WATER QUALITY TRENDS REPORT 2008 – 2022

Upper Cache la Poudre Watershed

Collaborative Water Quality Monitoring Program

June 1, 2023

PREPARED FOR:
City of Fort Collins Utilities
City of Greeley
City of Thornton
Soldier Canyon Water Treatment Authority

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LIST OF ABBREVIATIONS & ACRONYMS

%	percent
BMD	Barnes Meadow Reservoir below Dam (routine monitoring site)
cfs	cubic feet per second
CHD	Joe Wright Creek below Chambers Lake Dam (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
JWC	Joe Wright Creek above the Poudre River (routine monitoring site)
LRT	Laramie River Tunnel (routine monitoring site)
m	meter
mg/L	milligrams per liter
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
NTU	Nephelometric Turbidity Units
^{o}C	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)
RCM	Rabbit Creek Mouth (routine monitoring site)
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
TOC	Total Organic Carbon
µg/L	micrograms per liter
µS/cm	microSeimens per centimeter
USGS	United States Geological Survey

EXECUTIVE SUMMARY

BACKGROUND

The Upper Cache la Poudre (CLP) Watershed Collaborative Water Quality Monitoring Program is designed to assist the cities of Fort Collins, Greeley and Thornton, and the Soldier Canyon Water Treatment Authority in meeting current and future drinking water treatment goals by reporting current water quality conditions and trends within the Upper CLP watershed and summarizing issues that potentially impact watershed health. Annual trend reports have been published in 2008 through 2011, 2013 through 2016, and 2018 through 2021. Five-year water quality trend analyses reports were published in 2012 and 2017.

SCOPE OF THE 2022 WATER QUALITY TRENDS REPORT

This five-year water quality trend report analyzes the hydrology, climate, and water quality of the Upper CLP watershed over the last 15 years. Water quality data collected throughout the Upper CLP watershed were analyzed for short and long-term trends to determine if concentrations increased, decreased, or stayed the same over the five-year period of record from 2018 to 2022 and the long-term period of record from 2008 to 2022, respectively. 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.

UPPER CACHE LA POUDRE WATERSHED IMPACTS & TRENDS

Watershed Impacts & Issues of Concern

Over the past 15 years the Upper CLP watershed has experienced periods of wet and dry water years influencing both streamflow and water quality conditions in the Upper CLP watershed. Exceptionally hot and dry conditions in 2020 led to extreme drought and a major wildfire in the watershed called the Cameron Peak Fire. Post-fire impacts to water quality have been particularly extreme over the past two years and it is expected that these impacts will continue to impact the Poudre River water supply for years to come.

Forest insects and diseases have impacted the Upper CLP watershed over the past several decades. Recent surveys show the mountain pine beetle and spruce beetle epidemics are declining; however, isolated outbreaks of these insects throughout Colorado suggest that forested watersheds 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, water availability, 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 in the Upper CLP watershed.

Climate & Hydrology Trends

Air temperature significantly increased at higher elevations in the Upper CLP watershed over the last 15 years. Precipitation volume and the maximum amount of water contained within the snowpack did not change. No trends were measured in the magnitude or timing of streamflow; however, recent data suggest that snowmelt runoff is occurring earlier in the year and lasting for a shorter amount of time.

Trends in Water Quality

Short and long-term trends were identified in the Upper CLP watershed. Long-term trends were identified as gradual, continuous changes (increasing or decreasing) in the data over time and short-term trends were recognized as shifts (up or down) in the data over the past five years. Step-trends, an abrupt shift in data, were measured for several water quality parameters at monitoring sites throughout the Mainstem CLP river over the last two years (2021 and 2022). These trends occurred in response to the dramatic landcover change in the Mainstem CLP watershed caused by the 2020 Cameron Peak Wildfire. The water quality constituents that exhibited step-trends as a response to post-fire water quality impacts were all highly correlated with increased watershed erosion.

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 the basin influencing water quality at multiple monitoring locations.

Most trends detected in the Mainstem CLP watershed were associated with increased watershed erosion caused by wildfires that have impacted the watershed over the last 15 years. Water quality impacts from the Cameron Peak Fire have been particularly evident in the first two years following the fire (2021 and 2022). It is anticipated that water quality impacts from the recent wildfire will continue for many years as the watershed responds to and recovers from this unprecedented disturbance. Climate change impacts, specifically increasing air temperature, flooding and drought, and streamflow alterations are likely the main drivers of water quality trends in the North Fork CLP River.

Implications to Water Treatment

Short and long-term trends in certain water quality constituents may pose issues to water treatment processes in the future. Water quality changes were detected for the following parameters near the City of Fort Collins', City of Greeley's, and Soldier Canyon Water Treatment Authority's raw water intakes:

- Temperature & pH
- Alkalinity & hardness
- Total dissolved solids & specific conductivity
- Nutrients

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. The Watershed Program should continue to work with partners across the watershed to collaborate on source water protection projects that protect and restore human-constructed infrastructure and natural ecosystems in the Upper CLP watershed. Routine water quality monitoring throughout the Upper CLP watershed will allow the Upper CLP Collaborative Water Quality 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.

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, the City of Greeley-Bellvue Water Treatment Plant, and the Soldier Canyon Water Treatment Authority's Soldier Canyon Filter Plant. In the shared interest of sustaining this high-quality water supply, the City of Fort Collins, the City of Greeley, and Soldier Canyon Water Treatment Authority partnered in 2007 to design the Upper CLP Collaborative Water Quality Monitoring Program. The Program was subsequently implemented in spring 2008. The City of Thornton was added as a partner in 2022. 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 water treatment 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 trend reports for the monitoring program are prepared by City of Fort Collins' Watershed Program staff to keep participants informed of current issues and trends in water quality in the Upper CLP watershed. Seasonal updates are provided 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 of water quality data to historic baseline conditions, describe notable events and issues, and summarize the results of special studies. The five-year report provides a more in-depth analysis of short and 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*.

1.2 WATERSHED DESCRIPTION AND SAMPLING LOCATIONS

Sampling efforts are divided between the Mainstem CLP River watershed (including Joe Wright Creek, the Big South, and the Little South Fork CLP River) and North Fork CLP River watershed (including Rabbit Creek, Stonewall Creek, and Lone Pine Creek). Collectively these watersheds encompass approximately 645,500 acres of forest, other natural land types, and agricultural land (**Table 1**). An additional 4,700 acres, representing less than 1% of land surface, is developed for commercial, industrial, utility, urban or residential purposes.

Table 1 – Land use comparison between Upper North Fork and Mainstem CLP watersheds. Areas were calculated using US Geological Survey Seamless Geographic Information System data sets.

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

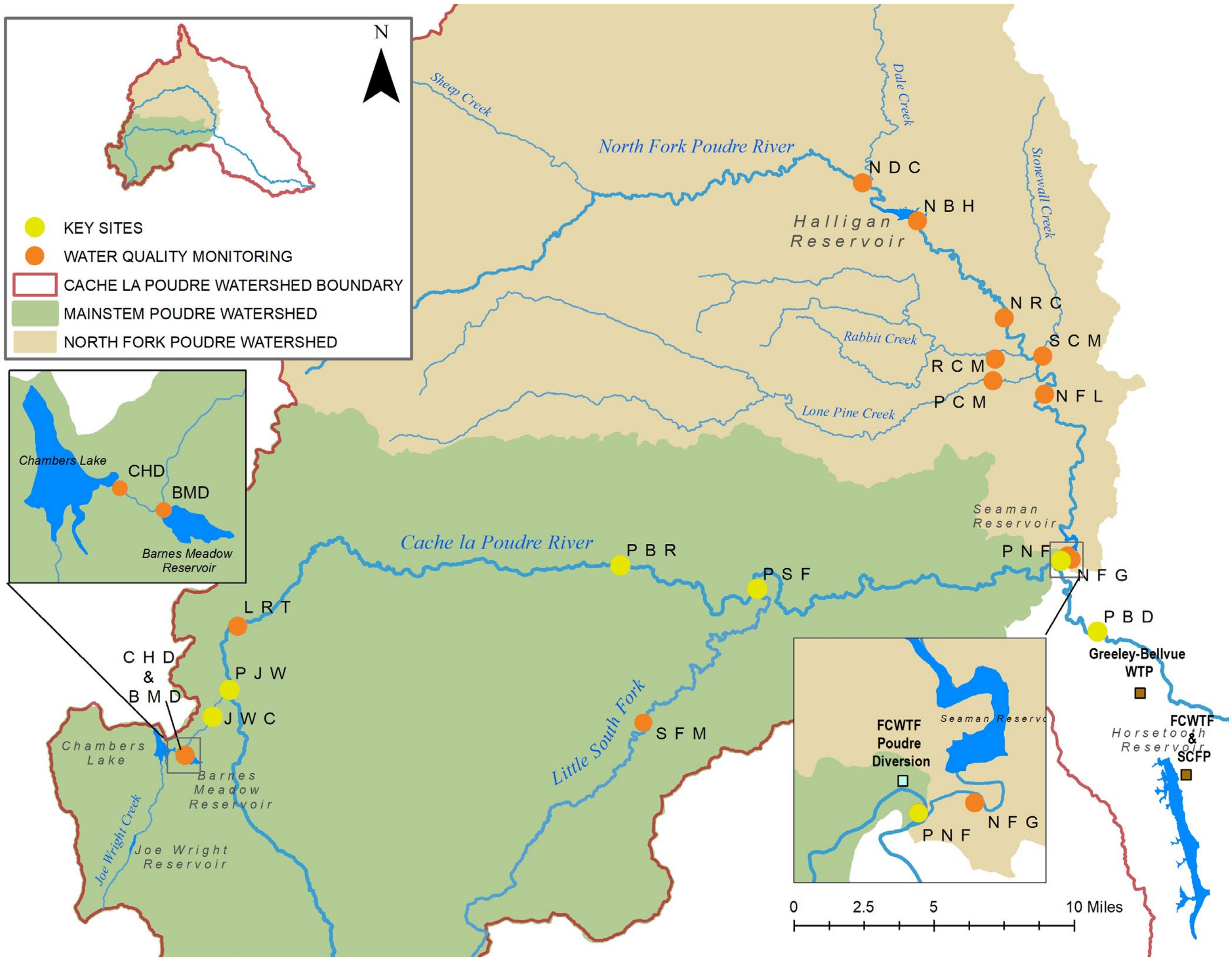

Figure 1.1 – Map of the Upper CLP collaborative water quality monitoring network.

When initially established in 2008, the monitoring network consisted of 20 water quality monitoring locations selected to characterize the headwaters, major tributaries, and downstream locations of the Upper CLP River near 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 CLP 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. In 2020, SFC was discontinued because the special use permit issued by the Forest Service expired. Water quality sampling in the South Fork CLP River was re-established at SFM. The sampling locations in Joe Wright Creek below Chambers Lake (CHR) and Barnes Meadow outfall (BMR) were moved in 2019 due to access issues at the original sites and are now formally known as Joe Wright Creek below Chambers Dam (CHD) and Barnes Meadow outfall below Dam (BMD). 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 full list of monitoring sites, abbreviations and descriptions is available in Attachment 1.

1.3 SAMPLING PLAN AND PARAMETERS

The sampling frequency for the Program is based on both statistical performance and cost considerations. Parameters were selected based on analyses of historical data and aim to provide the best information possible within current budgetary constraints. 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). The annual sampling schedule is provided in Attachment 3 of this report and the full list of water quality parameters is provided in Attachment 2.

1.4 SAMPLE COLLECTION AND ANALYSIS

Field sampling is conducted by staff members from the City of Fort Collins' Watershed Program, City of Greeley, and Timberline Aquatics, Inc. Sampling methods, including those for the collection of physical field measurements for temperature, pH, conductivity, turbidity, and dissolved oxygen are documented in the Program's Standard Operating Procedures. All water samples are analyzed by the City of Fort Collins Water Quality Lab. The analytical methods and detection limits for the City of Fort Collins Water Quality Lab parameters are included in Attachment 4.

Consistent with the quality assurance guidelines outlined in Section 5.5 of Billica, Loftis and Moore (2008), field blanks and field duplicates are collected alongside at least ten percent of samples for a subset of parameters, which are identified in the Annual Operating Plan (Attachment 3).

1.5 SCOPE OF FIVE-YEAR REPORT

Seasonal, annual, and five-year reports for the 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 watershed. 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 of current water quality data to water quality data from the baseline period of record (2008-2012).

Five-year reports provide an in-depth analysis of short-term and 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 short-term trends by comparing the recent five-year period of record from 2018 to 2022 to the baseline period of record from 2008 to 2012. Long-term trends were also evaluated to determine if constituent concentrations increased, decreased, or stayed the same over the 15-year period of record from 2008 to 2022. 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. Five-year water quality trend analyses reports are available for the years 2008-2012 (Oropeza and Heath, 2013) and 2013-2017 (Heath and Thorp, 2018).

2.0 WATERSHED IMPACTS & ISSUES OF CONCERN

2.1 CLIMATE CHANGE

Climate change is one of the most critical issues related to watersheds and the quality and availability of 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 to watersheds in Colorado 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's water resources are limited, in high demand and are extremely vulnerable to increasing extremes due to climate change. Many of the consequences of climate change will directly impact drinking water quantity and quality. Precipitation patterns in Colorado vary widely over space and time. Climate-related changes in precipitation patterns, timing, and type may result in periods of extended drought, as well as periods of intense precipitation events and flooding. 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 occur 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, including making it difficult to predict the quantity and quality of water that will be 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 the occurrence of prolonged droughts has led to an increased frequency of wildfires. Wildfires impact watershed hydrology by changing vegetation and soils and increasing pollution to drinking water supplies.

2.2 DROUGHT

Drought is a deficit in precipitation measured over an extended period that leads to drier than normal conditions for an area of land. Drought is part of the normal climate variability in Colorado and can vary over space and time (days, months, or years) depending on local and regional precipitation patterns. Extended periods of drought not only lead to impacts to the availability of water but can also influence water quality due to changes in streamflow and related disturbances such as wildfire. Potential impacts of drought on raw and treated water quality are summarized in **Table 2**.

Table 2 – 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

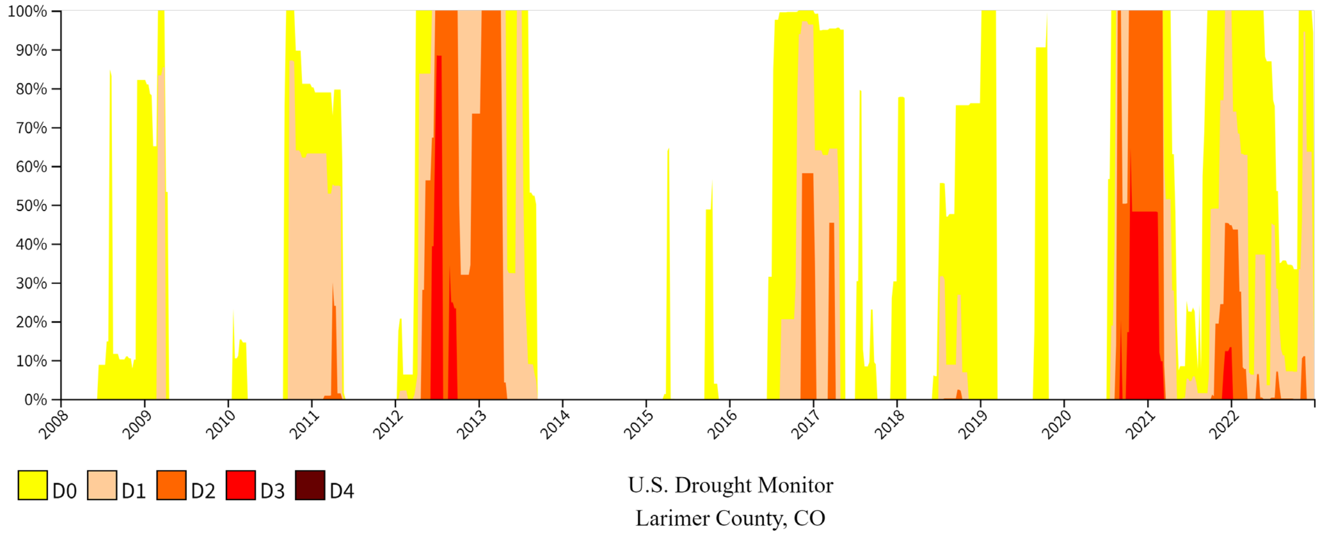

Figure 2.1 – Drought conditions in Larimer County, Colorado from 2008 through 2022 (*https://www.drought.gov/states/colorado*).

