Design of a Collaborative Water Quality Monitoring Program for the Upper Cache la Poudre River

Prepared for:

City of Fort Collins Utilities
City of Greeley
Tri-Districts


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EXECUTIVE SUMMARY

Water from the Cache la Poudre (CLP) River is a valuable resource for the City of Fort Collins, the City of Greeley, and the Tri-Districts. The water is utilized for many purposes including municipal supply, irrigation, and recreation. The Upper CLP is a drinking water source for over 200 thousand people. The Fort Collins Water Treatment Facility (FCWTF), the City of Greeley Bellvue Water Treatment Plant (Bellvue WTP), and the Tri-Districts Soldier Canyon Filter Plant (SCFP) all treat water from the Upper CLP. This report documents the Upper CLP collaborative water quality monitoring program designed for the three water providers. The primary focus of this monitoring program is the collection and assessment of water quality data to provide information that will help the collaborating entities meet present and future drinking water treatment goals.

The design process addressed five primary elements: objectives, parameters, monitoring locations, sampling frequency, and reporting. Each element was completed through a series of meetings with participating parties.

The resulting program was governed by seven main objectives and addressed four main water quality issues. The objectives included and addressed water treatment process needs, mass loads of specified variables, temporal and spatial trends, standards compliance, watershed protection, and the health of reservoirs. The key water quality issues included drinking water quality, ecological integrity, recreational use, and eutrophication of the reservoirs.

Monitoring locations were selected based on background data from existing monitoring locations, monitoring objectives, watershed hydrology, and cost effectiveness. Nineteen locations were chosen for the network design including nine on the main stem, eight on the North Fork and North Fork tributaries, one on the South Fork, and one on Seaman Reservoir.

The sampling frequency was determined on a seasonal basis using statistical design criteria. Four seasons were defined based on water temperature and flows. Background data from the existing monitoring programs were used to estimate the temporal variability for each season. The sample sizes were then determined to cost-effectively provide an adequate level of precision in estimated means and power of trend detection.

The completed program design variable list consists of 40 water quality parameters, defined as the minimum set of variables to meet information needs. The list includes 13 general field parameters, six nutrients, six major ions, five microbiological constituents, and 10 metals. Additional parameters are to be monitored on a site specific basis if needed.

The Upper CLP is a high quality water source for the City of Fort Collins, the City of Greeley, and the Tri-Districts. The monitoring program will aid in the identification of water quality changes or trends that are occurring in the watershed. The completion of the monitoring network design was made possible by the cooperation of all participating parties.

The future of the Upper CLP water quality will have a strong foundation provided by this sustainable, cooperative monitoring program.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

This report documents the Upper Cache la Poudre (CLP) River collaborative water quality monitoring program designed for the City of Fort Collins, the City of Greeley and the Tri-Districts (Fort Collins-Loveland Water District, East Larimer County Water District, and the North Weld County Water District). The primary focus of this monitoring program is the collection and assessment of water quality data to provide information that will help the collaborating entities meet present and future drinking water treatment goals.

The Fort Collins Water Treatment Facility (FCWTF), the City of Greeley Bellvue Water Treatment Plant (Bellvue WTP), and the Tri-Districts Soldier Canyon Filter Plant (SCFP) all treat water from the Upper CLP. SCFP receives Upper CLP water via the Munroe Tunnel and Pleasant Valley Pipeline. The FCWTF receives Upper CLP water via the Munroe Tunnel/Pleasant Valley Pipeline and from their diversion and pipelines at the City's abandoned Water Treatment Plant No.1 (now Gateway Park). The diversion for the Bellvue WTP is the farthest downstream and is located below the confluence of the Upper CLP main stem with the North Fork of the Cache la Poudre River (North Fork).

For purposes of this water quality monitoring program, the Upper CLP watershed is defined as the area upstream of the Bellvue WTP diversion. It includes the Upper CLP main stem, South Fork, and the North Fork (Figure 1.1).

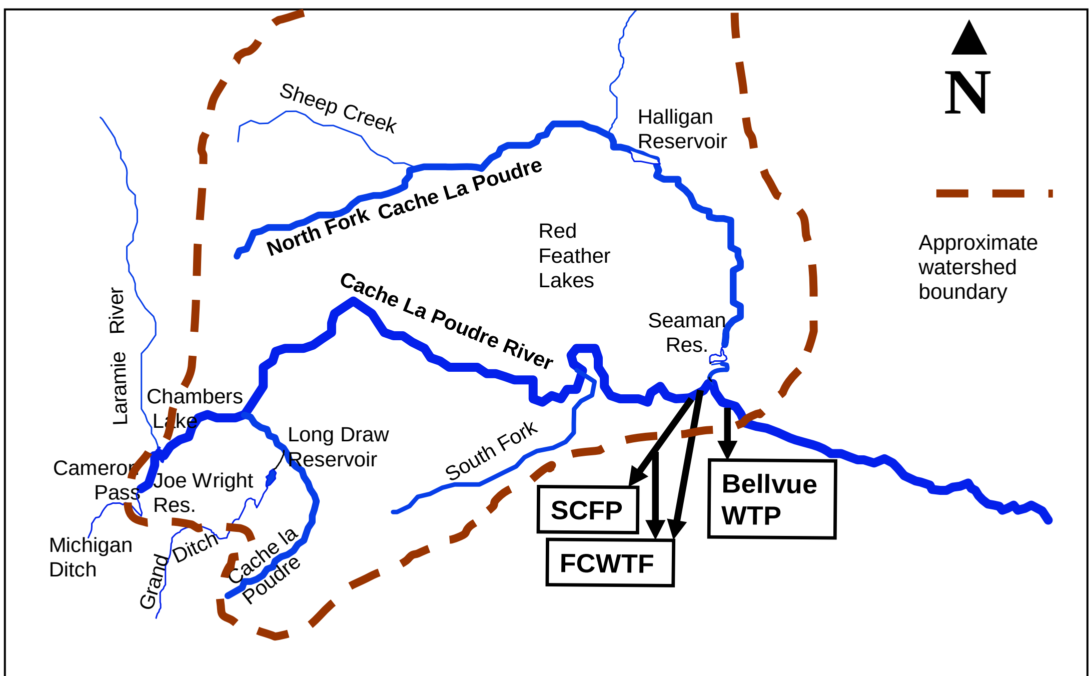


Figure 1.1 Upper Cache la Poudre (CLP) Watershed: main stem, North Fork, South Fork, and water treatment plant diversions.

In 2006, a project was conducted by George Weber, Inc. Environmental to develop a concept and strategic implementation plan for this Upper CLP collaborative water quality monitoring program. That study was jointly funded by the City of Fort Collins, City of Greeley, and the Tri-Districts and the findings are documented in Weber (2007): "First Step Assessment to Develop a Cooperative Water Quality Monitoring Program for Cache la Poudre Water Resources." The project determined that minimum prerequisites (including no significant barriers) are present for collaboration to occur among the three entities. The project developed consensus among the three entities on a general substantive scope for a collaborative program and strategies for its development, administration, and funding. The Weber (2007) project helped to establish the foundation for the subsequent detailed design of the collaborative monitoring program.

This design document contains the following sections:

- **Description of the Upper CLP Watershed**
  Includes discussions of the protected river segments, hydrology, reservoirs and diversions, land cover, geology, recreation use, stream classifications, and the presence of potential sources of contamination

- **Review of Existing Water Quality**
  Summarizes the current and historic monitoring efforts in the watershed, presents an overview of the water quality in comparison to the regulated drinking water standards, and provides a detailed discussion of water quality parameters of special concern to water treatment (total organic carbon, *Giardia* and *Cryptosporidium*, and geosmin)

- **Summary of the Design Methodology**
  Reviews the design process and methods used for this project

- **Monitoring Program Design**
  Summarizes the key design details including the objective list, site locations, parameter list, sampling frequencies, sampling protocols, laboratory methods, and reporting

- **Summary**

  Summarizes the information presented for each of the general topics above.

2.0 DESCRIPTION OF THE WATERSHED

The CLP main stem originates in northern Colorado near the east side of the Continental Divide. The Poudre River flows out of Rocky Mountain National Park, down the CLP canyon, through the City of Fort Collins, and eventually into the South Platte River near Greeley. The Upper CLP main stem drops approximately 5,100 feet in elevation, from 10,800 feet at Poudre Lake to 5,700 feet at the canyon mouth.

The North Fork CLP drainage includes Red Feather Lakes and areas north into Wyoming (Figures 2.1 and 2.2). The North Fork travels approximately 40 miles before flowing into the Poudre main stem near the canyon mouth. More than half of the Upper CLP watershed area is drained by the North Fork, but this sub-basin contributes less than half of the mean annual runoff (CWR&PDA, 1987).

Water is imported to the Upper CLP from other basins, and a number of small reservoirs are located within the Upper CLP. The CLP supports agriculture, municipal drinking water supplies, industry, recreation, and ecosystem health. The Upper CLP also provides many intangible benefits to the citizens of Colorado as described in the essays and poems in *Pulse of the River* (edited by Wockner and Pritchett, 2007). The Upper CLP is a high quality water source and contains the only designated "wild" river segments in Colorado.

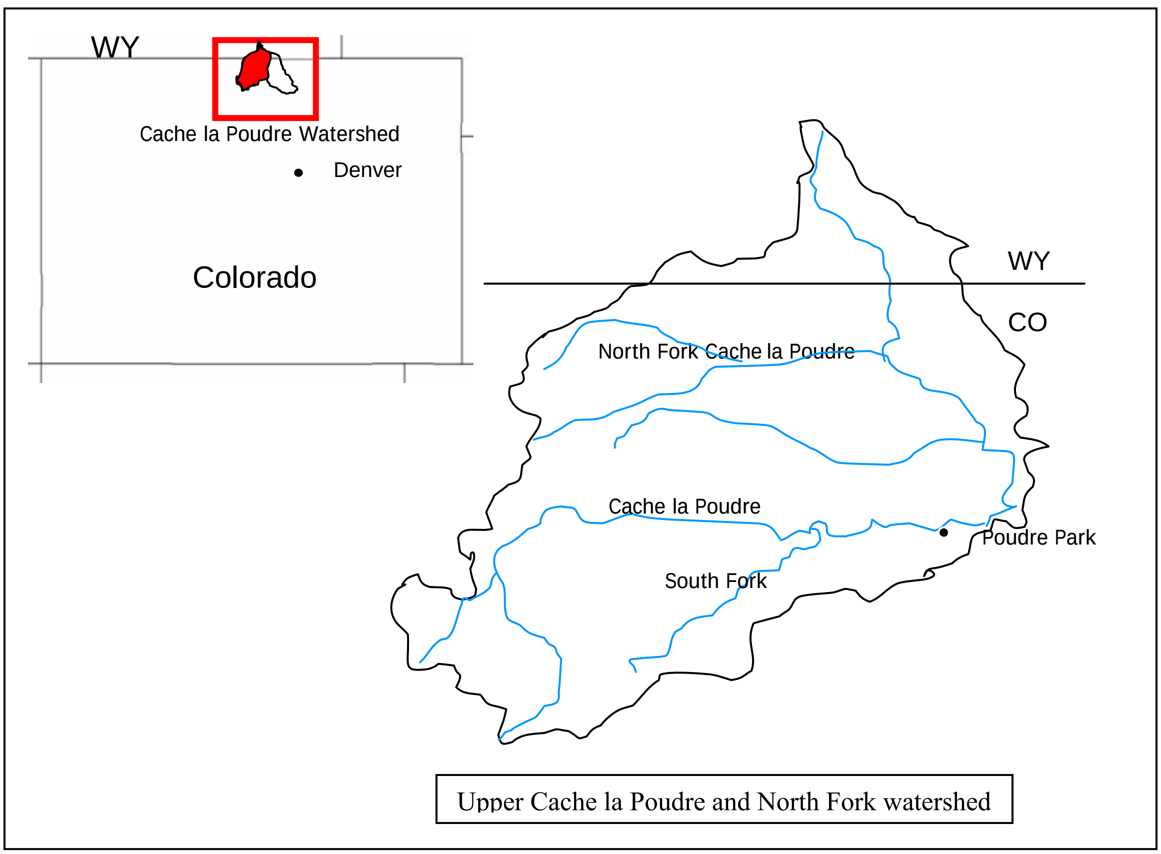


Figure 2.1 Study area of the Cache la Poudre watershed upstream of the Bellvue diversion.

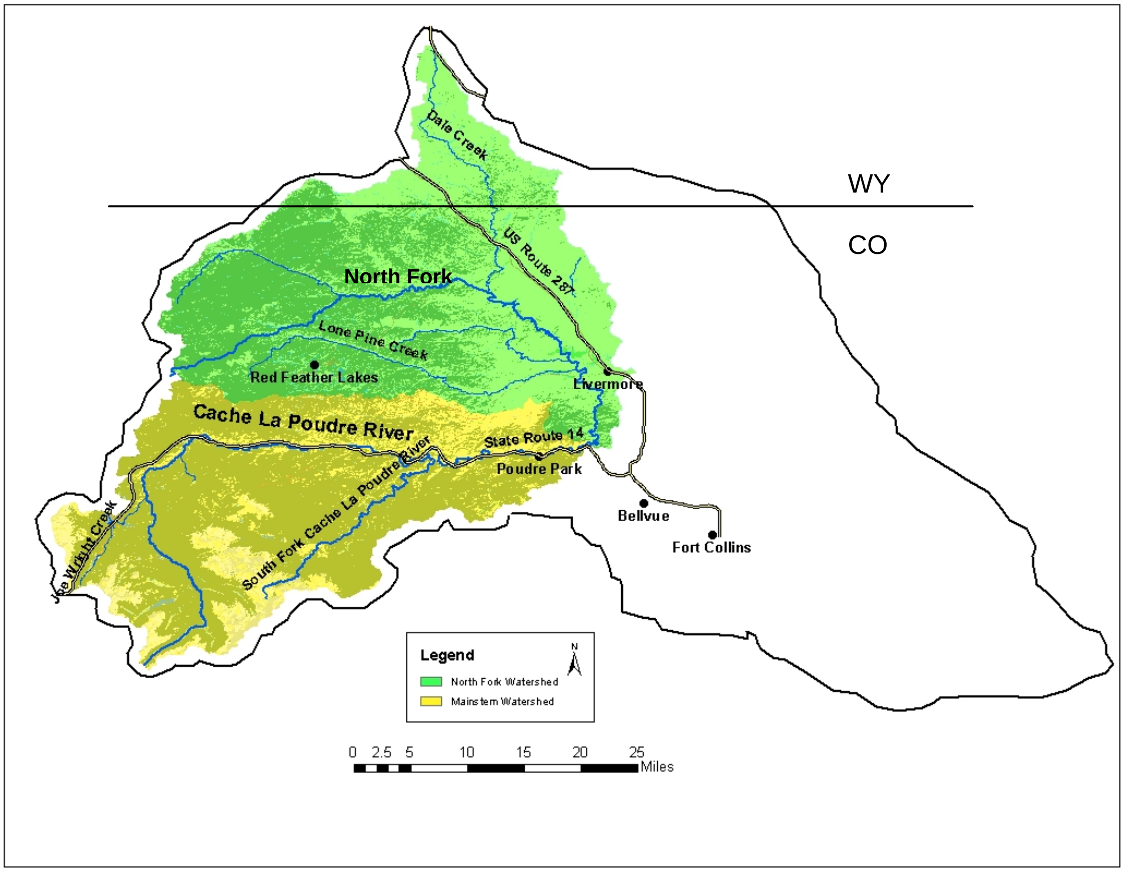


Figure 2.2 Upper CLP North Fork and main stem drainages above the Bellvue diversion (created using USGS Seamless GIS data sets).

2.1 Protected River Segments

President Lyndon B. Johnson signed the Wild and Scenic Rivers Act on October 2, 1968 safeguarding the future of our rivers for generations to come. The Wild and Scenic Act states:

> *"It is hereby declared to be the policy of the United States that certain selected rivers of the Nation which, with their immediate environments, possess outstandingly remarkable scenic, recreational, geologic, fish and wildlife, historic, cultural or other similar values, shall be preserved in free-flowing condition, and that they and their immediate environments shall be protected for the benefit and enjoyment of present and future generations. The Congress declares that the established national policy of dams and other construction at appropriate sections of the rivers of the United States needs to be complemented by a policy that would preserve other selected rivers or sections thereof in their free-flowing condition to protect the water quality of such rivers and to fulfill other vital national conservation purposes" (Wild & Scenic Rivers Act, 1968)*

The Act specifically:

- Prohibits dams and other federally assisted water resources projects that would adversely affect river values;

- Protects outstanding natural, cultural, or recreational values;
- Ensures water quality is maintained;
- Requires the creation of a comprehensive river management plan that addresses resource protection, development of lands and facilities, user capacities, and other management practices necessary to achieve purposes of the Act.

In 1986, a total of 30 miles of river within the headwaters of the CLP were designated "wild" under the National Wild and Scenic Rivers System, and another 46 miles of the Upper CLP were designated "recreational." Tyler (1992, pages 440-442) and Evans and Evans (1991, pages 230-232) discuss the local issues under which these designations were made and the implications for future water development projects on the Upper CLP. River segments that are designated as "wild" are "*free of impoundments and generally inaccessible except by trail, with watersheds or shoreline essentially primitive and waters unpolluted.*" The 30 miles of the CLP that were designated "wild" are divided into three segments and are the only designated "wild" river segments in Colorado. Two of the segments are located on the South Fork CLP. The third segment is in the headwaters of the main stem CLP, extending 18 miles from Poudre Lake in Rocky Mountain National Park downstream to Colorado Highway 14.

River segments that are designated as "recreational" are "*readily accessible by road or railroad, that may have some development along their shorelines, and that may have undergone some impoundment or diversion in the past.*" The 46 miles of the Upper CLP that were designated "recreational" are divided into two segments. The larger segment is along the main stem Upper CLP and Colorado Highway 14, extending from the confluence with Joe Wright Creek downstream to Poudre Park. A small segment along the South Fork CLP also has a "recreational" designation. The U.S. Forest Service and National Park Service are the federal agencies managing the wild and recreational designated sections.

The Nature Conservancy protects a track of land near Livermore known as Phantom Canyon Preserve. The preserve consists of approximately 1,700 acres of land surrounded by private property. Six miles of the North Fork CLP flow through the preserve. The Conservancy started protecting the Phantom Canyon Preserve in 1987. They are working to reintroduce the natural and ecological processes of grazing and fire, and are restoring the prairie through seed collection, planting, and invasive weed management.

2.2 Hydrology

Flows are measured at several locations within the Upper CLP watershed (Figure 2.3 and Table 2.1). The dramatic annual cycle of CLP streamflows is marked by the snowmelt that begins in late April or early May, causing the water level in the river to rise rapidly. The river flow usually peaks in mid-June, followed by typically moderate flows throughout July. By late August, the river is once again characterized by low flows. Low flows continue throughout the winter months until the snowmelt begins again in late April or early May. Average monthly discharge measured at the mouth of the canyon gage (CDWR CLAFTCCO11) ranges from 25 cubic feet per second (cfs) during low flow seasons to over 1,500 cfs during high flows (Figure 2.4). Average monthly discharge on the North Fork, measured at the USGS gage at Livermore (Station 06751490), can range from 10 cfs during low flows to over 300 cfs during the high flow season (Figure 2.5).

