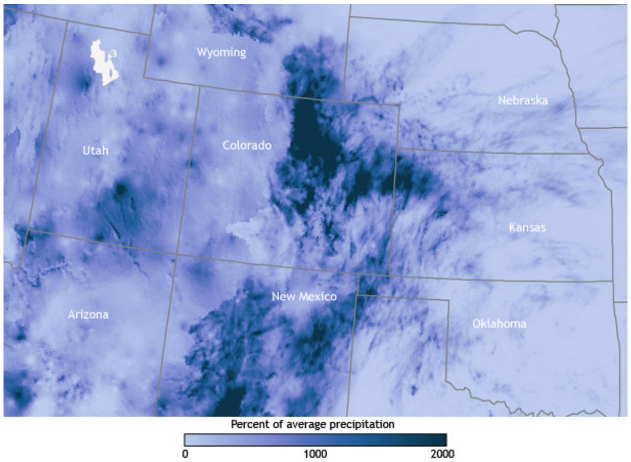


Figure 2.2 – Percent normal rainfall over the U.S. West between September 10 – 16, 2013. Part of Colorado received more than 1000% of their normal rainfall (Source: National Oceanic and Atmospheric Administration; www.climate.gov).

In the foothills of Larimer County, 15 inches of rainfall was recorded over this period with areas in Fort Collins receiving over 12 inches of rain. Higher intensities and rainfall depth likely occurred at higher elevations in the Upper CLP watershed. As a result, extreme flooding occurred within the Cache la Poudre watershed with a return interval ranging from a 25 to 50-year flood on the CLP river (Yochum, 2015). The flood peak at the Canyon Mouth was nearly five times greater than the average snowmelt peak and measured 9,730 cubic feet per second (cfs) on September 13th. Flood waters began to recede following the flood peak and returned to baseflow (low-flow) conditions by early October. Baseflows remained higher than average in the years following the flood and appeared to return to near normal conditions in 2016. Potential impacts related to flooding and extreme rainfall events are outlined in Table 2.3.

Table 2.3 – Potential raw and finished water quality impacts related to flooding and extreme rainfall. Adopted from Water Research Foundation Web Report #4324.

Raw Water Quality	Finished Water Quality
Increased nutrients, algae, cyanobacteria, MIB, geosmin	Taste and odor, and potential for cyanotoxins
Color and turbidity	Color and turbidity
Increased microbial contamination	*Cryptosporidium* and giardia in treated water
Increased TOC	DBPs (THMs and HAAs)
Low alkalinity	Corroded pipes
Increased concentrations of contaminants	Higher risk to public health

2.4 FOREST INSECTS AND DISEASE

Native forest insects and disease are common in Colorado's forests and play an important role in forest ecology and maintaining healthy, resilient forests that provide clean water to lakes, streams and rivers. Over the past two decades several forest insects and diseases have impacted Colorado's forests.

The mountain pine beetle (MPB), a native bark beetle that infests all pine species, impacted over 3 million acres of Colorado's forest over the past two decades. The mountain pine beetle epidemic began in 1996 and tree mortality peaked in 2008 at 1.2 million trees (Figure 2.3). Over the past 10 years, pine beetle-caused tree mortality steadily decreased to less than 900 acres of native pine forest affected in 2017 (Colorado State Forest Service, 2017). A large portion of the tree mortality caused by the mountain pine beetle was concentrated in lodge pole pine forest in north-central Colorado including portions of the Upper CLP watershed.

The spruce beetle has destroyed 1.78 million acres since 1996 and has been Colorado's most common forest insect over the past six years, destroying more than 200,000 acres of high-elevation Engelmann spruce forest. The highest spruce beetle-caused tree mortality was observed in 2014 at over 400,000 acres (Figure 2.3). State-wide tree morality has been on the decline over the past three years (Colorado State Forest Service, 2017). In 2017, the Colorado State Forest Service identified significant infestations in Larimer County and noted the potential for expanding outbreaks in susceptible Engelmann spruce forests in the northern portion of the state suggesting the potential for future infestations and tree mortality in the Upper CLP watershed.

Douglas-fir beetle has also infested dense, mature, and drought stricken Douglas-fir forests across Colorado, but the impact and extent is much less compared to the mountain pine beetle and spruce beetle infestations.

2.5 AIR POLLUTION

Air pollution along Colorado's Front Range and from other areas may impact water quality in the Upper CLP watershed through a process called atmospheric deposition. Atmospheric deposition occurs when pollutants emitted into the air are deposited on land and water with

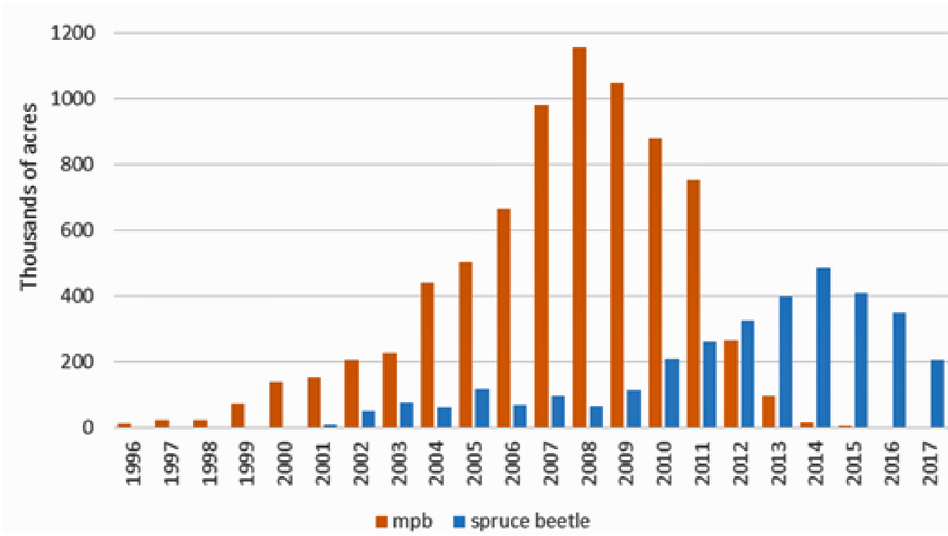


Figure 2.3 – Mountain pine beetle-caused mortality impacted nearly 3.4 million acres compared to 1.78 million acres impacted by spruce beetle statewide over the last 20 years. While mountain pine beetle-caused mortality is currently considered at background levels, spruce beetle-caused mortality continues to remain at outbreak epidemic proportions (from https://csfs.colostate.edu/)

precipitation (wet deposition) or as dry particles and gases (dry depositions). Acidic deposition has been the most widely studied form of atmospheric deposition, which has led to acidification of surface waters from acid compounds (sulfur and nitrogen) and other chemicals. The main source of sulfur dioxide to the atmosphere is large powerplants and the source of nitrogen oxide and ammonium emissions include vehicle emissions, oil and gas development, and agricultural practices.

The National Atmospheric Deposition Program (NADP; http://nadp.slh.wisc.edu/) is a cooperative effort between private, governmental and non-profit agencies that measures precipitation chemistry (wet deposition) throughout the United States with the goal of monitoring the chemistry of precipitation to determine changes over time. Atmospheric deposition has been monitored near the headwaters of the Cache la Poudre River in Rocky Mountain National Park since the early 1980s through the National Atmospheric Deposition Program.

Long-term records from monitoring stations in Rocky Mountain National Park and throughout Colorado show decreasing trends in sulfate since the early 1990s because of efforts to reduce emissions established under the 1990 Clean Air Act Amendments. The reduction in sulfur dioxide emissions has lessened the amount of sulfuric acid in the atmosphere and lead to declines in precipitation acidity and acidic deposition into Colorado's watersheds (Mast, 2011).

In contrast, trends in nitrogen species (nitrate and ammonium) have been less sensitive to emission reductions and voluntary management strategies aimed at limiting nitrogen to the atmosphere. Increasing trends were observed in ammonium with the largest increase near agricultural and urban areas in eastern Colorado (Mast, 2011; **Figure 2.4**). It is expected that these trends will continue in the future because of projected population growth along the Colorado Front Range and increasing oil and gas production in Colorado.

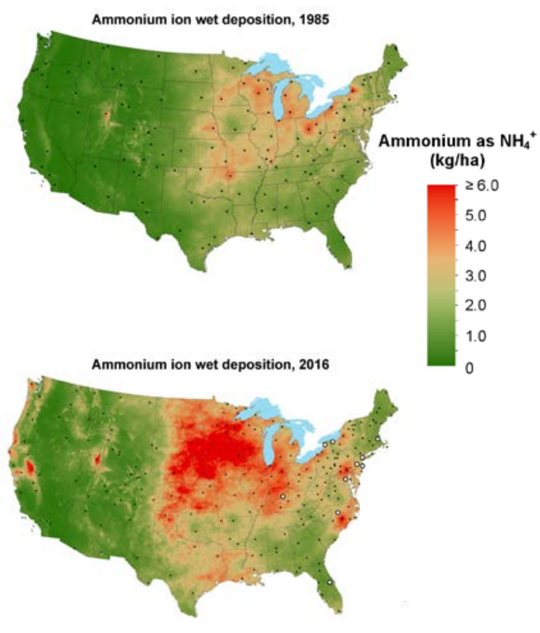


Figure 2.4 – Ammonia ion wet deposition has increased throughout the United States since the NADP began in 1985 (Source: http://nadp.slh.wisc.edu/).

3.0 WATERSHED HYDROLOGY AND CLIMATE

The hydrology of the Upper CLP plays an important role in regulating water quantity and quality. Precipitation events and snowmelt runoff largely control the quantity and timing of deliveries of material to the river, and the amount of water in the system at a given time influences the concentration of most water quality constituents. Changes to the timing, magnitude, and duration of snowmelt runoff and the effects on water quality have implications on water treatment operations that may need to be addressed in the future to continue to maintain a high-quality water supply to the public.

Evaluating Trends Short-Term and Long-Term Data

Short-term trends are presented for the most recent five years of data from 2013 to 2017 (current) and compared to baseline data from 2008 to 2012 (baseline). Annual and monthly mean air temperature, precipitation, and streamflow were calculated for the current period of record and compared to the baseline period of record.

Long-term trends are presented for the combined ten-year period of record from 2008 to 2017. The Seasonal Mann-Kendall test (SMKT) was used to evaluate long-term trends in air temperature, precipitation and streamflow. The SMKT was performed on 1) monthly average minimum, maximum and mean air temperature calculated from daily average minimum, maximum and mean air temperatures; 2) monthly cumulative precipitation calculated from daily precipitation; and 3) monthly mean streamflow calculated from daily average streamflow. The Mann-Kendall test was used to evaluated annual and seasonal trends. Seasons were defined as winter (December – February), spring (March – May), summer (June – August), and fall (September – November).

Statistical significance was determined to the 95% confidence level ($p \leq 0.05$), while notable trends were identified to the 90% confidence level ($p \leq 0.10$).

Hydrologic and Climatic Data Sources

The snow telemetry (SNOTEL) network, managed by the Natural Resource Conservation Service, includes approximately 600 automated monitoring sites located in remote mountain watersheds throughout the United States that measure snow water equivalent (SWE), accumulated precipitation, and air temperature. Joe Wright SNOTEL, located at an elevation of 10,120 feet, contains the longest record of continuous measurements in the Cache la Poudre Watershed dating back to 1978 (*https://wcc.sc.egov.usda.gov/nwcc/site?sitenum=551*).

The Cache la Poudre at Canyon Mouth near Fort Collins (CLAFTCCO) streamflow monitoring station managed by the Colorado Department of Water Resources (*http://www.dwr.state.co.us/*) contains the longest record of continuous streamflow in the Upper CLP watershed, dating back to 1883. The streamflow monitoring station is located at the Canyon Mouth and includes streamflow contributions from both the Mainstem and North Fork watersheds.

3.1 AIR TEMPERATURE

The annual mean air temperature measured at Joe Wright SNOTEL over the last five years was slightly warmer than baseline conditions. The mean temperature over the current five-year period was 35.6 degrees Fahrenheit (°F) (2.0 degrees Celsius (°C)) compared to a mean baseline temperature of 34.8°F (1.5°C) (Figure 3.1). Monthly mean air temperatures in the Upper CLP watershed were slightly warmer in most months over the recent five-year period compared to baseline conditions. Five-year monthly mean temperatures exceeded baseline monthly mean temperature in all months except April, May, and August (Figure 3.1).

Air temperature significantly increased at higher elevations in the Upper CLP watershed over the long-term period of record. A significant increase was detected in both the average monthly mean and minimum air temperatures. Average monthly mean temperatures increased at a rate of 0.24°F (0.13°C) per year, while average monthly minimum temperatures increased at a slightly greater rate of 0.32°F (0.18°C) per year (Table 3.1).

Seasonal trend analyses detected significantly increasing average monthly mean and minimum air temperatures during the winter season. Over the winter season, average monthly mean temperatures increased at a rate of 0.32°F per year, while average monthly minimum temperatures increased at a rate of 0.37°F (0.21°C) per year (Table 3.1).

No additional seasonal trends were detected in average monthly maximum air temperatures at the Joe Wright

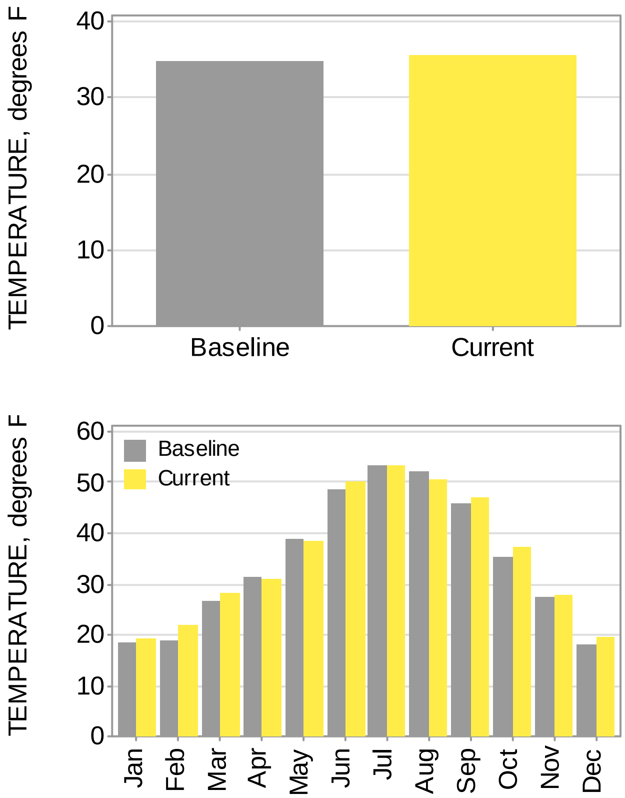


Figure 3.1 – Mean baseline and current air temperatures (top), and monthly mean air temperature over the baseline and current periods of record (bottom) reveal similar air temperature between the two periods.

SNOTEL. Trend analyses of air temperature data collected at the Cache la Poudre at Canyon Mouth near Fort Collins (CLAFTCCO) streamflow monitoring station revealed no discernable trends.