The United States Drought Monitor tracks drought conditions across the United States and releases weekly maps showing parts of the U.S. that are in drought. Drought conditions are rated from D0 (abnormally dry; yellow) to D4 (exceptional drought; dark red) using the best available data and local observations. Over the last 15 years, from 2008 to 2022, drought conditions in the CLP watershed, as illustrated by drought conditions in Larimer County, have varied in intensity and duration. Over the baseline period of record (2008 – 2012), short periods of low intensity drought (D0 – D1) were observed, but in general, normal drought and precipitation patterns were observed. An extend period of higher intensity (D2 – D3) drought was observed from 2012 to fall-2013, which led to the Hewlett Gulch and High Park Wildfires. Very minimal drought conditions occurred from fall-2013 through summer of 2016 due to an extended period of wet conditions throughout the watershed. 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. Several impacted areas measured record rainfall amounts that were greater than average annual precipitation totals. Variable drought conditions returned over the summer of 2016 through 2017. Over the past five years (2018-2022), drought conditions have been variable both in duration and intensity. Severe and extreme drought (D2 – D3) impacted the watershed from the summer of 2020 through the winter of 2021, contributing to the occurrence of the Cameron Peak Wildfire. Drought continued to persist to varying degrees through 2022.

2.3 WILDFIRE

Several large wildfires have impacted the CLP watershed over the last 15 years (**Figure 2.2**). 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 north-facing slopes, as well as shrubs 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 land 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 South Fork CLP Rivers.

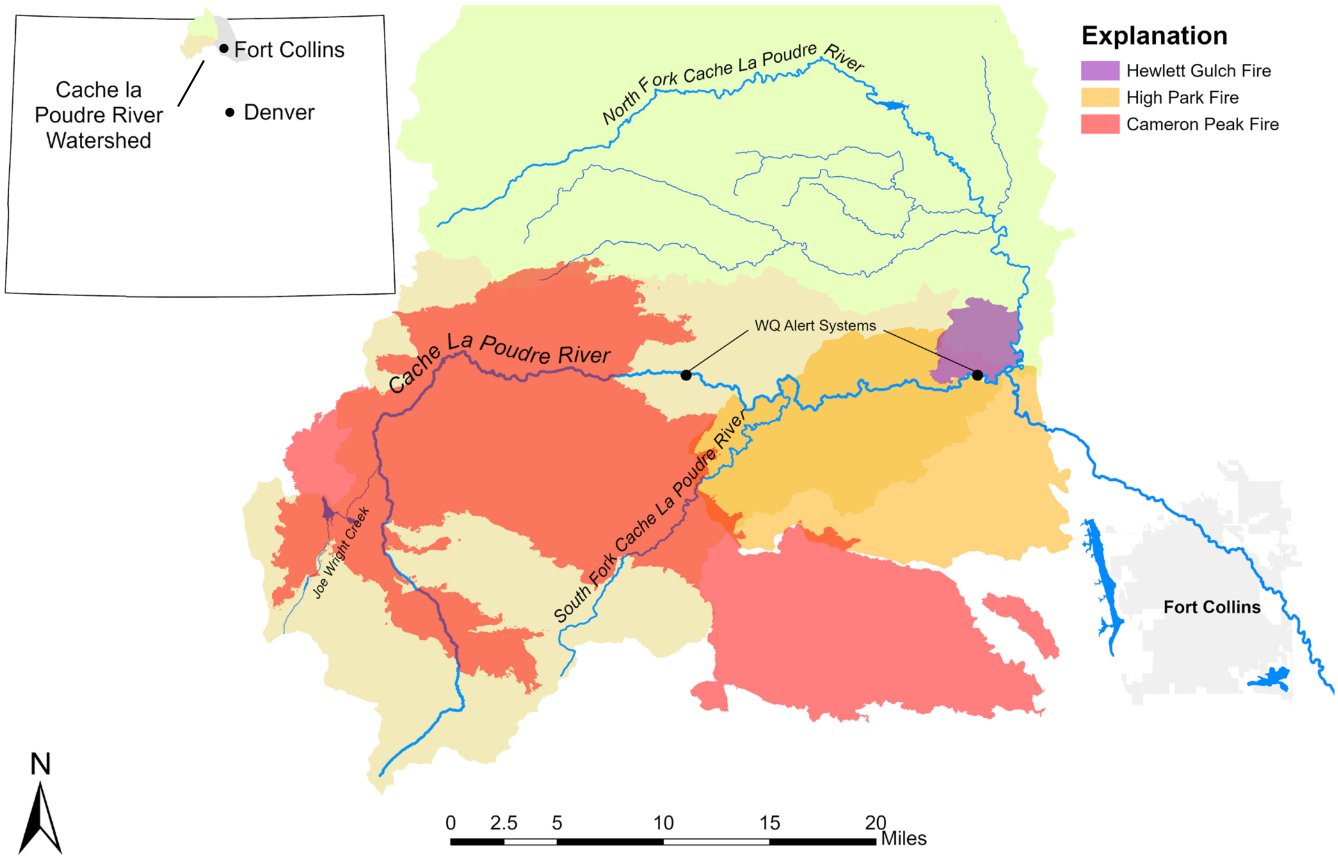

Figure 2.2 – Recent wildfire history (2008 – 2022) in the Cache la Poudre Watershed.

In 2020, the Cameron Peak Fire (August 13 – December 2) burned 208,663 acres of mixed conifer forest in the mid and upper elevations of the watershed. The burned area includes numerous sub-drainages that are tributaries to the Mainstem and the South Fork CLP Rivers as well as several high elevation water storage reservoirs that deliver water into the Mainstem CLP River.

The 2012 and 2020 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 impacting water quality in the CLP River. Potential impacts on raw and treated water quality from wildfires are summarized in **Table 3**.

Real-time water quality monitoring instruments were installed at two locations upstream of the Poudre supply. The Poudre at Indian Meadows site is located one mile downstream of the Town of Rustic and the Manners Bridge site is located approximately one mile upstream of the City of Fort Collins' raw water intake (**Figure 2.2**). This monitoring system provides water treatment operations near real-time water quality data to quickly respond to changes in Poudre River water quality that result from runoff from wildfire burn scars and other upstream events.

Table 3 – 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)

2.4 FOREST HEALTH

Native forest insects and diseases 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. Drought continues to influence forest health across much of the Upper CLP watershed.

The mountain pine beetle, a native bark beetle that infests all pine species, impacted several million acres of Colorado's forest over the past two decades. Nearly 80% of Colorado's pine forests were impacted by pine beetle as of 2014. The impact of pine beetle on Colorado's forests since 2014 has been low; however, impacted acres over the past two years have been on the rise indicating an increase in pine beetle populations and the potential for isolated pine beetle outbreaks on any remaining live pine trees (Colorado State Forest Service, 2022).

The spruce beetle has destroyed millions of acres of forest since 1996 and has been Colorado's most common forest insect impacting high-elevation Engelmann spruce forests throughout Colorado. Over the past 22 years, spruce beetle has impacted nearly 2 million acres in Colorado. The highest spruce beetle-caused tree mortality was observed in 2014 at over 400,000 acres. State-wide tree morality has been on the decline since 2014 (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.

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 in water with 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 power plants 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

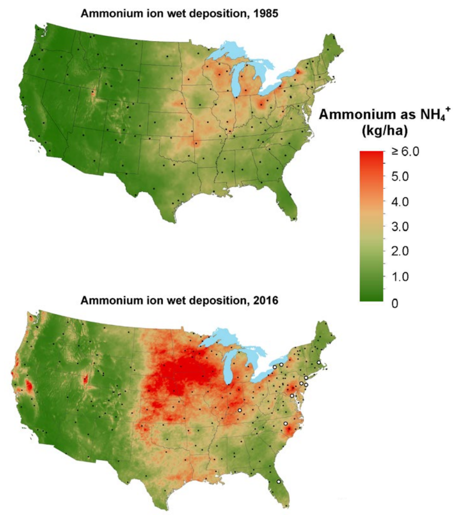

Figure 2.3 – Ammonia ion wet deposition has increased throughout the United States since the NADP began in 1985 (Source: http://nadp.slh.wisc.edu/).

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 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 2.3**). 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.

3.0 WATERSHED HYDROLOGY AND CLIMATE

The hydrology of the Upper CLP plays an important role in regulating water quantity and quality. Precipitation 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 to water treatment operations that may need to be addressed in the future to continue to maintain high-quality drinking water.

Evaluating Short-Term and Long-Term Data Trends

Short-term trends are presented for the most recent five years of data from 2018 to 2022 (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 15-year period of record from 2008 to 2022. 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 evaluate 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. CLAFTCCO 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 35.4 degrees Fahrenheit (°F) (1.9 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 current five-year period compared to baseline. Monthly mean temperature over the five-year period exceeded baseline monthly mean temperature in all months except February, March, October, and November. The most notable departure from baseline was observed in the month of September. Monthly mean temperature in September measured 2.8°F (1.6°C) warmer than baseline (**Figure 3.1**).

Air temperature significantly increased at higher elevations in the Upper CLP watershed over the long-term period of record. A significantly increasing trend was detected in both the average monthly mean and average monthly minimum air temperatures. Average monthly mean temperatures increased at a rate of 0.08°F (0.04°C) per year, while average monthly minimum temperatures increased at a slightly greater rate of 0.11°F (0.06°C) per year (**Table 4**). These trends were also observed over the previous long-term period of record from 2008-2017 as documented by Heath and Thorp (2018), although the rate of change over the current period was lower.

Seasonal trend analyses detected significantly increasing average monthly minimum air temperatures during the

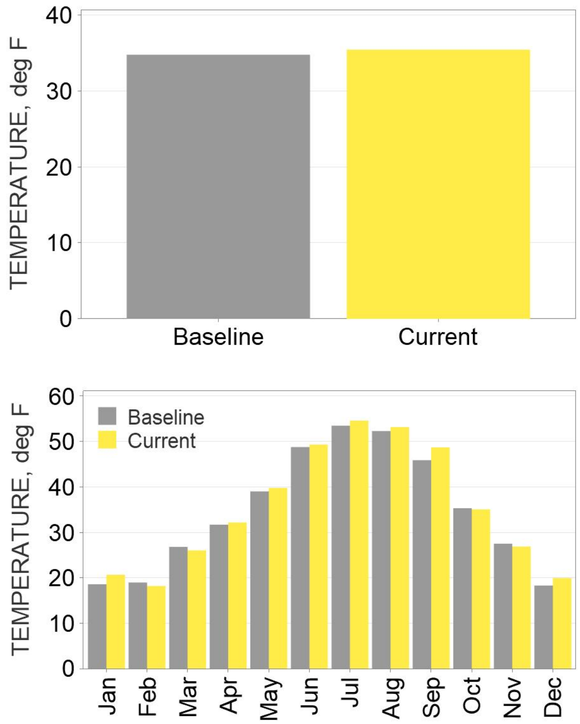

Figure 3.1 – Mean baseline and current air temperatures (top), and monthly mean air temperature over the baseline and current periods of record (bottom) reveal similar air temperature between the two periods.

summer season. Over the summer season, average monthly minimum temperatures increased at a rate of 0.15°F (0.08°C) per year (**Table 4**).

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

Mean precipitation measured over the last five years was slightly lower than the baseline. Mean precipitation measured over the five-year period was 95 percent (%) of baseline – 43.0 inches compared to 45.3 inches. A total of 215 inches of precipitation was recorded over the five-year period compared to 227 inches. The highest amount of precipitation was measured in the winter and spring seasons (32.3% and 32.4%, respectively) and the lowest amount was measured in the fall season (14.2%). Higher precipitation was measured over the current winter season compared to baseline. In all other seasons, precipitation over the five-year period was lower than baseline (**Figure 3.2**). The largest difference in precipitation was observed in the fall season which recorded 3% less precipitation. Precipitation in all fall months measured below baseline (**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 amount of precipitation was measured in 2022 with a total of 45.4 inches of precipitation (100% of baseline) and the lowest amount of precipitation was measured in 2020 with a total of 36.8 inches of precipitation (81% of baseline).

The maximum amount of water stored in the snowpack, referred to as peak snow water equivalent (SWE), measured 80% of baseline over the five-year period. Peak SWE was lower than baseline in all years (**Figure 3.3**). The ratio between peak SWE and total annual precipitation

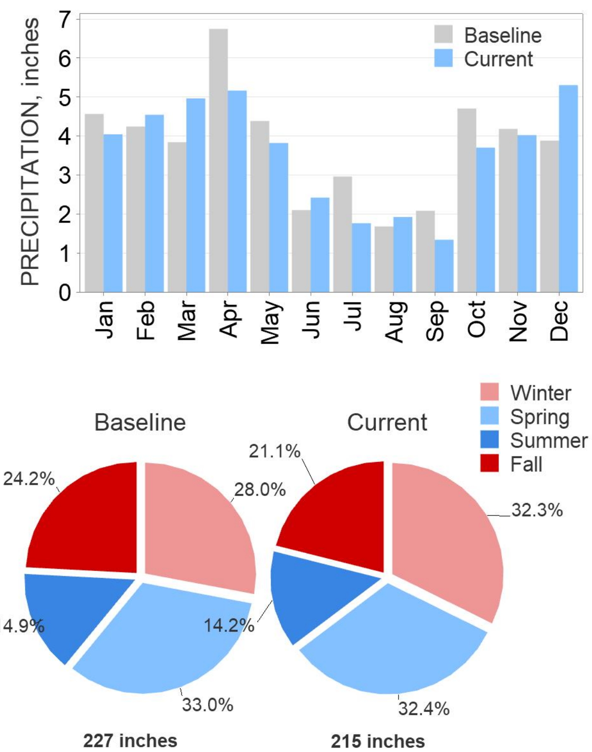

Figure 3.2 – Monthly mean precipitation totals for the baseline period compared to the recent five-year period (top) and seasonal distribution of precipitation for the baseline period and current period (bottom).

(peak SWE/total annual precipitation) was lower than baseline in all years, indicating that more precipitation fell as rain compared to snow in current years compared to baseline. More precipitation fell as snow compared to rain in 2020 when the ratio measured higher than baseline (**Figure 3.3**). There were no significant long-term trends detected in peak SWE or the peak SWE to annual total precipitation ratio over the long-term period of record.

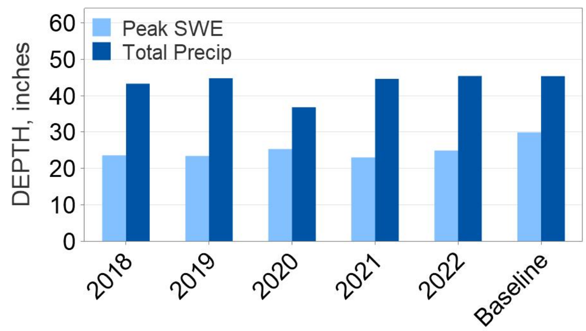

Figure 3.3 – Current five-year precipitation totals, and peak snow water equivalent measured at the Joe Wright SNOTEL compared to baseline.