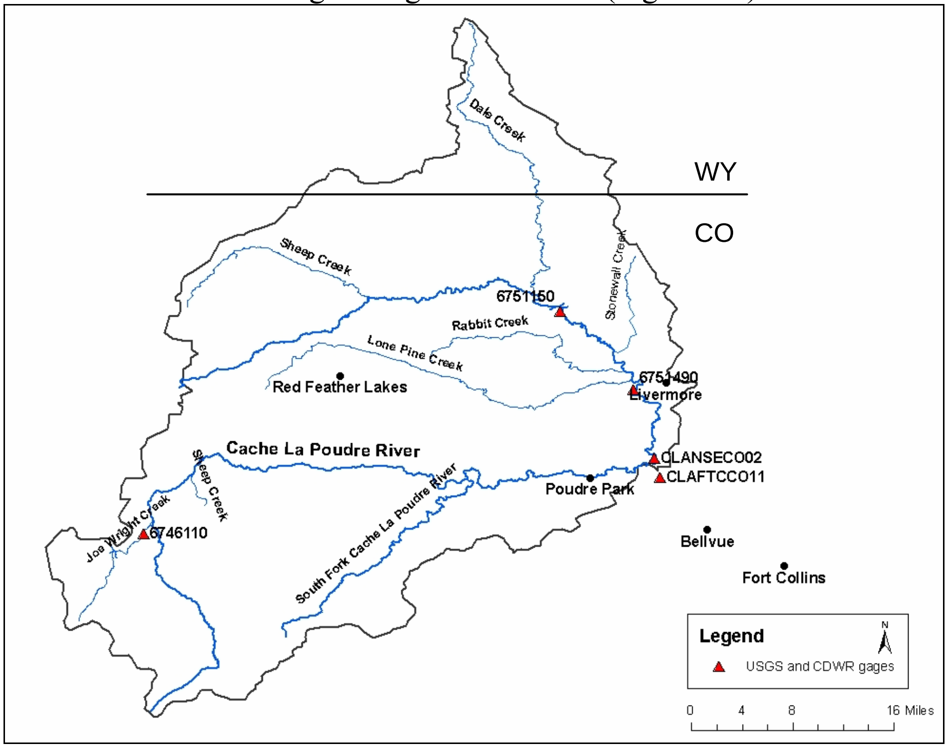


Figure 2.3 Upper CLP watershed map showing locations of USGS and CDWR gaging stations.

Table 2.1. Flow monitoring on the main stem and North Fork CLP.

Flow Stations	Method	Agency	Station Code	Contact
Poudre above North Fork (PNF)	Canyon Mouth Gage + Poudre Valley Canal - North Fork below Seaman			
Poudre below South Fork (PSF)	PNF + Munroe Tunnel + FCWTF diversion at Old WTP #1 (Gateway Park)			
Canyon Mouth Gage	CDWR gage	Colorado Division of Water Resources (CDWR)	CLAFTCCO11	http://www.dwr.state.co.us
Munroe Tunnel	Flow release record	Water Commissioner		George Varra (970) 484-1628
Poudre Valley Canal	Flow release record	Water Commissioner		George Varra (970) 484-1628
North Fork below Halligan	USGS gage	USGS	6751150	http://nwis.waterdata.usgs.gov/co/nwis/rt
North Fork at Livermore	USGS gage	USGS	6751490	http://nwis.waterdata.usgs.gov/co/nwis/rt
North Fork below Seaman	CDWR gage	Colorado Division of Water Resources	CLANSECO02	http://www.dwr.state.co.us
Joe Wright Creek	USGS gage	USGS	6746110	http://nwis.waterdata.usgs.gov/co/nwis/rt
Chambers Lake	Flow release record	Water Commissioner		George Varra (970) 484-1628
Barnes Meadow Reservoir	Flow release record	Water Commissioner		George Varra (970) 484-1628

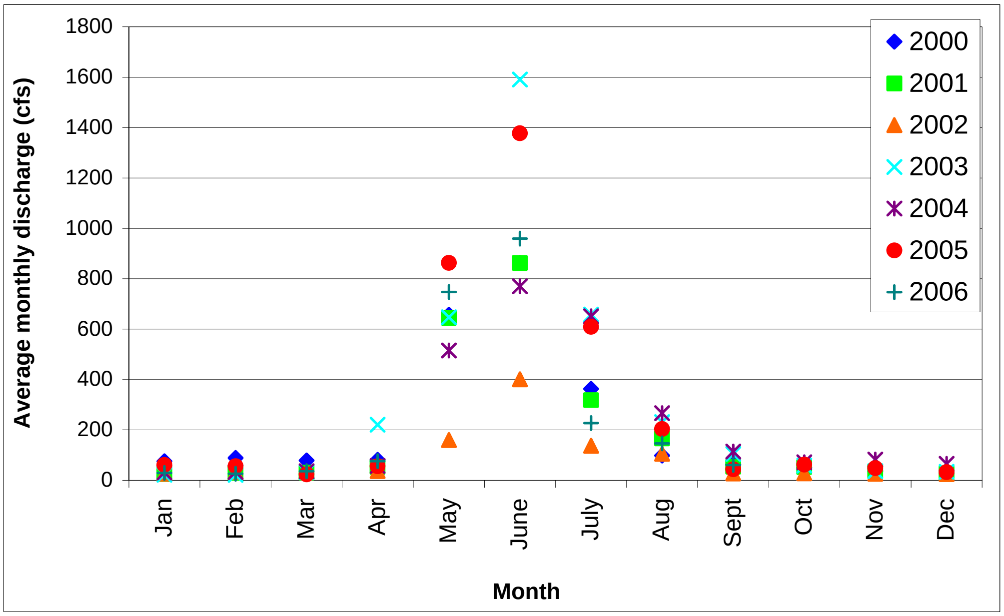


Figure 2.4 **Summary of CDWR discharge measurements from the gage on the main stem CLP at the mouth of the canyon (Station CLAFTCCO11).**

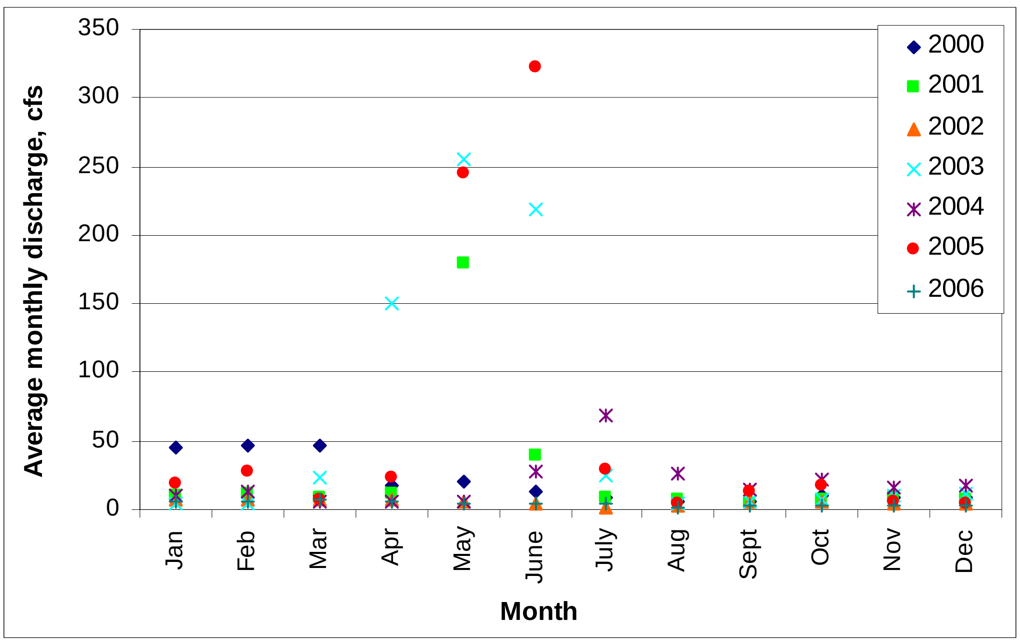


Figure 2.5 **Summary of USGS discharge measurements from the gage on the North Fork at Livermore (Station 06751490).**

2.3 Reservoirs and Diversions

Although gold and other precious metals were never found in significant amounts within the basin, early settlers prospered by supplying cash crops and livestock to the mining towns that developed along the Front Range (CWR&PDA, 1987). Irrigated agriculture became increasingly important to settlers and allowed the communities of Fort Collins and Greeley to thrive. The CLP was the water supply and key to success for farming the fertile but dry basin. When it became obvious that there was not enough water to support agricultural activities and the developing communities, water users looked to the area around the continental divide for supplemental sources of water. Diversion structures were constructed to bring extra water into the Upper CLP basin from adjacent hydrologic basins. At the same time, high mountain reservoirs were constructed to allow for the storage of spring snowmelt runoff water for later use throughout the summer and into the winter. The upper CLP now has eleven reservoirs that store and release water (Table 2.2). The major diversions that are still in operation are shown on Figure 2.6 and summarized in Table 2.3. Most of these diversions and reservoirs were built in the late 1800's and early 1900's.

The Grand River Ditch, one of the main trans-basin structures delivering water into the Upper CLP basin, is nearly 14 miles long, up to 20 feet wide and six feet deep. It is owned and operated by Water Supply and Storage Company (WSSC) of Fort Collins (RMNP, 2005). The ditch was constructed in the 1890s, and is one of Colorado's oldest trans-mountain diversions. It is located at an elevation of 10,250 ft in the northwest corner of Rocky Mountain National Park along the Never Summer Range.

The high mountain reservoirs are operated today by the City of Fort Collins, City of Greeley, North Poudre Irrigation Company, and Water Supply and Storage Company. On the North Fork, Halligan and Seaman Reservoirs are owned by the City of Fort Collins and the City of Greeley, respectively, and are both under consideration for possible expansion. The Northern Colorado Water Conservancy District has proposed a new off-channel reservoir, Glade Reservoir, which will take water from the CLP downstream of the North Fork confluence and will be filled during wet years. The City of Fort Collins, the Tri-Districts, and the City of Greeley all have senior water rights which secure water availability for municipal use.

Table 2.2 Reservoirs within the Upper Cache la Poudre Basin.

Reservoir	Tributary	Owner/Operator	Approx Storage (acre-ft)
Joe Wright	Joe Wright Creek	City of Fort Collins	7,200
Chambers Lake	Joe Wright Creek	WSSC	8,820
Barnes Meadow	Unnamed tributary to Joe Wright Creek	City of Greeley	2,350
Long Draw	Grand River Ditch & La Poudre Pass Creek	WSSC	10,520
Peterson Lake	Unnamed tributary to main stem	City of Greeley	1,250
Comanche	Beaver Creek	City of Greeley	2,600
Hourglass	Beaver Creek	City of Greeley	1,700
Twin Lake	Unnamed tributary to South Fork	City of Greeley	300
Eaton (Worster)	Sheep Creek	Larimer and Weld	3,880
Halligan	North Fork	NPIC & City of Fort Collins	6,400 (proposed expansion up to 40,000)
Milton Seaman	North Fork	City of Greeley	5,000 (proposed expansion up to 60,000)

WSSC = Water Supply & Storage Company; NPIC = North Poudre Irrigation Company

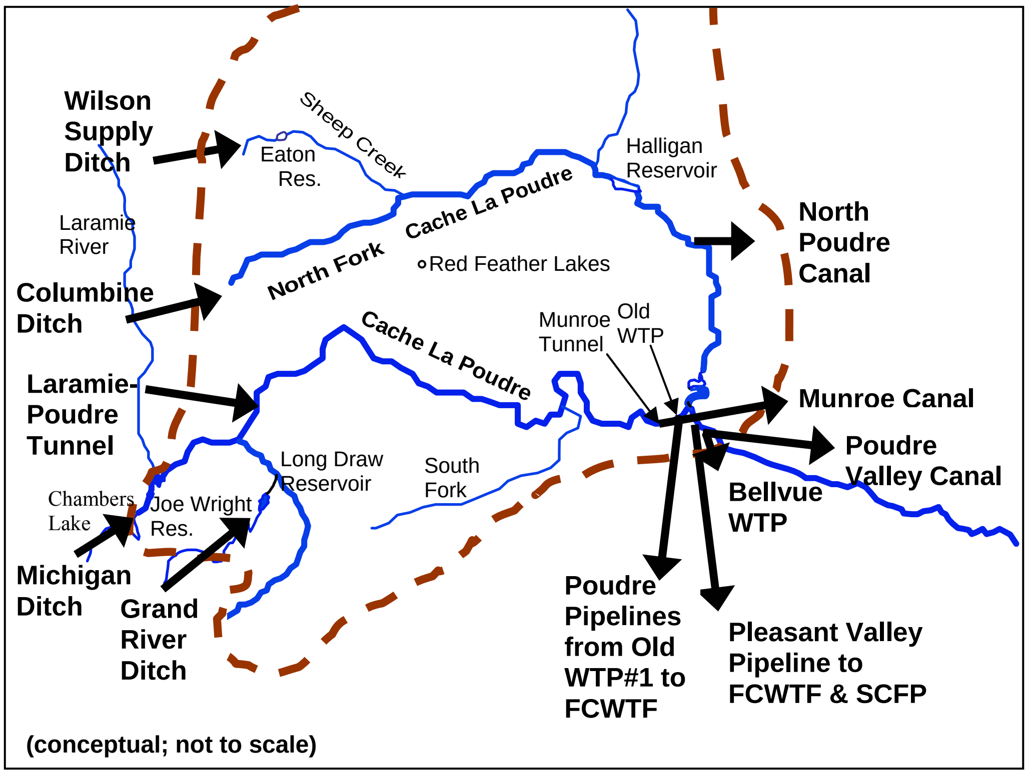


Figure 2.6 Major diversions into and out of Upper CLP watershed.

Several notable events have occurred in connection with the reservoirs and diversions associated with the basin. On May 30, 2003, WSSC officials notified Rocky Mountain National Park that a breach of the Grand River Ditch occurred two miles southwest of La Poudre Pass, within the park. The breach measured 100 feet wide, eroding away the side of the ditch and flowing at 105cfs.

In 1996, the State Engineer performed a safety check on the Halligan Reservoir release gates. This caused 7,000 cubic meters of sediment from the bottom of the reservoir to be released and flood the North Fork basin, including the North Fork as it flows through Phantom Canyon (Rathburn, 2003). Sediment accumulated at some locations at depths of up to 10 feet. Miles of insect and fish habitats were destroyed, and over 4,000 fish were killed.

Droughts in the Poudre basin are also of concern for river managers, farmers, and water providers. The most severe droughts in the late nineteenth and twentieth centuries occurred in the late 1880s and 1890s, between 1930 and 1937, in 1940, between 1953 and 1956, 1975 to 1977, and 2000 to 2002 (Laflin, 2005, page 105). Snowpack, streamflow, and reservoir levels are measured daily at hundreds of locations across Colorado to assess and prepare for drought. During the drought that began in 2000, the City of Fort Collins, the Tri-Districts, and the City of Greeley initiated water restrictions and rate hikes. Farmers held prayer services for rain and discussion again turned to storage proposals (Laflin, 2005, page 105).

Table 2.3. Diversions to and from the Upper Cache la Poudre River Basin (above the canyon mouth).

	Diverted from:	**Diversion Structure**	**Diverted to:**
Diversions **TO** Upper CLP Basin	Colorado River Basin	Grand River Ditch (WSSC)	Long Draw Reservoir
	Michigan River (North Platte Basin)	Michigan Ditch (City of Fort Collins)	Joe Wright Creek & Reservoir
		Cameron Pass Ditch	Joe Wright Creek & Reservoir
	Laramie River (North Platte Basin)	Skyline Ditch	Chambers Lake
	Laramie River (North Platte Basin)	Laramie-Poudre Tunnel (WSSC & WRCC)	Poudre main stem
	Laramie River, Nunn Creek (North Platte Basin)	Bob Creek Ditch	Roaring Creek (tributary to Poudre main stem)
	Laramie River, Deadman Creek (North Platte Basin)	Columbine Ditch	North Fork
	Laramie River, Sand Creek (North Platte Basin)	Wilson Supply Ditch	Sheep Creek (tributary to North Fork)
	Colorado –Big Thompson Project (Horsetooth Reservoir)	Hansen Supply Canal (NCWCD)	Poudre main stem at Canyon Mouth (below Greeley Bellvue WTP diversion)
Diversions **FROM** Upper CLP Basin (from above canyon mouth)	Upper CLP – North Fork	North Poudre Canal - water taken from North Fork below Phantom Canyon	North Poudre Irrigation Company shareholders
	Upper CLP – main stem above North Fork	Munroe Tunnel/Canal and Pleasant Valley Pipeline	Farmers & influent to FCWTF and Soldier Canyon Filter Plant
	Upper CLP – main stem above North Fork	FCWTF Intake at Gateway Park (Poudre Pipelines)	FCWTF
	Upper CLP – main stem below North Fork	Poudre Valley Canal	Windsor Reservoir & Canal Company reservoir system
	Upper CLP – main stem below North Fork	City of Greeley Bellvue WTP Diversion	City of Greeley Bellvue WTP

2.4 Land Cover

The entire watershed upstream of the Bellvue diversion encompasses 1,016 square miles of mostly forest and grasslands. Within this watershed area there are approximately 576 square miles of forested lands, 373 square miles of scrub, grasses, and rangeland, 60 square miles natural lands, and 7.4 square miles of developed land. These areas were derived from USGS Seamless GIS data sets. The land uses are described more fully in Table 2.4 and shown on Figure 2.7.

Vegetation throughout the main canyon is diverse. The lower canyon consists of open slopes of mountain mahogany, sagebrush, and bitterbrush. Tree species within the canyon include ponderosa and lodgepole pine, cottonwood, aspen, and Rocky Mountain juniper, while Douglas fir, subalpine fir and spruce are found only at higher elevations. Spruce budworm and mountain pine beetle infestations have resulted in extensive areas of standing dead trees.

Table 2.4 Land use within the Poudre watershed above the Bellvue Diversion (areas calculated using USGS Seamless GIS data sets).

Land Use	Area (%)	Area (mi^2)	Area (acres)
Developed land (commercial, industrial, residential, urban, and utilities)	0.73	7.4	4,700
Agricultural use and grassland (cropland, pasture, other agriculture, scrub and grasses)	36.7	373	238,700
Forest (forest and brush)	56.6	576	368,600
Natural lands (exposed rock, bare ground, wetlands, tundra, lakes)	5.91	60	38,400
Total	**100**	**1,016**	**650,200**

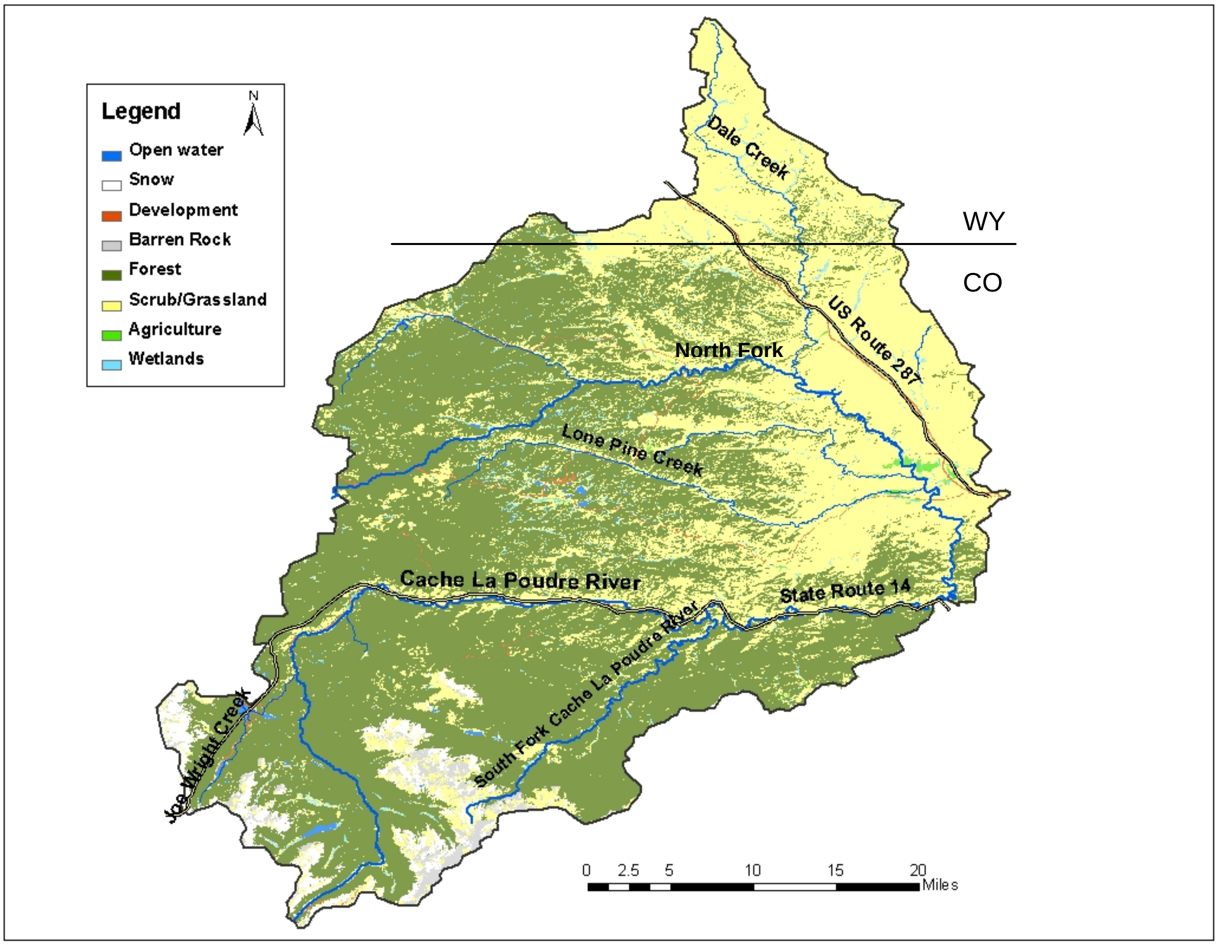


Figure 2.7 Land use within the Upper CLP watershed (created using USGS Seamless GIS data sets).