3.2 PRECIPITATION

Annual mean precipitation over the five-year period was slightly greater than baseline annual mean precipitation. The five-year annual mean precipitation was 46.4 inches compared to 45.3 inches. The higher precipitation that fell over the five-year period was due to wetter conditions in the winter, spring, and fall seasons (**Figure 3.2**). Monthly mean precipitation during these seasons was greater in all months except April and October. Less precipitation fell over the summer season with notably lower precipitation in the months of June and July (**Figure 3.2**).

There were no significant long-term trends in annual, monthly, or seasonal precipitation over the long-term period of record. Total precipitation was variable from year to year.

The highest precipitation was measured in water year 2011 with a total 64.4 inches of precipitation falling on the Upper CLP watershed. In contrast, only 32.2 inches of precipitation was measured in 2012 leading to severe drought conditions and wildfires in the Upper CLP watershed.

There were two notable long-term trends identified at the 90% confidence level for significance (p = 0.10). The maximum amount of water contained within the snowpack (peak snow water equivalent) showed a decreasing trend over the long-term period of record at a rate of 1.03 inches per year. Although there was considerable variability in peak SWE from year to year (**Figure 3.3**), the trend suggests higher elevations of the Upper CLP watershed may receive less snowfall over the snow accumulation season into the future. Another notable decreasing trend was detected in the peak SWE to precipitation ratio implying precipitation patterns may be shifting in the Upper CLP watershed with more precipitation falling as snow or rain in the spring following peak SWE or as rain in the fall.

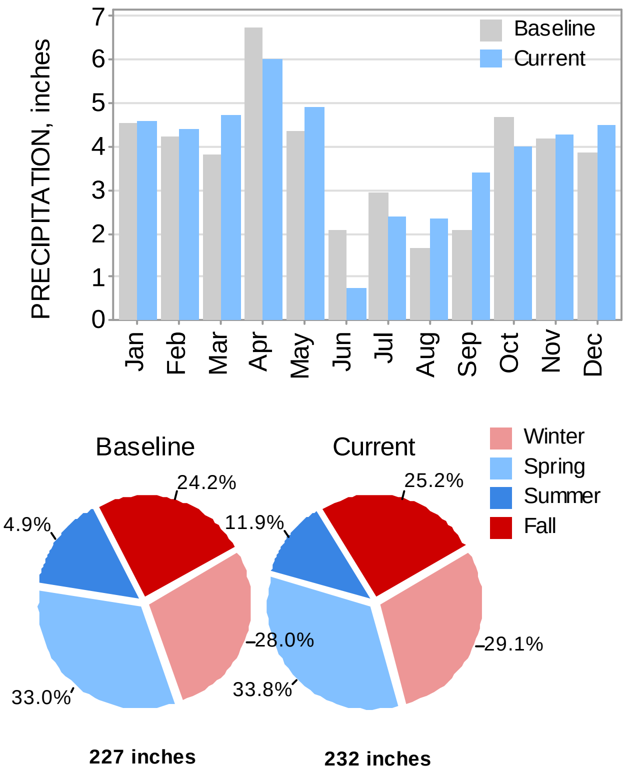


Figure 3.2 – Monthly mean precipitation totals for the baseline period compared to the recent five-year period (top) and seasonal distribution of precipitation for the baseline period and current period (bottom).

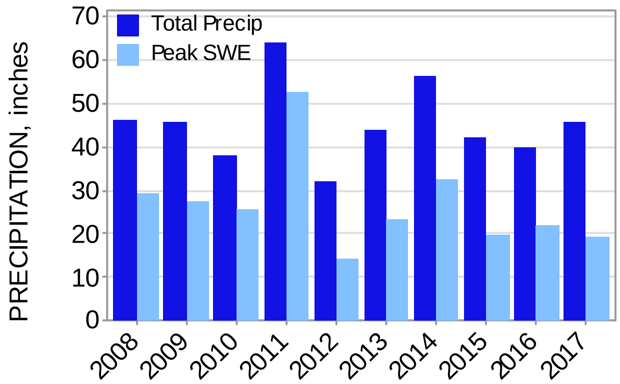


Figure 3.3 – Annual precipitation totals and peak snow water equivalent measured at the Joe Wright SNOTEL.

3.3 STREAMFLOW

The five-year annual mean streamflow was greater than baseline streamflow conditions. Annual mean streamflow during the five-year period of record was 513 cubic feet per second (cfs) compared to the baseline of 326 cfs. The higher streamflow over the five-year period was driven by notably higher streamflow in all months except July (Figure 3.4).

A shift in seasonal flow contributions was observed over the five-year period. The proportion of water delivered during the winter season was similar compared to baseline conditions, but a smaller amount of water was measured during the summer season, notably in the month of July. The amount of water delivered over the spring and fall seasons was considerably greater over the five-year period of record (Figure 3.4). Five-year monthly mean streamflow was more than two times higher in the spring months of March, April, and May (Figure 3.4). Streamflow during the fall months was also greater over the five-year period likely due to extreme precipitation and flooding in September of 2013 and elevated baseflows in the following years. As a result, 500,000 more acre-feet of water was measured over the five-year period of record compared to baseline.

Streamflow significantly increased in the Upper CLP watershed over the long-term period of record (2008-2017). A significant increase was detected in both monthly mean streamflow and streamflow during the winter season. Monthly mean streamflow increased at a rate of 13 cfs per year, while winter streamflow increased at a rate of 9 cfs per year (Table 3.1). An increasing trend in spring streamflow was detected at a rate of 7 cfs per year, but this trend was not statistically significant (p=0.08).

There were no significant trends in the magnitude or timing of peak streamflow. Peak streamflow over the long-term period was higher than the historic (1881-2017) peak in seven out of 10 years averaging 988 cfs higher than the historic average peak (2,000 cfs). The timing of peak streamflow occurred an average of 1.3 days later than the historic average (June 11). The latest peak was observed on July 1, 2011 (20 days late) and the earliest peak was observed on May 31, 2014 (11 days early).

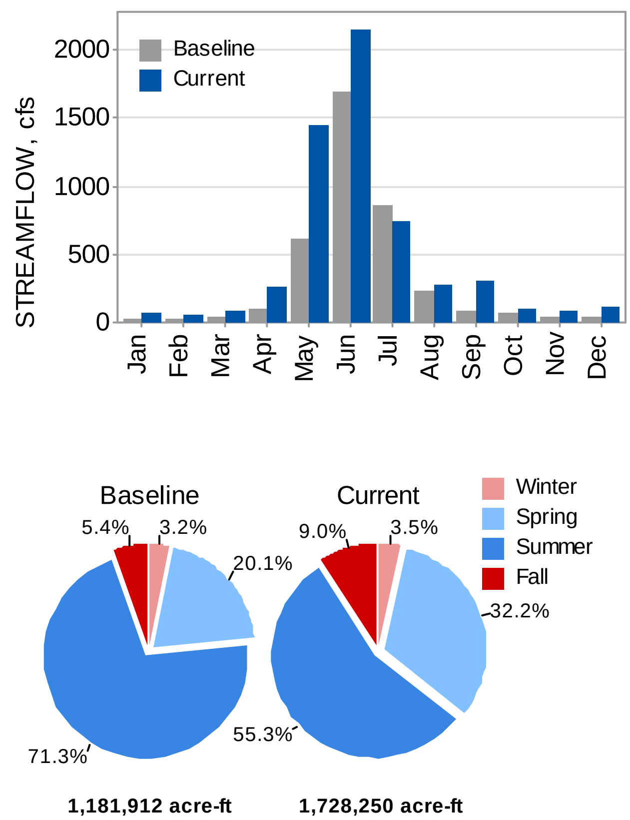


Figure 3.4 – Monthly average streamflow for the baseline period compared to the recent five-year period (top) and seasonal distribution of streamflow for the baseline period and current period (bottom).

Table 3.1 – Summary of statistically significant climatological variables detected in the Upper CLP watershed.

Paramater	Test Statistic	Season	Trend Direction	Trend Estimate	Significance (p-value)
Streamflow	Monthly Mean	Annual	Increasing	13 cfs per year	0.01
		Winter	Increasing	9 cfs per year	<0.01
Precipitation	Peak SWE	Water Year	Decreasing	1.03 inches per year	0.10
	SWE/Precipitation Ratio	Water Year	Decreasing	0.02 inches per year	0.07
Temperature	Monthly Mean	Annual	Increasing	0.24°F (0.13°C) per year	0.01
		Winter	Increasing	0.32°F (0.18°C) per year	0.02
	Monthly Minimum	Annual	Increasing	0.32°F (0.18°C) per year	<0.01
		Winter	Increasing	0.37°F (0.21°C) per year	0.05

4.0 TRENDS IN WATER QUALITY

Water quality data collected throughout the Upper CLP watershed were analyzed for long-term trends to determine if concentrations increased, decreased or stayed the same over the ten-year period of record from 2008 to 2017. Analysis of long-term water quality data for trends provides useful information about short and long-term impacts to water quality from watershed disturbances and pollution that may influence water treatment processes and direct watershed management now and in the future.

Preliminary data analyses

Preliminary data analyses were conducted to initially identify and characterize potential trends in the Upper CLP long-term data set. Time-series scatterplots were evaluated and data smoothing techniques were applied to further uncover general tendencies. Two types of trends were identified in this process: monotonic trends and step trends. Monotonic trends are defined as a gradual, continuous rate of change (increasing or decreasing) in the data over time and step trends are defined as an abrupt shift (up or down) in the data at a certain point in time.

Preliminary data analyses also provided additional information required for selecting the most robust trend test. Trend tests are generally categorized as parametric and nonparametric, and the statistical power of these analyses depends on the distribution of the data. Parametric trend tests are considered the most powerful analyses for normally distributed data sets and nonparametric tests are used on data where the assumption of normality for parametric statistics is not met (Lettenmaier 1976, Hirsch et al. 1991, Thas et al. 1998). Normality tests verified data distributions of water quality variables were not normal ($p<0.01$) and a nonparametric test would provide the most powerful and robust trend analyses.

Trend Analyses

Based on preliminary data analyses discussed above, two trend tests were selected to detect and quantify trends in water quality concentrations throughout the Upper CLP watershed. Monotonic trends were evaluated with the Seasonal Mann-Kendall Test (SMKT). Water quality in the Upper CLP watershed exhibits strong seasonal patterns and the SMKT accounts for variability in water quality due to seasonality (Helsel and Hirsch, 1992). The SMKT was performed on monthly concentrations measured over the ten-year period of record (2008 to 2017) with seasons defined by month. Bimonthly data collected in the months of April, May, and June were aggregated by month and a monthly median value was calculated for trend analyses. The output of the test provides a p-value and overall measure of the rate of change or trend slope. Statistical significance was determined to the 95% confidence level ($p \leq 0.05$), while notable trends were identified to the 90% confidence level ($p \leq 0.10$).

Step trends were evaluated with the nonparametric Mann-Whitney test. The Mann-Whitney test compares two population medians and calculates the corresponding point estimate and confidence interval. Step trends occurred in response to the dramatic landcover change in the Mainstem CLP watershed caused by wildfire that burned in the summer of 2012. Based on this extreme event, the long-term data set was divide into two separate periods of record and population medians were compared using the Mann-Whitney test at monitoring sites located within and downstream of the wildfire burn scar ((SFC, PSF, PNF and PBD). ‘Baseline conditions’ were defined as the period of record from 2008 to 2012 and ‘current conditions’ were defined as the period of record from 2013 to 2017. Statistical significance was determined to the 95% confidence interval ($p \leq 0.05$), while notable trends were identified to the 90% confidence interval ($p \leq 0.10$).

Selected Variables and Monitoring Sites

Trend analyses were performed on all monitoring sites throughout the Upper CLP watershed for the water quality parameters listed below:

- Physical Parameters
  Temperature, pH, Conductivity, Turbidity
- General Parameters
  Alkalinity, Hardness, Total Dissolved Solids
- Total Organic Carbon
- Nutrients
  Nitrogen and Phosphorus
- Microorganisms
  E. coli and Total Coliforms

These water quality parameters were selected because they either have a direct impact on water treatment processes or served as key indicators for other water quality parameters that may influence water treatment.

Presentation of Results

Presentation of the results focuses primarily on monitoring sites located directly on the Mainstem and North Fork CLP rivers that are considered representative of water quality conditions throughout the Mainstem CLP watershed; however, data collected from monitoring sites located on tributaries to the Mainstem and North Fork CLP rivers were analyzed and tested for trends. Significant and notable findings from these sites are also presented. A full list of monitoring sites, abbreviations and descriptions is available in Attachment 2. Finalized raw data are available upon request from the City of Fort Collins Watershed Program.

The graphics presented in the following sections of this report include time-series scatterplots customized with a smoothed line fit to the data. Data were smoothed using the locally weighted scatterplot smoothing (LOWESS) technique. The degree of smoothing (0-1) was set to 0.25 and the influence of outliners (0-10) was set to 10. The larger the weights, the more the smoothed values follow the data and the smaller the weights, the less jagged the pattern is in the smoothed values.

The colored bar graphs presented below the smoothed time-series graphs summarize trend test results from the SMKT. Bar graphs include the trend slope (rate of change over time), trend direction (increasing or decreasing), and statistical significance ($p<0.05$ and $p<0.10$). The trend slope is plotted on the y-axis and monitoring locations are on the x-axis. A positive value specifies an increasing trend and a negative value specifies a decreasing trend. Statistical significance and trend direction are color coded. Refer to table 4.1 for color codes and additional information for interpreting the results from monotonic trend analyses.

Trend tests detect significant trends and provide a measured rate of change, but do not provide insight to the cause of the trend. Interpretation of potential causes were based on technical expertise and local knowledge regarding specific events and impacts to watershed hydrology and land use over the period of record.

Table 4.1 – Color code matrix used to present trend results from the Seasonal Mann-Kendall test indicating trend direction and significance (p-value).

Color Code	Trend direction	Statistical Significance
	Increasing	95% confidence interval p-value < 0.05
	Decreasing	
	Increasing	90% confidence interval p-value < 0.10
	Decreasing	
	No Trend	Not statistical significant p-value > 0.10

4.1 PHYSICAL PARAMETERS

Water Temperature

Long-term trends were detected below Halligan and Seaman Reservoir in the North Fork CLP watershed. Water temperature at these monitoring sites (NBH and NFG) significantly increased 0.18°C (0.32°F) per year and 0.19°C (0.34°F) per year over the long-term (**Figure** 4.1). There were no trends observed in water temperature in the Mainstem CLP watershed. The noticeable decrease in temperature after 2013 was observed throughout the watershed and may be attributed to the 2013 flood event.