3.3 STREAMFLOW

Mean streamflow measured over the five-year period was 99% of baseline. Streamflow measured 233,941 acre-feet (acre-ft) compared 236,382 acre-ft measured over the baseline period (**Figure 3.4**). The highest proportion of streamflow was measured in the spring and summer seasons and the lowest was measured in fall and winter seasons. Streamflow measured above baseline in all months, except in June, July, and October (**Figure 3.4**).

A shift in seasonal flow contributions was observed over the five-year period compared to baseline. The biggest difference in streamflow was observed over the spring and summer seasons. A higher proportion of streamflow was measured over the current spring season compared to baseline, while a smaller proportion of streamflow was measured during the current summer season compared to baseline (**Figure 3.4**). These seasonal observations suggest that spring snowmelt runoff during the current period occurred earlier in the year and the rate of snowmelt may have occurred faster resulting in a lower contribution of water from snowmelt in the summer months of June and July. In contrast, the proportion of water delivered during the winter and fall seasons was similar compared to baseline conditions. During these seasons, the hydrology of the CLP watershed is largely controlled by water releases from high elevation water storage reservoirs.

Peak streamflow, in cubic feet per second (cfs), observed over the five-year period was like baseline. The average peak streamflow over the current period measured 2,438 cfs compared to 2,436 cfs measured over the baseline period. The highest peak streamflow measured 3,140 cfs in 2022 and the lowest measured 2,210 cfs in 2018. The timing of peak streamflow occurred an average of three days earlier than the baseline (June 9). The latest peak was observed on July 1, 2019, and the earliest peak was observed on May 23, 2014.

There were no significant trends detected in annual streamflow, peak streamflow, or the timing of peak streamflow over the long-term period of record.

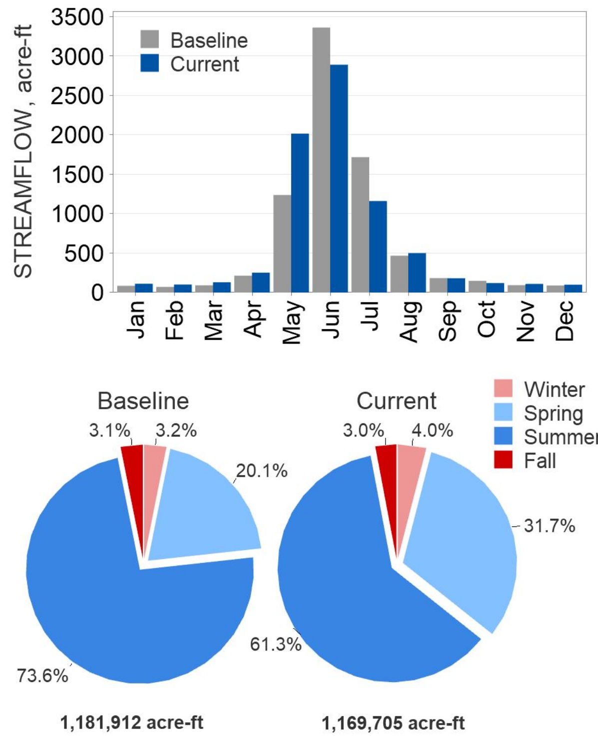

Figure 3.4 – Monthly average streamflow for the baseline period compared to the recent five-year period (top) and seasonal distribution of streamflow for the baseline period and current period (bottom).

Table 4 – Summary of statistically significant climatological variables detected in the Upper CLP watershed.

Paramater	Test Statistic	Season	Trend Direction	Trend Estimate	Significance (p-value)
Temperature	Average Monthly Mean	Annual	Increasing	0.08°F (0.04°C) per year	0.05
	Average Monthly Minimum	Annual	Increasing	0.11°F (0.06°C) per year	0.04
		Summer	Increasing	0.15°F (0.08°C) per year	0.04

4.0 TRENDS IN WATER QUALITY

Water quality data collected throughout the Upper CLP watershed were analyzed for short and long-term trends to determine if concentrations increased, decreased, or stayed the same over the recent five-year period of record (2018 – 2022) and long-term period of record (2008 – 2022). Trend analyses of long-term water quality data provides useful information about short and long-term impacts to water quality from watershed disturbances (e.g., wildfires and floods) 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 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 assist with observing patterns. Two types of trends were identified using this process: monotonic trends and step trends. A monotonic trend is defined as a gradual, continuous rate of change (increasing or decreasing) in the data over time, whereas a step trend is defined as an abrupt shift (up or down) in the data at a certain point in time.

Preliminary data analyses assisted with selecting the most appropriate trend test for the various water quality parameters. Monotonic and step trend tests can be used with both parametric (normally distributed) and nonparametric (non-normally distributed) datasets; however, tests with parametric datasets are considered more statistically powerful (Lettenmaier 1976, Hirsch et al. 1991, Thas et al. 1998). Normality tests verified data distributions of water quality variables were not normally distributed ($p<0.01$) and therefore nonparametric trend tests were used for trend analyses.

Trend Analyses

Based on the preliminary data analyses discussed above, two trend tests were selected to detect and quantify trends in water quality concentrations throughout the Upper CLP watershed. Long-term 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 15-year period of record (2008 to 2022) 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 ($p \leq 0.10$).

Short-term 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. The long-term data set was divided into two separate five-year periods of record and population medians were compared using the Mann-Whitney test. 'Baseline conditions' were defined as the period of record from 2008 to 2012 and 'current conditions' were defined as the period of record from 2018 to 2022. Statistical significance was determined to the 95% confidence interval ($p \leq 0.05$), while notable trends were identified to the 90% confidence interval ($p \leq 0.10$). The current period of record contained step-trends for a subset of water quality parameters that were impacted by the Cameron Peak Fire. In general, these step-trends were detected in 2021 and 2022.

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 key monitoring sites located directly on the Mainstem and North Fork CLP rivers (**Figure 1.1**) 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 1. Finalized raw data are available upon request from the City of Fort Collins Watershed Program.

Short-term trends are displayed using bar graphs of annual median concentrations compared to the baseline median concentration. Long-term trends are displayed with 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 2. 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 time-series scatterplots also include the estimated rate of change and p-value calculated from the SMKT test. A linear regression line was also included to display the general trend direction.

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

4.1 PHYSICAL PARAMETERS

Water Temperature

Water temperature in the Mainstem and North Fork CLP Rivers was variable over the current five-year period. The water temperature in the Mainstem CLP River measured near baseline in Joe Wright Creek (JWC) and in the Poudre River above Joe Wright Creek (PJW). Water temperature measured above baseline from the Poudre River below Rustic (PBR) downstream to the City of Greeley's diversion (PBD). In general, the warmer water temperature at these sites was driven by above baseline water temperatures measured from 2018 to 2020. The warmest temperatures were observed at the City of Greeley's Diversion (PBD; median = 11.9°C) and the coldest temperatures were measured in the Poudre above Joe Wright Creek (PJW; median = 2.1°C). Water temperature significantly increased over the long-term period of record at the City of Fort Collins diversion (PNF) at a rate of 0.13°C (0.23°F) per year. Long-term trends in water temperature were not detected at any other monitoring location along the Mainstem CLP River.

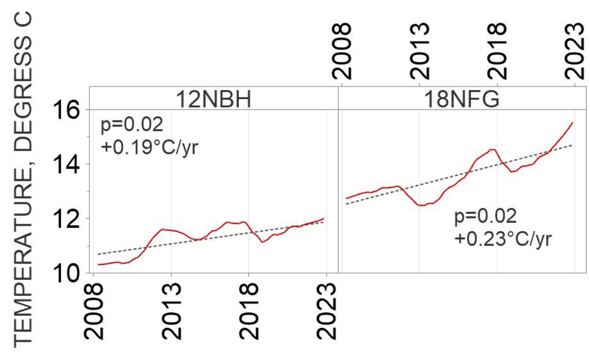

Figure 4.1 – Smoothed time-series plots for water temperature at NBH and NFG.

Water temperature in the North Fork CLP River measured above baseline in the North Fork above Dale Creek (NDC) downstream to the North Fork below Seaman Reservoir (NFG). Water temperature measured close to or above baseline in all years at nearly all monitoring sites. The warmest temperatures were observed in the North Fork near Livermore (NFL; median = 14.8°C) and the coldest temperatures were measured in the North Fork above Dale Creek (NDC; median = 8.7°C). Water temperature significantly increased over the long-term period of record in the North Fork below Halligan and Seaman Reservoir (NBH and NFG) at a rate of 0.19°C (0.34°F) per year and 0.23°C (0.41°F) per year (**Figure 4.1**). The increasing trend at these sites was also detected and reported by Heath and Thorp (2018). Long-term trends in water temperature were not detected at any other monitoring location along the North Fork CLP River suggesting that the cause of these trends is likely related to increasing water temperature within both Halligan and Seaman Reservoirs. Despite the signficantly increasing trends at the City of Fort Collins diversion (PNF) and in the North Fork below Seaman Resrvoir (NFG), a signficant trend was not detected downstream at the City of Greeley's diversion (PBD).

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 levels in the Mainstem and North Fork CLP Rivers were consistent over the five-year period. pH levels in the Mainstem CLP River measured near baseline in Joe Wright Creek (JWC) and significantly lower than baseline in the Poudre River above Joe Wright Creek (PJW). pH levels measured significantly higher than baseline from the Poudre River below the South Fork (PSF) downstream to the City of Greeley's diversion (PBD). In general, pH levels measured higher than baseline at these sites in all years (2018 to 2022). The highest pH levels were observed at the City of Greeley's Diversion (PBD; median = 7.79) and the lowest pH levels were measured in the Poudre above Joe Wright Creek (PJW; median = 7.19). pH levels significantly increased over the long-term period of record at the City of Fort Collins' diversion (PNF) and at the City of Greeley's diversion (PBD) at a rate of 0.02 pH units per year (**Figure 4.2**).

pH levels in the North Fork CLP River measured significantly lower than baseline in the North Fork above and below Halligan Reservoir (NDC and NBH) and significantly higher than baseline in the North Fork above Rabbit Creek (NRC) downstream to the North Fork below Seaman Reservoir (NFG) over the last five years. In general, pH levels measured slightly higher than baseline at these sites in all years (2018 to 2022) with slight variation across years. The highest pH levels were observed in the North Fork near Livermore (NFL; median = 8.37) and the lowest pH levels were measured in the North Fork below Halligan Reservoir (NBH; median = 7.58). pH levels significantly decreased over the long-term period of record in the North Fork below Halligan Reservoir (NBH) at a rate of -0.03 pH units per year. In contrast, significantly increasing trends were detected in the North Fork below Rabbit Creek (NRC), the North Fork near Livermore (NFL), and the North Fork below Seaman Reservoir (NFG) at a rate of 0.01, 0.01, and 0.02 pH units per year, respectively (**Figure 4.2**). Long-term trends were not detected in the North Fork tributaries (SCM, RCM and PCM).

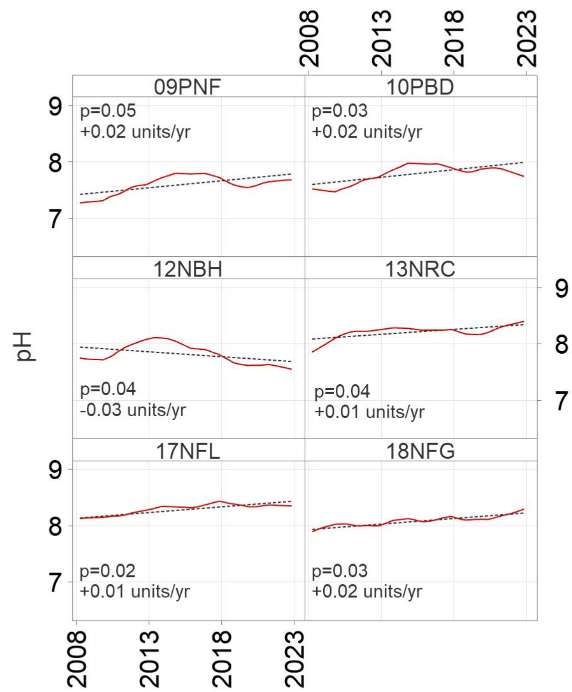

Figure 4.2 – Smoothed time-series plots for pH at monitoring locations on Mainstem and North Fork CLP Rivers that had significant trends over the 2008 to 2022 long-term period of record.

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.

Turbidity in the Mainstem and North Fork CLP Rivers was variable over the five-year period, but most notably in the Mainstem CLP River. Turbidity was lower than baseline in Joe Wright Creek (JWC) and slightly higher than baseline in the Poudre above Joe Wright Creek (PJW). Turbidity levels were notably higher in the Poudre River below Rustic (PBR) downstream to the City of Greeley's diversion (PBD).

Median turbidity values over the recent five-year period were approximately two times greater than baseline and the magnitude of change increased moving downstream. The higher median turbidity levels for the five-year period were driven primarily by an abrupt increase in turbidity levels measured in 2021 and 2022 following the Cameron Peak Fire (**Figure 4.3**). A significant increase was detected in the Poudre below the South Fork (PSF). The highest turbidity levels were observed at the City of Fort Collins' diversion (PNF; median = 3.55 NTU) and the lowest turbidity levels were measured in the Poudre River above Joe Wright Creek (PJW; median = 1.38 NTU). There were no long-term trends in turbidity detected in the Mainstem CLP River.

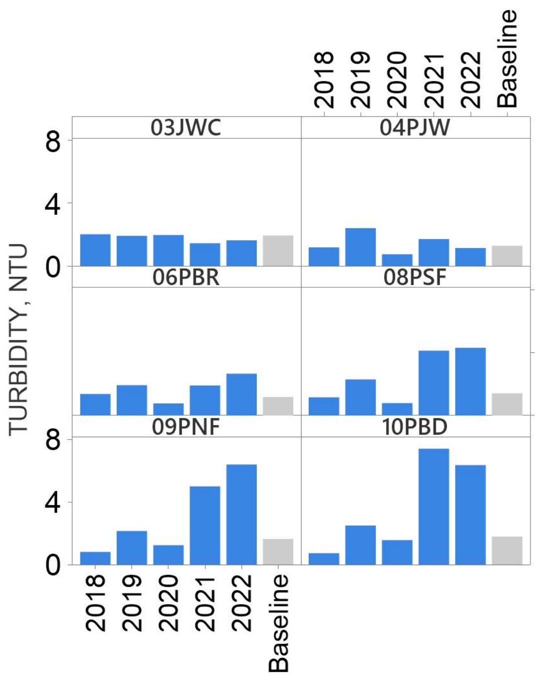

Figure 4.3 – Annual median turbidity values in the Mainstem CLP River over the five-year period of record compared to the baseline period of record.

Turbidity was higher than baseline in the North Fork above Dale Creek (NDC) and near baseline in the North Fork above Rabbit Creek (NRC) and in the North Fork near Livermore (NFL). Turbidity levels were significantly lower than baseline in the North Fork below Halligan and Seaman Reservoir (NBH and NFG) over the last five years. The highest turbidity levels were observed in the North Fork above Dale Creek (NDC; median = 5.11 NTU) and the lowest turbidity levels were measured in the North Fork near Livermore (NFL; median = 2.03 NTU). Long-term trends were detected in the North Fork below Halligan Reservoir (NBH) and in the North Fork above Rabbit Creek (NRC). Turbidity significantly decreased at these sites at a rate of -0.11 NTU and -0.05 NTU per year (**Figure 4.4**).