Many experts estimate that, at current rates of infestation, the majority of Colorado's mature lodgepole pine trees will be killed within three to five years. Since the beetles prefer lodgepole pine, and the primary pine along the Front Range is ponderosa pine, the damage could be less severe in the Poudre watershed, especially in the lower watershed, than west of the Continental Divide. However, some experts believe that beetles could ultimately kill as much as 60% of ponderosa pine as well (Prankst, 2008; Whaley and Schrader, 2008). Figure 2.8 shows the extent of pine beetle kill in the Upper CLP and adjacent watersheds based on U.S. Forest Service aerial surveys conducted between 1996 and 2007.

The impact of large areas of dead pine trees on water quality and quantity is difficult to predict but could be significant. Certainly a change in total organic carbon (TOC) is possible due to the potential for increased soil erosion and the presence of dead and decaying trees. Stednick and Jensen (2008) suggest that an increase in nutrient concentrations, especially nitrate nitrogen, is possible, having been observed in several watersheds that had severe dieback. In terms of water quantity, Stednick and Jensen (2008) suggest that extensive forest dieback would probably increase annual water yield in watersheds that have even-aged forests and that receive more than about 20 inches per year of precipitation. Watersheds with uneven-aged forests could experience little change or even a decrease in annual water yield since understory vegetation could effectively utilize increased soil moisture. Watersheds that receive less than 20 inches per year of precipitation are not likely to exhibit a measurable response in terms of annual water yield. Probably most significant is that as a result of the pine beetle kill, the forest is becoming increasingly subject to forest fires (Neary, 2005), which have a dramatic effect on water quality.

The North Fork of the CLP has different land use and topography than the watershed of the main stem (Figure 2.7). The land uses of the two subwatersheds are compared in Table 2.5. The North Fork subwatershed covers approximately 351,100 acres, or 54 % of the total watershed area. It has a significantly greater percentage of rangeland and grassland than the main stem, while the main stem has a greater percentage of forested land and natural landscape. These differences in watershed characteristics and land use contribute to differences in water quality between the two watersheds.

Table 2.5 Land use comparison of the North Fork and main stem CLP (areas calculated using USGS Seamless GIS data sets).

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

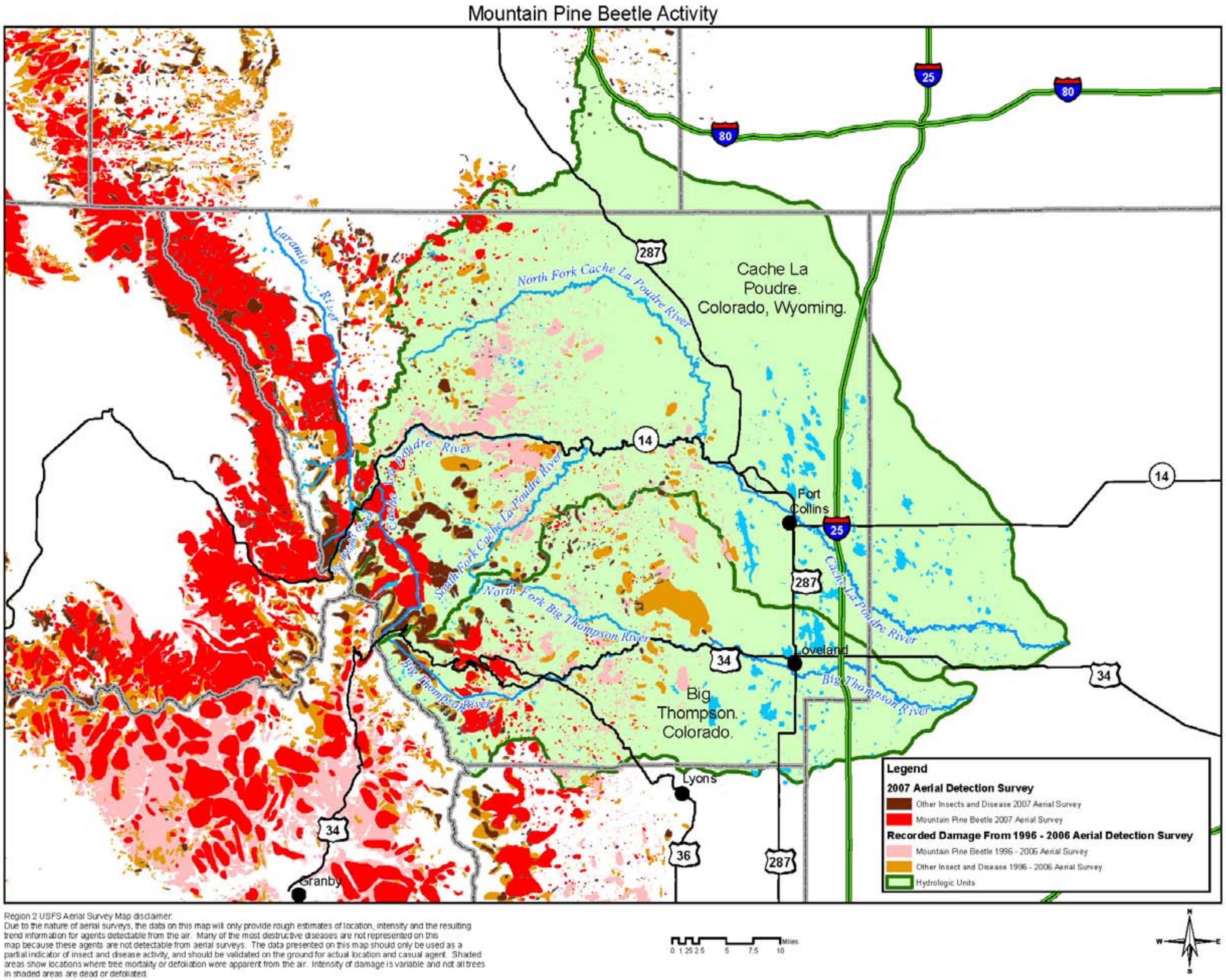


Figure 2.8. Extent of pine beetle infestation in the Upper CLP and neighboring watersheds.

2.5 Fires

Fires can result in little to substantial effects on the physical, chemical, and biological quality of the water in receiving waterbodies. The magnitude and severity of the effects of a fire is largely dependent on the size and intensity of the fire and the condition of the watershed (Neary et al, 2005). Fire affects water quality characteristics primarily through the changes that the burning causes in the hydrologic cycle and streamflow regimes. Watershed impacts include but are not limited to flooding, soil erosion, increased turbidity, higher sediment loading, reduced flow between runoff events, increased nutrient loading, and metals loading (Alexander, 2002). Increased soil erosion is often the most visible effect of a fire other than the loss of vegetation. The mudflows that often occur in runoff from burned forests can drastically alter in-stream habitat. Stream benthic organisms and fish can be buried and suffocated by sediment.

In addition to sediment, chemical compounds that are mobilized by fire are released either back into the atmosphere, or into the soil as ash. Nutrients such as nitrogen and phosphorous are abundant in ash. Nutrients are easily transported by runoff if they are not taken up by vegetation. The increase in excess nutrients to receiving water bodies can be problematic, especially for reservoirs where the resulting accelerated algae production can result in a variety of water quality problems for both municipal and recreational use.

Metals accumulate in vegetation, and fires can cause metals to be suddenly released and carried downstream. Mercury, manganese, lead, and other metals cause serious water quality issues for drinking water providers. Mercury is mostly released into the atmosphere (95%), and the remainder resides in the ash (Alexander, 2002).

Many small fires have occurred in the watershed over the years, impacting limited areas (Figure 2.9). Several fires larger than 1,000 acres have occurred in the Upper CLP watershed. The Killpecker Fire burned 1,200 acres west of Red Feather Lakes in 1978 (http://www.northfortynews.com/Archive/A200405fireStats.htm). The Beartrap Fire burned 2,700 acres near Crystal Lakes subdivision (northwest of Red Feather Lakes) in 1980.

Figure 2.9. A small burned area near Greyrock Mountain.

The Hourglass Fire occurred in 1994 and was located between Hourglass Reservoir and the Pingree Park Campus (Colorado State University Warner College, 2008). The cause of the fire is thought to be lightning, but the origin has never been precisely identified. By the time it was contained, the fire had burned 1,275 acres including 12 structures on the Pingree Park Campus.

The largest recorded fire that has occurred in the Upper CLP watershed is the Picnic Rock Fire which started on March 30, 2004 near the mouth of the canyon. It burned more than 8,900 acres in a week and destroyed two structures (Sokoloski, 2004). The fire was started by a canyon resident burning yard waste. The fire spread rapidly through the drought-parched foothills north of the Poudre River and burned areas near Seaman Reservoir. The Picnic Rock Fire forced the evacuation of homes along County Road 29C, Bonner Peak Ranch, and Cherokee Hills. Fire retardant slurry (generally consisting of water, ammonium sulfate and phosphate, iron oxide, and clay) was dropped from aircraft to help save structures. Lewis (2005, page 36) reported that the Picnic Rock Fire had no detectable effect on Seaman Reservoir water quality in 2004 because precipitation during the 2004 summer was low and, consequently, there was no transport mechanism for sediments and substances released by the fire. In 2005, much wetter conditions prevailed with the potential to mobilize substances released by the fire (Lewis, 2006, page 7). However, the water in Seaman Reservoir was not found to be of significantly poorer quality than had been observed in previous years.

2.6 Geology and Mining

The bedrock underlying the main stem watershed is primarily metamorphic and igneous rock of the Precambrian age (Colorado Geologic Highway Map, 1991). The metamorphic rocks (gneiss, schist and migmatite) and igneous rock (granite) formed 1.7 billion years ago. Crystalline granites are common throughout the watershed, including Greyrock Mountain. About 8,587 acres (or about 3 percent) of the main stem watershed is bare rock.

The North Fork geology is primarily granitic rock formed about 1.4 billion years ago and sedimentary rock formed about 245 million years ago. The Permian Pennsylvanian sedimentary rock is found mainly along the Highway 287 corridor from Ted's Place to Virginia Dale including the Livermore area. Large outcroppings of granite are found in many places of the North Fork watershed including areas around Virginia Dale and Red Feather Lakes (Evans and Evans, 1991, pg. 142). Less than one percent of the North Fork watershed is bare rock.

Mining of gold, copper, zinc, uranium, and lead has been conducted in many locations within the Upper CLP watershed, although none of the mines contained high grade ores (Evans and Evans, 1991, pg 10). The short-lived gold mining town of Manhattan supported approximately 4,000 prospectors after gold was discovered in 1886 a few miles north of Rustic (Evans and Evans, 1991, pg 17). The Copper King Mine, located on Prairie Divide near the North Fork, was a source of copper and zinc in the 1910's and uranium in the late 1940's and early 1950's (Evans and Evans, 1991, pg 17). A commercial diamond mine was operated in Chicken Park, located southeast of the confluence of Sheep Creek with the North Fork. Today, tailings from the many small historic mines are found scattered throughout the watershed. Although mine tailings are considered potential sources of contaminants, additional data and information will be required to determine if any of the tailings within the Upper CLP are significant sources of contaminants.

2.7 Recreation

Recreation draws many people to the Upper CLP throughout the year. The summer, in particular, brings thousands of people to the river for recreation. Colorado Highway 14 runs along the river from Ted's Place to the confluence with Joe Wright Creek. Skiers, fishermen, kayakers, rafters, tubers, hikers, rock climbers and picnickers are drawn to the canyon. Rafting operations run numerous day trips down the river, regulated by the United States Forest Service (USFS). Seven put-in and take-out locations dot the riverbanks providing easy access for whitewater enthusiasts.

The USFS has 13 campgrounds with a total of 257 overnight campsites and nine picnic areas along the main stem. These areas are mainly seasonal, providing camping, picnic, and restroom facilities. Popular picnic areas and state parks are heavily used throughout the summer months. Picnic Rock State Park is a common day use area that experiences high volumes of visitors each weekend. The restrooms at the USFS picnic areas and campgrounds are closed during the winter, although recreation within the watershed occurs year-round. The potential impact on water quality from not having restroom facilities available during the winter is unknown.

Many small resorts, lodges, and stores operate along Highway 14 and the banks of the CLP, including Indian Meadows Resort, Mountain Greenery Resort, Rustic Resort, Glen Echo, Columbine Lodge, and the Sportsman's Lodge. The Mishawaka Amphitheater is a popular restaurant and music venue on the banks on the CLP, and draws traffic up the canyon during the summer months. Campgrounds such as Ansel Watrous and Ouzel are less than 1.5 miles from the Mishawaka and often accommodate the Mishawaka concert guests. Poudre Park, Kinikinik, Rustic, and other small towns all contribute to the development of the CLP watershed. Septic tanks and leach fields associated with commercial and residential development can contribute a variety of contaminants to the river, especially if they are poorly designed or maintained.

On the South Fork of the CLP is Colorado State University's Pingree Park campus and Conference Center. Pingree Park is a remote satellite campus that operates from spring to fall. Farther up the main stem of the CLP, there is a Colorado Division of Wildlife trout rearing facility just below Kinikinik. It is currently in operation but has downsized due to problems with whirling disease.

Increasing recreational pressures will impact the water quality of the CLP, and detecting those changes is an important objective of the CLP monitoring program.

2.8 Stream Classifications

The Colorado Water Quality Control Commission, supported by the Colorado Department of Public Health and Environment (CDPH&E), sets stream classifications and water quality standards for rivers and other water bodies across the state. The stream classifications and numeric standards assigned to the stream segments of the Upper CLP watershed are listed in Appendix A. The stream classifications establish the beneficial use categories for each stream segment. Waters are classified according to the beneficial uses for which they are presently suitable, including aquatic life, recreation, agriculture, and domestic water supply. The water quality standards are adopted by the Commission to protect the specified classified uses. Numeric standards exist for physical, biological, inorganic, and metal constituents and are outlined in Appendix A (http://www.cdphe.state.co.us/regulations/wqccregs/wqccreg38southplattetable.pdf).

The stream segments within the Upper CLP watershed (Cache la Poudre River Basin Segments 1, 2, 6, 7, 8, and 9) are all classified for the following uses:

- **Recreation 1a**: Waters that are used for primary contact recreation where the ingestion of small quantities of water may occur. This stream classification results in a 200/100 mL fecal coliform numeric standard and a 126/100 mL E. coli numeric standard.

- **Domestic Water Supply**: After receiving standard treatment (defined as coagulation, flocculation, sedimentation, filtration, and disinfection with chlorine or its equivalent) these waters will meet Colorado drinking water regulations.

- **Agriculture**: Waters that are suitable for irrigation of crops and which are not hazardous as drinking water for livestock.

The main stem CLP upstream of the North Fork (Segment 1), and all associated tributaries and reservoirs (Segment 2), are designated as Class 1 – Cold Water Aquatic Life waters. The North Fork upstream of Halligan Reservoir (Segment 6) and two tributaries to the North Fork (Segment 9) -- Rabbit Creek and Lone Pine Creek – are also designated as Class 1 – Cold Water Aquatic Life waters. This classification is assigned for the following conditions:

- **Class 1 – Cold Water Aquatic Life**: Waters that are currently capable of sustaining a wide variety of cold water biota, including sensitive species.

The North Fork of the CLP from the Halligan Reservoir inlet to the confluence with the main stem CLP (Segment 7), and all associated North Fork tributaries and reservoirs (Segment 9) with the exception of Rabbit Creek and Lone Pine Creek, are classified as Class 2 – Cold Water Aquatic Life waters. This classification is assigned for the following conditions:

- **Class 2 – Cold Water Aquatic Life**: Waters that are not currently capable of sustaining a wide variety of cold water biota, including sensitive species, due to physical habitat, water flows or levels, or uncorrectable water quality conditions that result in substantial impairment of the abundance and diversity of species.

2.9 Potential Sources of Contamination

Potential sources of contamination (PSOCs) within the Upper CLP watershed include active and abandoned mines, animal grazing and other agricultural activities, automobile accidents along the river, underground and above ground fuel storage tanks, residential areas, road de-icing chemicals, erosion, recreational users, gas stations, and leaky septic tanks or improperly functioning leach fields from the various communities throughout the watershed. The larger communities within the watershed include the Colorado State University Pingree Park campus, Poudre Park, Rustic, Livermore, and Red Feather Lakes.

The Pingree Park campus is located on the South Fork of the CLP just north of Rocky Mountain National Park. The campus can accommodate approximately 300 people when at full capacity (Bertschy, 2008). The campus is in operation from May to October and reaches its highest occupancy during the summer months. The Pingree Park water source is a 120 foot well, treated by a filtration and chlorination system. The average water use on the campus is approximately 60 gallons per person per day. The wastewater treatment facility on the campus is a tertiary treatment system that handles on average 10,000 gallons per day. The treated wastewater is injected back into the ground via a well.

The Poudre Park community has both seasonal rentals and year-round residents and does not have a central wastewater treatment system. Livermore has a population of approximately 1,300 and does not have a central wastewater treatment system. The community of Red Feather Lakes has a population of about 525 during the winter months and over 800 during summer (Sands, 2008). Additionally, there are about 500 Boy Scouts and 300 Girl Scouts housed each week at their respective summer camps. Also in the region, the Shambhala center accommodates 300 people a month throughout the summer. Shambhala Center, Fox Acres, Glacier View and Crystal Lakes developments all have central wastewater treatment systems, while the remainder of the Red Feather Lakes region is served by septic or holding tanks.

The CDPH&E issues Source Water Assessment and Protection (SWAP) reports under the 1996 amendments to the federal Safe Drinking Water Act and in accordance with Colorado's SWAP Program. The SWAP Program requires states to assess the possible threat that potential sources of contamination pose to their public drinking water sources. SWAP is a two-phase program consisting of an assessment phase, in which the susceptibility of a public water supply is evaluated, followed by a protection phase. The CDPH&E is responsible for completing the assessment phase, while local water suppliers and decision makers are responsible for conducting the source water protection planning phase. Source water protection planning is voluntary and is not required by the CDPH&E.