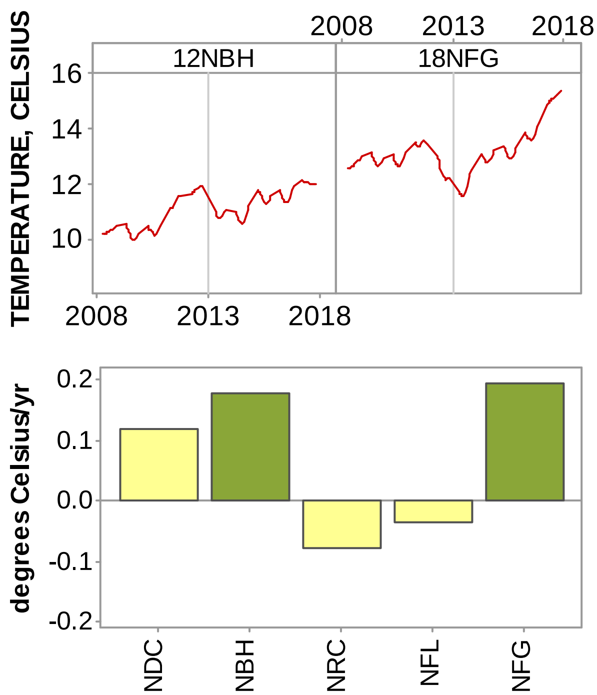


Figure 4.1 – Smoothed time-series plot for water temperature at NBH and NFG (top) and trend results for North Fork CLP river sites.

pH

pH is a measure of the amount of free hydrogen (H^+) and hydroxide (OH^-) ions in water and is measured on a logarithmic scale ranging from 0 to 14. Water with a pH near 7 is considered neutral, with more acidic conditions occurring below 7 and more basic, or alkaline, conditions occurring above 7. pH is an important water quality parameter to monitor because it influences the solubility and biological availability of chemical constituents, including nutrients and heavy metals.

pH increased at nearly all monitoring sites throughout the Upper CLP watershed over the long-term monitoring period (**Figure** 4.2). There were no trends detected at the highest elevation monitoring sites on Joe Wright Creek (CHR) and the Poudre River above the confluence with Joe Wright Creek (PJW). pH significantly decreased at BMR, but this trend did not influence pH trends downstream at JWC where pH significantly increased 0.03 units per year. Significantly increasing trends continued downstream with the greatest changes in pH measured on the Mainstem CLP river above and below the confluence with the North Fork CLP river (PNF and PBD). pH increased 0.07 units per year over the long-term period at PNF and slightly higher at PBD (**Figure** 4.2).

pH increased throughout the North Fork CLP watershed, but at a slower rate compared to the Mainstem CLP watershed. pH significantly increased 0.03 units per year at most sites, including Rabbit Creek (RCM) and Stonewall Creek (SCM). Although there was a slight increase in pH measured at PCM there the trend was not significant (**Figure** 4.2).

Turbidity

Turbidity is a measurement of the amount of light capable of passing through water. This water quality parameter is often monitored to track changes in water clarity, which is influenced by the presence of algae and/or suspended solids introduced to surface waters through various land use activities, including runoff and erosion, and urban storm water runoff and drainage from agricultural lands. Turbidity concentrations can signal changes in land use activity.

For water treatment, turbidity is an important indicator of the amount suspended material that is available to harbor pollutants such as heavy metals; bacteria and other pathogens; nutrients; and organic matter.

Step trends were measured at monitoring sites from the South Fork CLP river (PSF) downstream to the Mainstem CLP river below the confluence with the North Fork (PBD). Median turbidity values over the recent five-year period were 1.5 – 3 times greater than baseline conditions. Turbidity at these sites peaked in 2013 and gradually decreased in the following years to near baseline conditions. There were no trends in turbidity measured at

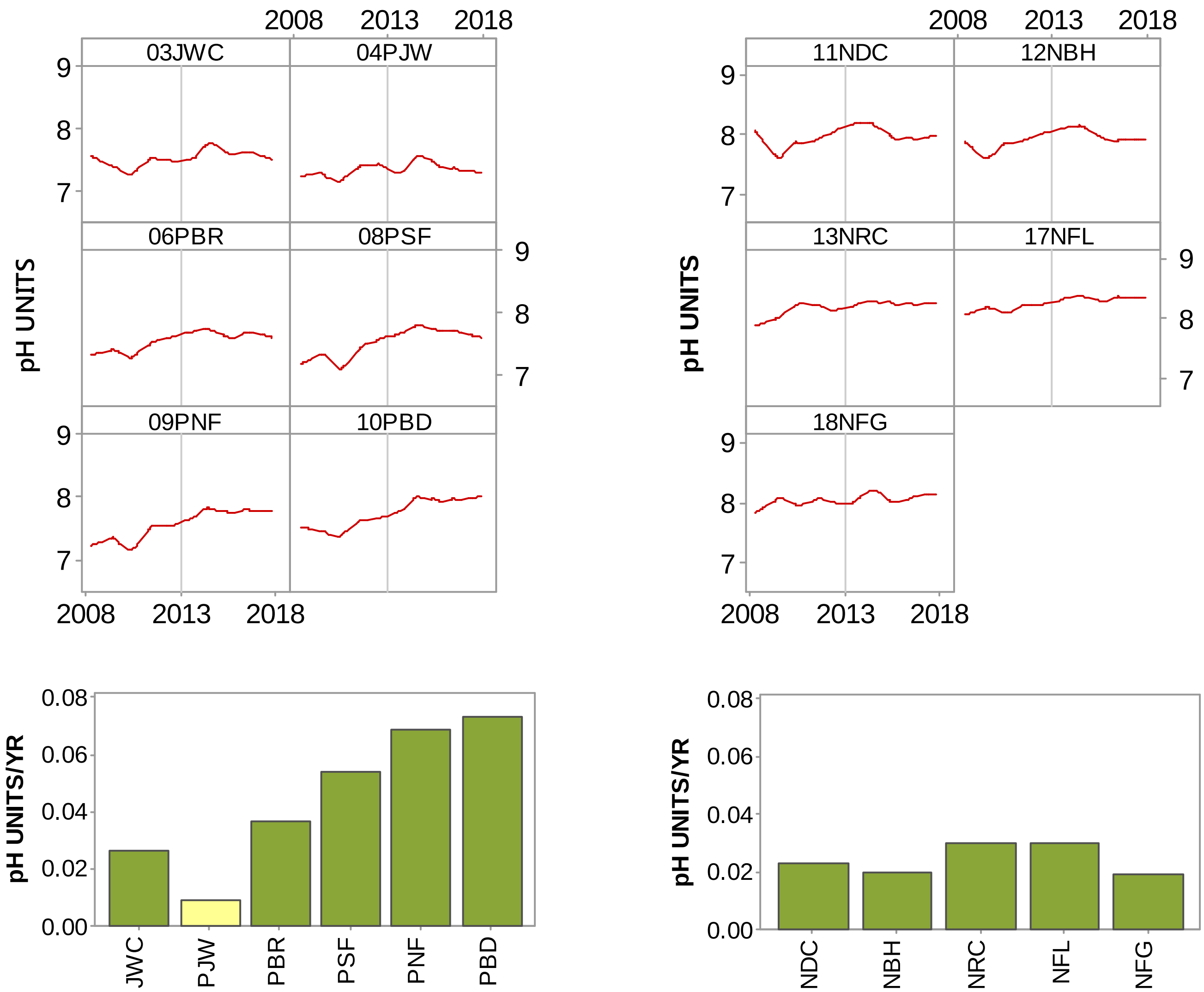


Figure 4.2 – Smoothed time-series plot for pH on the Mainstem (top left) and North Fork (top right) CLP rivers and corresponding trend results and estimated trend slope (bottom).

monitoring sites upstream of the wildfire burn scar suggesting that the abrupt increase in turbidity observed in 2013 was caused by post-fire erosion impacts. The decreasing trend in recent years provides evidence of watershed recovery (**Figure 4.3**).

Trend analyses of the recent five-year period of record detected significantly decreasing trends at wildfire impacted sites suggesting a return to baseline turbidity conditions. The highest turbidity was measured in 2013 and steadily decreased to near baseline conditions in 2017. Turbidity decreased 0.6 NTU per year at PNF and PBD over this period. The flood of 2013 likely accelerated the recovery to pre-fire turbidity levels by scouring the streambed. Turbidity also significantly increased 0.17 NTU per year at LRT in the Mainstem CLP watershed, but this trend did not influence water quality downstream at PBR.

Long-term trends were measured at two monitoring sites in the North Fork CLP watershed. Turbidity significantly increased 0.28 NTU per year on the North Fork CLP river below Seaman Reservoir at NFG (**Figure 4.3**). This trend did not translate downstream to the Poudre River at Greeley's water intake at PBD. A notable increase in turbidity was also observed on the North Fork CLP above Halligan Reservoir at NDC. Although there is less certainty

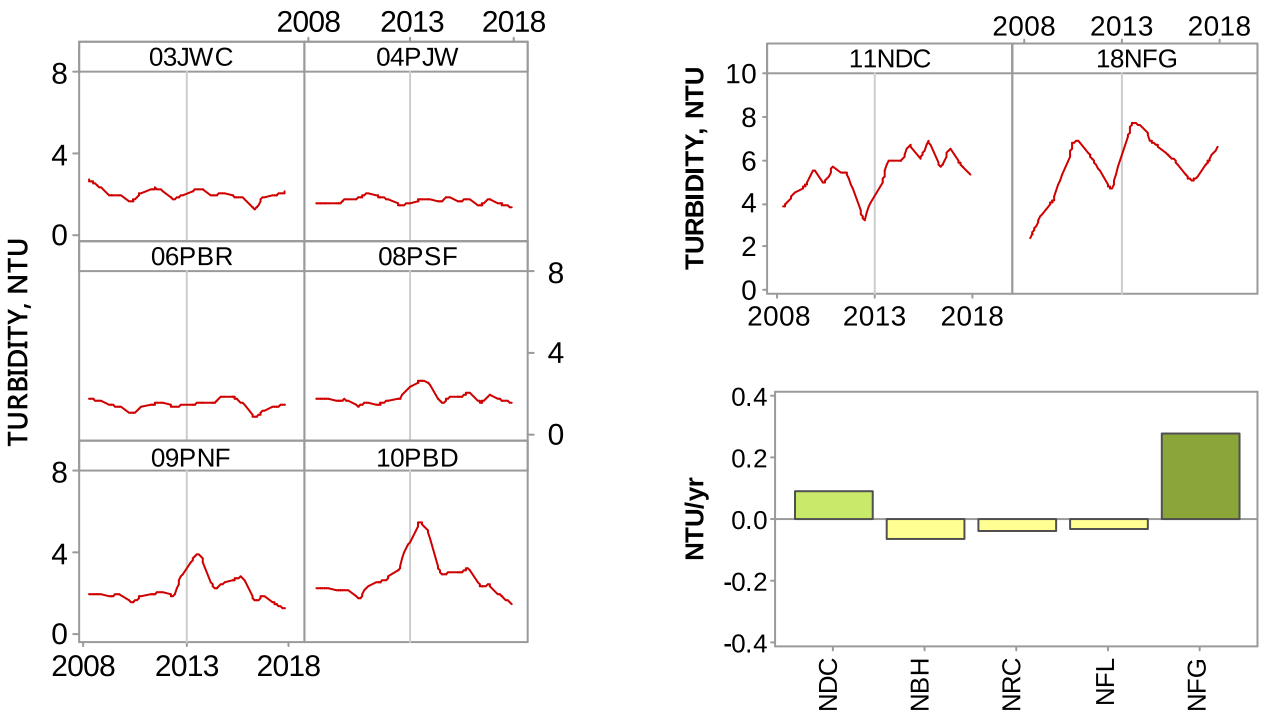


Figure 4.3 – Smoothed time-series plot for turbidity on the Mainstem CLP river (left) and North Fork sites NDC and NFG (top right). The corresponding trend results and estimated trend slope for all North Fork CLP rivers is located on the bottom right.

in this trend it will be important to continue to track this in the future as increased turbidity may indicate increased sediment loading into Halligan Reservoir. No trends were observed on the North Fork CLP or tributaries between Halligan and Seaman Reservoirs.

Specific Conductivity

Conductivity is an index of dissolved ionic solids in water, and hardness is an index of the total calcium (Ca) and magnesium (Mg) in water. Alkalinity is a measure of the effective acid buffering capacity of water, and is derived from the dissociation of mineral carbonates (CO_3^-), bicarbonates (HCO_3^-), and hydroxides (OH^-). Conductivity, hardness, and alkalinity are influenced by local geology, as well as other dissolved constituents derived from land use practices throughout the watershed.

In the Mainstem CLP watershed, long-term trends were identified at monitoring sites located above the wildfire burn scar and step trends were identified at monitoring sites located within the wildfire burn scar. Specific conductivity significantly decreased 0.5 µS/cm per year at PJW with notable decreasing trends at CHR and LRT (-0.28 and -0.90 µS/cm per year) over the long-term monitoring period (**Figure 4.4**).

Step trends were measured at monitoring sites located within the wildfire burn scar. Specific conductivity was significantly higher over the current five-year period compared to baseline conditions at PNF. The abrupt increase in specific conductivity was first observed in 2013 and continued through 2017. Median specific conductivity measured over this period was 1.5 times greater than baseline conditions (**Figure 4.4**). The elevated specific conductivity provides further evidence of post-fire effects that continue to impact water quality five years after the wildfire (**Figure 4.4**).

Specific conductivity increased over the long-term record at higher elevation monitoring sites in the North Fork CLP watershed and step trends were observed at mid- and low-elevation monitoring sites. Specific conductivity significantly increased 1.35 µS/cm per year at NDC and 1.83 µS/cm per year at NBH.

Step trends were observed from NRC downstream to NFG with an abrupt increase in 2012 followed by an abrupt decrease in 2013. These shifts are likely correlated with streamflow variability and the concentrating effects of low streamflow caused by drought conditions in 2012 and dilution effects of high streamflow following the 2013 flood event. Over the long-term period of record a decreasing trend was detected at these monitoring sites. Specific conductivity significantly decreased 5.25 µS/cm per year at NRC and 4.98 µS/cm per year at NFL (**Figure 4.4**). The slight decrease in the rate of change between NRC and NFL may be influenced by the inflowing waters of Stonewall Creek, which have characteristically higher specific conductivity. Specific conductivity significantly decreased 3.54 µS/cm per year at NFG and this trend may have abated the wildfire impacts downstream as no trends were observed at PBD (**Figure 4.4**).