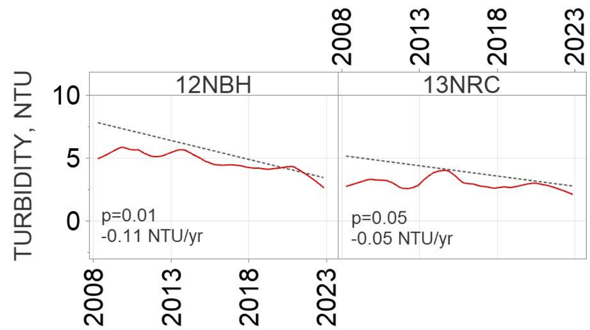

Figure 4.4 – Smoothed time-series plots for long-term trends in turbidity detected in the North Fork CLP River at NBH and NRC.

Specific Conductivity

Conductivity is a measure of water's ability to pass an electrical current. Its measure is proportional to the amount of dissolved salts in water, or the salinity of the water, because dissolved salts and other inorganic constituents conduct electrical current. Therefore, as the salinity of water increases so does its conductivity. Conductivity is a useful water quality indicator that can be used to detect changes in water quality over time or indicate if pollution has impacted water supplies. In general, changes in conductivity imply changes to the hardness and alkalinity of water, which can affect the suitability of water for domestic and other uses. Conductivity is also influenced by water temperature, so specific conductance accounts not only for the concentration of dissolved solids in the water, but also water temperature. Specific conductivity is influenced by local geology, as well as other dissolved constituents derived from land use practices throughout the watershed.

Specific conductivity in the Mainstem CLP River measured above baseline at all sites over the five-year period. Specific conductivity was generally near or above baseline in all years; however, a notable increase in specific conductivity was observed at all sites in 2021 and 2022 (**Figure 4.5**). The higher levels during these years were caused by increased erosion of sediment and ash into the Mainstem CLP River from the Cameron Peak Fire. Elevated concentrations during the past two years resulted in significantly higher specific conductivity in the Poudre

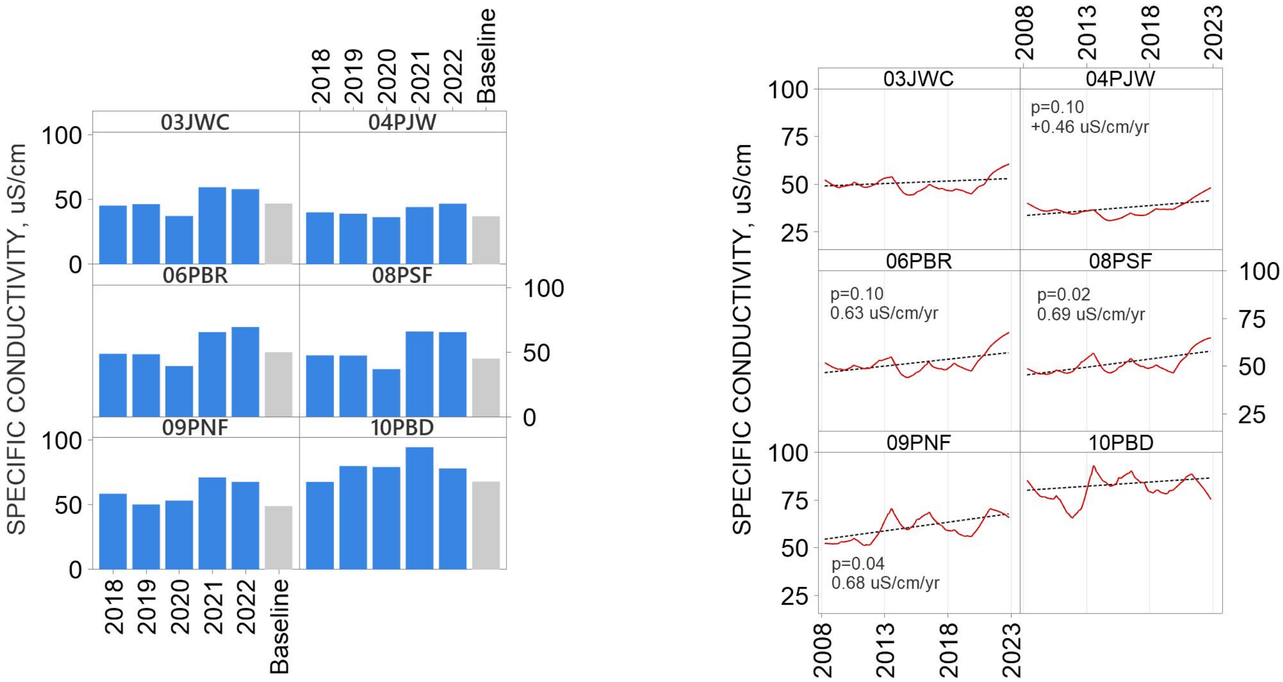

Figure 4.5 – Annual median specific conductivity levels in the Mainstem CLP River over the five-year period of record compared to median specific conductivity measured over baseline period of record (left) and smoothed time-series plots displaying long-term trends detected in specific conductivity in the Mainstem CLP River (right).

above Joe Wright Creek (PJW) downstream to the City of Fort Collins' diversion (PNF) over the current five-year period compared to baseline. A significant step-trend was not detected in the Poudre below Rustic (PBR), despite the elevated specific conductivity measured in the past two years. The highest specific conductivity concentrations were observed at the City of Greeley's diversion (PBD; median = 71.8 µS/cm) and the lowest specific conductivity concentrations were measured in the Poudre above Joe Wright Creek (JWC; median = 43.6 µS/cm). Specific conductivity significantly increased over the long-term period in the Little South Fork Poudre River (SFM), the Poudre below the South Fork (PSF) and at the City of Fort Collins' diversion (PNF) at a rate 0.85, 0.69, 0.68 µS/cm per year, respectively. Additionally, a notable increase in specific conductivity was detected upstream of these sites in the Poudre below Rustic (PBR) at a rate of 0.63 µS/cm per year (**Figure 4.5**). The long-term trends detected at these sites may be driven by the step-trend identified over the past two years.

Specific conductivity in the North Fork CLP River was variable across monitoring sites. Specific conductivity was near baseline in the North Fork above and below Halligan Reservoir (NDC and NBH) and in the North Fork near Livermore (NFL). Specific conductivity was well below baseline in the North Fork above Rabbit Creek (NRC) and above baseline in the North Fork below Seaman Reservoir (NFG). The variability in specific conductivity between monitoring sites and over the five-year period is likely correlated with streamflow variability across the North Fork CLP River. The highest specific conductivity concentrations were observed in the North Fork near Livermore (NFL; median = 265.0 µS/cm) and the lowest specific conductivity concentrations were measured in the North Fork above Dale Creek (NDC; median = 64.8 µS/cm). There were no trends detected for specific conductivity in the North Fork CLP River.

4.2 GENERAL PARAMETERS

Alkalinity and Hardness

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^-). Alkalinity is important in terms of water treatment because it can change the pH of the water, which ultimately influences key processes for treating raw water. Low alkalinity in the CLP water supplies, specifically during snowmelt runoff, poses challenges to water treatment operations, as the lower alkalinity levels impact the flocculation process and the water treatment plant's ability to effectively remove solids and organic carbon. Blending of water sources or the addition of lime helps to increase alkalinity and raise the pH level, which aids in the removal of unwanted solids and pollutants and controls the hardness of drinking water.

Hardness is an index of the total calcium (Ca) and magnesium (Mg) in water. Hard water does not pose any health risks to the public, but it can lead to scaling in the distribution system and home water systems, as well as taste concerns. Calcium and magnesium concentrations are generally low in the CLP water supplies leading to slightly hard water. Like specific conductivity, hardness and alkalinity are influenced by local geology, as well as other dissolved solids entering surface water from land use practices throughout the watershed.

Alkalinity and hardness concentrations in the Mainstem CLP River measured higher than baseline at all sites over the five-year period. Concentrations were generally near or above baseline in all years. The lowest concentrations were observed in 2020, which were slightly lower than or near baseline. Alkalinity and hardness concentrations measured higher than baseline at all sites in 2021 and 2022, except in the Poudre above Joe Wright Creek (JWC) and at the City of Greeley's diversion (PBD) (**Figure 4.6**). The higher levels during these years were likely caused by increased erosion of sediment and ash into the Mainstem CLP River from the Cameron Peak Fire. Alkalinity measured significantly higher than baseline in the Poudre below the South Fork (PSF) and at the City of Fort Collins diversion (PNF) over the past five years (**Figure 4.6**). Hardness measured significantly higher than baseline in Joe Wright Creek (JWC) downstream to the City of Fort Collins diversion. The highest alkalinity concentrations were observed at the City of Greeley's diversion (PBD; median = 28.0 mg/L) and the lowest alkalinity concentrations were measured in the Poudre above Joe Wright Creek (PJW; median = 13.8 mg/L). Hardness concentrations exhibited a similar trend. A significantly increasing trend in alkalinity was detected in the Poudre below the South Fork (PSF). A significantly increasing trend in hardness was detected in Joe Wright Creek (JWC) downstream to the City of Fort Collins' diversion (PNF; **Figure 4.7**). The long-term trends detected at these sites may be driven by the step-trend identified over the past two years.

Alkalinity and hardness concentrations were variable across monitoring sites in the North Fork CLP River over the five-year period. Alkalinity and hardness concentrations measured near baseline above and below Halligan Reservoir (NDC and NBH), lower than baseline in the North Fork below Rabbit Creek and near Livermore (NRC and NFL), and higher than baseline in the North Fork below Seaman Reservoir (NFG). In general, concentrations were similar from year to year above and below Halligan Reservoir (NDC and NBH). In the North Fork above Rabbit Creek (NRC) and near Livermore (NFL), concentrations steadily increased over the past four years from 2019 to 2022. Alkalinity and hardness concentrations

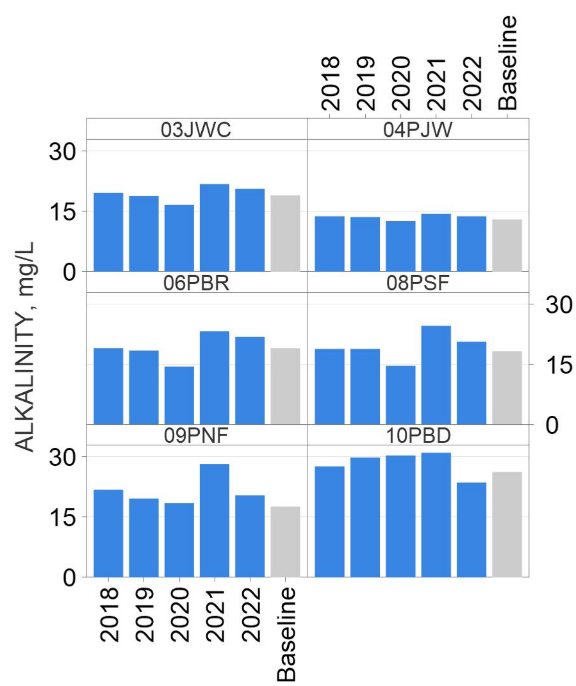

Figure 4.6 – Annual median alkalinity values in the Mainstem CLP River over the five-year period of record compared to the baseline period of record.

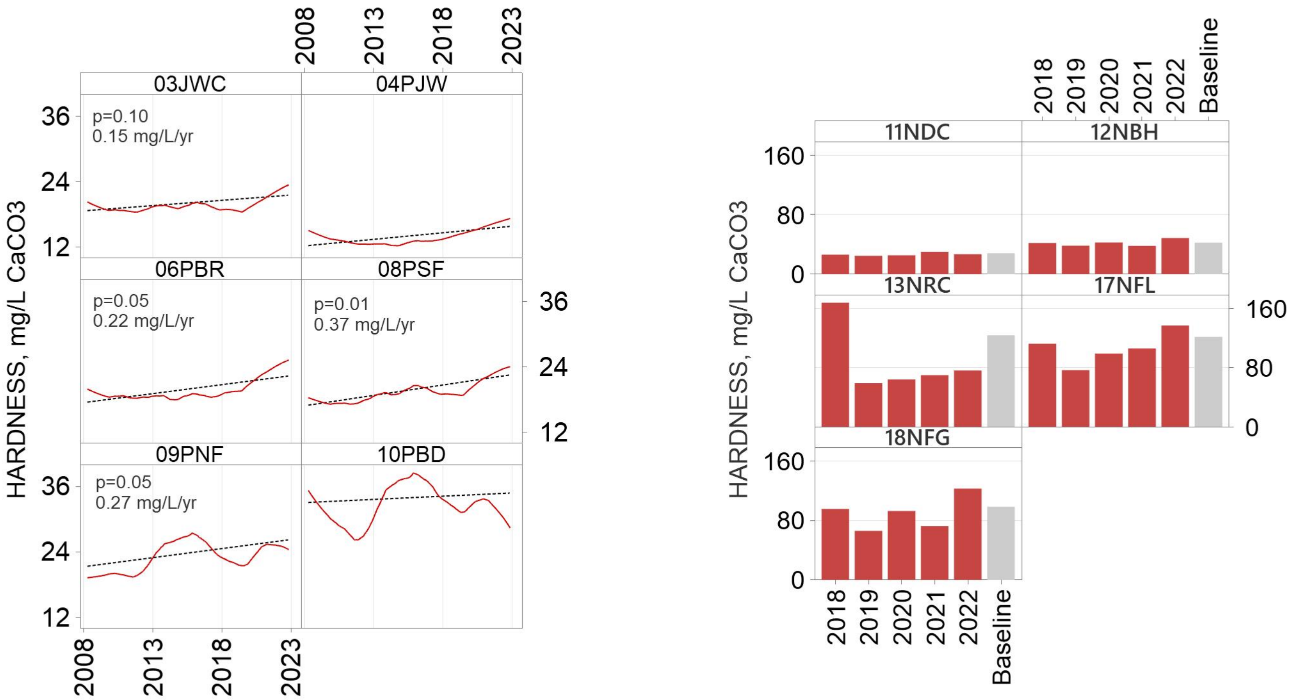

Figure 4.7 – Smoothed time-series plots indicating long-term trends in hardness concentrations in the Mainstem CLP River (left, and annual median hardness concentrations measured in the North Fork over the five-year period of record compared to baseline (right).

were variable in the North Fork below Seaman Reservoir (NFG) over the past five-years (**Figure 4.7**). The highest alkalinity concentrations were observed in the North Fork near Livermore (NFL; median = 101.5 mg/L) and the lowest alkalinity concentrations were measured in the North Fork above Dale Creek (NDC; median = 28.0 mg/L). Hardness concentrations exhibited a similar trend. There were no significant short or long-term trends detected for alkalinity or hardness in the North Fork CLP River.

Total Dissolved Solids

Total dissolved solids (TDS) provide 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.