SWAP reports prepared by the CDPH&E for the City of Fort Collins (SWAP PWSID CO0135291, November 2004), the Town of Greeley (SWAP PWSID CO0162321, November 2004), and the Tri-Districts Soldier Canyon Filter Plant (SWAP PWSID CO0135718, November 2004) can all be found on the CDPH&E website, http://www.cdphe.state.co.us/wq/sw/swapreports/swapreports.html. SWAP reports have also been completed for the small communities within the Upper CLP watershed, all of which use groundwater as a source of drinking water. All of the SWAP reports identify potential point and non-point sources of contamination based on searches of existing databases. The accuracy of the databases is unknown and the findings require verification. The SWAP reports are screening-level evaluations only, and a more intensive field effort is required to verify SWAP report findings.

The November 2004 SWAPs prepared by the CDPH&E for Fort Collins, Greeley and Soldier Canyon FP cover the following source waters:

- City of Fort Collins: Horsetooth Reservoir and Upper CLP above the North Fork
- City of Greeley: Horsetooth Reservoir, Boyd Lake, and the Upper CLP including the North Fork
- Tri-Districts Soldier Canyon FP: Horsetooth Reservoir

The City of Fort Collins and City of Greeley SWAPs contain information that applies to the Upper CLP watershed. The databases that the CDPH&E used to prepare these two SWAPs were reviewed, and two tables in the SWAPs (Table 2. Susceptibility of Water Source(s) to Discrete Contaminant Sources, and Table 3. Susceptibility of Water Source(s) to Dispersed Contaminant Sources) were modified to reflect only the PSOCs located within the Upper CLP watershed. A modified SWAP Table 2, indicating the potential *point sources* of contamination, was prepared for the Upper CLP above the North Fork (Table 2.6). A separate modified Table 2 was prepared for the North Fork (Table 2.7).

Table 2.6. Susceptibility of water source to discrete (point) contaminant sources – Upper CLP *above* the North Fork (adapted from City of Fort Collins and City of Greeley SWAPs).

	Individual Susceptibility Rating Summary				
Contaminant Source Type	**Low**	**Mod. Low**	**Moderate**	**Mod. High**	**High**
EPA Superfund Sites	0	0	0	0	0
EPA Abandoned Contaminated Sites	0	0	0	0	0
EPA Hazardous Waste Generators	0	0	0	0	0
EPA Chemical Inventory/Storage Sites	0	0	0	0	0
Permitted Wastewater Discharge Sites	0	0	1	0	0
Aboveground, Underground and Leaking Storage Tank Sites	1	13	1	**8**	0
Solid Waste Sites	0	0	0	0	0
Existing/Abandoned Mine Sites		1	19	**29**	**17**
Concentrated Animal Feeding Operations	0	0	0	0	**1**
Other Facilities	0	0	3	0	0
Total:	**1**	**14**	**24**	**37**	**18**

Table 2.7 Susceptibility of water source to discrete (point) contaminant sources – North Fork Cache la Poudre River (adapted from City of Greeley SWAP).

	Individual Susceptibility Rating Summary				
Contaminant Source Type	**Low**	**Mod. Low**	**Moderate**	**Mod. High**	**High**
EPA Superfund Sites	0	0	0	0	0
EPA Abandoned Contaminated Sites	0	0	0	0	0
EPA Hazardous Waste Generators	0	0	0	0	0
EPA Chemical Inventory/Storage Sites	0	0	0	0	0
Permitted Wastewater Discharge Sites	0	1	0	0	0
Aboveground, Underground and Leaking Storage Tank Sites	0	0	13	**2**	0
Solid Waste Sites	0	0	0	**1**	0
Existing/Abandoned Mine Sites	0	1	6	**8**	2
Concentrated Animal Feeding Operations	0	0	0	0	0
Other Facilities	0	0	0	**2**	0
Total:	**0**	**2**	**19**	**13**	**2**

The SWAP analysis indicates that the Upper Poudre main stem and North Fork water sources have the greatest risk to potential contamination from discrete (point) sources in the "Existing/Abandoned Mine Sites" category. Table 2.6 for the main stem above the North Fork shows a moderately high susceptibility rating for 29 sites in the "Existing/Abandoned Mine Sites" category and a high susceptibility rating for 17 sites in this category. Table 2.7 for the North Fork shows a moderately high susceptibility rating for 8 sites in the "Existing/Abandoned Mine Sites" category and a high susceptibility rating for two sites in that category. The CDPH&E used the USGS/Dept. of Mines & Geology database on existing and abandoned mines to identify the existing/ abandoned mine sites. However, as stated previously, the output from this database has not been verified so the actual potential for contamination is currently unknown. Some of these sites may be mine claims that have yet to result in any mining activity.

The SWAP analysis also indicates that there are a significant number of sites in the "Aboveground, Underground and Leaking Storage Tank Sites" category. Table 2.6 shows a moderately high susceptibility rating for 8 sites in the "Aboveground, Underground and Leaking Storage Tank Sites" category, while Table 2.7 indicates a moderately high susceptibility rating for two sites in that category. The CDPH&E used the Department of Labor & Employment/Oil Inspection Section databases on aboveground, underground and leaking underground storage tanks sites to identify sites in this category.

Both Tables 2.6 and 2.7 show sites in the "Permitted Wastewater Discharge Sites" category. The site indicated in Table 2.6 is identified in the CDPH&E database as a Colorado Division of Wildlife site (fish rearing unit). The site indicated in Table 2.7 is identified in the CDPH&E database as the Fox Acres resort community near Red Feather Lakes.

Other point sources of special interest in Tables 2.6 and 2.7 include a high susceptibility rating for one site in the "Concentrated Animal Feeding Operations" category (Table 2.6).

The CDPH&E used their own databases to identify sites in the "Concentrated Animal Feeding Operations" category. Table 2.7 indicates one site in the "Solid Waste Sites" category with a moderately high susceptibility rating. This site has been identified in the database as the Red Feather Lakes Transfer Station. The transfer station is a place where residents can locally drop off household trash instead of having to take it to the county landfill in Fort Collins. Larimer County pays to have the trash periodically hauled from the transfer station to the landfill.

Non-point (or dispersed) sources of contamination are summarized in the SWAP Table 3 (Susceptibility of Water Source(s) to Dispersed Contaminant Sources). Table 3 from the City of Greeley SWAP was modified to reflect only the non-point sources located within the Upper CLP watershed including the North Fork. The modified table is shown below as Table 2.8. Note that in this table, a "1" indicates presence and a "0" indicates absence; the numbers in this table do not indicate numbers of sites within a category.

Table 2.8 shows that the CDPH&E SWAP analysis assigned a moderate susceptibility rating for the "Evergreen Forest," "Road Miles," "Septic Systems," and "Oil/Gas Wells" dispersed contaminant sources within the Upper CLP. Activities on forest lands that could result in contaminants reaching source waters include erosion runoff from burned areas, and large scale use of pesticides and herbicides. The U.S. Forest Service is currently implementing a mountain pine beetle control program in the Roosevelt National Forest that includes the spraying of the insecticide Carbaryl (Sevin) on trees in popular campgrounds (Long Draw, Grandview, and Chambers Lake) that have not yet been infested by beetles.

The presence of Colorado Highway 14 adjacent to the main stem results in the moderate susceptibility rating for "Road Miles" as shown in Table 2.8. Activities related to roads that could result in contaminants reaching source waters include the potential for accidental spills of contaminants, and runoff from road sanding/salting operations. The moderate susceptibility rating for "Septic Systems" and "Oil/Gas Wells" is due to their numbers and locations as identified in the databases used by the CDPH&E. However, the output from these databases has not been verified so the actual potential for contamination is currently unknown.

Table 2.8. Susceptibility of water source to dispersed (non-point) contaminant sources – Upper CLP including the North Fork (adapted from City of Greeley SWAP).

	Individual Susceptibility Rating Summary				
Contaminant Source Type	**Low**	**Mod. Low**	**Moderate**	**Mod. High**	**High**
LAND USE / LAND COVER TYPES:					
Commercial/Industrial/Transportation	0	1	0	0	0
High Intensity Residential	0	0	0	0	0
Low Intensity Residential	0	1	0	0	0
Urban Recreational Grasses	0	1	0	0	0
Quarries / Strip Mines / Gravel pits	0	0	0	0	0
Row Crops	0	1	0	0	0
Fallow	0	1	0	0	0
Small Grains	0	1	0	0	0
Pasture / Hay	0	1	0	0	0
Orchards / Vineyards / Other	0	0	0	0	0
Deciduous Forest	0	1	0	0	0
Evergreen Forest	0	0	**1**	0	0
Mixed Forest	0	1	0	0	0
OTHER TYPES:					
Septic Systems	0	0	**1**	0	0
Oil/Gas Wells	0	0	**1**	0	0
Road Miles	0	0	**1**	0	0
Total:	**0**	**9**	**4**	**0**	**0**

3.0 Existing Water Quality

Section 3.0 summarizes the current monitoring efforts in the Upper CLP watershed and presents an overview of the water quality in comparison to the regulated drinking water standards. Flow versus quality relationships and load estimations are also presented. Finally, a detailed discussion of water quality parameters of special concern to water treatment, including total organic carbon (TOC), pathogens (*Giardia* and *Cryptosporidium*), and geosmin, is presented in this section.

3.1 Monitoring Programs in the Watershed

Through 2007, the Cities of Fort Collins and Greeley have operated separate water quality monitoring programs for the Upper CLP. The Tri-Districts Soldier Canyon Filter Plant has not been involved in a historic monitoring program because they only began treating Upper CLP water in 2005, one year after the Pleasant Valley Pipeline became operational. Greeley's program for the Upper CLP main stem and North Fork started in 2000, while the City of Fort Collins program for the Upper CLP started in 1989. Additionally, there are over 20 years of data from the FCWTF raw Poudre sample tap. These efforts have varied in sampling frequency, sampling parameters, and sampling locations (Appendix B).

The City of Fort Collins sampled the FCWTF raw Poudre sample tap and 10 sites along the Upper CLP and its tributaries (Figure 3.1). The sampling frequency for the Upper CLP sites was twice a year, typically once in May and in October. The data record for the FCWTF raw Poudre sample tap represents samples collected as frequently as weekly with analysis for 39 water quality parameters including metals. A retrospective analysis report was performed in 2007 to assess the spatial patterns and trends in water quality and to obtain statistical information to serve as a basis for future improvements to the monitoring program (Loftis and Moore, 2007a; included in Appendix J).

Dr. William Lewis managed the City of Greeley monitoring program from 2000-2007 (Lewis, 2001-2008). The sampling program was conducted on 14 sites on the Upper CLP and North Fork (Figure 3.1) as well as vertical profiles of water quality in Milton Seaman Reservoir, samples from the Bellvue Treatment Plant intake and ponds, and samples of the Hansen Canal inflow to the ponds. The sampling frequency was typically bi-weekly from April through August and monthly from September to November, with no sampling from December through March. Each year the data were analyzed and presented in an annual report to describe and interpret the results of the sampling program from a limnological perspective. A retrospective analysis report was prepared for Greeley's monitoring program to assess the spatial patterns and trends in water quality using data collected during the period 2000 - 2006 (Loftis and Moore, 2007b; Appendix K).

Results from the two retrospective studies are briefly summarized in Section 3.2.1. A direct comparison of results between the two studies is difficult because the programs have had different sampling frequencies and have used different field and laboratory methods. However, a limited comparison of data from the two programs is described in Section 3.3.

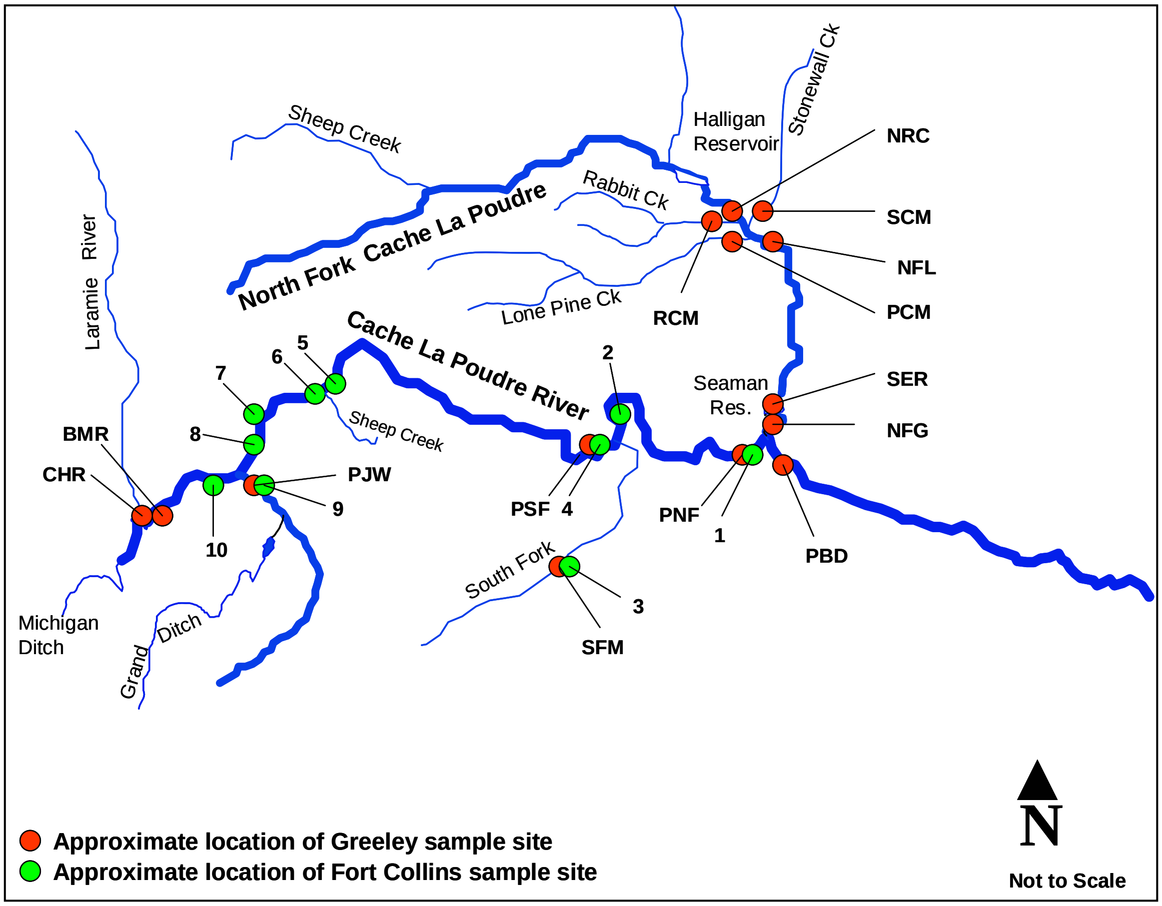


Figure 3.1 Approximate locations of historic monitoring sites (through 2007) for the cities of Fort Collins and Greeley.

3.2 Overview of Water Quality

3.2.1 Summary of Retrospective Analyses and Dr. Lewis Reports

The Fort Collins retrospective analysis reported that the dominant characteristics of the Poudre River water quality is its dramatic annual cycle in which spring snowmelt greatly reduces alkalinity and hardness, while greatly increasing TOC and turbidity. For all of the variables studied, the magnitudes of time trends were quite small, and the actual changes in water quality over the study period were not of concern from a practical standpoint. There were noticeable increases in *E. Coli* and total coliforms as one moves downstream, associated with greater development and human impact in the lower part of the canyon. There were small increases in turbidity and total phosphorous in the downstream direction as well. In terms of the constituents considered, the analysis confirmed that the Upper Poudre River remains a high-quality water source from a water treatment perspective.

The Greeley retrospective analysis concluded that the North Fork is significantly different and of lower quality in comparison to the Upper CLP main stem. Additionally, seasonal patterns are much less pronounced at the North Fork sites than at the main stem sites. The greatest differences spatially exist between the North Fork sites as a group and the main stem sites as a group. The North Fork sites generally have higher nutrient concentrations and conductance than do the main stem sites. TOC concentrations on the North Fork are consistently greater than those on the main stem.

The significant findings in the Lewis reports produced for the City of Greeley are that the water reaching the Bellvue plant is of good quality, but a few special water quality issues have emerged. Specifically, the water supply is sometimes high in TOC, and there is concern over the quality of water in Seaman Reservoir compared to that of other Poudre water that reaches the Bellvue intake. Seaman Reservoir experiences thermal stratification every year, in some cases as early as April, surprisingly early for reservoirs at this elevation. Thermal stratification of Seaman Reservoir results in the development of anoxic conditions at depths below five meters. Anoxic conditions can lead to the release of phosphorus, manganese, and iron from the bottom sediments. Nutrient enrichment of Seaman Reservoir has resulted in algal blooms, including blue-green algae which are known sources of geosmin. Geosmin (discussed further is Section 3.7.3) is an organic compound that imparts an earthy odor to water at extremely low concentrations (below 10 ng/L) and is difficult to remove during water treatment.

3.2.2 2002-2003 U.S. Geological Survey Study

The U.S. Geological Survey (USGS) recently conducted a research study on the Upper CLP to assess the quality of water as a drinking water source (Collins and Sprague, 2005). Water samples were collected from the Upper CLP main stem just upstream of the confluence with the North Fork. Samples were collected monthly from October 2002 through September 2003 with one additional sample collected each month from May through September when recreational use of the river was at its peak.

The study focused primarily on the presence or absence of organic chemicals and included dissolved organic carbon, 89 volatile organic compounds (VOCs), 123 pesticide compounds, 59 wastewater compounds, and *E. coli* bacteria. Of the 271 organic compounds monitored, only 14 were detected, including three VOCs (acetone, benzene, and toluene), one pesticide (the herbicide Siduron), and 10 wastewater compounds (including caffeine and the insect repellant DEET). Most compounds were detected at concentrations well below 1 μg/L, and no water quality standards were exceeded. The detected compounds are related to recreation, automobile emissions, and use of various household and personal-care products in the watershed. Low concentrations of *E. coli* bacteria were detected during the months of April through September. *E. coli* were found during this period most likely due to increased recreation and cattle grazing within the watershed, combined with warmer stream water temperatures. The USGS concluded that the Upper CLP provides a high quality drinking water source.

3.2.3 Other Studies

A study was performed at five sites along the CLP to determine the presence of antibiotics (Carlson and Yang, 2003). No antibiotics were detected at the most pristine site, upstream of the Greyrock National Recreation Trail, before the river encounters urban or agricultural lands. The study showed the presence of antibiotics at all other sites on the Poudre. These sites were located from downstream of Shields Street in Fort Collins to Greeley, all below the Upper CLP watershed and municipal intakes discussed in this report. By the time the river exited Fort Collins, six of the 11 compounds that were monitored were detected. A second study along the CLP was performed after the 2003 study to evaluate the effect of land-use on the concentrations of antibiotics in sediments (Pei et al, 2006). The results indicated that tetracyclines and sulfonamides were found to be highest at sites impacted by urban and agricultural activity, with no antibiotics at the Greyrock site.

Young et al (2008) are currently conducting research on the potential occurrence, transport, and fate of steroid hormones in the Cache la Poudre River. Samples are being collected at six locations along the Poudre River, including two sites on the Upper CLP main stem (below Poudre Falls at the Hwy 14 bridge, and at the Greyrock Trailhead). Samples are analyzed for 17β-estradiol (the most common natural estrogen), estrone (a typical degradation product of 17β-estradiol), progesterone, testosterone, androstenedione, and cis-androsterone. These substances can enter surface waters in discharges from septic systems, wastewater treatment plants, and runoff from animal feeding operations. Only data from the first sampling event (July 2007) have been reported and showed that 17β-estradiol was detected at five of the six sites, including the two Upper CLP sites. Additional work to be conducted as part of this project will be additional water sampling events, sediment sampling to determine if hormones are binding to river sediments, and laboratory studies to investigate photodegradation, reaction of steroids with dissolved organic matter and nitrates, and microbial degradation.