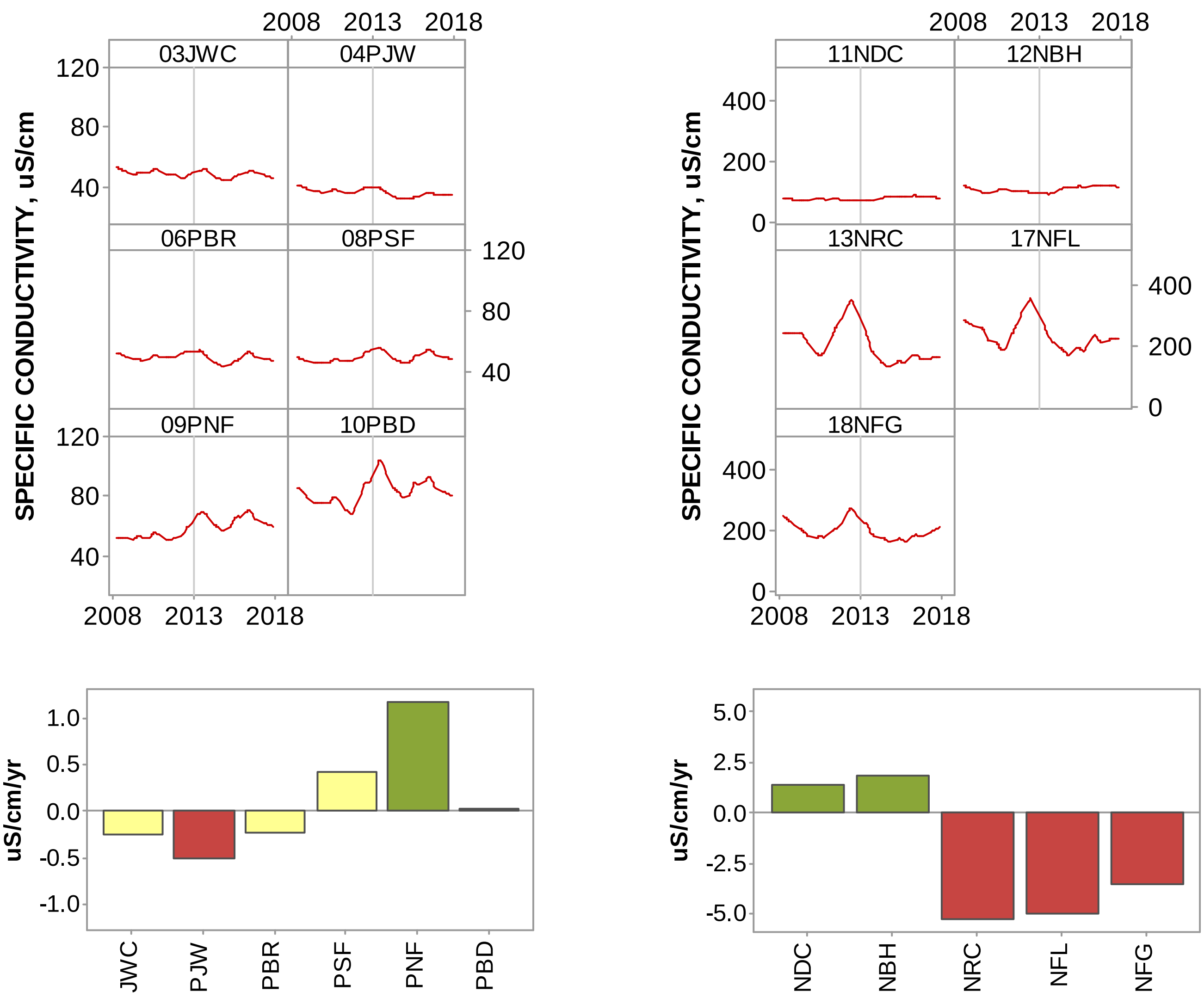


Figure 4.4 – Smoothed time-series plot for specific conductivity on the Mainstem (top left) and North Fork (top right) CLP rivers and corresponding trend results with estimated trend slope (bottom).

4.2 GENERAL PARAMETERS

Alkalinity and Hardness

Long-term trends in alkalinity and hardness were nearly identical to specific conductivity (**Figure 4.4**). Significant trends were detected in both the Mainstem and North Fork CLP watersheds, but there was no indication of watershed wide changes except for monitoring locations impacted by wildfire.

Hardness significantly decreased at BMR and PJW over the long-term period, but these trends did not translate downstream (**Figure 4.5b**). Step trends were observed at monitoring sites located within and downstream of the wildfire burn scar. Like specific conductivity, median alkalinity and hardness concentrations were 1.5 – 2 times greater over the recent five-year period compared to baseline conditions and remained elevated through 2017.

Alkalinity and hardness significantly increased above and below Halligan Reservoir (NDC and NBH, respectively). Decreasing trends were detected at NRC and SCM, but these trends were not detected downstream at NFL or NFG (**Figure 4.5**).

Total Dissolved Solids

The total dissolved solids (TDS) concentration provides a qualitative measure of dissolved ions and comprise inorganic salts (calcium, magnesium potassium, sodium, bicarbonates, chlorides, and sulfates) and a small portion of organic matter. Sources of TDS in surface water consist of natural weathering and erosion of geologic material, mining, industrial and sewage effluent, and agriculture.

Elevated TDS concentrations in drinking-water sources do not pose a health risk, but high levels can cause aesthetic risks including corrosion, salty or brackish taste, and scale formation. Because of these potential risks the Environmental Protection Agency established a secondary drinking water standard for TDS. Elevated TDS concentrations may also be used as an indicator of elevated ions; some of which have primary or secondary drinking water standards.

A watershed wide increase was observed in total dissolved solids throughout the Mainstem CLP watershed over the long-term monitoring period. Significantly increasing trends were identified at all sites along the Mainstem CLP river and on Joe Wright Creek at JWC. Concentrations gradually

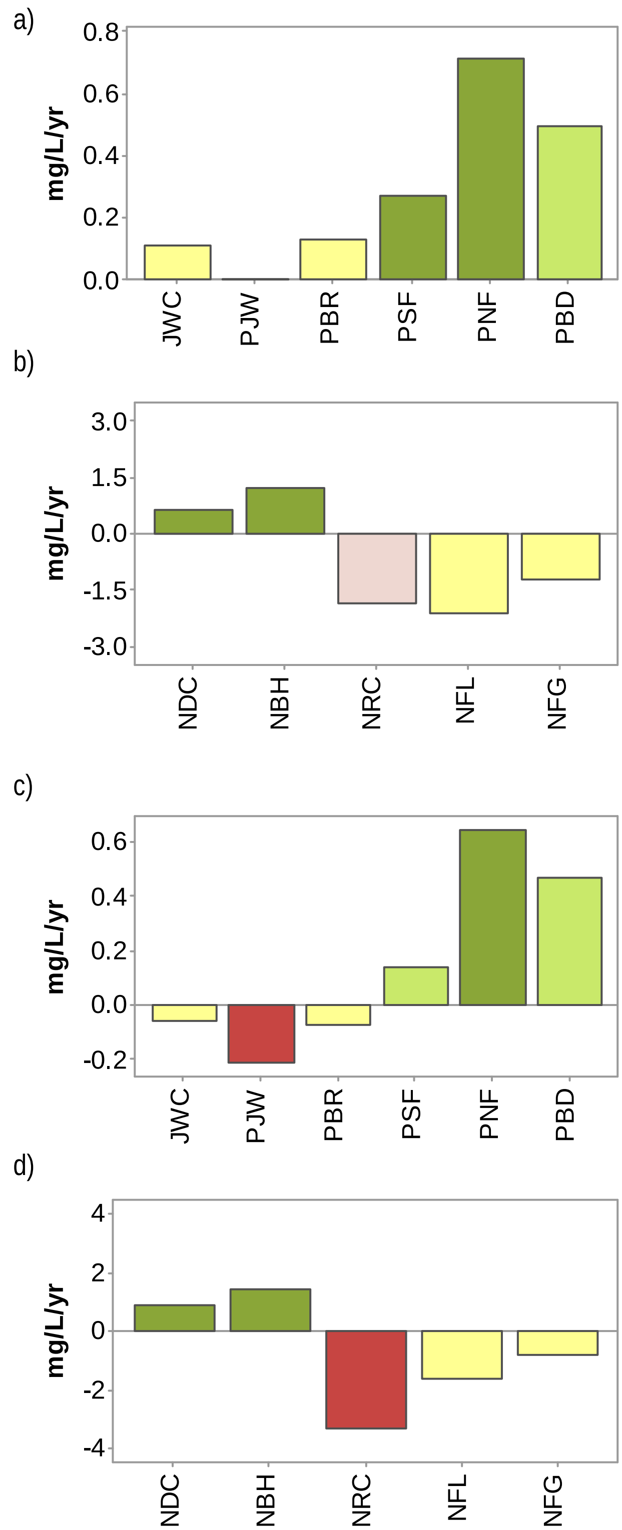


Figure 4.5 – Alkalinity trends on the Mainstem (a) and North Fork (b) CLP river and hardness trends on the Mainstem (c) and North Fork (d) CLP river

increased at mid- and high-elevation monitoring sites at a rate of 1.1 mg/L per year (**Figure** 4.6). TDS at these monitoring sites steadily increased in the years following the 2013 flood highlighting the persisting impacts of extreme flooding on water quality.

Step trends were identified at monitoring sites from the South Fork CLP river downstream and within the wildfire burn scar. Median TDS concentrations measured over the recent five-year period were 20 mg/L greater at PNF and PBD compared to baseline conditions (**Figure** 4.6). Total dissolved solids remained elevated in 2017 at PNF and PBD, but concentrations at PBD appear to be returning to baseline conditions.

Total dissolved solids significantly increased above and below Halligan Reservoir (NDC and NBH, respectively), and on Stonewall Creek over the long-term monitoring record in the North Fork CLP watershed. Step trends were observed from NRC downstream to NFG with an abrupt increased in 2012 followed by an abrupt decreased in 2013. Analogous to the trends observed in specific conductivity, the shifts in TDS are likely correlated with streamflow variability and the concentrating effects of low streamflow caused by drought conditions in 2012 and dilution effects of high streamflow following the 2013 flood event.

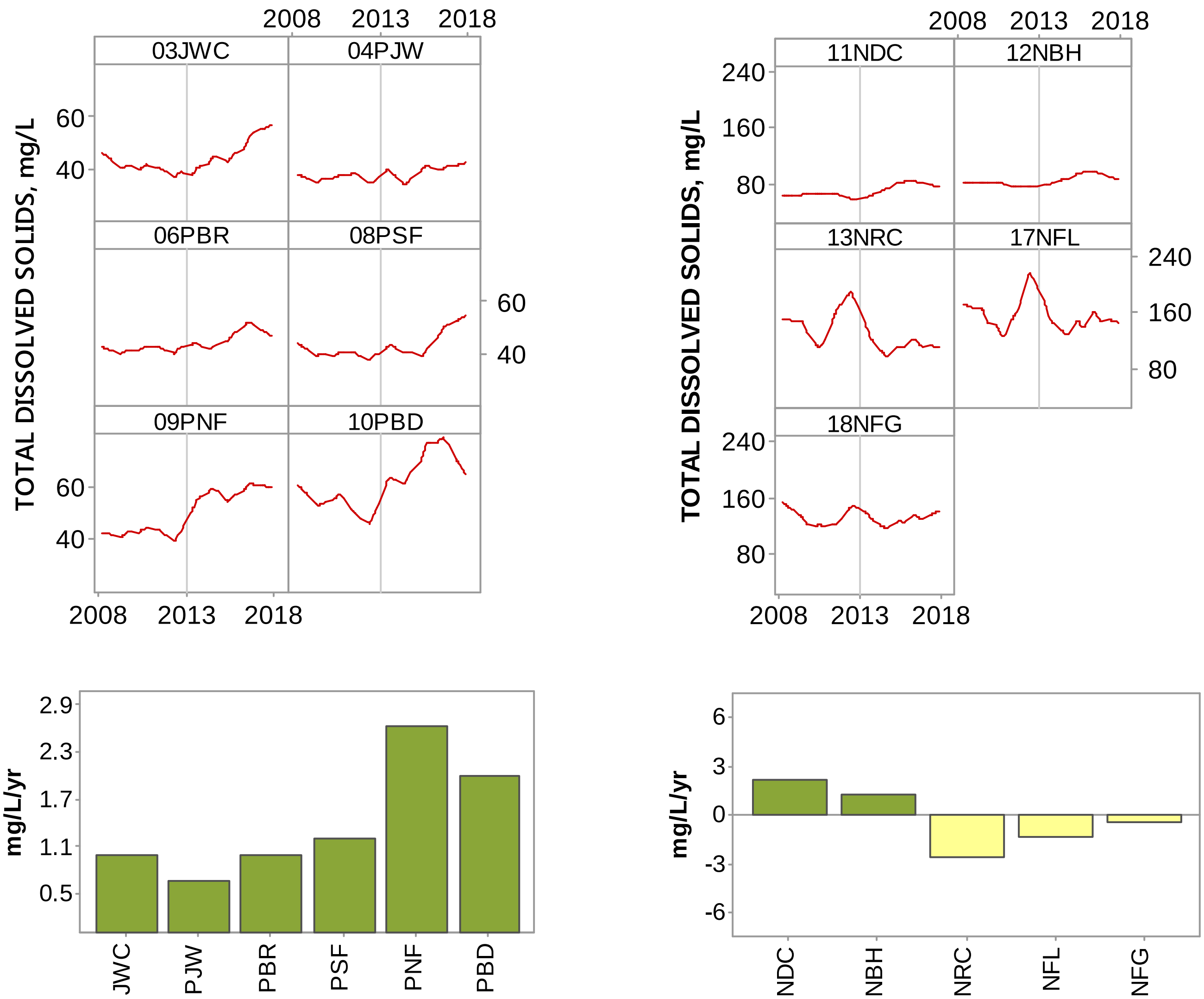


Figure 4.6 – Smoothed time-series plot for total dissolved solids on the Mainstem (top left) and North Fork (top right) CLP rivers and corresponding trend results with estimated trend slope (bottom).

4.3 TOTAL ORGANIC CARBON

Total organic carbon (TOC) is a measure of the total concentration of dissolved and particulate organic matter in water. TOC is derived from both terrestrial and aquatic sources. Terrestrial TOC originates from soils and plant materials that are leached and/or delivered to surface waters during storms and spring snowmelt runoff, whereas aquatic-derived TOC originates from algal production and subsequent decomposition within surface waters.

Total organic carbon is an important indicator of water quality, particularly as it relates to water treatment. Water treatment requires the effective removal of TOC because the interaction between residual TOC and chlorine can form regulated disinfection by-products (DBPs). DBPs are strictly regulated due to their carcinogenic potential. Increases in source water TOC concentrations pose concern due to the potential for higher residual TOC (post-filtration) and increased DBP formation potential. In addition, increased levels of TOC in source waters require additional removal requirements at the water treatment facility based on alkalinity levels (Table 4.2).

Table 4.2 – Total organic carbon removal requirements for water treatment facilities based on source water alkalinity and total organic carbon concentrations.

TOC (mg/L)	Source water alkalinity (mg/L as $CaCO_3$)		
	<60	60-120	>120
2-4	40%	30%	20%
4-8	45%	35%	25%
>8	50%	40%	30%

Total organic carbon concentrations gradually increased throughout the Mainstem CLP watershed over the long-term period of record. Significantly increasing trends were measured at all monitoring sites. The greatest increase was measured at the Barnes Meadow outflow diversion (BMR) where TOC concentrations increased 0.29 mg/L per year. TOC concentrations on the Mainstem CLP river changed at a slower rate. The greatest change was observed at the highest elevation monitoring site at PJW. Although, the rate of change was similar at mid- to lower-elevation monitoring sites (PBR to PNF), there was a slight increase in the trend slope moving downstream (Figure 4.7).