Total dissolved solids measured significantly higher than baseline at all monitoring sites in the Mainstem CLP River over the five-year period. Concentrations were generally higher than or near baseline in all years from 2018 to 2022 at all sites, except in 2020 when concentrations in Joe Wright Creek (JWC) downstream to the Poudre below Rustic (PBR) measured below baseline. Total dissolved solids concentrations appeared to be slightly elevated over the past two years compared to baseline following the Cameron Peak Fire; however, concentrations at this level were observed in previous years over the five-year period of record. Elevated concentrations during the past five years resulted in significantly higher total dissolved solids in Joe Wright Creek (JWC) and in the Poudre above Joe Wright Creek (PJW) downstream to the City of Greeley's diversion over the current five-year period compared to baseline (**Figure 4.8**). The highest total dissolved solids concentrations were observed at the City of Greeley's diversion (PBD; median = 66 mg/L) and the lowest concentrations were measured in the Poudre above Joe

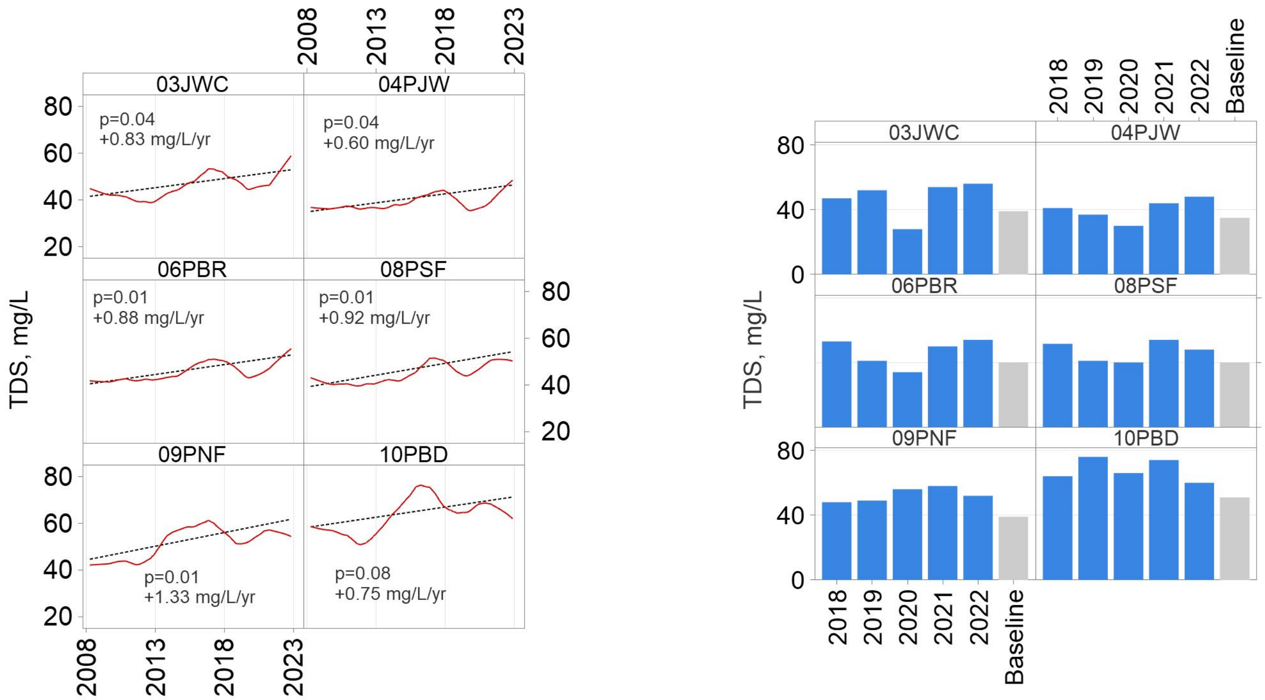

Figure 4.8 – Smoothed time-series plots indicating long-term trends in total dissolved solids concentrations in the Mainstem CLP River (left), and annual median total dissolved solids concentrations measured in in the Mainstem CLP River over the five-year period of record compared to baseline (right).

Wright Creek (PJW; median = 41 mg/L). As expected, major ions followed a similar trend over the five-year period of record. Significantly increasing trends were detected in total dissolved solids at all sites in the Mainstem CLP River over the long-term period of record (**Figure 4.8**). A notable increasing trend was observed at the City of Greeley's diversion (PBD). In general, the rate of change increased from upper elevation monitoring sites moving downstream to lower elevation monitoring sites. Similar long-term trends were detected in major cations, specifically calcium, magnesium, potassium, and sodium, across the Mainstem CLP watershed. Major anions exhibited different trends. Chlorine concentrations significantly increased in the Poudre below Rustic (PBR), in the South Fork (SFM) and in the Poudre below the South Fork (PSF), and no trends were detected in sulfate concentrations.

Total dissolved solids were variable across monitoring sites in the North Fork CLP River over the five-year period. Total dissolved solids concentrations measured near baseline above and below Halligan Reservoir (NDC and NBH), lower than baseline in the North Fork below Rabbit Creek and near Livermore (NRC and NFL), and slightly higher than baseline in the North Fork below Seaman Reservoir (NFG). In general, concentrations were similar from year to year above and below Halligan Reservoir (NDC and NBH). In the North Fork above Rabbit Creek (NRC) and near Livermore (NFL), concentrations varied over the five-year period. Total dissolved solids concentrations were consistent in the North Fork below Seaman Reservoir (NFG) over the past five-years, except in 2022 when concentrations measured higher than the previous four years. The highest total dissolved solids concentrations were observed in the North Fork near Livermore (NFL; median = 163 mg/L) and the lowest alkalinity concentrations were measured in the North Fork above Dale Creek (NDC; median = 64 mg/L). There were no trends detected in total dissolved solids concentrations in the North Fork CLP River.

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

Table 5 – 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%

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 5**).

Total organic carbon measured higher over the five-year period compared to baseline at all monitoring sites in the Mainstem CLP River, except in the Poudre River above Joe Wright Creek (PJW). In general, total organic carbon concentrations were similar across monitoring locations and concentrations were variable over the five-year period. The highest concentrations were observed in Joe Wright Creek (JWC; median = 4.22 mg/L) and the lowest concentrations were measured at the City of Fort Collins' diversion (PNF; median = 3.97 mg/L). Concentrations were higher or near baseline in all years, except for 2020 when concentrations measured below baseline in Joe Wright Creek (JWC), and in the Poudre above Joe Wright Creek (PJW) downstream to the Poudre below Rustic (PBR). Significantly higher concentrations were detected in Joe Wright Creek (JWC) over the five-year period compared to baseline. There were no long-term trends detected in total organic carbon concentrations in the Mainstem CLP River.

Total organic carbon in the North Fork CLP River measured lower than baseline over the five-year period at all monitroing sites, except in the North Fork above Dale Creek (NDC). Concentrations were similar across monitoring locations and were variable over the five-year period. The highest concentrations were measured in the North Fork above Dale Creek (NDC; median = 5.62 mg/L) and the lowest concentrations were measured in the North Fork below Halligan Reservoir (NBH; median = 5.02 mg/L). Total organic carbon concentrations fluctuated around baseline over the five-year period, but concentrations were lower than baseline in most years. Significantly lower concentrations were detected in the North Fork below Halligan (NBH) over the five-year period compared to baseline. Total organic carbon significantly decreased in the North Fork below Halligan and Seaman Reservoirs at a rate of -0.06 mg/L and -0.08 mg/L per year over the long-term period of record (**Figure 4.9**).

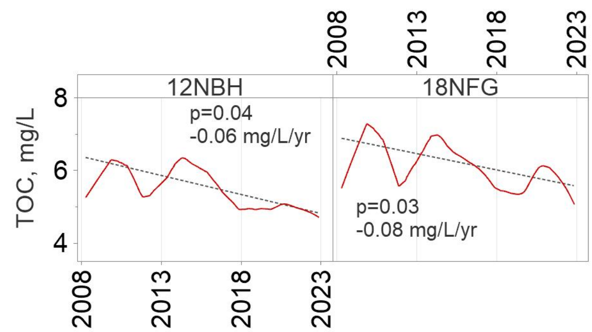

Figure 4.9 – Smoothed time-series plot displaying long-term trends in total organic carbon in the North Fork below Halligan and Seaman Reservoirs (NBH and NFG).

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 excessive algal and cyanobacteria growth. Cyanobacteria are particularly concerning, because some species can produce taste and odor compounds and cyanotoxins which present significant water treatment challenges. Potential sources of nutrients in surface waters include animal waste, poorly functioning septic systems, fertilizer run-off, sediment 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 nitrogen (TN) and total phosphorus (TP) serve as aggregate measures of potential nitrogen and phosphorus availability to the system.

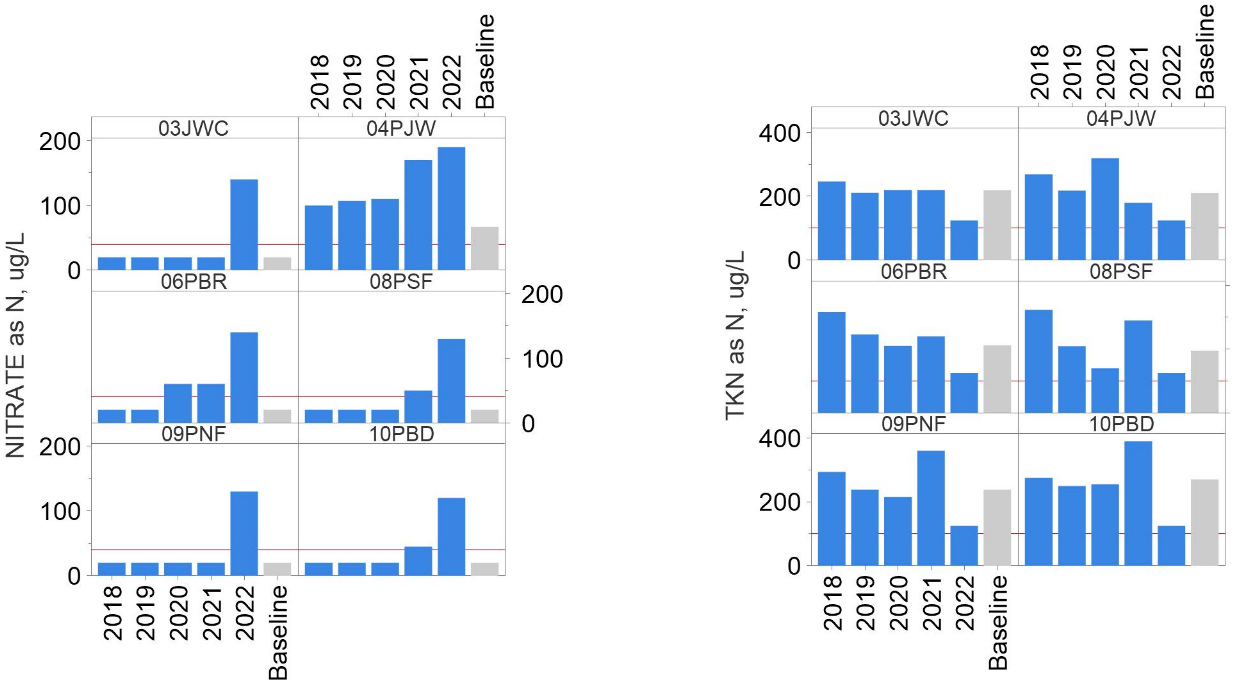

Figure 4.10 – Annual median nitrate concentrations in the Mainstem CLP River over the five-year period of record compared to median nitrate concentrations measured over baseline period of record (left) and annual median total kjeldahal nitrogen concentrations in the Mainstem CLP River over the five-year period of record compared to median total kjeldahal nitrogen concentrations measured over baseline period of record (left). The red line indicates the water quality laboratory's report limit.

Total nitrogen (TN) is the sum of total kjeldahal nitrogen (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 a 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.

Nitrogen

Total nitrogen measured higher than baseline at all monitoring sites in the Mainstem CLP River over the five-year period. There were no consistent trends across monitoring sites; however, concentrations were elevated at most sites in 2021 following the Cameron Peak Fire and near or slightly above baseline in all other years. Total nitrogen concentrations were significantly higher over the past five years compared to baseline in the Poudre above Joe Wright Creek (PJW). The highest total nitrogen concentrations were observed at the City of Greeley's diversion (PBD; median = 380 ug/L) and the lowest total nitrogen concentrations were measured in the Poudre above Joe Wright Creek (PJW; median = 280 ug/L). Despite the general increasing concentrations from upstream to downstream, total nitrogen concentrations in the Poudre above Joe Wright Creek (PJW) were similar to concentrations measured at the City of Greeley's diversion (PBD). Total nitrogen concentrations significantly increased in the Poudre above Joe Wright Creek (PJW) at a rate of 9 ug/L per year over the long-term period of record.

There were no other long-term trends detected in the Mainstem CLP River.

Ammonia concentrations were low in all years and measured below the reporting limit (baseline) except in 2018 when concentrations measured slightly above the reporting limit at all sites. Nitrite was not detected in the Mainstem CLP over the five-year period. There were no long-term trends detected in ammonia or nitrite concentrations in the Mainstem CLP River; however, ammonia was significantly higher in Joe Wright Creek (JWC) over the past five years compared to baseline.

Nitrate concentrations over the last five years measured above baseline in the Poudre above Joe Wright (PJW) and the Poudre below Rustic (PBR) and near baseline at all other sites. Nitrate concentrations followed similar trends across the five-year period. Very low nitrate concentrations were measured from 2018 to 2020. Slightly higher concentrations were detected in 2021 and much higher concentrations were measured in 2022 following the Cameron Peak Fire. Nitrate concentrations measured 3 – 5 times higher than baseline across all monitoring sites in 2022 (**Figure 4.10**). Despite, the recently elevated nitrate concentrations, most sites measured a median concentration below the report limit (40 ug/L) over the long-term period of record; however, concentrations over the past five years were significantly higher than baseline in the Poudre above Joe Wright Creek (PJW) downstream to the City of Greeley's diversion (PBD). The highest concentrations were measured in the Poudre above Joe Wright Creek (PJW; median = 136 ug/L) and in the Poudre below Rustic (PBR; median = 54 ug/L). Nitrate concentrations significantly increased in the Poudre above Joe Wright Creek (PJW) and in the Poudre River below Rustic (PBR) over the long-term period of record. A notable increasing trend was also detected in the Poudre below the South Fork (PSF; **Figure 4.11**). The long-term trends may be influenced by elevated concentrations observed in recent years.

Organic nitrogen (total kjeldahal nitrogen) measured near or slightly above baseline at all monitoring sites across the Mainstem CLP River. Concentrations exhibited a slightly decreasing pattern over the five-year period, except in 2021 when concentrations were higher than baseline at nearly all monitoring sites (**Figure 4.10**). Surprisingly, organic nitrogen concentrations were lower than baseline in 2022, which were the lowest concentrations measured over the past five years. There were no short or long-term trends

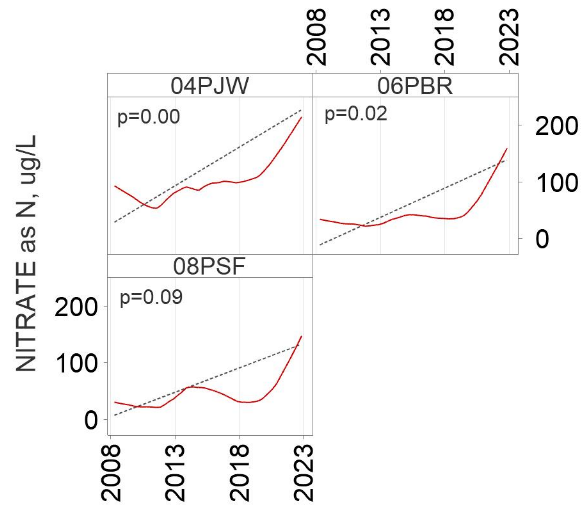

Figure 4.11 – Smoothed time-series plot displaying long-term trends in nitrate concentrations in the Mainstem above Joe Wright Creek (PJW), below Rustic (PBR) and below the South Fork (PSF). Note that the rate of change is less than the water quality laboratory's reporting limit (<40 µg/L); therefore, it is not displayed above.

detected in organic nitrogen concentrations in the Mainstem CLP River.