3.3 Comparability of Data from Earlier Monitoring Programs

Data from different monitoring programs are often not comparable because of differences in sampling frequencies, monitoring parameters, and field and laboratory methods. Ideally, data from the City of Fort Collins and City of Greeley monitoring programs compare favorably against each other and against data from the proposed future monitoring program. A brief study of data comparability was performed of the historic Fort Collins and Greeley monitoring programs. The two historic programs have four sampling sites in common: the main stem Poudre above the North Fork confluence, the South Fork on Pingree Park Road, the main stem Poudre above the confluence with South Fork, and the main stem Poudre above the confluence with Joe Wright Creek. A cross-study comparison of three selected parameters (conductance, total organic carbon, and nitrates) was performed at these locations. An example of the data comparison is shown in Figure 3.2 for the Poudre above Joe Wright Creek site (PJW from the Greeley program and FCWTF9 for the Fort Collins program). A comparison for two additional sampling sites is found in Appendix C. Although the two sampling programs are different, the two data sets compare well and do not have any obvious major inconsistencies.

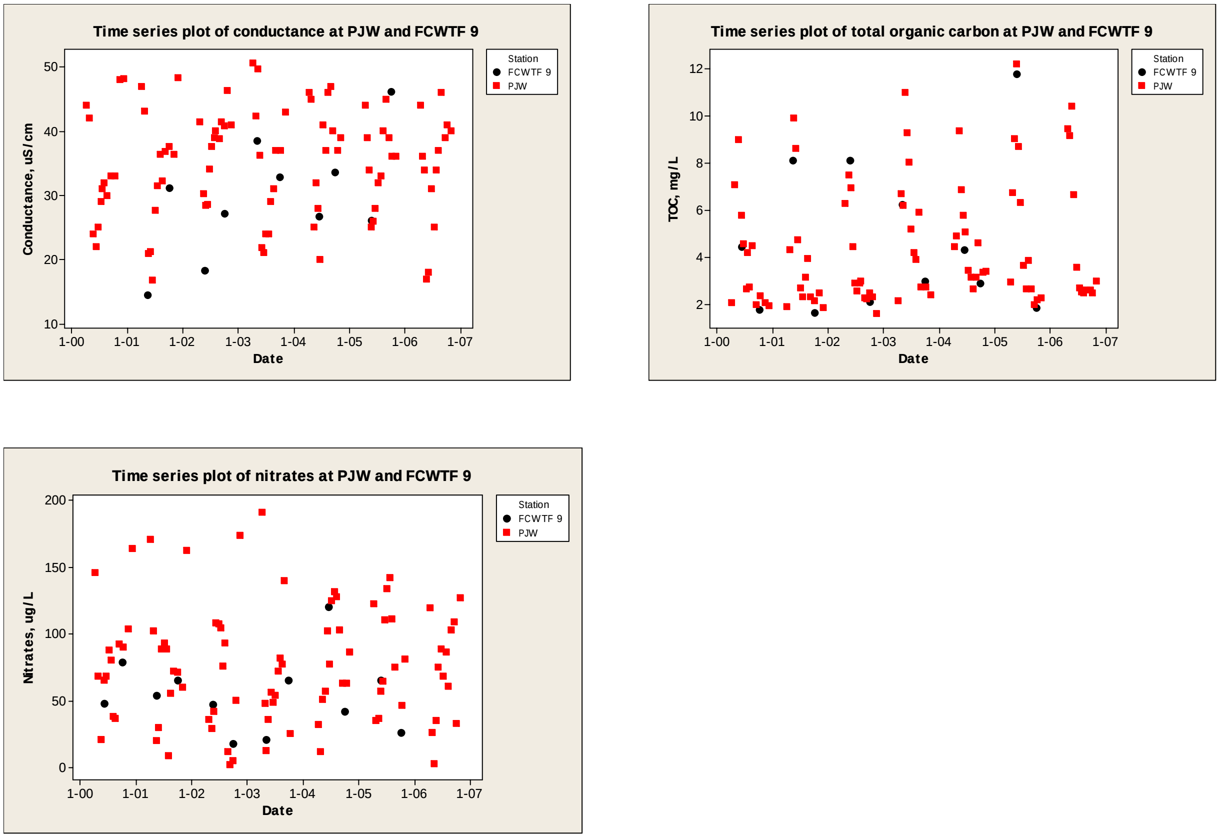


Figure 3.2. Cross-study data comparison of time series analysis for conductance, total organic carbon, and nitrates at PJW (Greeley monitoring program) and FCWTF 9 (Fort Collins monitoring program).

3.4 Flow versus quality relationships

Relationships between water quality and flow can be extremely useful for estimating water quality at times when flow is measured but concentration is not, for estimating loads by a rating curve approach, and for interpreting water quality behavior. A decreasing relationship or negative correlation indicates a dilution effect, while an increasing relationship or positive correlation indicates a washoff or first-flush effect, or a connection with eroded sediment.

Concentration versus discharge plots for total phosphorus, nitrate, and TOC at five monitoring stations are shown in Appendix D. As one example, plots for station PSF (Poudre above the South Fork), are shown in Figures 3.3, 3.4 and 3.5. Overall the analysis did not show a significant relationship between flow and water quality for nitrates or phosphorous. The analysis did identify a direct relationship between TOC and flow. This was anticipated as the highest TOC concentration occurs in the spring during the high-flow period.

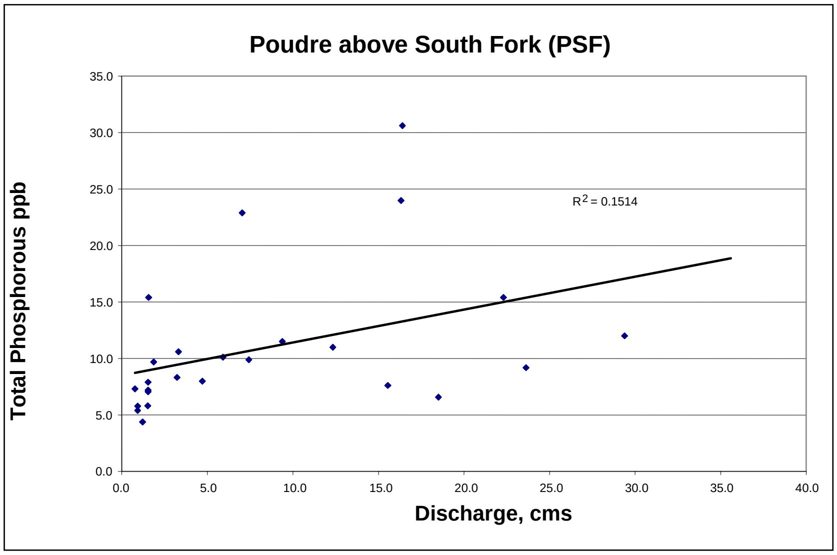


Figure 3.3 Total phosphorous concentration versus discharge at PSF.

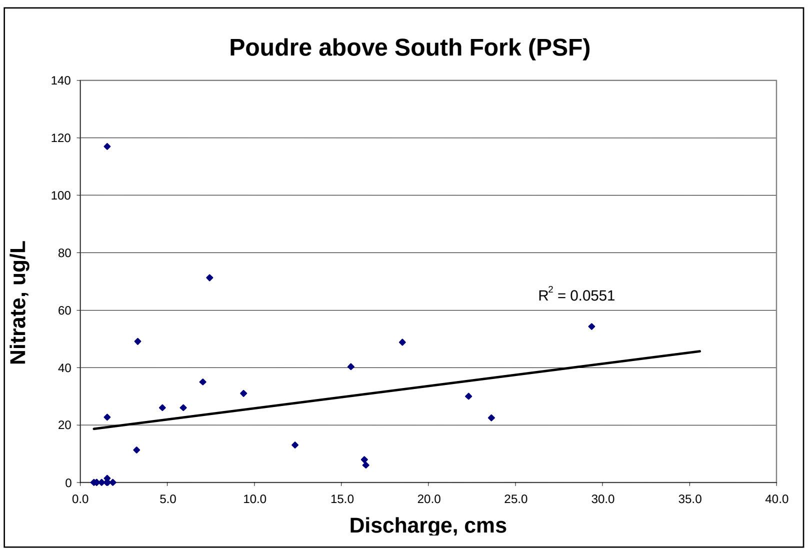


Figure 3.4 Nitrate concentration versus discharge at PSF.

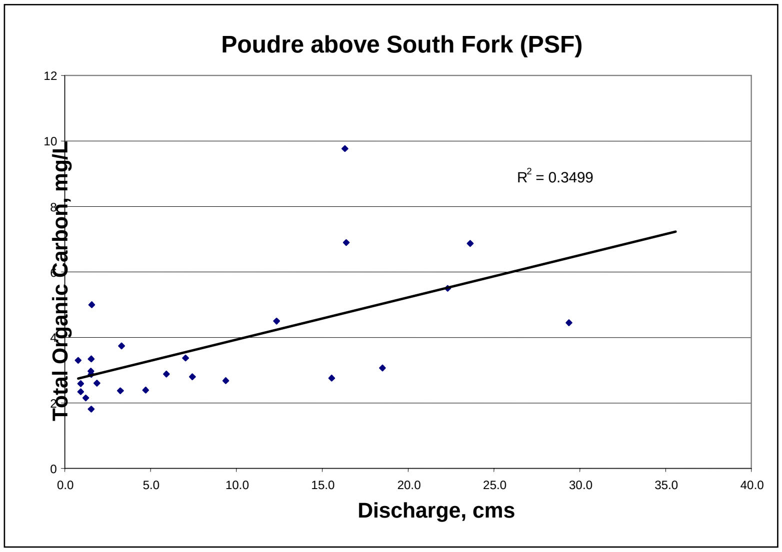


Figure 3.5 Total organic carbon concentration versus discharge at PSF.

3.5 Load Estimation for Nutrients and TOC

Loads for selected constituents (TOC, nitrate and total phosphorus) were computed for the Greeley monitoring network by multiplying concentrations by flow rates over the 2000 – 2006 period of record. Plots of calculated loads are included in Appendix E. On the North Fork, the TOC load ranged from 9.0 kg/day to 5,038 kg/day at the North Fork at Livermore site (NFL). Over the same period, the nitrate (as N) load at NFL was on average 2.6 kg/day. Lone Pine Creek (PCM) and Rabbit Creek (RCM) contribute a larger nitrate load than Stonewall Creek (SCM), contributing on average 1.1 kg/day, 0.52 kg/day, and 0.16 kg/day, respectively. Phosphorous loading from tributaries on the North Fork was largest from Lone Pine Creek with an average of 1.42 kg/day. Average phosphorous loads were 2.89 kg/day at the NFL site.

The main stem carries greater loads of TOC and nutrients than does the North Fork, primarily because of its greater flow. The TOC load on the main stem was on average 2,125 kg/day at PJW (above Joe Wright Creek), 917 kg/day at SFM (on the South Fork), and 3,755 kg/day at PSF (above the South Fork). The spatial distribution of nitrate and total phosphorus loads was similar to that of TOC. The total phosphorous load on the main stem was on average 4.05 kg/day at PJW, 2.4 kg/day at SFM, and 9.9 kg/day at PSF. The nitrate load on the main stem was on average 28.5 kg/day at PJW, 7.0 kg/day at SFM, and 24.7 kg/day at PSF.

3.6 Comparison of Data to Drinking Water Standards

Primary and secondary drinking water standards have been established by the U.S. EPA and the CDPH&E. Primary drinking water standards have been set to protect public health, while secondary standards control substances that affect the aesthetic qualities of drinking water (www.epa.gov/safewater/contaminants/index.html). Maximum and average values for raw Poudre water quality parameters measured at the FCWTF are compared to the existing primary and secondary standards (maximum contaminant levels or MCLs) in Table 3.1.

Table 3.1. Drinking water standards compared to mean and maximum values for raw Poudre River water collected at FCWTF sample tap - 1997 to 2007 (analysis by Fort Collins Water Quality Lab).

Parameter	Primary or Secondary (P or S)	MCL	Sample Size	Mean	Maximum	Standard Error
pH	S	6.5-8.5	537	7.55	8.65	0.01
Total Dissolved Solids (mg/L)	S	500	125	46.9	86	1.31
Total Organic Carbon (mg/L)			340	3.21	11.3	0.11
Turbidity (NTU)		0.3 / 1 (1)	555	2.13	42.1	0.16
Fluoride (mg/l)	P/S	[4.0] (2.0)	498	0.16	0.47	0.00
Nitrate (mg/l as N)	P	10	498	0.05	0.50	0.00
Nitrite (mg/l as N)	P	1	493	< 0.04	< 0.04	
Chloride (mg/l)	S	250	116	1.59	11.4	0.13
Sulfate (mg/l)	S	250	116	3.53	12.9	0.14
Aluminum - total by AA (ug/l)	S	50-200	76	255	2974	58.4
Aluminum - total reactive (ug/l)	S	50-200	346	<15	99.9	
Antimony (ug/l)	P	6	30	<2.0	<2.0	
Arsenic (ug/l)	P	10	32	<2.0	<2.0	
Barium (ug/l)	P	2,000	30	17.9	47.5	1.59
Beryllium (ug/l)	P	4	30	<0.5	<0.5	
Cadmium (ug/l)	P	5	31	0.01	0.15	0.01
Copper (ug/l)	P/S	[1,300] (1,000)	126	<3.0	24.7	
Iron (ug/l)	S	300	125	241	4,243	45
Lead (ug/l)	P	15	124	<1.0	2.50	
Manganese (dissolved) (ug/l)	S	50	107	<1.0	14.3	
Manganese (total) (ug/l)	S	50	124	11.2	231	2.83
Mercury (ug/l)	P	2	24	<1.0	<1.0	
Selenium (ug/l)	P	50	30	<2.0	<2.0	
Silver (ug/l)	S	100	31	<0.5	<0.5	
Thallium (ug/l)	P	2	30	<1.0	<1.0	
Zinc (ug/l)	S	5,000	31	<100	<100	
[Primary Standard] (Secondary Standard)						
All metals are total unless otherwise indicated.						
"<" values are "< Reporting Limit" where Reporting Limit is the lowest reportable number based on the lowest calibration standard routinely used.						
(1) For treated water, turbidity may never exceed 1 NTU, and must be < 0.3 NTU in 95% of daily samples in any month.						

The mean value for total aluminum (analyzed by AA) exceeded the secondary MCL of 200 ug/L. No other mean values exceeded the MCLs. However, there are a few recorded values for pH, total iron, and total manganese that do exceed their respective MCLs. Overall, water from the Upper CLP is of high quality compared to current drinking water standards.

3.7 Water Quality Parameters of Special Concern to Water Treatment

The Upper CLP is a high quality water source for the FCWTF, the Bellvue WTP, and the SCFP. However, there are some water quality parameters of special concern to water treatment. Poudre River water experiences a period of high TOC each spring during the snowmelt runoff period. Poudre River water also contains the pathogens *Giardia lamblia* (*Giardia*) and *Cryptosporidium*. In addition, waters of the Upper CLP are seasonally affected by geosmin and other taste and odor (T&O) compounds. TOC, pathogens, and geosmin are discussed in more detail in this section.

3.7.1 Total Organic Carbon

TOC is one of the most important water quality parameters for the source waters of the FCWTF, SCFP, and the Bellvue WTP. TOC in the Upper CLP is important to understand because it affects the optimization and efficiency of water treatment unit operations including coagulation and settling, and serves as the main substrate for the formation of disinfection by-products (DBPs). DBPs are carcinogens that are formed when TOC reacts with chlorine that is added at the treatment plants. Trihalomethanes (such as chloroform ($CHCl_3$)) and haloacetic acids (such as trichloroacetic acid (Cl_3CCOOH)) are two groups of DPBs that can be formed during chlorination. Treated water delivered from the FCWTF, SCFP, and the Bellvue WTP must meet maximum contaminant levels for these two groups of DPBs as set forth in the US EPA Disinfectants/Disinfection By-Products Rule. These regulations also require the removal of TOC to minimize DBP formation if raw water TOC concentrations are greater than 2.0 mg/L. TOC removal and DBP formation both depend on the nature, composition, structure, and reactivity of the various organic compounds that make up the TOC in the raw water.

Disinfectant Byproducts (DBPs):
Examples of a Trihalomethane and a Haloacetic Acid

```
     Cl                  Cl   O
     I                   I    II
Cl - C -  H         Cl - C -  C - OH
     I                   I
     Cl                  Cl

Chloroform          Trichloroacetic acid
```

High TOC concentrations in waters of the Upper CLP during the spring snowmelt runoff period, combined with low alkalinity, have historically presented a significant treatment challenge. The leaching of soil organic matter in the watershed during spring snowmelt results in the TOC rising with the snowmelt hydrograph. During the six to eight week snowmelt runoff period, TOC concentrations in the Upper CLP start at a baseline of about 2 mg/L, rise to a peak that in most years ranges between 8 and 12 mg/L, and then gradually fall back down to the baseline (Figure 3.6). The peak TOC concentration is generally related to the moisture content of the snowpack just prior to runoff, with drought years resulting in peak TOC concentrations less than 8 mg/L. Day to day changes in TOC concentrations are related to the weather conditions that impact the snow melting process. Variations in the yearly snowpack and daily weather result in varying TOC concentrations during each snowmelt runoff period that are impossible to predict.

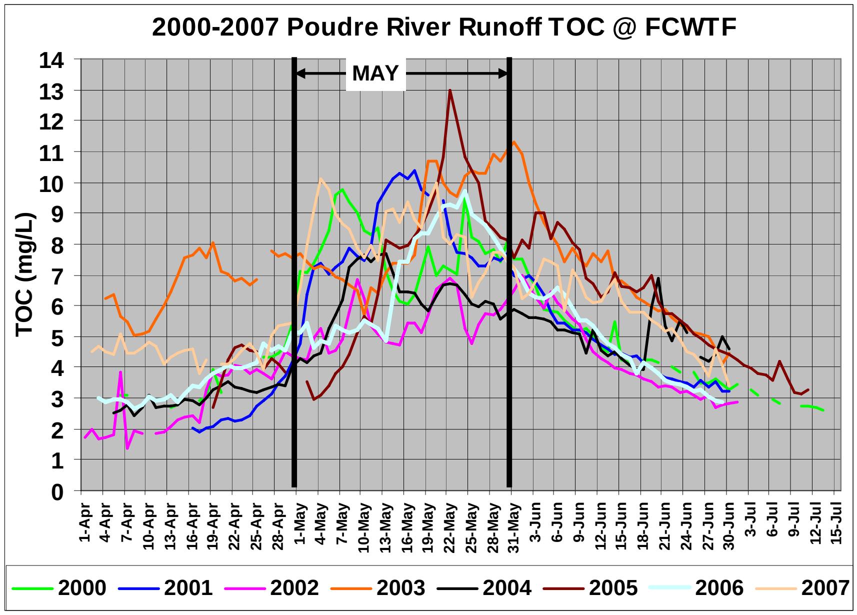


Figure 3.6 Upper main stem CLP TOC measured at the FCWTF during the spring snowmelt runoff period.

The naturally occurring organic matter that is represented by measurements of TOC is chemically complex and reflects the soil and vegetative conditions of the originating watershed. Previous studies conducted at the FCWTF have characterized the nature of Poudre River TOC during the spring runoff period (Carlson et al, 1994; Billica and Gertig, 2000; Sharp et al, 2005; Sharp, Parsons and Jefferson, 2005; Billica and Gertig 2006). The natural organic matter is primarily in the dissolved form with dissolved organic carbon making up approximately 95% of the TOC. A strong correlation exists between TOC and ultraviolet absorbance at a wavelength of 254 nm (UV-254) during the runoff period, resulting in an almost constant specific ultraviolet absorbance (SUVA; SUVA = UV-254/DOC) after the initial rise in TOC. This can be seen for the 2001 data plotted in Figure 3.7 and indicates that, while the concentration of organics changes during runoff, the characteristics of the organics (as represented by UV-254 values) do not change.