In the North Fork CLP watershed, TOC concentrations have been steadily decreasing over the most recent five-year period, but significant trends were only detected on Stonewall Creek and on the North Fork CLP river below Seaman Reservoir at NFG. TOC significantly increased 0.07 mg/L per year at SCM and significantly decreased 0.06 mg/L per year at NFG (Figure 4.7). It appears the decreasing TOC trend at NFG had a slight influence on downstream at PBD where the rate of change over the long-term period was slightly less than PNF upstream (0.08 mg/L per year and 0.10 mg/L per year; Figure 4.7).

There was a short-term decrease in TOC at all monitoring sites throughout the Upper CLP watershed in 2012 further highlighting the impacts of severe drought on water quality. In contrast to other water quality variables, severe drought and resultant low snowpack and streamflow limit the delivery of organic carbon to surface waters. Potential drivers of increasing TOC in the Mainstem CLP watershed include:

- Catchment characteristics
- Hydrology, climate and weather
- Declining atmospheric acid deposition
- Increasing In-stream algal production
- Increasing algal production in high alpine lakes

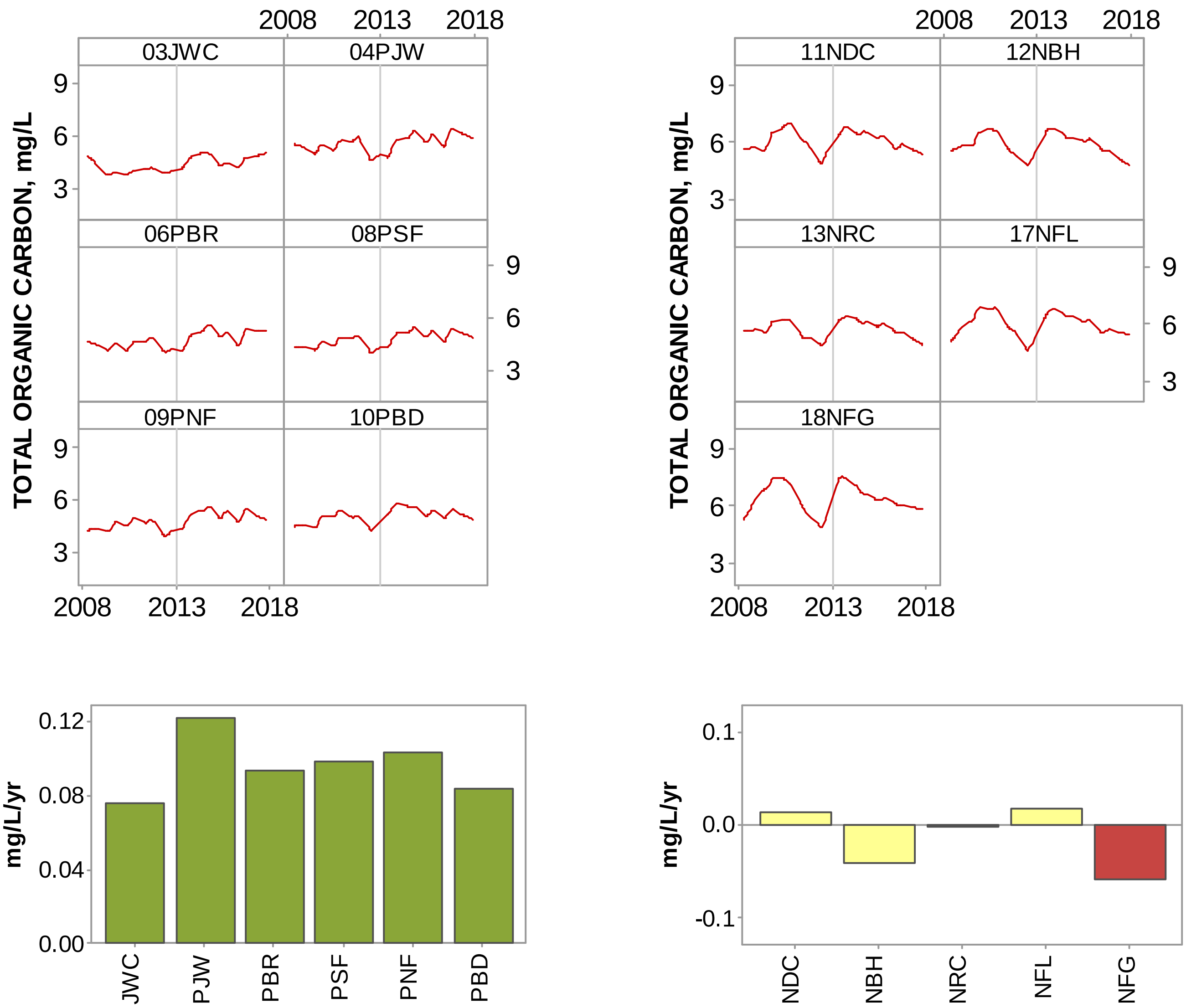


Figure 4.7 – Smoothed time-series plot for total organic carbon on the Mainstem (top left) and North Fork (top right), and corresponding trend results with estimated trend slope (bottom).

4.4 NUTRIENTS

Nutrients are an important component of source water quality monitoring. In high concentrations and under certain environmental conditions, nutrients can lead to algal growth. In extreme situations, nutrients can cause abundant growth of cyanobacteria, which are responsible for the production of cyanotoxins and other compounds that can affect the taste and odor of drinking water supplies. Potential sources of nutrients in aquatic systems include animal waste, leaking septic systems, fertilizer run-off, erosion, and atmospheric deposition.

Ammonia (NH_3-N), nitrate (NO_3-N), nitrite (NO_2-N), and ortho-phosphate (PO_4) are dissolved forms of nitrogen and phosphorus that are readily available for plant uptake. Both Total Kjeldahl Nitrogen (TKN) and Total Phosphorus (TP) serve as aggregate measures of potential nitrogen and phosphorus availability to the system.

Total nitrogen (TN) is the sum of TKN and inorganic nitrogen (NO_3-N and NO_2-N). TKN is a measure of ammonia plus organic nitrogen and comprises the largest fraction of TN, with inorganic nitrogen representing lesser fraction. Likewise, TP is a measure of dissolved phosphorus as well as phosphorus bound to sediments and organic matter. For this report, the discussion of results only pertains to values above the reporting limits currently used by the FCWQL. Current reporting limits are 0.005 mg/L (5 µg/L) for PO_4, 0.01 mg/L (10 µg/L) for ammonia and TP, and 0.04 mg/L (40 µg/L) for nitrate and nitrite. In the calculation of TN (TKN + NO_3-N + NO_2-N), concentrations below their respective reporting limit were reported as half the reporting limit (Helsel and Hirsch, 2002).

Caution should be taken when interpreting the observed long-term trends for most nutrient water quality constituents because of the uncertainty associated with values reported below the reporting limit. In most cases, trend slope output from the SMKT revealed zero rate of change for significant trends, and therefore, corresponding trend results bar graphs were not included in the presentation of results. Instead, median values measured over the recent five-year period were compared to the baseline median values.

Nitrogen

Total nitrogen appeared to increase at all monitoring sites over the long-term period of record throughout the Mainstem CLP watershed. Total nitrogen gradually increased at high- to mid-elevation monitoring sites from Joe Wright Creek to Mainstem CLP river above the South Fork CLP river (PBR). TN significantly increased 9 µg L^{-1} per year at PJW over the long-term period, but this trend did not appear to influence TN downstream at PBR. Step trends in TN were observed at monitoring sites from the South Fork CLP river downstream to PBD (Figure 4.8). A notable increase in TN was also measured in the North Fork CLP watershed at NDC. No trends were observed for TKN.

Nitrate followed a similar pattern to that of total nitrogen over the long-term period of record, but there was uncertainty in the observed long-term trend because

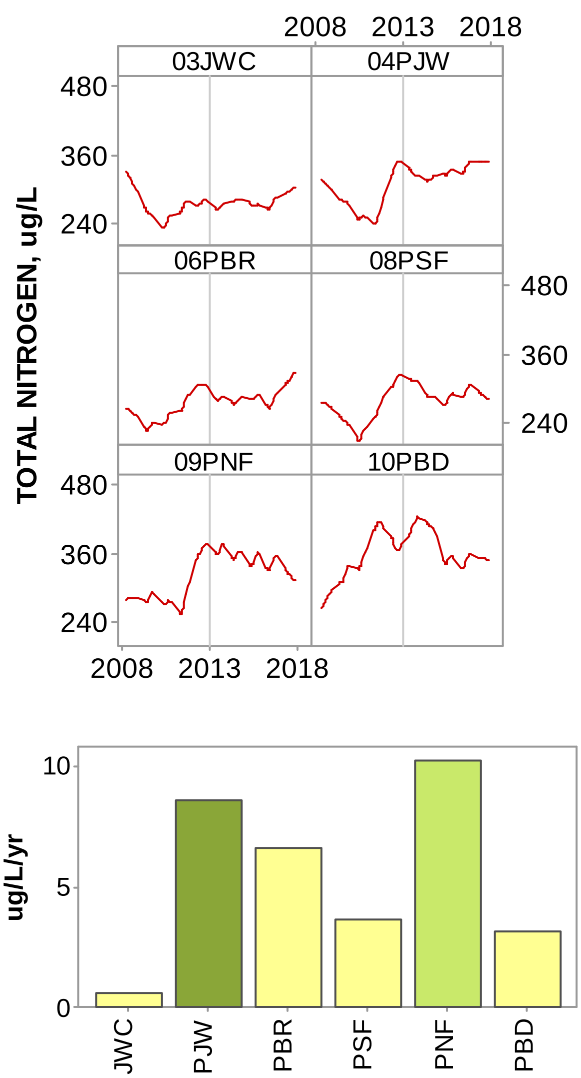


Figure 4.8 – Smoothed time-series plot for total nitrogen on the Mainstem (top) and corresponding trend results with estimated trend slope (bottom).

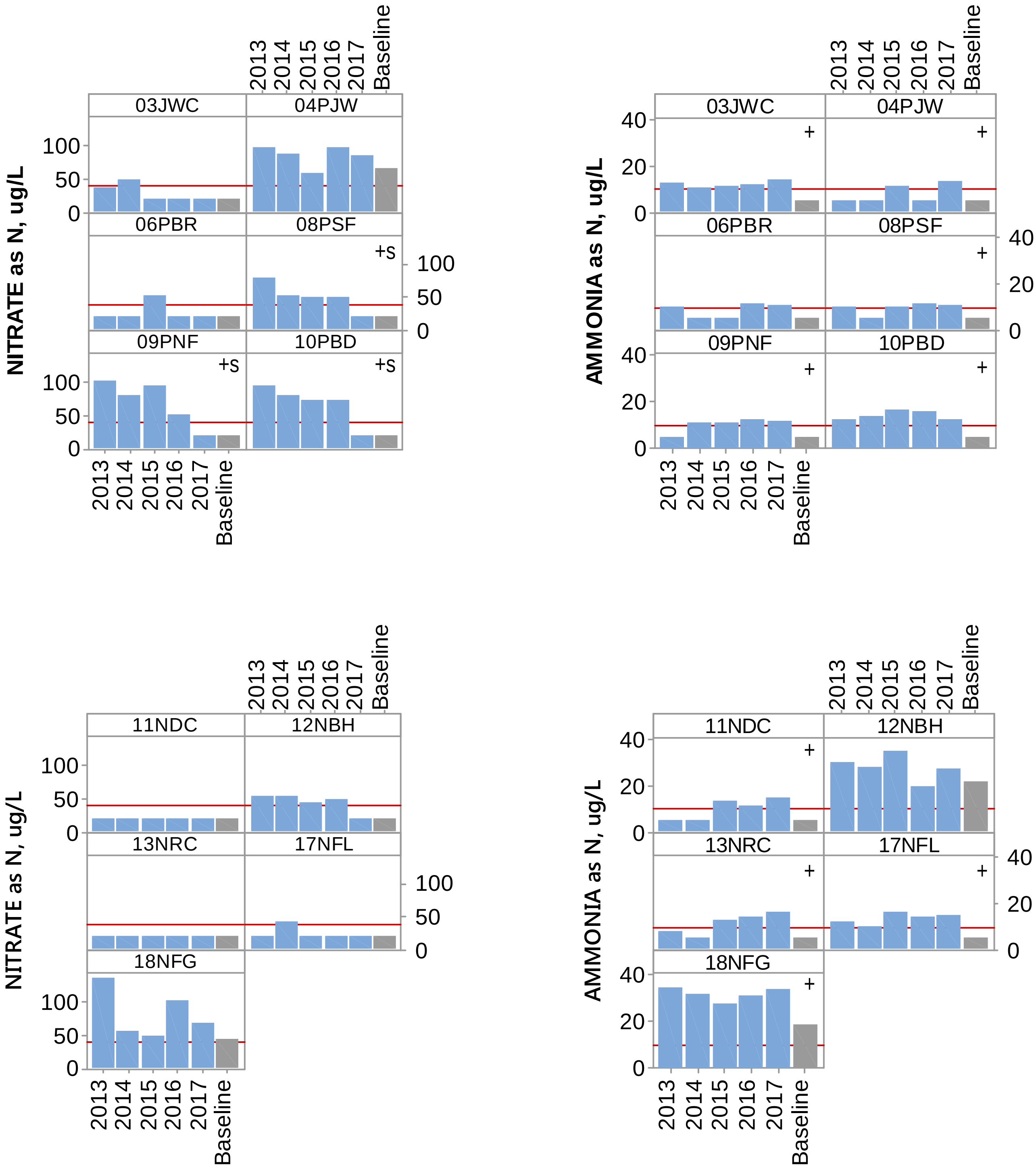


Figure 4.9 – Median nitrate and ammonia concentrations over the recent five-year period compared to baseline concentrations on the Mainstem and North Fork CLP rivers. The red line indicates the City of Fort Collins Water Quality Laboratory's reporting limit. +s = significantly increasing step trend and + = significant increasing long-term trend

concentrations were below the reporting limit at most sites over the baseline period. Significant step trends were observed at monitoring sites from the South Fork CLP river downstream to PBD in the years following wildfire. In contrast, there were no step trends detected at higher elevation monitoring sites in the Mainstem CLP watershed providing further evidence of wildfire related impacts on water quality (Figure 4.9).

Nitrate concentrations in the years following the wildfire were 1 – 2 times greater than baseline conditions, but still relatively low (Figure 4.9). Median nitrate concentrations were trending down to baseline conditions over the recent five-year period suggesting watershed recovery (Figure 4.9). No long-term trends were detected in nitrate on the North Fork CLP watershed, but nitrate concentrations below Halligan and Seaman Reservoir were slightly higher over the recent five-year period compared to baseline conditions (Figure 4.9).

A significantly increasing trend was detected in ammonia at most monitoring sites throughout both the Mainstem and North Fork CLP watersheds. Higher concentrations over the recent five-year period were responsible for the observed long-term trend. Ammonia concentrations measured during the baseline period of record were routinely below the laboratory's reporting limit (20 µg/L) at most sites, except below Halligan and Seaman Reservoirs where concentrations are usually detected above the reporting limit (Figure 4.9). In recent years, ammonia concentrations throughout the Upper CLP watershed were detected above the reporting limit more often and median ammonia concentrations over the five-year period were greater than baseline conditions, especially on the North Fork CLP river where median concentrations were 1 – 3 times greater than baseline conditions (Figure 4.9). The exact cause of elevated ammonia throughout the watershed is unknown; however, atmospheric deposition may be an attributable source.