Total nitrogen was below baseline at all sites in the North Fork CLP River, except in the North Fork below Seaman Reservoir (NFG) where concentrations measured slightly above baseline. In general, concentrations were similar across monitoring sites and varied over the last five years. The highest concentrations were measured below Halligan and Seaman Reservoirs (median at NBH = 417 ug/L and median at NFG = 487 ug/L) and the lowest concentration was observed in the North Fork above Dale Creek (NDC; median = 349 ug/L). Organic nitrogen followed similar spatial and temporal trends compared to total nitrogen.

Nitrate concentrations were low in the North Fork CLP River and measured below the reporting limit (baseline) in all years except in the North Fork below Halligan and Seaman Reservoirs (NBH and NFG). Higher nitrate concentrations were measured below the reservoirs in 2021 and 2022, especially below Seaman Reservoir where concentrations measured nearly two times higher than baseline in the recent two years. Significantly higher concentrations were detected in the North Fork above Rabbit Creek (NRC) over the last five years compared to baseline.

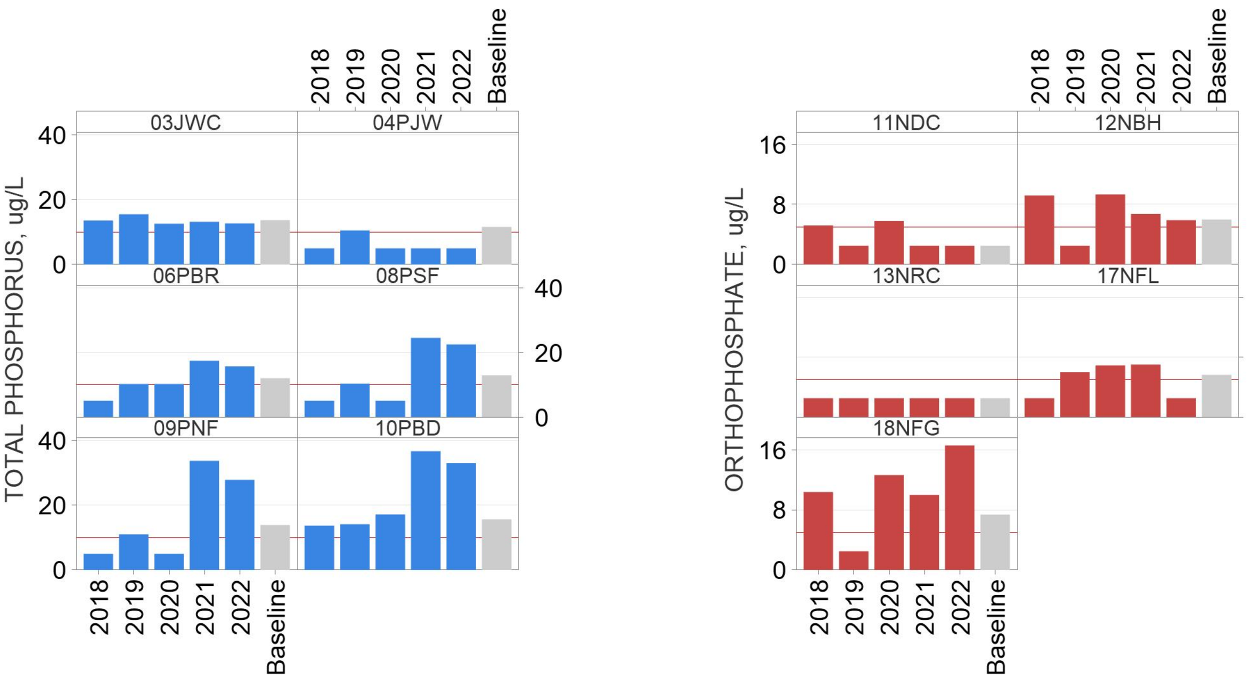

Figure 4.12 – Median total phosphorus concentrations in the Mainstem CLP River (left) and median orthophosphate concentrations in the North Fork CLP River (right) over the recent five-year period compared to baseline. The red line indicates the City of Fort Collins Water Quality Laboratory's reporting limit.

Ammonia concentrations were below baseline in the North Fork above and below Halligan Reservoir (NDC and NBH) and above baseline from the North Fork above Rabbit Creek (NRC) downstream to the North Fork below Seaman Reservoir (NFG). Concentrations were variable across sites and over the last five years. Concentrations were significantly higher in the North Fork below Halligan and Seaman Reservoirs (NBH and NFG), and in the North Fork above Rabbit Creek (NRC) over the last five years compared to baseline. There were no significant long-term trends measured in nitrogen (inorganic or organic) concentrations in the North Fork CLP River.

Phosphorus

Total phosphorus concentrations measured lower than baseline in Joe Wright Creek (JWC) and in the Poudre above Joe Wright Creek (PJW) and higher than baseline in the Poudre below Rustic (PBR) downstream to the City of Greeley's diversion (PBD) over the last five years. Total phosphorus concentrations measured below the reporting limit at nearly all sites from 2018 through 2020, except in the Joe Wright Creek (JWC) and in the Poudre near the City of Greeley's diversion (PBD). Concentrations at these sites measured slightly above the reporting limit. Over the past two years, total phosphorus concentrations were elevated in the Poudre River below Rustic (PBR) downstream to the City of Greeley's diversion (PBD) and measured 1.5 – 2.5 times higher than baseline (**Figure 4.12**). The highest total phosphorus concentrations measured over the five-year period were observed at the City of Greeley's diversion (PBD; median = 15 µg/L) and the lowest total phosphorus concentrations were measured in the Poudre above Joe Wright Creek (PJW; median <10 µ/L). There were no significant short or long-term trends detected in total phosphorus concentrations in the Mainstem CLP River.

Median orthophosphate concentrations measured below the reporting limit at all monitoring sites in the Mainstem CLP River. Concentrations were generally not detected above the reporting limit at any sites over the five-year period, except in 2021. Orthophosphate measured 1.5 – 2 times the reporting limit in the Poudre below the South Fork (PSF) and at the City of Fort Collins' and Greeley's diversions (PNF and PBD). Median orthophosphate concentrations measured below the reporting limit at all sites indicating minimal detections of orthophosphate in the

Mainstem Poudre River over the last five years; however, concentrations were significantly higher than baseline in the Poudre above Joe Wright Creek (PJW) downstream to the City of Greeley's diversion (PBD). A significant trend was not detected at the City of Fort Collins' diversion (PNF). Significantly increasing concentrations were detected in the Laramie River Tunnel diversion (LRT) and in the South Fork above the Mainstem (SFC) over the long-term period of record.

Total phosphorus concentrations measured lower than baseline at all monitoring sites in the North Fork CLP River over the last five years, except in the North Fork below Seaman Reservoir (NFG). In general, total phosphorus concentrations measured slightly above the reporting limit at all sites. The highest total phosphorus concentrations measured over the five-year period were observed in the North Fork below Seaman Reservoir (NFG; median = 37 µg/L) and the lowest total phosphorus concentrations were measured in the North Fork above Rabbit Creek (NRC; median = 19 µg/L). Significantly lower concentrations were measured in the North Fork near Livermore (NFL) over the past five years compared to baseline. There were no other long-term trends detected in total phosphorus concentrations in the Mainstem CLP River. A significantly decreasing trend in total phosphorus concentrations was detected in Stonewall Creek (SCM) and in the North Fork near Livermore (NFL) over the long-term period of record.

Orthophosphate concentrations measured near or below baseline at all monitoring sites in the North Fork CLP River, except below Halligan and Seaman Reservoirs (NBH and NFG). Concentrations were variable across monitoring locations, especially below the reservoir (NBH and NFG). The highest orthophosphate concentrations over the five-year period were measured in the North Fork below Seaman Reservoir (NFG; median = 11 µg/L) and the lowest concentrations were measure in the North Fork above Rabbit Creek (NRC median <5 µg/L; **Figure 4.11**). There were no long-term trends detected in orthophosphate concentrations in the North Fork CLP River.

4.5 MICROORGANISMS

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 other warm blooded animal fecal waste pollution. Total coliform counts are greater than *E. coli* counts because total coliform includes all types and sources of coliform bacteria.

Total Coliform

Total coliform counts were near or above baseline in the Mainstem and North Fork CLP Rivers over the five-year period compared to baseline. Counts were generally consistent across monitoring locations in all years, except in the Poudre near the City of Greeley's diversion where total coliform counts were about two times higher than monitoring sites located upstream. Median total coliform counts at the City of Greeley's diversion (PBD) measured 550 cells/100 mL while the lowest counts were measured in the Poudre below Rustic (PBR; median = 207 cells/100 mL). The higher counts at the City of Greeley's diversion (PBD) are likely related to total coliform contributions from the North Fork CLP River. Total coliform counts in the North Fork below Seaman Reservoir (NFG) measured higher than baseline over the five-year period (median = 1,026 cells/100 mL). Much higher concentrations were measured in 2021 when median cell counts were higher than 3,000 cells/100 mL, which measured three times higher than baseline. There were no long-term trends detected for total coliform counts in the Mainstem or North Fork CLP Rivers.

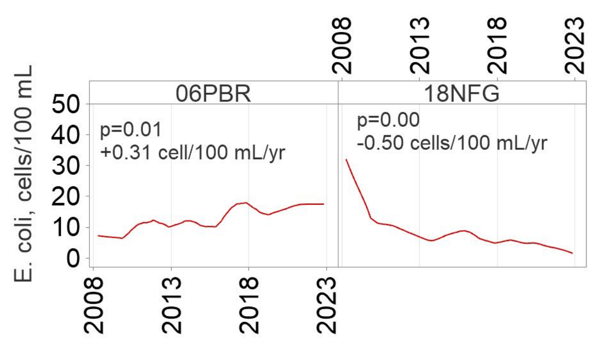

Figure 4.13 – Smoothed time-series plot displaying long-term trends in *E. coli* counts in the Poudre below Rustic (PBR) and in the North Fork below Seaman Reservoirs (NFG).

E. coli

E. coli counts were higher than baseline in the Mainstem CLP River over the five-year period compared to baseline at all sites except in the Poudre near the City of Greeley's diversion (PBD) and in the North Fork below Seaman Reservoir (NFG). Counts were variable between monitoring sites over the past five years. The highest counts were measured in the Poudre below the South Fork (PSF; median = 16 cells/100 mL) and the lowest counts were measured in the Poudre near the City of Greeley's diversion (PBD; median = 8 cells/100 mL) and in the North Fork below Seaman Reservoir (NFG; median = 2 cells/100 mL). In fact, significantly lower counts were measured in the North Fork below Seaman Reservoir (NFG) over the last five years. A significantly decreasing trend was detected at this monitoring site at a rate of -0.50 cells/100 mL per year over the long-term period of record. Despite the lower counts observed downstream in the Poudre near the City of Greeley's diversion (PBD), no long-term trend was detected at this site. In contrast, a significantly increasing trend in *E. coli* counts was detected in the Poudre below Rustic (PBR) at a rate of 0.31 cells/100 mL per year over the long-term period of record (**Figure 4.13**). Significantly higher concentrations were also measured at this site over the past five years compared to baseline.

4.6 MACROINVERTEBRATES

Aquatic macroinvertebrates are animals that live in water, lack a backbone and are visible without the aid of a microscope. The Poudre River supports a diverse community of aquatic macroinvertebrates, including insects, shrimp, crayfish, worms, leeches, snails, clams, and other groups. These animals live most of their lives on or within the streambed of the river, where they occupy a wide variety of ecological roles or "niches" in terms of their modes of feeding habits, habitat preferences, life cycles and other factors.

Key monitoring locations occur in three separate *EPA Level IV Ecoregions* (**Table 6**). The Mainstem above Joe Wright Creek (PJW) is located within the Crystalline Subalpine Forests Ecoregion; the Mainstem below Rustic (PBR), the Mainstem below the South Fork (PSF) and the Mainstem near the City of Fort Collins' Diversion (PNF) are located within the Crystalline Mid-Elevation Forests; and the Mainstem near the City of Greeley's Diversion (PBD) is located within the Foothills Shrublands Ecoregion. Macroinvertebrate communities in the Crystalline Subalpine Forests Ecoregion are naturally less productive, are structured differently and are not directly comparable to communities in the two lower elevation ecoregions. Communities in monitoring locations in the Crystalline Mid-Elevation Forests and Foothills Shrublands are considered directly comparable for the purposes of this report.

Macroinvertebrate community metrics are often used to evaluate water quality and ecological health in streams and can be particularly useful when paired with chemical and physical water quality data to better understand cause and effect relationships between pollutants and the biota. Baseline biological condition was determined by calculating averages of routine macroinvertebrate community metrics using data from 2019 and 2020. Baseline (pre-fire) data were compared to 2022 data to understand macroinvertebrate community changes within and between key study locations following the Cameron Peak Fire. Data from 2021 and 2022 were also compared to identify positive and negative trends. Differences of 20% or greater were deemed notable and are highlighted below (**Table 6**). It is important to note that analyses in subsequent years will be expanded to include long-term trends, and to further monitor impacts and watershed recovery following the fire.

Species Diversity

Species diversity is a measure of the number of macroinvertebrate species within a community. Communities with good water quality generally have higher species diversity than those with poor water quality. Except for PNF, study sites had less species diversity than baseline However, there was an increasing trend in species diversity at most study locations between 2021 to 2022, with PBR adding seven additional species over this timespan. Species diversity at PBR was heavily impacted by sedimentation from the Black Hollow debris flow event in 2021. Fine sediment – including silt, sand and gravel blanketed the streambed in 2021 and degraded habitat at this site. Based on field observations, much of this sediment was subsequently removed from this site by high flows between 2021 and 2022 during snowmelt runoff. The sharp increase in diversity at this site in 2022 indicates that the community is recovering.

Shannon's H

Shannon's H combines measures of species diversity and the relative abundance of each species within a macroinvertebrate community. Values > 3 generally indicate that the community is healthy and water quality is good, whereas values <1 indicate poor community condition and water quality. Shannon's H was >3 at all study locations in 2022, whereas only PBR and PBD were >3 in 2021. Shannon's H was only 20% less than baseline at PSF, and besides PBD, all study sites showed an increasing trend in Shannon's H between 2021 and 2022. The increase in Shannon's H across most monitoring locations generally indicates that macroinvertebrate community health is improving following the Cameron Peak Fire.

EPT Diversity and % EPT

EPT is an abbreviation for the sum of species within the orders Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies). EPT are widely regarded as intolerant of water quality pollution, and therefore, higher measures of EPT diversity and the relative percent of EPT in a community generally indicate that water quality is good. EPT diversity and % EPT was the same or greater than baseline at all sites and increased between 2021 and 2022 at all sites except PBD. The notable improvement in the diversity and relative abundance of EPT is likely related to a reduction in post-fire sedimentation in 2022 compared to 2021.

Density

Density is a measure of the number of individual organisms living within a square meter of the streambed. Changes in density can be associated with water quality pollution. Macroinvertebrate density was comparable to baseline at all sites except PJW. Density at PJW and PNF was reduced between 2021 and 2022 and increased at PBR, PSF and PBD. These changes in density are likely related to a post-fire community level response at these study locations. Specific changes in organisms with various feeding strategies are explored below.

Collector-Gatherers

Percent collector-gatherers refers to the relative percentage of macroinvertebrates in the community that feed on tiny organic particles deposited on or within the streambed. The percentage of collector-gatherers is much lower at PBR, PSF, PNF and PBD than baseline, which is likely related to less organic matter entering the river within the burn scar. Much of the upland forest, riparian vegetation and associated soils within the burn scar were moderately or severely burned and therefore less organic matter is entering the river. The decrease in the percentage of collector gatherers at these study locations corresponds to an increase in the percentage of algae scrapers.