The increased raw Poudre TOC during the snowmelt period is predominantly made up of high molecular weight, hydrophobic humic substances - fulvic and humic acids (Carslon et al, 1994; Sharp et al, 2005; Sharp, Parsons and Jefferson, 2006). TOC characterization analysis conducted during the 2004 runoff indicated that about 70% of the raw Poudre TOC is made up of hydrophobic humic substances, and about 30% is made up of hydrophilic non-humic substances (Sharp et al, 2005). The hydrophobic humic substances consist of high molecular weight compounds that produce colored water, have a high charge density, and are relatively easy to remove during coagulation. The hydrophilic non-humic substances consist of low molecular weight compounds that do not produce color, have a low charge density, and are difficult to remove by conventional treatment.

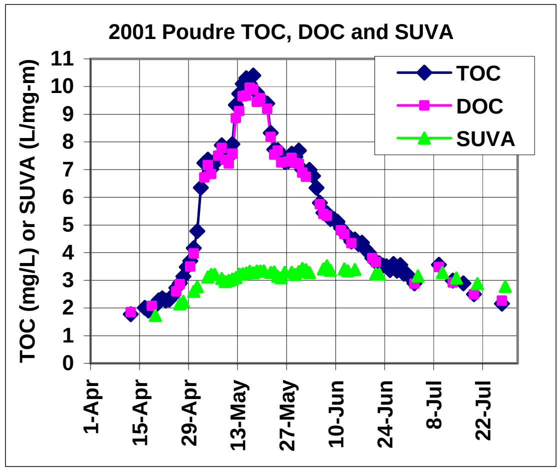


Figure 3.7 Upper CLP TOC, DOC and SUVA measured at the FCWTF during the 2001 spring snowmelt runoff period.

Humic substances are the major contributors to color in water, and there is a strong correlation between raw Poudre color, and TOC during the runoff period (Figures 3.8, 3.9, and 3.10). Analysis conducted in April 2004 (prior to runoff) and May 2004 (during runoff) showed that the increase in TOC during the 2004 runoff was accompanied by a 96% increase in the total hydrophobic humic substances fraction with only a 19% increase in the non-humic, hydrophilic fraction (Sharp et al, 2005). Charge density characterization of the Poudre River humic acid fraction, fulvic acid fraction and hydrophilic fraction showed that the majority of the charge resides in the hydrophobic fractions (Sharp et al, 2005; Parsons et al, 2005). The hydrophobic content of the raw water controls the coagulant demand due to its high negative charge density (Edzwald, 1993), and, as a result, treatment of Poudre River water during the snowmelt runoff period requires high coagulant doses.

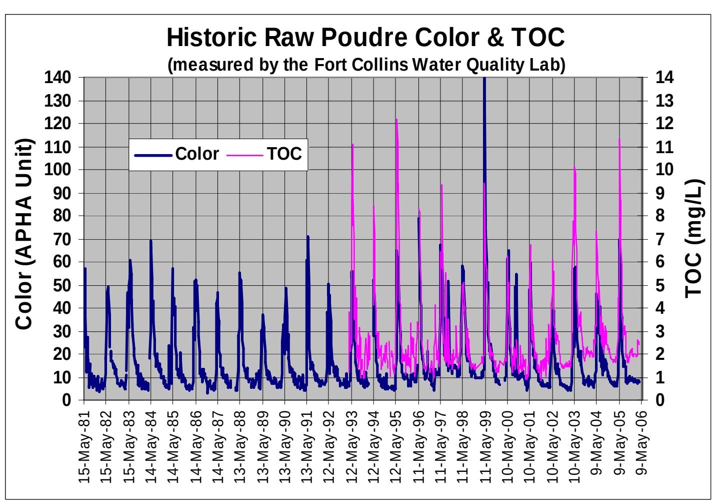


Figure 3.8. Historic Upper main stem CLP color and TOC measured at the FCWTF.

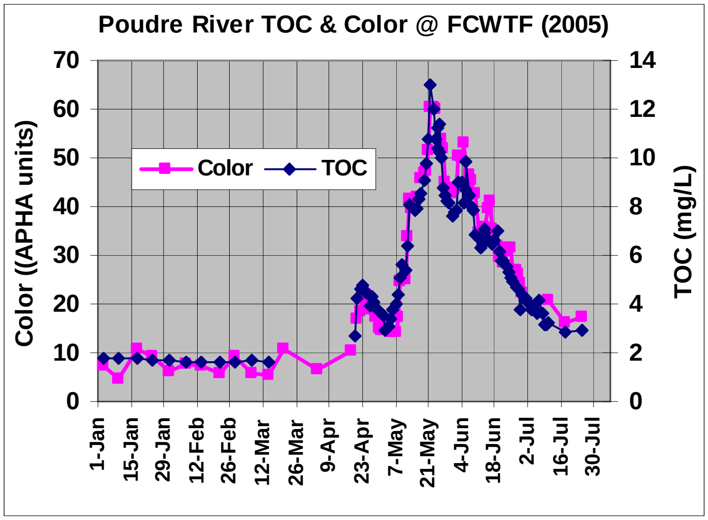


Figure 3.9. **Upper CLP color and TOC measured at the FCWTF during the 2005 runoff period, showing the correlation between color and TOC.**

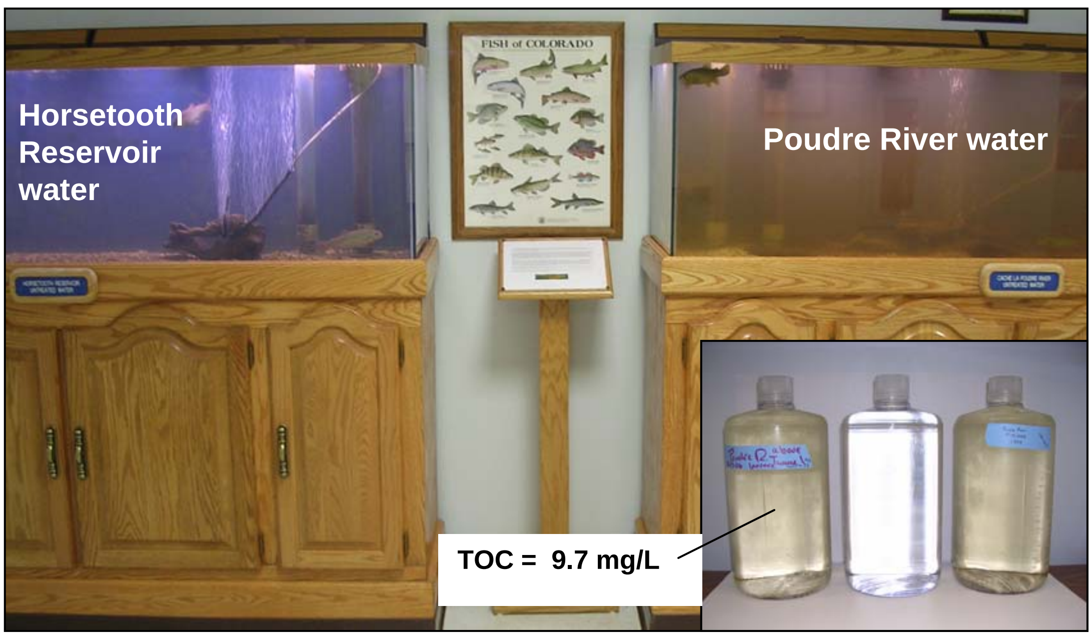


Figure 3.10. **Color in Poudre River water during the spring runoff high TOC period as seen in water samples and the fish tank at the FCWTF.**

As the TOC increases during the spring snowmelt period, the raw water alkalinity quickly drops from a baseline value of 30 to 40 mg/L (as $CaCO_3$) down to 15 mg/L (as $CaCO_3$) or lower as shown for the 2005 runoff period in Figure 3.11. The raw water turbidity can increase to values of 20 ntu or higher, but generally the turbidity is below 15 ntu. The low alkalinity combined with high TOC presents a significant treatment challenge. High alum doses are required to remove the elevated TOC and turbidity that are present in the raw water. However, since alum consumes alkalinity, high alum doses can consume the entire raw water alkalinity. The pH of the water can then drop to values that result in a very ineffective coagulation process with poor turbidity removal. The FCWTF, SCFP, and

Bellvue WTP all blend raw Poudre River water with Horsetooth Reservoir water during the spring snowmelt runoff period which helps to minimize these treatment issues. The FCWTF also has the ability to precondition raw Poudre River water with lime and carbon dioxide to adjust the pH and alkalinity for treatment during this period.

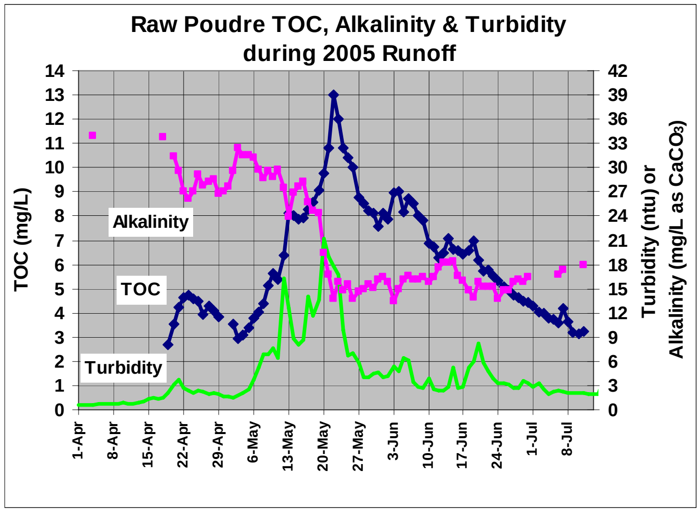


Figure 3.11. Typical Poudre River turbidity, alkalinity and TOC plots measured at the FCWTF during the spring snowmelt runoff period.

TOC data collected as part of the historic City of Greeley Water Quality Monitoring Program allow for comparisons between TOC concentrations on the North Fork and on the Upper main stem above the North Fork. Figure 3.12 is a plot of TOC data from the North Fork at Livermore (NFL), the North Fork below Seaman Reservoir (NFG), and the main stem above the North Fork (PNF). Two things can be observed from this figure. First, the TOC concentrations on the North Fork are generally higher than those on the main stem, especially in the months after the spring snowmelt runoff period. Second, the TOC below Seaman Reservoir (as measured at the NFG site) is higher than the TOC in waters entering Seaman Reservoir (as measured at the NFL site). The TOC concentrations in waters below Seaman Reservoir may be higher due to in-reservoir production of TOC from algal growth within the reservoir. Also, the reservoir stores high-TOC spring runoff water that is blended with other inflows and released over the course of the year.

TOC data for sites in the headwaters and upper reaches of the main stem are compared on Figure 3.13. The sites include Chambers Lake outflow (CHR), Barnes Meadow Reservoir outflow (BMR), Poudre above Joe Wright Creek (PJW), and the South Fork Cache la Poudre (SFM). These data are from the historic City of Greeley Water Quality Monitoring Program. TOC concentrations from Barnes Meadow Reservoir (BMR) are historically higher than those from any other site because of boggy conditions in its subwatershed. TOC concentrations in waters released from Barnes Meadow Reservoir can exceed 14 mg/L. Releases from Chambers Lake (CHR) have significantly lower TOC concentrations, and CHR peak TOC concentrations are generally lower than those observed in the stream sites (PJW, SFM, and PNF) by 2 to 4 mg/L. The South Fork (SFM) TOC data are similar to the data on the main stem above the North Fork (PNF) and essentially overlap on Figure 3.13.

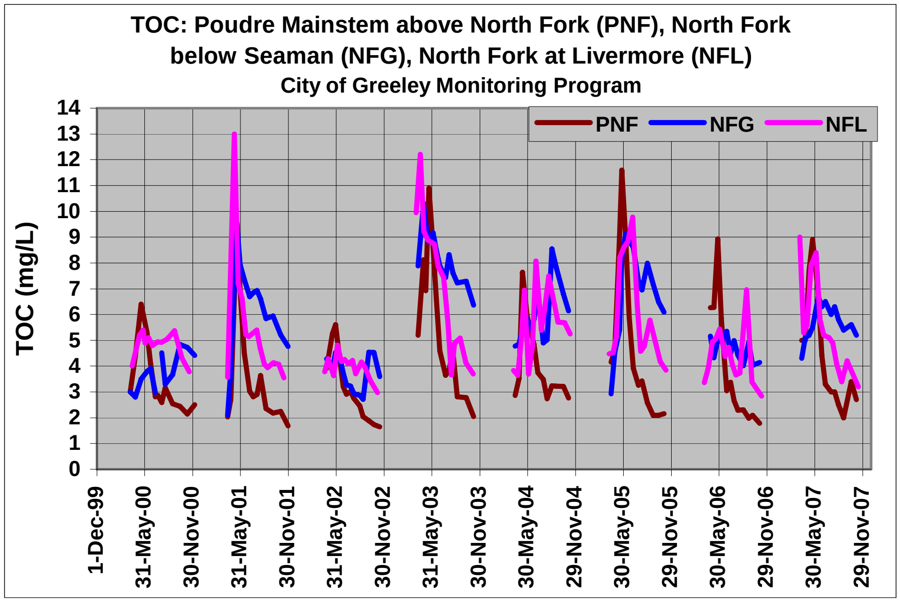


Figure 3.12. Comparison of TOC values for the North Fork and the main stem above the North Fork.

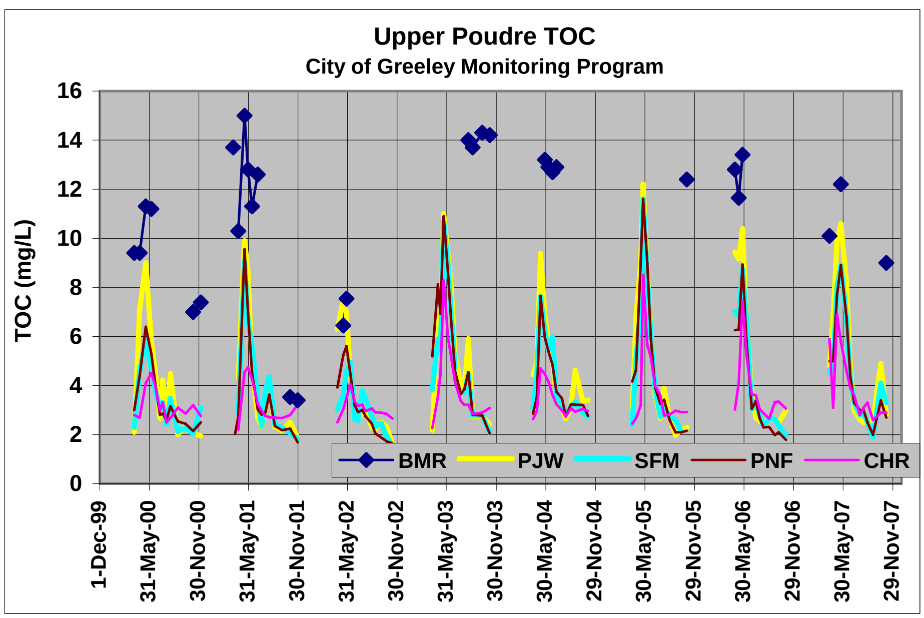


Figure 3.13. TOC values for Upper CLP sites.

The City of Fort Collins began collecting TOC data above and below Halligan Reservoir in 2006. Figure 3.14 is a plot of the TOC data collected to date. The data differ between 2006 and 2007, so more data will be required at these two sites before conclusions can be drawn. However, it can be seen that TOC values at these two locations are generally above 4 mg/L. Also, the data to date indicate that TOC concentrations in the North Fork above Halligan Reservoir (North Fork at Dale Creek) are higher than concentrations in the North Fork below Halligan Reservoir during the spring and early summer; by mid to late summer this pattern appears to reverse itself. Algal blooms observed in Halligan Reservoir may result in some in-reservoir production of TOC.

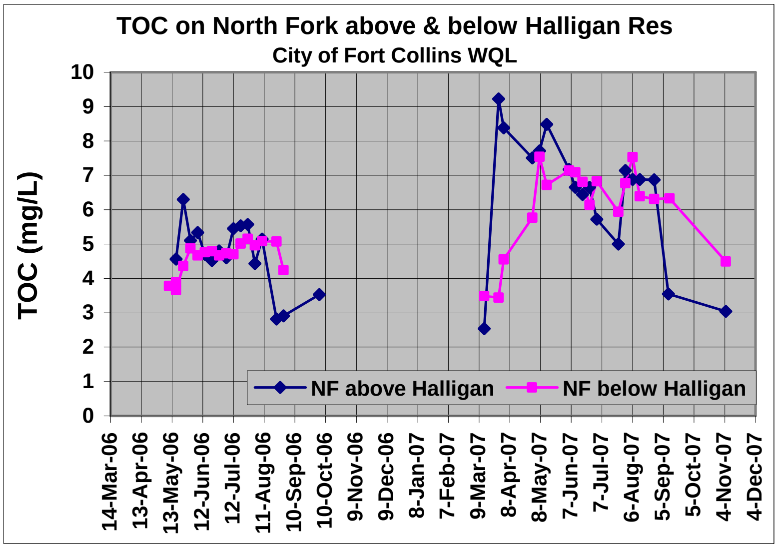


Figure 3.14. TOC values above and below Halligan Reservoir.

Although the City of Fort Collins has conducted several studies in the past that have helped to characterize the nature of the TOC in the Upper CLP, a more comprehensive TOC characterization study is being conducted in 2008. This study will provide information that will be used to help make decisions into the future regarding raw water blending, treatment, minimization of disinfectant byproduct formation, and watershed management. Changes in the Upper CLP watershed from pine beetle kill, forest fires and climate change could all influence TOC concentrations into the future. TOC characterization data collected now will provide a baseline for future comparisons. The study is being conducted by Dr. Mel Suffet (Professor at UCLA) and is jointly funded by the City of Fort Collins, City of Greeley, Tri-Districts, and the Northern Colorado Water Conservancy District. The study area includes the Upper CLP as well as Horsetooth Reservoir and associated components of the Colorado-Big Thompson Project. Laboratory analyses to be conducted as part of this study include fluorescence, size exclusion chromatography, XAD resin fractionation, and polarity rapid assessment method.

3.7.2 *Giardia* and *Cryptosporidium*

Probably the most important public health risk associated with local water supplies is the presence of microbial pathogens such as *Giardia* and *Cryptosporidium*. *Giardia* and *Cryptosporidium* cause gastrointestinal illness if they are not removed during treatment. The illness caused by these protozoan pathogens can be especially serious in the young, elderly, and those with compromised immune systems. *Giardia* and *Cryptosporidium* have been responsible for the majority of waterborne illness outbreaks in the United States (EPA, 1999). *Giardia* and *Cryptosporidium* are more resistant to traditional chlorine disinfection than many other waterborne pathogens. In particular, chlorine applied in concentrations practical for drinking water treatment is ineffective for controlling *Cryptosporidium*. A multi-barrier concept of source water protection, followed by optimized coagulation, filtration, and disinfection, is considered the optimal approach for controlling *Cryptosporidium* and *Giardia*. The US EPA Surface Water Treatment Rule and the Enhanced Surface Water Treatment Rule regulate microbial pathogens in treated water supplies and specify disinfectant contact times and filtered water turbidity for protecting human health from pathogenic contaminants.

Giardia is commonly found in the Upper CLP watershed. Wild and domestic animal feces, including those of beaver which are abundant in the Upper CLP, are a source of *Giardia*. Figure 3.15 includes a plot of *Giardia* cysts/L counted in raw Poudre River water samples collected at the FCWTF (all *Giardia* and *Cryptosporidium* analyses were conducted by CH Diagnostic and Consulting Services, Inc., Berthoud, CO). *Giardia* has been detected in every sample collected since 2002. *Cryptosporidium* is not commonly found in raw Poudre River water, although it is occasionally detected in low numbers (Figure 3.16).