Phosphorus

Site specific long-term trends were identified in total phosphorus in both the Mainstem and North Fork CLP watersheds. Significantly increasing trends in TP were measured on Joe Wright Creek (CHR and JWC), the South Fork CLP river and the Mainstem CLP river below the confluence with the North Fork (PBD). TP concentrations on Joe Wright Creek steadily increased over the long-term period of record, whereas an abrupt increase in TP

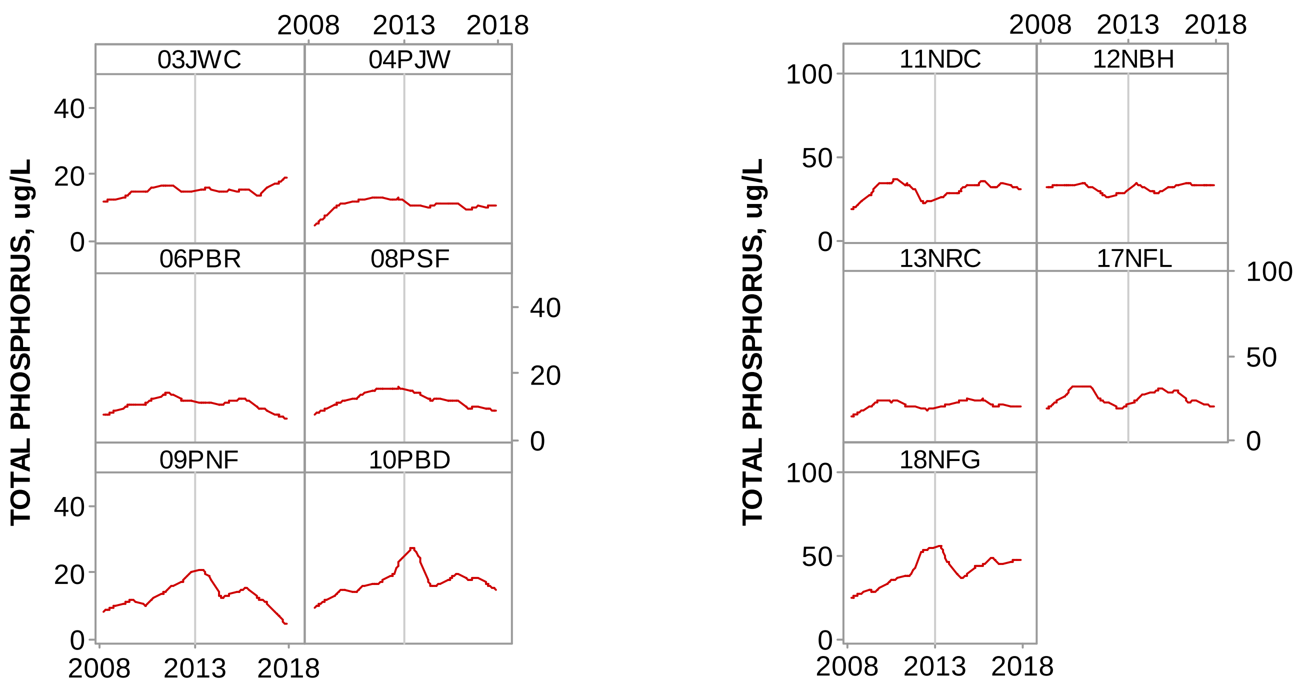
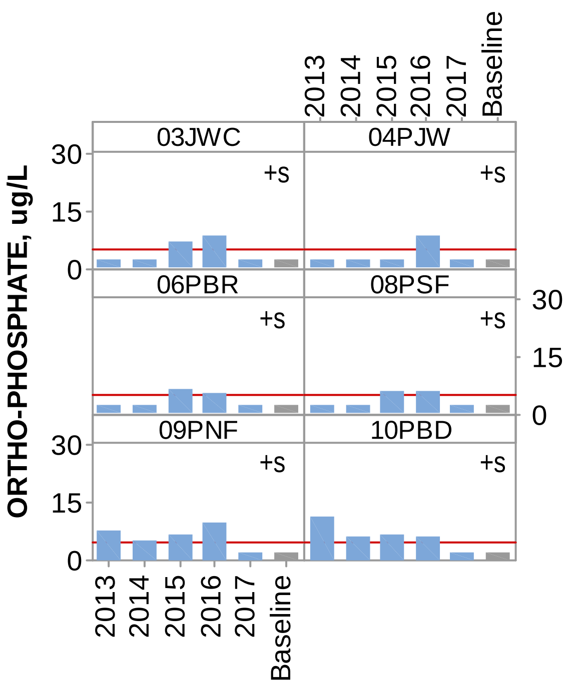


Figure 4.10 – Smoothed time-series plot for total phosphorus on the Mainstem (left) and North Fork (right).

concentrations was observed at monitoring sites located within the High Park wildfire burn scar (**Figure 4.10**). Median TP concentrations measured over the recent five-year period were elevated compared to baseline conditions.

The highest concentrations were measured in the year immediately following the wildfire at PNF and PBD, but concentrations fell in subsequent years. Median TP concentrations at PNF were below baseline conditions in 2017, implying watershed recovery and a return to pre-fire conditions. TP concentrations remained elevated at PBD, which may be attributed to significantly increasing TP concentrations on the North Fork CLP river below Seaman Reservoir at NFG. A significantly increasing trend was also measured on the North Fork CLP river above Halligan Reservoir at NDC (**Figure 4.10**). Median TP concentrations steadily increased over the recent five-year period with the highest median concentration measured in 2017.

Step trends were detected in ortho-phosphate at most monitoring sites throughout the Mainstem and North CLP watersheds. Median ortho-phosphate concentrations over the current five-year period were measured slightly above the laboratory reporting limit, while baseline conditions were generally below the reporting limit (**Figure 4.11**). Ortho-phosphate concentrations were slightly higher than the reporting limit from JWC downstream to PSF in 2015 and 2016, which may be attributable to flooding in 2013. In general, ortho-phosphate steadily increased from 2013 to 2015 and then slowly returned to baseline conditions by 2017. This short-term watershed wide trend in ortho-phosphate provides further evidence of water quality impacts associated with the 2013 flood event.



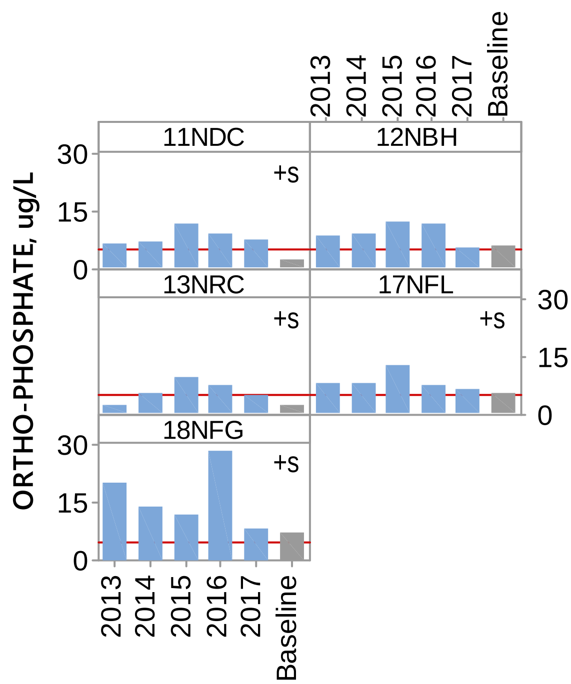


Figure 4.11 – Median ortho-phosphate over the recent five-year period compared to baseline concentrations on the Mainstem and North Fork CLP rivers. The red line indicates the City of Fort Collins Water Quality Laboratory's reporting limit. +s = significant increasing step trend and + = significantly increasing long-term trend

4.5 MICROORGANISMS

Total Coliform and *E. coli*

Coliforms are types of bacteria found naturally in the environment in plant and soil material, but can also found in the digestive tract of animals, including humans. Disease causing bacteria or pathogens can be introduced to the raw drinking water supply from fecal contamination. The Upper CLP Collaborative Monitoring Program tests its source water supply for the presence of bacterial contamination by measuring the total amount of coliforms, an indicator organism for the presence of pathogenic bacteria. In addition, *Escherichia coli* (*E. coli*) is measured and used as an indicator of human or animal fecal waste pollution since the source of origin is more specific than total coliforms. Total coliform counts are greater than *E. coli* counts because total coliform includes all types and sources of coliform bacteria.

Site specific trends were identified in total coliforms and *E. coli* in the Upper CLP watershed. Median total coliforms were greater over the current five-year period compared to baseline conditions at all sites (Figures 4.12). A step trend was identified at PNF with significantly higher counts of total coliforms over the current five-year period. Median total coliform counts were 1.5 times higher than baseline conditions (327 CFU/100 mL and 488 CFU/100 mL measure for current and baseline, respectively). A similar step trend was measured downstream at PBD, but contributions from the North Fork may have diluted the trend considering total coliforms significantly decreased on North Fork CLP river at NFG over the long-term period of record. The abrupt increase at monitoring sites on the Mainstem CLP river is likely a result of increased erosion and delivery of coliforms following the wildfire.

E. coli significantly increased 0.50 CFU/100 mL per year at PBR over the long-term monitoring period, which is likely caused by a steadier increase in recent years. This trend may indicate aging and leaking septic systems located near the river in the Town of Rustic. No other trends were identified in E. coli in the Mainstem CLP watershed or at NFG on the North Fork CLP river, although cell counts were higher over the current five-year period compared to baseline conditions (Figure 4.12).

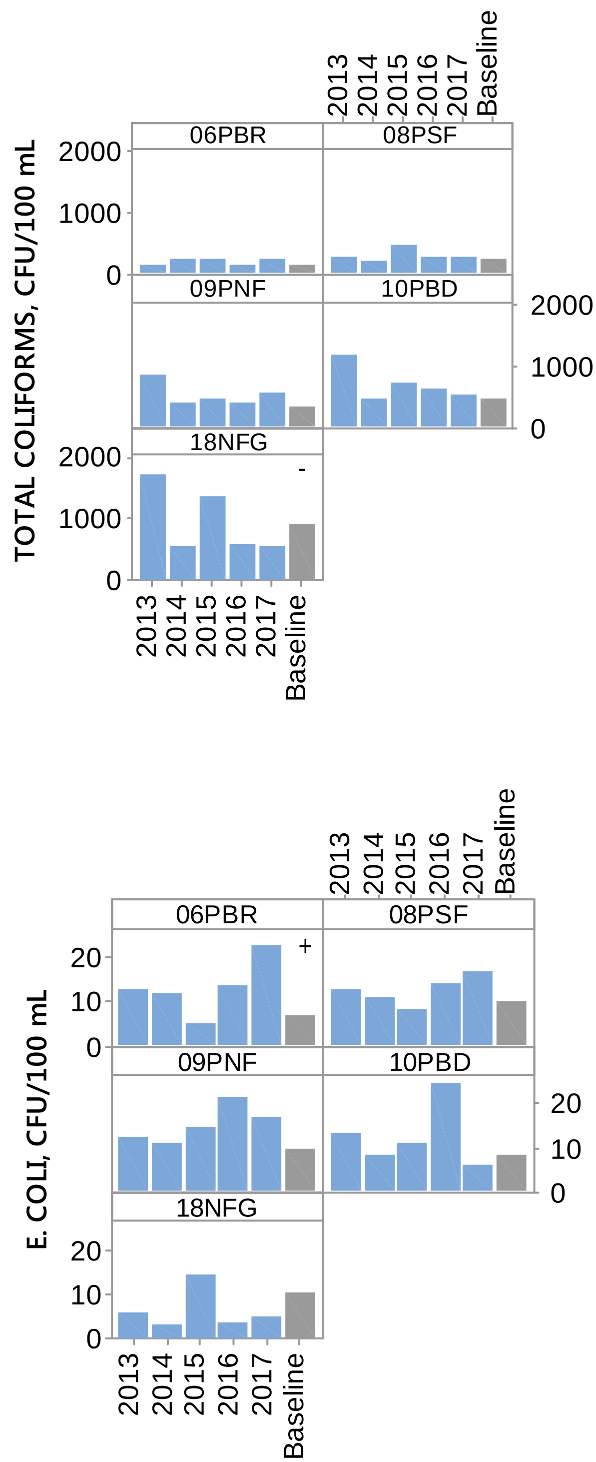


Figure 4.12 – Median total coliforms (top) and *E. coli* (bottom) over the recent five-year period compared to baseline concentrations on the Mainstem and North Fork CLP rivers. + = significantly increasing trend and - = significantly decreasing trend.

5.0 SUMMARY & IMPLICATIONS

5.1 WATERSHED IMPACTS & ISSUES OF CONCERN

Over the past ten years (2008 – 2017) the Upper CLP watershed has experienced periods of wet and dry water years influencing both streamflow and water quality conditions in the CLP watershed. It is projected with current climate models that the frequency and timing of wet and dry years will be more unpredictable in the future. The most serious consequences of climate change on Colorado watersheds include: changes in precipitation and streamflow patterns, increasing severity and frequency of droughts and wildfires, and increasing frequency and intensity of forest insects and disease.

Over the past two decades several forest insects and diseases have impacted Colorado's forests. The mountain pine beetle (MPB), a native bark beetle that infests all pine species, impacted over 3 million acres of Colorado's forest over the past two decades. The spruce beetle has destroyed 1.78 million acres since 1996 and has been Colorado's most common forest pest insect over the past six. In 2017, the Colorado State Forest Service identified significant infestations in Larimer County and noted the potential for expanding outbreaks in susceptible Engelmann spruce forests in the northern portion of the state suggesting the potential for future infestations and tree mortality in the Upper CLP watershed.

Exceptionally hot and dry conditions in 2012 lead to extreme drought and two major wildfires causing extensive disturbance to mid- and low- elevations of the Mainstem CLP watershed and the area surrounding Seaman Reservoir on the North Fork CLP river. Following the wildfires, high intensity rainfall over the burn scar caused severe flooding, erosion, and debris flows on the Mainstem CLP river, often impacting water quality and water treatment with little or no warning for WTP staff. The years following the fires brought mostly average or above average snowfall and precipitation to the watershed, which has aided in watershed recovery; however, impacts to water quality persist five years after these events.

In the year following the fire, the Upper CLP watershed experienced a long-duration, high intensity rainfall event, which caused severe flooding in streams and rivers throughout the watershed. Flood peaks were several orders of magnitude greater than expected baseflows during that time of year, which may have lessened the impacts to water quality following the wildfires by scouring the river channel of ash and sediment deposits from previous debris flow events; however, changes in water quality in recent years may be attributable to the flood disturbance caused by elevated baseflows and erosion.

The watershed response to atmospheric deposition is less clear. The reduction in sulfur dioxide emissions has lessened the amount of sulfuric acid in the atmosphere and lead to declines in precipitation acidity and acidic deposition into Colorado's watersheds. Nitrogen deposition is more of a concern as increasing trends in ammonium have been observed in Colorado (Figure 2.4). It is expected that these trends will continue in the future because of projected population growth and oil and gas development along the Colorado Front Range.