Collectors-Filters

Percent filter-feeders refers to the percentage of macroinvertebrate species in a community that feed by filtering tiny organic particles suspended in the streamflow. The abundance of these organisms often dramatically increases in locations with elevated organic pollution. The percentage of collector-filterers on the Mainstem was 20% less than baseline at PJW, PBR, PSF and PNF. The exception was PBD, where the percentage of collector-filterers was near baseline and increased 46% between 2021 and 2022. The change in the relative percentage of this feeding group at sites closer to the burn scar is likely associated with a reduction of organic matter entering the river. The increase in filter-feeders at PBD is related to organics entering the river from the Seaman Reservoir outflow into the North Fork Poudre River.

Leaf Shredders

Percent shedders refers to the percentage of macroinvertebrate species that feed on leaves, pine needles, twigs and other large organic matter that is washed into the river from the riparian corridor. Decreases in the percentage of shredders in a community often indicate that riparian vegetation has been degraded and there is less food available for these organisms. Shredders were reduced by more than 20% compared to baseline and from 2021 and 2022 at both PBR and PSF. These changes are likely related to the loss of riparian vegetation in the burn scar. The number of shredders at PJW, PNF and PBD were similar to baseline conditions.

Algae Scrapers

Percent algae scrapers refers to the relative percentage of macroinvertebrates in a community that feed by scraping algae from the tops of rocks and logs. Algae scrapers can become more abundant in the presence of elevated nutrients and associated increases algal productivity and less abundant due to excessive sedimentation. Nutrient concentrations have increased following the Cameron Peak Fire, which may explain the sharp increase of algae scrapers across all study sites.

MMI Version 4

The MMI Version 4 is the Colorado Department of Public Health and Environment's (CDPHE) multi-metric water quality index, which combines several ecological metrics into a single score. The score can range from 0-100 and there is a separate MMI for each of CDPHE's three biotypes. The Mainstem above Joe Wright Creek (PJW) is in CDPHE's biotype 1. The Mainstem below Rustic (PBR), the Mainstem below the South Fork (PSF), the Mainstem near the City of Fort Collins' Diversion (PNF) and the Mainstem near the City of Greeley's Diversion (PBD) are in CDPHE's biotype 2. The MMI Version 4 is used by CDPHE to determine whether the State's surface water quality standards for the Aquatic Life Use are attained. All study locations remained above CDPHE's MMI Version 4 aquatic life standards thresholds for attainment. It is important to note that CDPHE is responsible for determining whether surface water standards are attained, and beneficial uses are supported.

Table 6 – Routine 2022 macroinvertebrate community metrics from key study locations along the Mainstem CLP. Data from 2022 were compared to baseline data (average of 2019 and 2020 data, shown in parentheses) and notable negative and positive percentage departures (20% or more) are indicated in using red and blue, respectively. Metrics were also compared between 2021 and 2022 to determine whether there were notable (20% or more) positive (green, upward arrow) or negative (red, downward arrow) trends between years.

	PJW	PBR	PSF	PNF	PBD
Level IV Ecoregion	Crystalline Subalpine Forests	Crystalline Mid-Elevation Forests	Crystalline Mid-Elevation Forests	Crystalline Mid-Elevation Forests	Foothills Shrublands
Species Diversity	28 (34) ↑2	39 (41) ↑7	36 (41)	33 (31) ↑2	34 (39) ↑2
Shannon's H	3.1 (3.1) ↑0.2	3.2 (4.0) ↑0.1	3.0 (4.2) ↑0.2	3.5 (3.4) ↑1.2	3.1 (3.3)
EPT Diversity	17 (17) ↑1	23 (23) ↑8	23 (22) ↑1	23 (19) ↑5	23 (23)
Percent EPT	86% (82%) ↑6%	89% (75%) ↑22%	93% (70%) ↑35%	89% (81%) ↑45%	95% (68%) ↑11%
Density (#/m^2)	2,679 (4,393) ↓412	5,571 (3321) ↑2,798	4,867 (2,558) ↑1,246	2,616 (2,405) ↓863	7,089 (8,225) ↑560
Percent Collector-Gatherers	59% (60%) ↓10%	30% (42%) ↓58%	26% (50%) ↑28%	30% (58%) ↑26%	13% (27%) (↓19%)
Percent Algae Scrapers	29% (25%) ↑26%	56% (24%) ↑175%	64% (15%) ↓28%	55% (22%) ↑77%	47% (33%) ↓37%
Percent Predators	8% (7%) ↑28%	8% (13.5%) ↑22%	4% (11.5%) ↓35%	6% (8.5%) ↑58%	4% (5%)
Percent Collector-Filterers	5% (6.5%) ↓46%	6% (15.5%) ↓90%	5% (10.5%) ↓28%	7% (9.5%) ↓400%	35% (35.5%) ↑46%
Percent Leaf Shredders	2% (1%)	1% (4.5%) ↓134%	1% (8%) ↓38%	2% (1.5%) ↑133%	1% (0.5%)
CDPHE Biotype	1	2	2	2	2
MMI version 4	76 (68.6) ↑6.5 (Attainment)	74 (78.2) ↑7.7 (Attainment)	74.9 (75.5) ↓1.4 (Attainment)	76.4 (75.6) ↑10.3 (Attainment)	78.3 (80.5) ↑1.8 (Attainment)

5.0 SUMMARY & IMPLICATIONS

5.1 WATERSHED IMPACTS & ISSUES OF CONCERN

Over the past 15 years (2008 – 2022) the Upper CLP watershed has experienced periods of wet and dry water years influencing both streamflow and water quality conditions in the CLP watershed. Current climate models predict 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 insect outbreaks and other diseases.

The greatest climate-related impacts to the Upper CLP watershed over the past-five years have been drought and wildfire. Exceptionally hot and dry conditions in 2020 lead to extreme drought and the ignition of the Cameron Peak Wildfire. The fire caused extensive damage to upper- and mid- elevation areas of the Mainstem CLP watershed, including areas surrounding several high elevation water storage reservoirs. High intensity monsoonal rainfall over the burn scar has caused severe flooding, erosion, and debris flows in the Mainstem CLP River, resulting in impacts to raw water quality and water treatment challenges. Water quality monitoring instruments were installed at two locations upstream of water supply intake facilities on the Poudre. The monitoring systems provide water treatment operations with near real-time water quality data to quickly respond to changes in Poudre River water quality that result from runoff from the Cameron Peak burn scar or other upstream events.

High-intensity precipitation events driven by the summer monsoon caused several significant erosion, sedimentation, post-fire debris flows and flood events in the CLP Watershed. The real-time water quality instruments measured nearly two dozen post-fire storm events in 2021 and 2022 combined. Many of these events resulted in severely impacted water quality and required water treatment plants to shut down their raw water intakes on the Poudre River for an extended period (**Figure 5.1**). These events led to drastic increases in river turbidity, pH, and specific conductivity in the Poudre River. The magnitude of water quality impacts was extreme with maximum turbidity values ranging from 400 NTU to >1,000 NTU compared to pre-storm event values of less than 5 NTU. The duration of these events was relatively short lived, with most lasting approximately 24 hours.

In contrast, the Black Hollow flood, that occurred on July 20, 2021, delivered a large amount of debris, sediment, and ash into the CLP river. The debris flow destroyed several structures and the roadway and resulted in the death of four residents and thousands of fish. The initial surge of debris and sediment resulted in extremely high turbidity levels in the CLP river (several thousand NTU), which required water treatment facilities to shut down their intakes on the CLP river and treat alternate water supplies. Turbidity

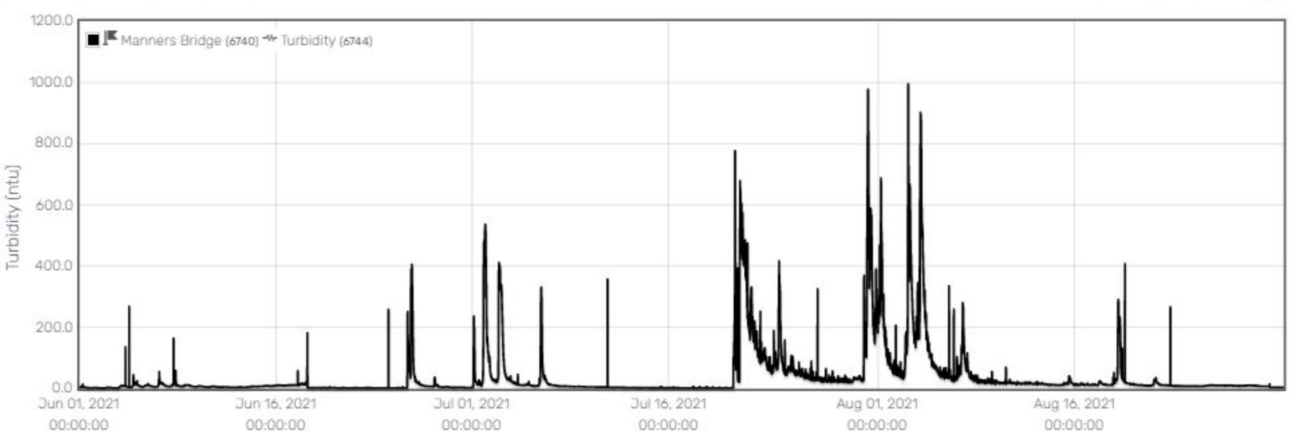

Figure 5.1 – Turbidity measured in the Poudre River at the Manners Bridge real-time water quality instruments. Several rain events over the Cameron Peak burn scar caused turbidity in the river to increase rapidly over a short amount of time and remain elevated for several hours before returning to normal. Note: These data are preliminary and subject to change and some outlier data may be present.

remained elevated and highly variable for several weeks following the event, which continued to pose treatment challenges. The extreme amount of sediment from this event eventually settled on the banks and bottom of the river channel providing an additional source of sediment during subsequent flood events in August and snowmelt runoff in 2022. The sediment and ash that were stored on the bottom and banks of the Poudre River in 2021 were mobilized during snowmelt runoff in 2022, leading to elevated turbidity and suspended sediment. Turbidity levels in 2022 were much higher and more variable than pre-fire conditions and required water treatment plants to shut down their intakes on the CLP river on several occasions to avoid the polluted water.

Post-fire water quality impacts are expected to continue for several years as the watershed recovers. Water quality data collected by the Upper CLP Collaborative Water Quality Monitoring Program are key to tracking short and long-term impacts and recovery from wildfire and other disturbances in the watershed.

5.2 CLIMATE & WATERSHED HYDROLOGY TRENDS

Global air temperatures have been trending upward over the past several decades (Intergovernmental Panel on Climate Change, 2007). Long-term climate records throughout the Rocky Mountains indicate that annual mean minimum air temperatures have increased 0.7°C per decade with stronger trends in the Colorado Rocky Mountains. Similar trends were detected in air temperature at higher elevations in the Upper CLP watershed with monthly mean air temperatures increasing 0.08°F (0.04°C) per year. This trend was driven by increasing annual minimum temperatures, specifically during the summer season. In contrast to the previous five-year water quality trend report (Heath and Thorp 2017), there were no long-term trends detected in precipitation or streamflow.

5.3 WATER QUALITY TRENDS

Water quality data collected as part of this program were analyzed for short and long-term trends over the 15-year period of record from 2008 to 2022. Trend analyses were performed on all monitoring sites for the following water quality parameters:

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

Both monotonic (gradual increasing or decreasing) and step (abrupt positive or negative change) trends were identified. Step-trends were observed in 2021 and 2022 in response to landcover changes and increased watershed erosion following the 2020 Cameron Peak Fire.

Table 7 summarizes significant trends detected throughout the Upper CLP watershed over the recent five-year period from 2018 – 2022 and the long-term period from 2008 – 2022. 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. A summary of these trends is discussed below for both the Mainstem and North Fork CLP watersheds.

Mainstem CLP Watershed

Both short and long-term trends in pH, alkalinity, hardness, and total dissolved solids may pose challenges to current and future water treatment processes and operations. Most water quality trends detected in the Mainstem CLP watershed were associated with increased watershed erosion caused by the Hewlett Gulch, High Park and Cameron Peak wildfires that have impacted the watershed over the last 15 years. Water quality impacts from the Cameron Peak Fire have been particularly evident in the recent two years (2021 and 2022) following the fire. Recent impacts from the Cameron Peak fire are comparable to water quality impacts measured after the High Park fire, which include:

1) Abrupt changes in turbidity and suspended sediment, especially during and following storm events and snowmelt runoff.
2) Elevated background (non-storm event) concentrations in alkalinity, hardness, and total dissolved solids.
3) Increased background (non-storm event) concentrations in nutrients.
4) Elevated turbidity, total organic carbon, nutrients, and metals (dissolved and total) during snowmelt runoff and storm events.

Table 7 – Summary of water quality trends detected throughout the Upper CLP watershed.

Water Quality Parameter (Short-term trends)	MAINSTEM CLP WATERSHED						NORTH FORK CLP WATERSHED				
	JWC	PJW	PBR	PSF	PNF	PBD	NDC	NBH	NRC	NFL	NFG
Temperature					L			L			L
pH		S		S	S/L	S/L	S	S/L	S/L	S/L	S/L
Specific Conductivity		S ¦ L	L	S/L	S/L						
Turbidity				S				S/L	L	L	S
Alkalinity				S ¦ L	S/L						
Hardness	S/L	S/L	S/L	S/L	S/L						
Total Dissolved Solids	S/L	S/L	S/L	S/L	S/L	S ¦ L					
Total Organic Carbon	S							S ¦ L	L	L	L
Total Nitrogen		S/L									
Nitrate		S/L	S/L	S ¦ L	S	S			S		
Ammonia	S						S		S		S
Total Phosphorus										L	
Orthophosphate		S	S	S		S	S	S			
E. coli			S/L								S/L

- Increasing - 95% confidence interval (p-value < 0.05)
- Increasing - 90% confidence interval (p-value < 0.10)
- Decreasing - 95% confidence interval (p-value < 0.05)
- Decreasing - 90% confidence interval (p-value < 0.10)

S Short-term trend (2018 – 2022)

L Short-term trend (2008 – 2022)

wildfire will continue for many years as the watershed responds and recovers from a rather unprecedent disturbance. Water quality data collected following the High Park Fire indicated watershed recovery occurred six to seven years after the fire; however, there is uncertainty in how long it will take the watershed to recovery from the Cameron Peak Fire due to the magnitude, severity, and geographic extent at which the fire burned.

The Cameron Peak Fire burned over two times the amount of land compared to the High Park Fire and much of the burn scar is in the mid to upper elevations of the watershed. The upper portion of the watershed experiences higher amounts of precipitation, much of which is stored as seasonal snowpack. In contrast, mid and lower elevation portions of the burn are comparatively arid. Higher elevation areas will therefore likely better support vegetation regrowth and recovery.

There are several high elevation water storage reservoirs that are susceptible to post-fire impacts and changes in reservoir water quality may have long-term impacts to water quality in the Poudre River. These reservoirs posed seasonal water treatment challenges before the fire due to suspected algae blooms. Because of the fire's likely long-lasting impacts of elevating nutrients to reservoirs, the fire may exacerbate the occurrence of algae blooms. The Upper CLP Collaborative Water Quality Monitoring Program partners (cities of Fort Collins, Greeley, and Thornton) and Northern Water are working with researchers at Colorado State University and Rocky Mountain Research Station to better understand these impacts and develop decision support tools to better inform water treatment plants of degraded water quality released from these reservoirs. This study will help to better understand the pre-fire reservoir water quality dynamics that led to algae blooms in the first place, but also identify the true risk of these algae blooms becoming more frequent now that the watershed has been impacted by wildfire.