Monitoring for *Giardia* and *Cryptosporidium* was begun in 2006 on the North Fork above and below Halligan Reservoir. Similar to the Upper Poudre data collected at the FCWTF, the data show that *Giardia* is commonly found on the North Fork (Figure 3.15) while *Cryptosporidium* is found only occasionally and in low numbers (Figure 3.16). The North Fork has a significantly greater percentage of land identified as agricultural use (rangeland and grassland) than the main stem (52% versus 18% as shown in Table 2.5). Because of this, and the fact that grazing cattle can be a source of *Cryptosporidium* cysts, it has been thought that the North Fork waters might contain higher amounts of *Cryptosporidium* cysts than the main stem. The data collected to date do not indicate that this is the case. However, samples collected further downstream on the North Fork may show higher concentrations. *Giardia* and *Cryptosporidium* samples will be collected on the North Fork downstream of Seaman Reservoir beginning in 2008 to determine if higher concentrations of these pathogens are present at the most downstream North Fork sampling site.

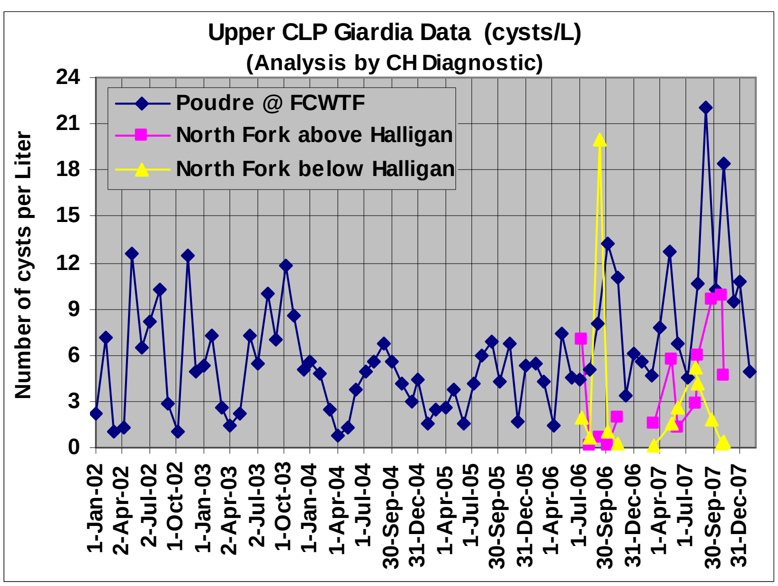


Figure 3.15. ***Giardia* cysts per liter in raw Poudre River water at the FCWTF, North Fork above Halligan Reservoir, and North Fork below Halligan Reservoir.**

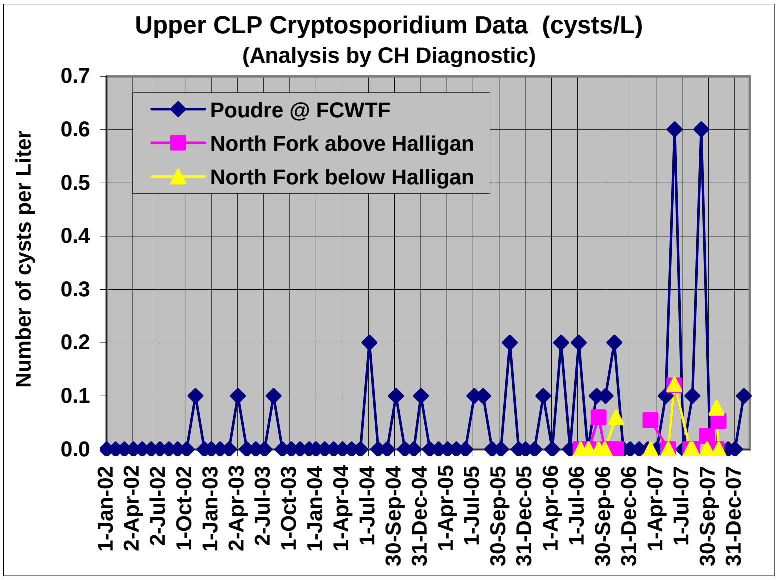
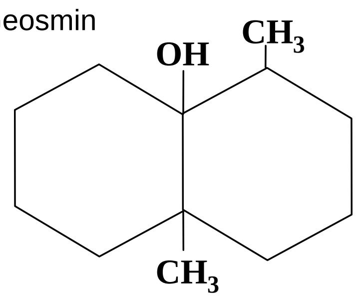


Figure 3.16. ***Cryptosporidium* cysts per liter in raw Poudre River water at the FCWTF, North Fork above Halligan Reservoir, and North Fork below Halligan Reservoir.**

3.7.3 Geosmin

Geosmin is a naturally occurring organic compound produced by blue-green algae (Cyanobacteria) and actinomycetes (filamentous bacteria). When these organisms die and decompose, geosmin is released into the water. Geosmin imparts an earthy odor to water and can be detected by the most sensitive noses at extremely low concentrations (about 5 nanograms per liter (ng/L) or 5 parts per trillion (ppt)). Geosmin does not pose a public health risk, but its presence in treated drinking water can cause customers to feel that their drinking water is unsafe or unhealthy. It is one of the most difficult taste and odor (T&O) compounds to remove during water treatment. It has been found in raw Poudre River water at the FCWTF and at the Greeley-Bellvue WTP, as well as in water samples from Seaman and Halligan Reservoirs. The analytical techniques to quantify the low levels of geosmin were not developed until the late 1990's, so the historic database for geosmin concentrations is relatively small.

Geosmin



Blue-green algae that are reported producers of geosmin include *Anabaena*, *Aphanizomenon, Lyngbya*, *Oscillatoria, Phormidium, Schizothrix*, and *Symploca* (Mallevialle, J. and Suffet, I.H., 1987, page 69). Several species of both *Anabaena* and *Oscillatoria* produce geosmin, although not every species of *Anabaena* and *Oscillatoria* produce geosmin. The matter is also complicated by the fact that the ability to produce geosmin may be a strain-specific property, i.e. at the subspecies level (Suffet, I.H., Mallevialle, J., and Kawczynski, E., 1995, page 27). *Anabaena* is found in both Seaman and Halligan Reservoirs. Figure 3.17 is a photo of an *Anabaena* bloom that occurred at Halligan Reservoir in August 2005, while Figure 3.18 is a photo taken of *Anabaena* under the microscope from a water sample from Halligan Reservoir. *Aphanizomenon* and *Anabaena* have been the most abundant geosmin producing species in Seaman Reservoir as observed by Lewis (2001 – 2007). *Lyngbya* and *Oscillatoria* have also been found in Seaman Reservoir samples on various occasions, although in low abundance.

Figure 3.17. *Anabaena* bloom at Halligan Reservoir in August 2005 (photo by Bill Tomerlin).

Figure 3.18. *Anabaena* from Halligan Reservoir (Photo by Grant Jones, 7/23/07)

Geosmin was detected for the first time in FCWTF raw waters during Fall 2001. In Spring 2001, the FCWQL began using newly developed, dual-coated solid phase microextraction (SPME) silica fibers (divinylbenzene-carboxen-polydimethylsiloxane, Supelco No. 57348-U) that can extract geosmin at concentrations as low as 1 ppt (0.000001 mg/L) in water samples for subsequent analysis by GC/MS. The use of this fiber greatly enhanced the ability of the FCWQL to detect geosmin. The fact that geosmin was detected in Fall 2001 and not in previous years may be related to the extraction technique. Although the FCWQL detected geosmin in raw water samples, the concentration of geosmin was not determined because the FCWQL had not yet obtained a suitable geosmin standard with which to calibrate the method.

The FCWQL took steps during early 2002 that enabled them to begin determining geosmin concentrations in raw and finished waters at the ppt level. A suitable geosmin standard (from beet extract) that allows for quantification of geosmin was located and obtained in 2002. The FCWQL was also aided by the purchase of a new gas chromatogram (GC). The combination of the new GC, the geosmin standard, and the use of SPME fibers (as per Standard Method 6040D, page 6-19, 21st Edition, 2005) now allow the FCWQL to provide geosmin concentration data in a timely manner with a high level of quality control.

A plot of geosmin data measured by the FCWQL for Poudre River samples collected at the FCWTF raw water sample tap is shown on Figure 3.19 for the period of September 2002 through December 2007. The odor threshold for geosmin (5 ng/L) was exceeded in November 2003, March 2004, and November 2005. The highest concentration measured in raw Poudre water at the FCWTF (water from the Upper CLP above the North Fork) was 18 ppt in November 2003.

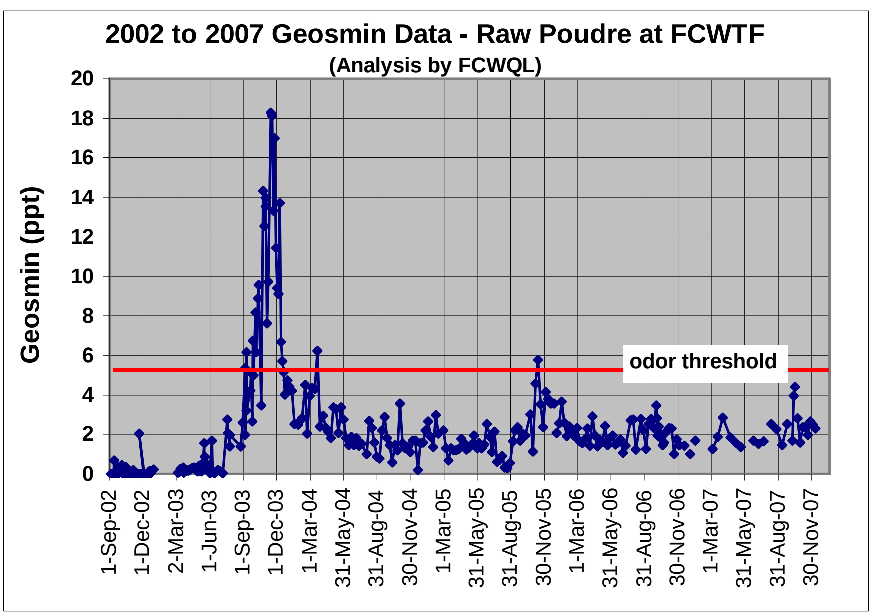


Figure 3.19. Geosmin concentrations in raw Poudre River water at the FCWTF.

The FCWQL has also conducted geosmin analysis on samples collected from Seaman and Halligan Reservoirs on the North Fork. The period of record for Seaman Reservoir geosmin data is from April 2005 through the present. Figure 3.20 is a plot of Seaman Reservoir data for 2005 through 2007. Many of the geosmin concentrations in Seaman Reservoir in 2005 and 2006 were significantly higher than the odor threshold value of 5 ppt. During 2006, geosmin concentrations greater than 100 ppt were observed in August, September and October. Values greater than 15 to 20 ppt are problematic for water treatment plants because of the difficulty of removing geosmin to concentrations below the odor threshold level.

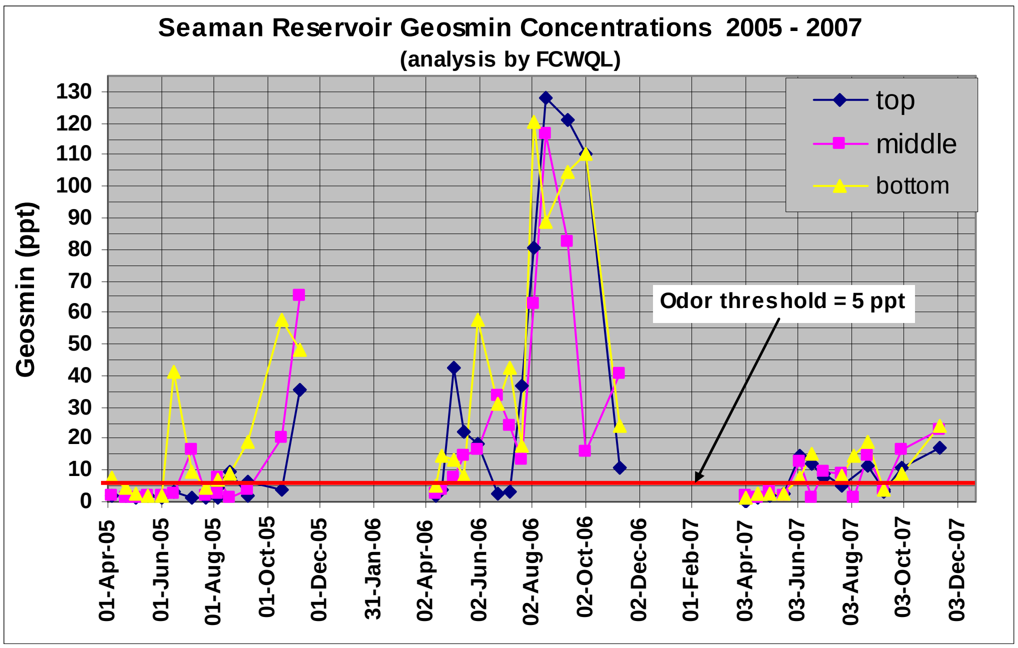


Figure 3.20. Geosmin concentrations in samples taken from the top, middle and bottom of Seaman Reservoir.

Reports by Dr. Bill Lewis on the historic City of Greeley Water Quality Monitoring Program provide information on algal species and abundance (number of cells per mL) in Seaman Reservoir that can be evaluated in terms of the geosmin data (Lewis, 2006; Lewis, 2007). Those reports indicate that in 2005, there was a high abundance of *Anabaena* and *Aphanizomenon*, both producers of geosmin. The report for 2006 data indicated low abundances of *Anabaena* and virtually no *Aphanizomenon*. This information about the blue-green algae populations for 2006 does not correlate with the very high geosmin levels observed in 2006. The literature indicates that it is very difficult to establish correlations between the number of microorganisms and the presence of T&O compounds, even though such correlations would be of important practical value. Small populations of some species may be able to produce considerable amounts of T&O compounds (Juttner, 1984).

The geosmin data for Seaman Reservoir indicate the presence of a peak in late summer to fall. The presence of nitrogen-fixing blue-green algae often coincides with nitrogen shortages toward the end of the growing season; blooms of blue-green algae, including the geosmin producing *Anabaena* and *Aphanizomenon*, can occur when nitrogen depletion occurs (Lewis, 2002, pg. 31). Chlorophyll-a concentrations can also peak in the fall. However, geosmin producing blue-green algae are generally not the predominant group contributing to the chlorophyll-a content, so the data do not show a strong correlation between chlorophyll-a and geosmin. Lewis (2006 and 2007) indicates that fall chlorophyll-a maxima are typical for Seaman Reservoir because phytoplankton growth (primarily *Chlorella* and both geosmin-producing and non-geosmin producing blue-green algae) is stimulated in the fall by nutrient upwelling from deep water.

Geosmin data for grab samples collected from the surface of Halligan Reservoir near the dam are shown on Figure 3.21. Six samples were collected in 2006 and one sample in 2007. Geosmin concentrations measured at Halligan Reservoir in 2006 exceeded the odor threshold concentration of 5 ppt with a peak concentration of 26 ppt. The one sample collected in 2007 (7/30/07) had a concentration of 157 ppt. The predominant algal genera that have been observed in Halligan Reservoir include the geosmin-producing *Aphanizomenon* and *Anabaena*. Algal species identification has been performed at the FCWTF on water samples collected from the surface of Halligan Reservoir, but algae counts have not been obtained so information on species abundance is not available.

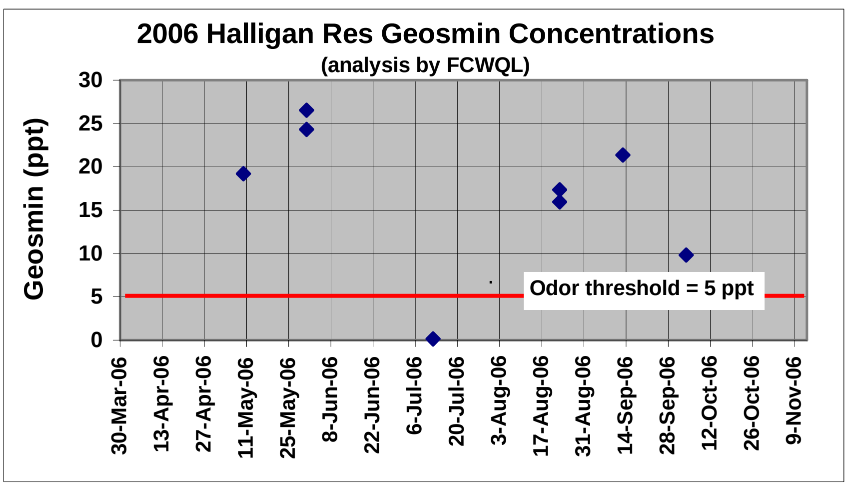


Figure 3.21. Geosmin concentrations in samples taken from the top of Halligan Reservoir.

Geosmin is not removed by conventional treatment processes. It can be partially removed by adsorption onto powdered activated carbon (PAC). The FCWTF upgraded their PAC feed system in 2006 to provide for PAC dosages of up to 10 mg/L. However, the current plant design does not provide for significant PAC contact time with the water (time during which the geosmin can adsorb onto the PAC surfaces). The relatively short contact time limits the ability of the PAC to remove geosmin. The ability of the FCWTF to achieve significant removal of geosmin with the upgraded PAC feed system is unknown for raw water geosmin concentrations greater than about 20 ppt. The City of Greeley Bellvue WTP and the Tri-Districts Soldier Canyon Filter Plant do not have PAC feed systems and do not treat for geosmin removal. The City of Greeley water supply includes flows from the North Fork and Seaman Reservoir, although contributions from the North Fork are relatively small compared to the main stem. The high geosmin concentrations observed in Seaman Reservoir are currently not present at the Bellvue WTP intake. However, the potential issues related to high geosmin concentrations will become more important in the future if water from Seaman Reservoir makes up a greater proportion of the raw water supply to the Bellvue WTP. The potential geosmin issues that may be associated with an expanded Seaman Reservoir are unknown.

4.0 METHODOLOGY

The design of this Upper CLP monitoring program focused on developing a cooperative data collection, analysis, and reporting system. It is important to distinguish between data collection and information generation. In order for the monitoring program to be a successful information system, the data must be effectively used in analysis and reporting.

4.1 The Design Process

The objective of a collaborative monitoring program is to meet the informational needs and priorities of all the participating parties. The design process addressed five primary elements: objectives, parameter list, monitoring locations, sampling frequency, and reporting. Each element was discussed and analyzed in a series of meetings with all of the participating parties present. Decisions were made by group consensus to ensure the monitoring program would satisfy the needs of all three participating parties.

4.2 Monitoring Objectives

Monitoring objectives were determined based strictly on information needed to address water treatment issues. All three stakeholders cooperatively decided on the objective list. The final step in the design process will be to evaluate the success of the program once the project is completed and a yearly report has been produced. This evaluation will compare the design goals and objectives of monitoring with what is actually being achieved.

4.3 Parameter List

The parameter list was developed by starting with a combined list from the current sampling constituents being monitored by Fort Collins and Greeley (Appendix B). The retrospective analysis reports for the Upper CLP (Loftis and Moore, 2007a and 2007b) and the annual reports for the City of Greeley Monitoring Program (Lewis, 2001 – 2007) all provided valuable insight into the importance of specific water quality constituents. The combined list from both monitoring programs resulted in a lengthy list of constituents including everything from the most basic parameters to an extensive list of metals. Through the series of meetings, the initial parameter list was scaled back for a more cost effective program while still meeting the program's objectives. Parameters were dropped from the initial list if historic data consisted primarily of "non-detects."

4.4 Monitoring Network

Monitoring locations were selected based on a combination of the current monitoring sites for Fort Collins and Greeley (Appendix B). The redundant sites were eliminated. Each monitoring station was then individually discussed in terms of its rationale and relevance to goals of the program and its water quality characteristics as determined from the retrospective analyses. That discussion resulted in a decision to maintain or remove each site and, in one case, to move a site to fill an information gap in the current network.