5.2 TRENDS IN CLIMATE & WATERSHED HYDROLOGY

Long-term climate records throughout the Rocky Mountains have indicated that annual mean minimum air temperatures increased 0.7^{o}C per decade with stronger trends in the Colorado Rocky Mountains. These trends are consistent with global air temperature trends (Intergovernmental Panel on Climate Change, 2007). Over the past decade, similar trends were detected in air temperature at higher elevations in the Upper CLP watershed. Monthly mean air temperatures increased 0.24°F (0.13°C) per year. This trend was driven by increasing minimum temperatures during the winter season.

Precipitation trends were not detected over the long-term period of record. However, the maximum amount of water contained within the snowpack (peak snow water equivalent; SWE) decreased 1.03 inches per year over the past decade suggesting higher elevations of the Upper CLP watershed may receive less snowfall in the future. In addition, the peak SWE to precipitation ratio decreased over the last decade implying that precipitation patterns may be shifting in the Upper CLP watershed.

Streamflow significantly increased in the Upper CLP watershed over the long-term period of record. Monthly mean streamflow increased 13 cfs per year and winter streamflow increased 9 cfs per year. No trends were observed in the magnitude or timing of peak streamflow.

5.3 TRENDS IN WATER QUALITY

Water quality data collected throughout the Upper CLP watershed were analyzed for long-term trends to determine if concentrations of water quality parameters that have historically had the most impact on treatment at the three treatment plants have increased, decreased or stayed the same over the ten-year period of record from 2008 to 2017. Trend analyses were performed on all monitoring sites throughout the Upper CLP watershed for the following water quality parameters:

- Physical Parameters
- General Parameters
- Total Organic Carbon
- Nutrients
- Microorganisms

Two types of trends were identified in the Upper CLP watershed. Monotonic trends were identified as gradual, continuous changes (increasing or decreasing) in the data over time and step trends were recognized as an abrupt shift (up or down) in the data at a certain point in time. In general, step trends were measured for most water quality parameters at monitoring sites from the South Fork CLP river (PSF) downstream to the Mainstem CLP river below the confluence with the North Fork (PBD). These trends

Table 5.1 – Summary of water quality trends detected throughout the Upper CLP watershed over the long-term period from 2008 to 2017. (+ = increasing trend; - = decreasing trend; and +s = increasing step trend)

Water Quality Parameter	*MAINSTEM CLP WATERSHED*						*NORTH FORK CLP WATERSHED*				
	JWC	PJW	PBR	PSF	PNF	PBD	NDC	NBH	NRC	NFL	NFG
Temperature								+			+
pH	+		+	+	+	+	+	+	+	+	+
Specific Conductivity		-			+s		+	+	-	-	-
Turbidity					+s	+s				-	-
Alkalinity				+	+s	+s	+	+			
Hardness		-			+s	+s					
Total Dissolved Solids	+	+	+	+s	+s	+s	+	+			
Total Organic Carbon	+	+	+	+	+	+					-
Nutrients	+	+	+	+s	+s	+s	+	+	+	+	+
Microorganisms			+		+						-

occurred in response to the dramatic landcover change in the Mainstem CLP watershed caused by wildfire that burned in 2012.

Trends were detected at varying scales. Both site-specific and watershed-wide trends were detected in the Upper CLP watershed. Site-specific trends capture impacts to a specific site, while watershed-wide trends imply a large disturbance that impacted the entire basin or large areas of basin impacting multiple monitoring locations.

Table 5.1 summarizes significant trends detected throughout the Upper CLP watershed over the long-term period from 2008-2017.

5.4 IMPLICATIONS TO WATER TREATMENT

Long-term trends in certain water quality parameters may pose issues to water treatment processes in the future. It is anticipated that water quality impacts caused by recent wildfire and flooding will recover with time. Wildfire impacted water quality parameters are trending toward baseline conditions in recent years implying watershed recovery. However, climate change projections for Colorado point to a warmer climate and unpredictable precipitation patterns that will likely increase the frequency and severity of drought and wildfires, and other extreme-weather events that can impact to water quality.

Water quality changes and trends on the Mainstem CLP river at PNF and PBD have the most direct impact to water treatment at the City of Fort Collins', Soldier Canyon Water Authority and City of Greeley water treatment plants. The following bullets summarize water quality trends detected at PNF and PBR and implications to water treatment:

- Alkalinity and hardness were 1.5 – 2 times greater over the recent five-year period compared to baseline conditions. Elevated levels over this time were caused by post-fire erosion and flood effects. More alkaline water influences water pH and may affect the taste of drinking water. Despite elevated concentrations in recent years, alkalinity remains relatively low in CLP raw water. Because of seasonal influences on alkalinity levels in CLP raw water, blending and chemical additions will continue to be the best practice to meet drinking water treatment goals.

- pH increased 0.07 units per year over the past decade at PNF and PBD indicating that CLP raw water is becoming more alkaline. Increasing CLP raw water pH may affect the taste of drinking water requiring additional blending with an alternate raw water source or chemical additions to adjust pH levels to meet drinking water treatment goals. pH increased throughout the Upper CLP watershed indicating a watershed wide change potentially attributable to the watershed's response to declining precipitation acidity over the past two decades. Elevated carbonates associated with post-fire erosion and flooding may be elevating the alkalinity at PNF and PBD.

- Total dissolved solids increased abruptly at PNF and PBD following wildfire. Concentrations were 20 mg/L (median) greater over the recent five-year period compared to pre-fire baseline conditions, but remain very low compared to finished drinking water levels throughout the country. Elevated TDS concentrations in CLP raw water do not pose a health risk, but high concentrations indicate elevated levels of minerals, salts, metals, cations or anions. High levels of dissolved solids in finished water can cause water quality concerns including corrosion, scale formation or taste issues if not addressed through treatment.

- Total organic carbon gradually increased 0.10 mg/L per year at PNF and 0.08 mg/L per year at PBD over the past decade. Higher TOC levels in CLP raw water pose concern due to the potential for higher residual TOC (post-filtration) and increased disinfection by-products (DBPs) formation. Increasing TOC in the CLP raw water supply may require additional blending with other raw water sources or increased coagulant for efficient TOC removal. Additional treatment implications for higher CLP raw water TOC may include increased removal requirements as concentrations more frequently exceed 4.0 mg/L.

- Elevated nutrients (nitrate and ortho-phosphate) were observed at PNF and PBD in years following the wildfire. Concentrations were still relatively low, but even small increases in nutrient loads in low nutrient environments can lead to algal growth and potential taste and odor issues. Nutrient concentrations over the recent five-year period have steadily decreased at PNF and PBD indicating watershed recovery and a return to pre-fire baseline conditions.

- Total coliforms were greater over the recent five-year period compared to baseline conditions at PNF. Median total coliform counts were 1.5 times higher than baseline conditions. A similar trend was observed at PBD, but contributions from the North Fork may have lessened the trend. The abrupt increase at monitoring sites on the Mainstem CLP river is likely a result of increased erosion and delivery of coliforms following the wildfire.

6.0 DATA QUALITY ASSURANCE AND CONTROL

The Upper CLP watershed collaborative monitoring program assures comparability and validity of data by complying with monitoring methods and implementing quality assurance and quality control (QAQC) measures. QAQC measures are good practice in environmental monitoring and can be used to determine potential error in data due to contamination of water samples, sampling error, equipment contamination, and/or laboratory error. The Upper CLP monitoring sites are representative of the goals and objectives outline previously and demonstrate the true character of the watershed at the time of sampling. The following summarizes QAQC data collected over the 2017 monitoring season. Refer to Upper CLP annual reports for QAQC summaries for subsequent years (2013-2016).

6.1 FIELD QUALITY CONTROL

In 2017, field duplicates were collected during each Mainstem CLP monitoring event. Field duplicates (11 duplicates in total) were obtained at PNF during each monitoring event to determine precision of data, while field blanks (22 blanks in total) were collected at different monitoring locations on both the Mainstem and North Fork, to identify potential for sample contamination. The field data quality sampling schedule is outlined in the 2017 annual sampling plan (Attachment 4). QAQC samples and accuracy of field equipment is reviewed by Source Watershed Program staff.

Field Duplicates

In 2017, twelve percent (33 out of 183) of the environmental samples collected were QAQC samples. Precision is a measure of the deviation from the true value. For most constituents, duplicate determinations should agree within a relative percent difference of 10%. Duplicate samples that differ greater than 10% were flagged for further quality assurance and control measures. Blank samples should not contain analytes above the reporting limit. The results of the field quality assurance and control sampling indicate that precision and accuracy were acceptable.

Table 5 outlines relative percent difference statistics for duplicate samples collected in 2017 and illustrates that UCLP water quality data are of high precision. All duplicate samples were within 10% agreement at the 50th percentile, except for total phosphorus. Ammonia, orthophosphate, total coliforms, TDS, TKN and total phosphorus were slightly outside of the 10% agreement at the 75th percentile,

Field Blanks

Eighty-seven percent of field blank samples reported below the constituent's respective reporting limits in 2017. The 13% of field blank samples that were detected above the reporting limits included Ni, NH_3-N, turbidity, and TDS

Table 6.1 – Data quality assurance statistics calculated for duplicate samples collected at PNF monitoring location in 2017.

Constituent	Range in QAQC sample concentration		Reporting Limit	Absolute Mean Difference	Relative Percent Difference (%) Percentile		
	min	*max*			*25th*	*50th*	*75th*
Alkalinity (mg/L)	31.6	32.2	2	0.44	0.2	0.4	1.4
Hardness (mg/L)	34.0	34.3	5	0.3	0.2	0.5	0.7
Ammonia (ug/L)	18.2	26.3	10	3.1	5.5	9.6	16.2
Turbidity (NTU)	8.64	9.06	0.05	0.18	0.7	2.5	3.6
ortho-Phosphate (ug/L)	6	36	5	4	5.8	7.3	21.7
E. coli (cells/mL)	0	727	-	19	-	-	-
T. coli (cells/mL)	79	1046	-	137	5.7	7.5	15.0
TDS (mg/L)	85	97	10	11	5.8	7.9	12.6
TKN (ug/L)	475	511	100	54	3.2	7.1	16.2
TOC (mg/L)	9.57	9.62	0.5	0.1	0.7	0.8	1.0
Total P (ug/L)	44.2	60.3	10	7.0	4.6	12.1	23.6

(Table 6.2). Water quality constituents that exceeded their respective reporting limit were similar to blank exceedances reported in previous years.

Concentrations exceedances were reported only slightly above the reporting limit for most samples and concentrations were minimal compared to concentrations of environmental samples. Potential causes of these contaminants are listed below:

- Atmosphere/particulates in the air slightly increasing Ni, ammonia, turbidity, and total dissolved solids. It is recommended to cap sample bottles between rinses and as quickly as possible following the blank sample collection.

- Inadequate rinsing of sample bottles either in the field or laboratory may have left residuals increasing turbidity and total dissolved solids. It is recommended that sample bottles be subject to a final rinse with deionize water in the laboratory prior to storage and triple rinsed in the field with deionize water prior to blank sample collection.

- Ammonia contamination may be introduced by the field sampler and/or laboratory staff accidentally breathing on the sample. It is suggested to limit the amount of time the sample is exposed to the environment by immediately capping the sample bottle following sample collection and/or sample processing in the laboratory.

Instrument Accuracy

Accuracy is a measure of the degree of closeness a measurement is to the true measurement. Equipment calibrations were conducted prior to field monitoring exhibitions using certified standards to assure the accuracy of sensors on the multi-parameter water quality sonde.

6.2 LABORATORY QUALITY CONTROL

Upper CLP water quality samples analyzed by the Fort Collins Water Quality Laboratory are reviewed by the Quality Assurance Coordinator to ensure data are free of sample contamination, analytical, and/or data entry errors.

The City of Fort Collins Water Quality Laboratory implements analytical QAQC measures by conducting laboratory blank, duplicate, replicate, and spiked samples. The City of Fort Collins WQL conducts a majority of analyses for the Source Water Quality Monitoring Program, and is a U.S. EPA Certified Drinking Water Laboratory with an established QA plan that is applied to all samples received by the laboratory (Elmund et al, 2013). The primary features of their QA protocol include:

- Precision: one duplicate sample is analyzed for every 10 samples; relative deviation should be less than 10%.

- Accuracy: one external QCS sample is analyzed with each set of samples analyzed. Methods may specify an acceptable recovery range. In general, Standard Methods limits are ± 5% and EPA methods are ± 10%.

- Recovery: one sample is spiked for every 10 samples; if there are different matrices, at least one sample per matrix is spiked. Limits for most methods are ± 15%. If one type of matrix spike fails and all other QC passes, those samples may be flagged.

A complete description of laboratory personnel, equipment, and analytical QA methods is outside of the scope of this report and is not addressed in detail here. As part of the City's Environmental Services Division the WQL operates under the guidance of a general QA plan (Elmund et al., 2013).

Table 6.2 – Blank samples detected above their respective detection limit from 2013 to 2017.