Macroinvertebrate communities at key study sites along the mainstem were degraded by post-fire pollution in the first year following the Cameron Peak Fire. While suspended sediment and bedload are not directly measured as part of this program, extremes in turbidity and field observations of sediment aggradation indicate that sedimentation was a major stressor. Macroinvertebrate communities at all sites are trending toward recovery, based on several metrics, including measures of diversity, density, increases in pollution sensitive species and other measures. Improvements in overall community health align with field observations of less streambed sediment. Notable increases in algae scraping species is likely related to less sediment and elevated background, runoff and post-storm nutrient concentrations and resultant increased algal productivity. Reductions in species that feed on organic matter at sites above the confluence with the North Fork is likely related to less organic materials entering the river from areas within the burn scar. In contrast, these species increased below the confluence of the North Fork. This trend is likely driven by organic materials being discharged from Seaman Reservoir.

North Fork CLP Watershed

Short and long-term water quality trends in the North Fork CLP River varied across the watershed. Watershed wide trends were detected for pH, turbidity and total organic carbon and site-specific trends were detected for temperature, nutrients and *E. coli*. Climate change impacts, specifically increasing air temperature, flooding and drought, and streamflow alterations are likely the main drivers of water quality changes in the North Fork CLP River. Increasing water temperature was detected in the North Fork CLP River below Halligan and Seaman Reservoirs, which may imply that water temperature in the reservoirs is increasing. Most of the significant trends detected in the North Fork CLP River were observed downstream of the North Poudre Canal in the Livermore Valley. A significant portion of North Fork CLP River water is diverted from the North Poudre Canal from early summer through late fall. During this time, groundwater and agricultural return flows are the main inputs to the hydrology of the North Fork CLP River in the Livermore Valley downstream to Seaman Reservoir, which result in different water quality compared to surface water upstream of the North Poudre Canal.

Water quality trends in recent years imply that water quality conditions in this area have recovered from the 2013 flood. During the flood and for several years following the flood, streamflow in the North Fork was higher than normal, which may have shifted the proportion of surface water and groundwater contributions in the Livermore Valley. Over the past five years, the magnitude and timing of streamflow has shifted to a shorter and earlier runoff season leading to longer periods of low flows in the North Fork, especially below the North Poudre Canal. These conditions may be contributing to the observed trends in pH, turbidity, and total organic carbon.

Less water and the addition of groundwater inputs in this reach of the North Fork CLP River could lead to lower turbidity and total organic carbon. While there were no trends in temperature, increasing pH in this reach may be correlated to increased biological activity due to longer periods of low flow conditions caused by flow alterations at the North Poudre Canal. Low streamflow in combination with increasing nutrient inputs observed in the North Fork above Rabbit Creek may be producing suitable conditions for prolonged algae growth. Trends in nutrients in the North Fork were generally site specific and either driven by changes to in-reservoir or in-stream nutrient cycling due to changes in algal growth, water temperature and/or changes in streamflow.

5.4 IMPLICATIONS TO WATER TREATMENT

Water quality trends in the Mainstem CLP River at the cities of Fort Collins' and Greeley's diversions (PNF and PBD) are the most representative measures for water treatment at the City of Fort Collins', Soldier Canyon Water Treatment Authority and City of Greeley water treatment plants. The following sections summarize water quality trends detected at PNF and PBD and other sites that have potential implications to water treatment

Alkalinity and Hardness

Alkalinity and hardness were both 1.2 times greater than baseline values over the recent five-year period. Concentrations were higher in all years and notably higher in 2021 and 2022 following the Cameron Peak Fire. The higher concentrations of these constituents predominantly occurred during late-summer and fall months. Higher alkalinity 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

pH increased 0.02 units per year over the past 15 years at PNF and PBD and was significantly higher than baseline at both sites over the last five years. These increases in pH indicate that CLP raw water is generally becoming more alkaline. This trend is likely related to elevated carbonates associated with post-fire erosion. Elevated 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.

Total Dissolved Solids

Total dissolved solids (TDS) measured 1.3 – 1.4 times higher over the recent five-year period compared to baseline conditions. There was a discernable post-fire response in total dissolved solids; however, concentrations were only slightly higher than concentrations three years prior to the fire. TDS was particularly high during the fall and spring seasons, which may correlate to below average streamflow. Post-fire water quality impacts during the spring snowmelt and summer monsoon and seasons may also be a factor. TDS significantly increased at a rate of 1.33 mg/L over the past 15 years at the City of Fort Collins' diversion (PNF). This increase is likely related to the cumulative impacts of erosion from wildfires, floods, natural weathering, and streamflow variability. 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. It is important to note that though raw CLP TDS concentrations were elevated, they remained very low as compared to finished drinking water concentrations throughout much of the country.

Total Organic Carbon

There were no short-term or long-term trends detected in total organic carbon concentrations; however, over the past five years, higher TOC concentrations have been observed over the spring season, which is likely due to a shift in the timing and duration of snowmelt runoff. Elevated TOC levels in CLP raw water pose treatment concerns due to the potential for higher residual TOC (post-filtration) and increased disinfection by-products (DBPs) formation. Increased TOC in the CLP River 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 River raw water TOC may include increased removal requirements as concentrations more frequently exceed 4.0 mg/L.

Nutrients

Nitrate and ortho-phosphate were relatively low and measured below the reporting limit throughout much of the monitoring season. The largest changes were observed during snowmelt runoff. Post-fire watershed conditions are likely resulting in a greater release and delivery of nutrients from the burned landscape into surface waters over the past two years because of changes to the cycling and processing of nutrients and water across the impacted areas of the watershed. Background, non-storm event, concentrations are still quite low; however, even a small increase in nutrients in normally low nutrient environments, like surface waters in the Mainstem CLP water, may lead to algal blooms in the river and/or water supply reservoirs. Higher algal productivity in the source water supply may pose water treatment challenges such increased filtration times and the potential for taste and odor compounds that may require process changes to maintain high quality drinking water.

Furthermore, post-fire storm events are also delivering much higher levels of nutrients to surface waters in the Mainstem CLP watershed. In 2021, nutrient concentrations measured in the Mainstem CLP River during storm events were six times higher than baseline for nitrate and over 40 times higher than baseline for ortho-phosphate (Heath, 2022). The impacts of elevated nutrient concentrations are of particular concern for high elevation water supply reservoirs that were impacted by post fire erosion and are now more susceptible to related water quality impacts. These surface waters are serving as nutrient sinks, storing nutrients delivered during snowmelt runoff and storm events. The elevated nutrients in these reservoirs may lead to algal blooms and potential downstream water quality impacts.

6.0 REFERENCES

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ATTACHMENT 1

UPPER CLP COLLABORATIVE WATER QUALITY MONITORING PROGRAM SAMPLING SITE

	Site ID	Station Name	Lat/Long
Mainstem	100CHR	Joe Wright Creek below Chambers Lake	40.60065, -105.8367
	101CHD	Joe Wright Creek below Chambers Lake Dam	40.6023, -105.843
	090BMR	Barnes Meadow Reservoir Outflow	40.60065, -105.8367
	091BMD	Barnes Meadow Reservoir Dam	40.60044, -105.837
	080JWC	Joe Wright Creek	40.61979, -105.819
	070PJW	Poudre above Joe Wright	40.63411, -105.807
	060LRT	Laramie River Tunnel	40.66803, -105.808
	050PBR	Poudre Below Rustic	40.70002, -105.545
	040SFM	South Fork above Mainstem	40.61824, -105.5254
	041SFC	South Fork at Confluence	40.68506, -105.447
	030PSF	Poudre below South Fork	40.69464, -105.448
	020PNF	Poudre Above North Fork	40.70157, -105.241
	010PBD	Poudre at Bellvue Diversion	40.66436, -105.217
North Fork	280NDC	North Fork above Dale Creek	40.89759, -105.376
	270NBH	North Fork below Halligan Reservoir	40.87763, -105.3386
	240SCM	Stonewall Creek Mouth	40.80754, -105.2535
	260NRC	North Fork above Rabbit Creek	40.8092, -105.2685
	250RCM	Rabbit Creek Mouth	40.81023, -105.2857
	230PCM	Lone Pine Creek Mouth	40.79478, -105.2873
	220NFL	North Fork at Livermore	40.78773, -105.2525
	200NFG	North Fork below Seaman Reservoir	40.70222, -105.234

ATTACHMENT 2

2018 – 2022 UPPER CLP MONITORING PARAMETER LIST

Field Parameters		
Specific 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, SFM 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.	
Orthophosphate (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
Biological Constituents		
E. Coli	Indicator of human or animal waste contamination; water quality standard.	Only from Rustic downstream, and NFG
Total Coliform	Indicator of human or animal waste contamination.	Only from Rustic downstream, and NFG
Macroinvertebrates	Community species metrics can be used to indicate pollution and overall watershed health.	PJW, PBR, PSF, PNF, PBD
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

ATTACHMENT 3

UPPER CLP COLLABORATIVE WATER QUALITY MONITORING PROGRAM 2022 SAMPLING PLAN

2022 Upper Cache la Poudre Water Quality Monitoring Program											
Mainstem Cache la Poudre River											
	Apr 11	**Apr 25**	**May 9**	**May 23**	**Jun 13**	**Jun 27**	**Jul 11**	**Aug 8**	**Sep 12**	**Oct 10**	**Nov 7**
CHD	F,GM,N	F,GM,I,N	F,GM,I,N	F,GM,I,N	F,GM,I,N	F,GM,I,N	F,GM,N	F,G,GM,I,N	F,G,GM,N	F,G,GM,I,N	F,G,GM,I,N
BMD[1]	F,GM,N	F,GM,I,N	F,GM,I,N	F,GM,I,N	F,GM,I,N	F,GM,I,N	F,GM,N	F,GM,I,N	F,GM,N	F,GM,I,N	F,GM,I,N
JWC	F,GM,N	F,GM,I,N	F,GM,I,N	F,GM,I,N	F,GM,I,N	F,GM,I,N	F,GM,N	F,GM,I,N	F,GM,N	F,GM,I,N	F,GM,I,N
PJW	F,GM,N	F,GM,I,N	F,GM,I,N	F,GM,I,N	F,GM,I,N	F,GM,I,N	F,GM,N	F,G,GM,I,N	F,G,GM,Mc,N	F,G,GM,I,N	F,G,GM,I,N
LRT	F,GM,N	F,GM,I,N	F,GM,I,N	F,GM,I,N	F,GM,I,N	F,GM,I,N	F,GM,N	F,GM,I,N	F,GM,N	F,GM,I,N	F,GM,I,N
PBR	E,F,G,GM,N	E,F,GM,I,N	E,F,G,GM,I,N	E,F,GM,I,N	E,F,G,GM,I,N	E,F,GM,I,N	E,F,G,GM,N	E,F,G,GM,I,N	E,F,G,GM, Mc,N	E,F,G,GM,IN	E,F,G, GM,I,N
SFM	D,F,GM,N	D,F,GM,I,N	D,F,GM,I,N	D,F,GM,I,N	D,F,GM,I,N	D,F,GM,I,N	D,F,GM,N	D,F,G,GM, I,N	D,F,G, GM,N	D,F,G,GM, I,N	D,F,G,GM, I,N
PSF	E,F,GM,N	E,F,GM,I,N	E,F,GM,I,N	E,F,GM, I,N	E,F,GM,I,N	E,F,GM, I,N	E,F,GM,N	E,F,GM, I,N	E,F,GM, Mc,N	E,F,GM, I,N	E,F,GM, I,N
PNF[2,3]	E,F,G,GM, M,N	E,F,GM,I, M,N	E,F,G,GM,I, M,N	E,F,GM,I, M,N	E,F,G,GM,I M,N	E,F,GM,I, M,N	E,F,G,GM, M,N	E,F,G,GM,I, M,N	E,F,G,GM,Mc, M,N	E,F,G,GM,I, M,N	E,F,G,GM,I, M,N
PBD	E,F,GM, M,N	E,F,GM,I, M,N	E,F,GM,I, M,N	E,F,GM,I, M,N	E,F,GM,I M,N	E,F,GM,I, M,N	E,F,GM, M,N	E,F,GM,I, M,N	E,F,GM,Mc, M,N	E,F,GM,I, M,N	E,F,GM,I, M,N
North Fork Cache la Poudre River											
	Apr 12	**Apr 26**	**May 10**	**May 24**	**Jun 14**	**Jun 28**	**Jul 12**	**Aug 9**	**Sep 13**	**Oct 11**	**Nov 8**
NDC	F,GM,M,N	F,GM,I,M,N	F,GM,M,N	F,GM,I,M,N	F,GM,M,N	F,GM,I,M,N	F,GM,M,N	F,GM,I,M,N	F,GM,M,N	F,GM,I,M,N	F,GM,I,M,N
NBH	F,GM,M,N	F,GM,I,M,N	F,GM,M,N	F,GM,I,M,N	F,GM,M,N	F,GM,I,M,N	F,GM,M,N	F,GM,I,M,N	F,GM,M,N	F,GM,I,M,N	F,GM,I,M,N
NRC	D,F,GM, M,N	D,F,GM,I, M,N	D,F,GM, M,N	D,F,GM,I, M,N	D,F,GM, M,N	D,F,GM,I, M,N	D,F,GM, M,N	D,F,GM,I, M,N	D,F,GM, M,N	D,F,GM,I, M,N	D,F,GM,I, M,N
RCM	D,F,GM, M,N	D,F,GM,I, M,N	D,F,GM, M,N	D,F,GM,I, M,N	D,F,GM, M,N	D,F,GM,I, M,N					
SCM	D,F,GM, M,N	D,F,GM,I, M,N	D,F,GM, M,N	D,F,GM,I, M,N	D,F,GM, M,N	D,F,GM,I, M,N					
PCM	D,F,GM, M,N	D,F,GM,I, M,N	D,F,GM, M,N	D,F,GM,I, M,N	D,F,GM, M,N	D,F,GM,I, M,N					
NFL	F,GM,M,N	F,GM,I,M,N	F,GM,M,N	F,GM,I,M,N	F,GM,M,N	F,GM,I,M,N	F,GM,M,N	F,GM,I,M,N	F,GM,M,N	F,GM,I,M,N	F,GM,I,M,N
NFG[2]	E,F,GM, M,N	E,F,GM,I, M,N	E,F,GM, M,N	E,F,GM,I, M,N	E,F,GM, M,N	E,F,GM,I, M,N	E,F,GM, M,N	E,F,GM,I, M,N	E,F,GM, M,N	E,F,GM,I, M,N	E,F,GM,I, M,N

[1]Call River Commissioner to determine whether water is flowing.
[2] Field blanks and duplicates (denoted with red text in table) will be collected for the following parameters: *E. coli*; general and miscellaneous; major ions; metals; nutrients and TOC; and geosmin/MIB

D = discharge
E = *E. coli* and total coliform
F = field data (dissolved oxygen, pH, temperature, and turbidity)
G = geosmin/MIB
GC = *Giardia/Cryptosporidium*

GM = general and miscellaneous (alkalinity, hardness as $CaCO_3$ and total dissolved solids)
I = major ions (sulfate, chloride, calcium, potassium, sodium, magnesium)
M = metals (aluminum, arsenic, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, selenium, silver, and zinc
N = nutrients (ammonia-N, nitrate-N, nitrite-N, Total Kjeldahl Nitrogen, Total Phosphorus and ortho phosphorus) and TOC

ATTACHMENT 4

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.					