Constituent	Samples above DL	Total samples	% exceedance	Reporting Limit	Max Exceedance
Ni (ug/L)	1	4	25%	1	1.11
NH_3-N (ug/L)	8	22	36%	0.01	0.04
Turbidity (NTU)	16	22	73%	0.05	0.99
TDS (mg/L)	13	22	59%	10	23

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ATTACHMENT 1

LAND USE COMPARISON OF THE NORTH FORK AND MAINSTEM CLP (AREAS CALCULATED USING USGS SEAMLESS GIS DATA SETS)

Land Use Comparison	North Fork (acres)	Main Stem (acres)	North Fork Area (%)	Main Stem Area (%)
Developed land (commercial, industrial, residential, urban, and utilities)	2,817	1,945	0.8	0.7
Agricultural use and grassland (Cropland, pasture, other agriculture, scrub and grasses)	183,719	54,765	52.3	18.3
Forest (forest and brush)	154,654	213,879	44.1	71.5
Natural lands (exposed rock, bare ground, wetlands, tundra, lakes)	9,926	28,473	2.8	9.5
Total	351,116	299,062	100	100

ATTACHMENT 2

UPPER CLP COLLABORATIVE WATER QUALITY MONITORING PROGRAM SAMPLING SITE

MAIN STEM	Description	Rationale	GPS Coordinates
100CHR	Chambers Lake Outflow	Outflow from Chambers Lake	N 40° 36.039 W 105° 50.203
090BMR	Barnes Meadow Reservoir outflow	High TOC and nutrients compared to CHR	N 40° 36.039 W 105° 50.203
080JWC	Joe Wright Creek at Aspen Glen Campground	Joe Wright Creek above confluence with main stem	N 40° 37.233 W 105° 49.098
070PJW	Poudre at Hwy14 crossing (Big South Trailhead)	Above confluence Joe Wright Creek	N 40° 38.074 W 105° 48.421
060LRT	Laramie River at Tunnel at Hwy 14 crossing	Laramie River diversion water	N 40° 40.056 W 105° 48.067
050PBR	Poudre below Rustic	Midpoint between Laramie River Tunnel and South Fork; impacts to river from Rustic	N 40° 41.967 W 105° 32.476
040SFM	South Fork at bridge on Pingree Park Rd. *Discontinued in 2015*	Only access point on South Fork; South Fork water quality differs from main stem	N 40° 37.095 W 105° 31.535
041SFC	South Fork above confluence with Mainstem	Capture 15% more watershed area than SFM	
030PSF	Poudre below confluence with South Fork - Mile Marker 101	Below confluence with South Fork	N 40° 41.224 W 105° 26.895
020PNF	Poudre above North Fork 1/2 mile upstream from Old FC WTP#1	Represents water diverted at Munroe Tunnel and at Old FC WTP #1	N 40° 42.087 W 105° 14.484
010PBD	Poudre at Bellvue Diversion	Greeley WTP Intake	N 40° 39.882 W 105° 12.995
	NORTH FORK		
280NDC	North Fork above Halligan Reservoir; above confluence with Dale Creek	Inflow to Halligan Reservoir	N 40° 53.852' W 105° 22.556'
270NBH	North Fork at USGS gage below Halligan Reservoir	Outflow from Halligan Reservoir	N 40° 52.654' W 105° 20.314'
260NRC	North Fork above Rabbit Creek	Main stem North Fork above Rabbit Creek; downstream of Phantom Canyon	N 40° 49.640 W 105° 16.776
250RCM	Rabbit Creek Mouth	Tributary to North Fork; drainage area includes agricultural/grazing lands; significant flows late spring to early summer only	N 40° 48.615 W 105° 17.146
240SCM	Stonewall Creek Mouth	Tributary to North Fork; drains area east of Hwy 287	N 40° 48.458 W 105° 15.195
230PCM	Lone Pine Creek Mouth	Tributary to North Fork; drainage area includes Red Feather Lakes; significant flows late spring to early summer only	N 40° 47.696 W 105° 17.231
220NFL	North Fork at Livermore	At USGS gage	N 40° 47.269 W 105° 15.130
210SER	Seaman Reservoir *Discontinued in 2015*	Reservoir profiles; impacts to water quality from nutrient loadings	N 40° 42.274 W 105° 14.210
200NFG	North Fork below Seaman Reservoir	At gage below Seaman Res; sample before flow enters Poudre main stem	N 40° 42.143 W 105° 14.064

ATTACHMENT 3

2016 UPPER CLP MONITORING PARAMETER LIST

	Rationale	Notes
Field Parameters		
Conductance	Indicator of total dissolved solids.	All sites with water quality sonde.
Dissolved Oxygen	Profile indicates stratification, importance for aquatic life and chemical processes.	All sites with water quality sonde.
Temperature	Reflects seasonality; affects biological and chemical processes; water quality standard.	All sites with water quality sonde.
pH	Measure of acidity.	All sites with water quality sonde.
General & Miscellaneous Parameters		
Alkalinity	Indicator of carbonate species concentrations; Acid neutralizing capacity of water; treatment implications.	
Discharge	Necessary for flow dependent analysis and load estimation.	Measured during sampling at NRC, RCM, SCM, PCM, PJW, SFC when conditions allow
Geosmin	Taste and odor compound	Measured monthly at PBR and PNF
Hardness	Treatment implications. Hard water causes scaling and soft water is considered corrosive.	
Total Dissolved Solids (TDS)	Indicator of overall water quality; includes both ionic and non-ionic species.	
Total Organic Carbon (TOC)	Important parameter for water treatment; precursor of disinfection byproducts.	
Turbidity	Indicator of suspended material; important for water treatment.	
Nutrients		
Nitrogen, Ammonia	Primary source of nitrogen to algae, indicator of pollution by sewage, septic tanks, agriculture and atmospheric deposition; water quality standard.	
Nitrate	Primary source of nitrogen to algae; indicator of pollution by sewage, septic tanks, agriculture, and atmospheric deposition; water quality standard.	
Nitrite	Toxic inorganic nitrogen species; rarely encountered at significant concentrations; water quality standard.	
Total Kjeldahl Nitrogen	Sum of organic nitrogen and ammonia.	
Ortho-Phosphorus (Soluble Reactive Phosphorus)	Form of phosphorous (dissolved PO_4^{-3}) most available to algae; indicator of pollution by sewage, septic tanks, agriculture and atmospheric deposition.	
Total Phosphorus	Includes dissolved and adsorbed, organic and inorganic forms of phosphorus, indicator of pollution by sewage, septic tanks, agriculture and atmospheric deposition.	

Major Ions		
Calcium	Major ion.	6x/yr
Chloride	Major ion.	6x/yr
Magnesium	Major ion.	6x/yr
Potassium	Major ion, minor importance as a nutrient.	6x/yr
Sodium	Major ion.	6x/yr
Sulfate	Major ion.	6x/yr
Microbiological Constituents		
E. Coli	Indicator of human or animal waste contamination; water quality standard.	Only from Rustic downstream, NFL, NFG, SER
Total Coliform	Indicator of human or animal waste contamination.	Only from Rustic downstream, NFL, NFG, SER
Cryptosporidium	Pathogen, indicator of human or animal waste contamination.	Monthly above and below Halligan Reservoir, and below Seaman Reservoir
Giardia	Pathogen, Indicator of human or animal waste contamination.	Monthly above and below Halligan Reservoir, and below Seaman Res
Metals		
Aluminum, total & dissolved	Natural occurs in rocks and soil. Indicator of pollution from mining activity at elevated levels; Aesthetic effects to drinking water	Only PNF & NFG
Arsenic, total & dissolved	Natural occurs in rocks and soil. Indicator of pollution from mining activity at elevated levels; water quality standard.	Only PNF & NFG
Cadmium, total & dissolved	Natural occurs in rocks and soil. Indicator of pollution from mining activity at elevated levels; water quality standard.	Only PNF & NFG
Chromium, dissolved	Natural occurs in rocks and soil. Water quality standard.	Only PNF & NFG
Copper, dissolved	Natural occurs in rocks and soil. Water quality standard.	Only PNF & NFG
Iron, total & dissolved	Natural occurs in rocks and soil. Affects aesthetic quality of treated water.	Only PNF & NFG
Lead, total & dissolved	Natural occurs in rocks and soil. Indicator of pollution from mining activity at elevated levels; water quality standard.	Only PNF & NFG
Manganese, total & dissolved	Natural occurs in rocks and soil. Aesthetic effects to drinking water; water quality standard	Only PNF & NFG
Nickel, dissolved	Natural occurs in rocks and soil. Indicator of pollution from mining activity at elevated levels; water quality standard.	Only PNF & NFG
Silver, dissolved	Natural occurs in rocks and soil. Indicator of pollution from mining activity at elevated levels.	Only PNF & NFG
Zinc, total & dissolved	Natural occurs in rocks and soil. Indicator of pollution from mining activity at elevated levels.	Only PNF & NFG
Mercury, Low Level	Accumulates in fish tissue even when present in very low concentrations.	Sample every 3 to 5 yrs.

ATTACHMENT 4

UPPER CLP COLLABORATIVE WATER QUALITY MONITORING PROGRAM 2016 SAMPLING PLAN

	2017 Sampling Dates										
	Apr 10 -11	Apr 24-25	May 8-9	May 22-23	Jun 5-6	Jun 20-21	Jul 10-11	Aug 14-15	Sep 11-12	Oct 16-17	Nov 13-14
Station											
North Fork CLP											
NDC	F,G,P,	F,G,I,B	F,G,P	F,G,I	F,G,P	F,G,I	F,G,P	F,G,I,P	F,G,P	F,G,I,P	F,G,I,P
NBH	F,G,P,	F,G,I,	F,G,P	F,G,I	F,G,P	F,G,I	F,G,P	F,G,I,P	F,G,P	F,G,I,P	F,G,I,P,B
NRC	F,G,D	F,G,I,D	F,G,D	F,G,I,D	F,G,D	F,G,I,D,B	F,G,D	F,G,I,D	F,G,D	F,G,I,D	F,G,I,D
RCM	G,D	F,G,I,D	F,G,D	F,G,I,D	F,G,D	F,G,I,D	----------	----------	----------	----------	----------
SCM	G,D	F,G,I,D	F,G,D	F,G,I,D	F,G,D	F,G,I,D	----------	----------	----------	----------	----------
PCM	G,D	F,G,I,D	F,G,D	F,G,I,D	F,G,D	F,G,I,D	----------	----------	----------	----------	----------
NFL	F,G	F,G,I	F,G	F,G,I,B	F,G	F,G,I	F,G,	F,G,I	F,G	F,G,I	F,G,I
NFG	F,G,E,P	F,G,I,E	F,G,E,P	F,G,I,M,E	F,G,E,P	F,G,I,E	F,G,E,P	F,G,I,E,P,B	F,G,E,P	F,G,I,M,P,E	F,G,I,P,E
Mainstem CLP											
CHR	F,G	F,G,I	F,G	F,G,I	F,G	F,G,I	F,G	F,G,I	F,G	F,G,I	F,G,I
BMR[2]	F,G	F,G,I	F,G	F,G,I	F,G	F,G,I	F,G	F,G,I	F,G	F,G,I	F,G,I
JWC	F,G, B	F,G,I	F,G	F,G,I	F,G	F,G,I	F,G	F,G,I	F,G	F,G,I	F,G,I
PJW	F,G,D	F,G,I,D	F,G,D	F,G,I,D	F,G,D	F,G,I,D	F,G,D	F,G,I,D	F,G,D	F,G,I,D,B	F,G,I,D
LRT	F,G	F,G,I	F,G	F,G,I	F,G	F,G,I	F,G	F,G,I	F,G	F,G,I	F,G,I
PBR	F,G,E,T	F,G,I,E	F,G,E,T, B	F,G,I,E	F,G,E,T	F,G,I,E	F,G,E,T	F,G,I,E,T	F,G,E,T	F,G,I,E,T	F,G,I,E,T
SFC[3]	F,G,D	F,G,I,D	F,G,D	F,G,I,D	F,G,D,B	F,G,I,D	F,G,D	F,G,I,D	F,G,D	F,G,I,D	F,G,I,D
PSF	F,G,E	F,G,I,E	F,G,E	F,G,I,E	F,G,E	F,G,I,E	F,G,E	F,G,I,E	F,G,E	F,G,I,E	F,G,I,E
PNF	F,G,E,T,2	F,G,I,E,2	F,G,E,T,2	F,G,I,E,M,2	F,G,E,T,2	F,G,I,E,2	F,G,E,T,2	F,G,I,E,T,2	F,G,E,T,2	F,G,I,E,M,T,2	F,G,I,E,T,2
PBD	F,G,E	F,G,I,E	F,G,E	F,G,I,E	F,G,E	F,G,I,E	F,G,E,B	F,G,I,E	F,G,E	F,G,I,E	F,G,I,E

[1] Grab samples taken at two depths (Top & Bottom); depth profiles at 1-m intervals.
[2] Call River Commissioner to find out if water is flowing. If not flowing, skip sample.
[3] SFC = South Fork above Confluence w/ Mainstem, new site in 2014 to capture fire impacts.
Blanks analyzed for NH_3, NO_3, TOC, TDS, NTU and Cl^-

2 = Duplicate, A = Algae (Lugol's); B=Blank, C = Chlorophyll (500 mL sample); D = Flow; F = Field data (Temp, pH, conductance streams + Secchi, DO for lake); G = 1 liter sample for general, nutrients, TOC; E = *E. coli*, coliform (500 mL sterile bottle); I = Major ions; M = Metals; P = *Giardia/Cryptosporidium*; T= Geosmin

ATTACHMENT 5

ANALYTICAL METHODS, REPORTING LIMITS, SAMPLE PRESERVATION, AND HOLDING TIMES

	Parameter	**Method**	**Reporting Limit**	**Preser-vation**	**Holding Time**
Micro-biological	Total Coliform, *E.coli* - QT	SM 9223 B	0	cool, 4C	6 hrs
	Giardia & Cryptosporidium (CH Diagnostics)	EPA 1623	0	cool, 4C	4 days
	Algae I.D. (Phyto Finders)	SM 10200E.3, SM 10200F.2c1		Lugol's Solution, cool, 4C	12 mo
General & Misc.	Alkalinity, as $CaCO_3$	SM 2320 B	2 mg/L	cool, 4C	14 days
	Chlorophyll a	SM10200H modified	0.6 ug/L	cool, 4C	48 hrs
	Hardness, as $CaCO_3$	SM 2340 C	2 mg/L	none	28 days
	Specific Conductance	SM 2510 B		cool, 4C	28 days
	Total Dissolved Solids	SM 2540 C	10 mg/L	cool, 4C	7 days
	Turbidity (NTU)	SM2130B,EPA180.1	0.01 units	cool, 4C	48 hrs
Nutrients	Ammonia - N	Lachat 10-107-06-2C	0.01 mg/L	H_2SO_4	28 days
	Nitrate	EPA 300 (IC)	0.04 mg/L	cool, 4C (eda)	48 hrs
	Nitrite	EPA 300 (IC)	0.04 mg/L	cool, 4C (eda)	48 hrs
	Total Kjeldahl Nitrogen	EPA 351.2	0.1 mg/L	H_2SO_4 pH<2	28 days
	Phosphorus, Total	SM 4500-P B5,F	0.01 mg/L	H_2SO_4 pH<2	28 days
	Phosphorus, Ortho	SM 4500-P B1,F	0.005 mg/L	filter, cool 4C	48 hrs
Major Ions	Calcium	EPA 200.8	0.05 mg/L	HNO_3 pH <2	6 mos
	Chloride	EPA 300 (IC)	1.0 mg/L	none (eda)	28 days
	Magnesium, flame	EPA 200.8	0.2 mg/L	HNO_3 pH <2	6 mos
	Potassium	EPA 200.8	0.2 mg/L	HNO_3 pH <2	6 mos
	Sodium, flame	EPA 200.8	0.4 mg/L	HNO_3 pH <2	6 mos
	Sulfate	EPA 300 (IC)	5.0 mg/L	cool, 4C (eda)	28 days
Metals	Cadmium	EPA 200.8	0.1 ug/L	HNO_3 pH <2	6 mos
	Chromium	EPA 200.8	0.5 ug/L	HNO_3 pH <2	6 mos
	Copper	EPA 200.8	3 ug/L	HNO_3 pH <2	6 mos
	Iron, (total & dissolved)	EPA 200.8	10 ug/L	HNO_3 pH <2	6 mos
	Lead	EPA 200.8	1 ug/L	HNO_3 pH <2	6 mos
	Nickel	EPA 200.8	2 ug/L	HNO_3 pH <2	6 mos
	Silver	EPA 200.8	0.5 ug/L	HNO_3 pH <2	6 mos
	Zinc	EPA 200.8	50 ug/L	HNO_3 pH <2	6 mos
TOC	TOC	SM 5310 C	0.5 mg/L	H_3PO_4 pH <2	28 days
Analysis conducted by City of Fort Collins Water Quality Lab (FCWQL), unless otherwise noted.					
Reporting Limit = lowest reportable number based on the lowest calibration standard routinely used.					