4.5 Sampling Frequency Calculations

Design sampling frequencies for the new monitoring program were determined based on two statistical criteria and, of course, on cost. The primary statistical criterion was precision of estimating annual and seasonal mean concentrations. The sampling frequency selected for mean estimation was also evaluated in terms of the resulting ability to detect long-term trends. Both of these criteria depend both on sample sizes and the underlying variability of water quality. Since water quality and its variability are strongly seasonal, varying with both flow and temperature, the year was divided into four seasons with separate sampling frequencies selected for each season.

Seasons were determined based on annual water temperature and flow cycles. Four seasons were designated to depict the CLP cycles: high flow and low temperature (mid-April through June), moderate flow and moderate temperature (July and August), low flow and moderate temperature (September and October), low flow and low temperature (November through mid-April).

Historical data from City of Greeley network for the period 2000 through 2006 were used to determine background variances for key water quality parameters (ammonia, total organic carbon, conductance, and total phosphorous) for each season. The standard deviation for each season is the square root of the variance, and both are equivalent measures of temporal variability.

The historical standard deviations were then averaged over appropriate groups of similar stations and used to evaluate a range of alternative sampling frequencies in terms of the resulting precision (standard error) of estimating annual and seasonal means and power of detecting trends. The sampling frequency that appeared to provide the best compromise between performance and cost was selected. More details on the calculations follow.

The sampling frequencies considered as alternatives ranged from 10 samples to 22 samples per year, always with the greatest number of samples allocated to the highest variability seasons. This allocation strategy provides both the best estimate of annual means and the best estimate of means for the individual seasons of greatest interest and importance. Sample size calculations were broken into two groups, one for the main stem of the CLP and one for the North Fork. Historical data were used from main stem stations CHR, PBD, PJW, PNF, and PSF and North Fork stations NFL, NFG, NFRC, and PCM. Sample sizes were separately evaluated for the South Fork site, SFM.

To evaluate a particular sampling frequency alternative, such as 4, 3, 2, and 2 samples in each of four seasons respectively, the statistical sampling design approach described below was followed. The approach and associated equations are based on stratified random sampling, which is appropriate when the year is divided into somewhat homogeneous seasons or strata (Gilbert, 1987). This is essentially the same approach used in national opinion polls.

In the stratified sampling approach, the overall (annual) mean is computed as a weighted sum of means for each of the strata (seasons) as follows:

$$\bar{x}_{st} = \sum_h w_h \bar{x}_h$$

In the above equation, the summation is performed over all seasons, and

$\bar{x}_{st}$ = annual sample mean from stratified sampling
$\bar{x}_h$ = sample mean for stratum (season) h
w_h = stratum weight associated with season h

Three alternative weighting schemes were used in this analysis: time weighting, flow weighting, and assigning a weight of 0.4 to the spring and 0.2 to the other three seasons. The choice of weighting scheme did not greatly affect the results.

The performance of a given sampling frequency alternative is quantified by the following equation for the standard error of the sample mean, which is a quantitative measure of precision, for a given sample size:

$$s(\bar{x}_{st}) = \sqrt{\sum_h \frac{s_h^2 * w_h^2}{n_h}}$$

where:

$s(\bar{x}_{st})$ = standard error of the annual sample mean
s_h^2 = variance of stratum (season) h, determined from historical data
n_h = number of samples to be collected in stratum (season) h

For those who are accustomed to the concept of confidence intervals, a 95% confidence interval for the mean is approximately equal to the estimated mean ± two standard errors.

The percent error for the estimation of the annual mean using a given sampling frequency is calculated by dividing the standard error by the seasonally weighted average of the means, computed from historical data:

$$percent\ error = \frac{s(\bar{x}_{st})}{\sum w_h \bar{x}_h} 100$$

Alternative sampling frequencies are compared in terms of their percent errors.

The ability of a monitoring program to detect trends is usually characterized by the magnitude of the trend (expressed as a change in the mean) that can be detected with a given number of samples at a specified confidence level and power. The number of samples will be equal to a specified time horizon (in years) times a specified sampling frequency (in samples/year). This analysis considered both 5-year and 10-year time horizons, a 90% confidence level, and powers of 75% and 90%.

A confidence level of 90% implies that the probability (or significance level, α) that a trend will be detected if it does not actually exist is only 10%. The power of the test, denoted as 1-B, is the probability that a trend of the given magnitude will be detected if it does actually exist. Therefore, B is the probability that a real trend will not be detected, even though it exists.

The detectable trend for a given sample size, confidence level, and power is approximated by the following equation (Lettenmaier, 1976):

$$trend = \sqrt{\frac{12s^2(t_{\frac{\alpha}{2}(n-2)} + t_{\beta(n-2)})^2}{n}}$$

where:

trend	= the detectable trend magnitude, expressed as a total change in the mean that occurs over the time period during which n samples are collected. The trend is assumed to be roughly linear.
s^2	= variance of historical data (weighted over all four seasons)
$t_{\alpha/2(n-1)}$	= Student's t statistic for given confidence level (1-α) and sample size
$t_{\beta(n-1)}$	= Student's t statistic for given power (1-B) and sample size
n	= total number of samples over any sampling time horizon

For a given time horizon, such as 5 or 10 years, the total number of samples, n, is the annual sampling frequency times the number of years.

The calculated trend magnitude is represented as a percent of the historical mean weighted over all seasons, $\bar{x}_{wh}$, as follows:

$$percent\ trend = \frac{trend}{\bar{x}_{wh}} 100$$

The results of the sampling frequency calculations for both estimation of means and detection of trends are discussed in section 5.4. The numerical results of the calculations are presented in Appendix F for estimation of annual means and Appendix G for detection of trends. The trend detection calculations, in particular, can be somewhat difficult to interpret. A specific example is presented in section 5.4 to aid in interpretation.

5.0 MONITORING PROGRAM

The Upper CLP Collaborative Water Quality Monitoring Program is defined by the established objectives, monitoring network, water quality parameters, sampling frequency, sampling protocol, laboratory protocol, and data analysis and reporting procedures. Each of these elements is discussed in section 5.0.

5.1 Monitoring Objectives

The key water quality issues that could be considered within the Upper CLP watershed include:

- Drinking Water Quality: The presence of contaminants that pose health, aesthetic, or treatment problems for the use of water as a drinking water supply
- Ecological Integrity: Habitat protection to maintain a healthy diversity of flora and fauna of the streams and reservoirs
- Recreational Uses: The suitability of water for recreational use and the subsequent impact on water quality due to recreational use
- Eutrophication: The presence of increased nutrient loads and the occurrence of algae blooms

The specific objectives established for the Upper CLP Collaborative Water Quality Monitoring Program are to:

1. Assess water quality to address present and future water treatment process issues
2. Assess the seasonal and annual mass loads of specified water quality variables through the watershed
3. Assess the magnitude and statistical significance of temporal trends of selected variables
4. Assess the statistical significance of spatial trends of selected variables
5. Assess compliance with standards set by the CDPH&E for surface waters used as drinking water supplies
6. Detect changes in water quality due to land use activities in the watershed to support watershed protection efforts
7. Assess the health (trophic state) of reservoirs (Halligan and Seaman) on a seasonal and annual basis

The cooperative monitoring program was designed such that all data generated will be shared among the three participating entities.

5.2 Monitoring Network

The Upper CLP monitoring network is divided into two groups of stations: North Fork sites and main stem sties. Historically, there was a combined total of 28 sampling sites from these two areas that were sampled by the Cities of Greeley and Fort Collins (Figure 3.1 and Appendix B). The updated sampling design presented in this report includes 19 sites (Figure 5.1) and reflects group decisions to eliminate redundant sampling sites and add a new sampling location on the main stem. New site names were assigned and are shown in Table 5.1 along with brief rationale for their inclusion and GPS coordinates. A detailed discussion of the new set of 19 sites follows.

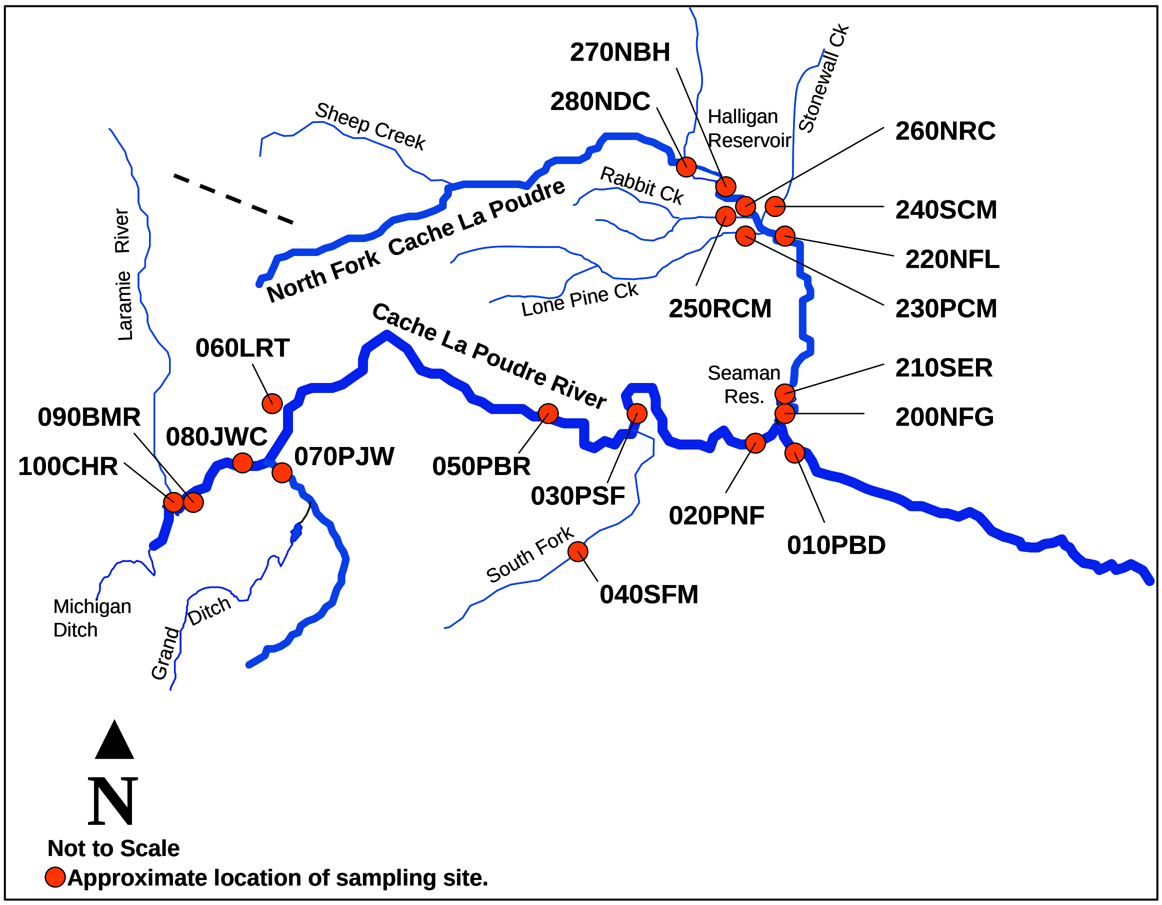


Figure 5.1 Map of the Upper CLP collaborative water quality monitoring network.

Table 5.1. Upper CLP collaborative water quality monitoring program sampling sites.

	MAIN STEM	Description	Rationale	GPS Coordinates
1	100CHR	Chambers Lake Outflow	Outflow from Chambers Lake	N 40° 36.039 W 105° 50.203
2	090BMR	Barnes Meadow Reservoir outflow	High TOC and nutrients compared to CHR	N 40° 36.039 W 105° 50.203
3	080JWC	Joe Wright Creek at Aspen Glen Campground	Joe Wright Creek above confluence with main stem	N 40° 37.233 W 105° 49.098
4	070PJW	Poudre at Hwy14 crossing (Big South Trailhead)	Above confluence Joe Wright Creek	N 40° 38.074 W 105° 48.421
5	060LRT	Laramie River at Tunnel at Hwy 14 crossing	Laramie River diversion water	N 40° 40.056 W 105° 48.067
6	050PBR	Poudre below Rustic	Midpoint between Laramie River Tunnel and South Fork; impacts to river from Rustic	N 40° 41.967 W 105° 32.476
7	040SFM	South Fork at bridge on Pingree Park Rd	Only access point on South Fork; South Fork water quality differs from main stem	N 40° 37.095 W 105° 31.535
8	030PSF	Poudre below confluence with South Fork - Mile Marker 101	Below confluence with South Fork	N 40° 41.224 W 105° 26.895
9	020PNF	Poudre above North Fork 1/2 mile upstream from Old FC WTP#1	Represents water diverted at Munroe Tunnel and at Old FC WTP #1	N 40° 42.087 W 105° 14.484
10	010PBD	Poudre at Bellvue Diversion	Greeley WTP Intake	N 40° 39.882 W 105° 12.995
	NORTH FORK			
11	280NDC	North Fork above Halligan Reservoir; above confluence with Dale Creek	Inflow to Halligan Reservoir	N 40° 53.852' W 105° 22.556'
12	270NBH	North Fork at USGS gage below Halligan Reservoir	Outflow from Halligan Reservoir	N 40° 52.654' W 105° 20.314'
13	260NRC	North Fork above Rabbit Creek	Main stem North Fork above Rabbit Creek; downstream of Phantom Canyon	N 40° 49.640 W 105° 16.776
14	250RCM	Rabbit Creek Mouth	Tributary to North Fork; drainage area includes agricultural/grazing lands; significant flows late spring to early summer only	N 40° 48.615 W 105° 17.146
15	240SCM	Stonewall Creek Mouth	Tributary to North Fork; drains area east of Hwy 287; significant flows late spring to early summer only	N 40° 48.458 W 105° 15.195
16	230PCM	Lone Pine Creek Mouth	Tributary to North Fork; drainage area includes Red Feather Lakes; significant flows late spring to early summer only	N 40° 47.696 W 105° 17.231
17	220NFL	North Fork at Livermore	At USGS gage	N 40° 47.269 W 105° 15.130
18	210SER	Seaman Reservoir	Reservoir profiles; impacts to water quality from nutrient loadings	N 40° 42.274 W 105° 14.210
19	200NFG	North Fork below Seaman Reservoir	At gage below Seaman Res; sample before flow enters Poudre main stem	N 40° 42.143 W 105° 14.064

The Greeley sampling program included both Chambers Lake outflow (CHR) and Barnes Meadow Reservoir outflow (BMR), located in the headwaters of the CLP watershed near the Continental Divide. The water quality of Barnes Meadow is significantly different than Chambers Lake, and thus both reservoir releases will continue to be sampled. Historically Barnes Meadow Reservoir water has high TOC. Samples will be taken at these sites only when the reservoirs are releasing water. The water commissioner should be contacted to ensure flows from the reservoirs before each sampling event. The new site names are 100CHR and 090BMR for Chambers Lake and Barnes Meadow Reservoir, respectively.

Samples in the headwaters area are also collected on Joe Wright Creek downstream of Joe Wright Reservoir, and on the CLP main stem upstream of the confluence with Joe Wright Creek. The new name for the site on Joe Wright Creek is 080JWC. A USGS gage (USGS6746110) is located on Joe Wright Creek at approximately the same location and provides supplemental discharge data for this site. The site on the CLP main stem upstream of the confluence with Joe Wright Creek was formerly the redundant sites Greeley PJW and FCWTF 9. The new site name at this location is 070PJW.

Fort Collins historically sampled above the Laramie Tunnel outfall (FCWTF 8). This site was dropped from the monitoring program because water is already sampled above the tunnel on Joe Wright Creek and on the main stem site, as well as from the tunnel outfall itself (FCWTF 7). The new designation for the Laramie Tunnel outfall is 060LRT.

The successive downstream Fort Collins sites (FCWTF 5 and 6) are located above and below Sheep Creek. Site 5 was removed because the data did not show significant differences in water quality above and below the Sheep Creek confluence. Nitrates, turbidity, alkalinity, and hardness data were plotted for both sites and show similar water quality (Figure 5.2). Historically, Sheep Creek had a reservoir and was added to the monitoring program for that reason. The reservoir dam was vandalized, destroyed, and never replaced.

Site FCWTF 6 was moved to a new monitoring location downstream of Rustic. This site gives a better representation of the water quality throughout the stretch from the Laramie Tunnel to the South Fork confluence and monitors potential impacts from Rustic. The new site name for the location on the Poudre near Rustic is 050PBR.

Next in succession downstream, Fort Collins and Greeley have historically sampled at the same approximate location above the South Fork confluence (FCWTF 4 and PSF) and on the South Fork on Pingree Park Road (FCWTF 3 and SFM). Fort Collins also samples below the South Fork confluence on the CLP at mile marker 101 (FCWTF 2). The main stem site above the South Fork confluence was dropped from the network. The site below the South Fork confluence and the site on the South Fork were kept as monitoring locations because there are significant differences in water quality between the main stem and the South Fork. The new site designation on the Poudre below the South Fork confluence is 030PSF, and 040SFM is the new site name on the South Fork. The sampling frequency at 040SFM was reduced to six samples per year to optimize the monitoring program based on sample size calculations and cost.

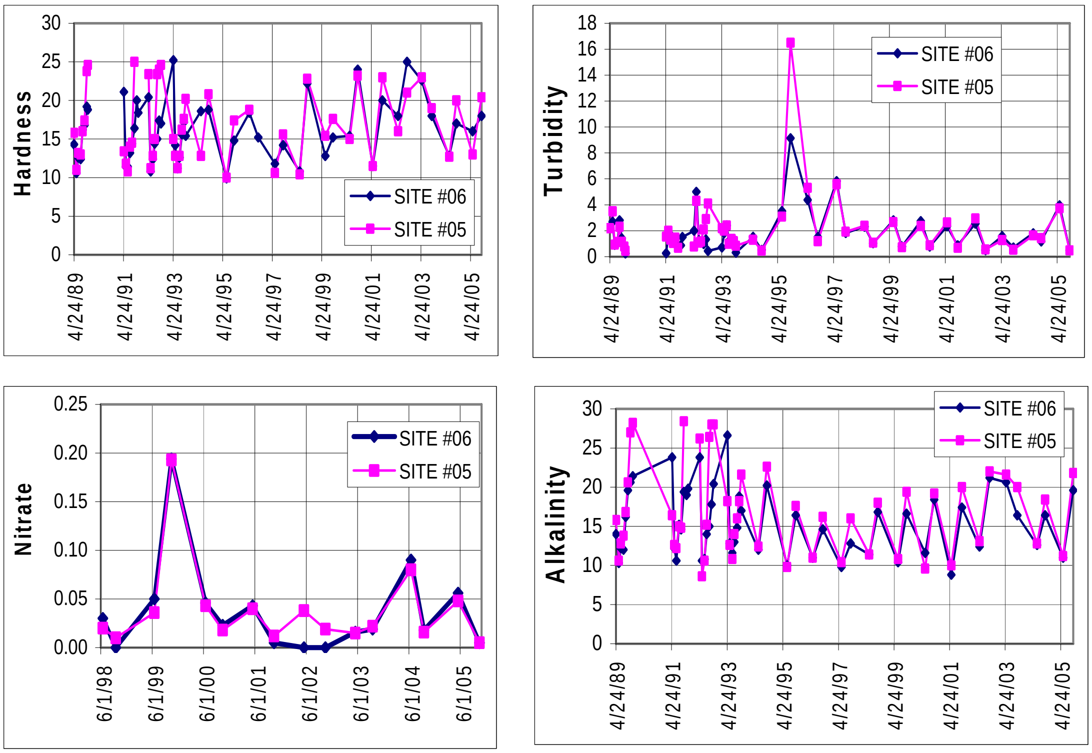


Figure 5.2. Time series comparison of nitrates, turbidity, alkalinity, and hardness at the sites above and below Sheep Creek (FCWTF 5 and 6).

The historic sites FCWTF 1 and Greeley PNF are redundant sites located just upstream of the confluence with the North Fork. The new site will be located at the Greeley PNF location with the new name 020PNF. The most downstream site on the Upper CLP main stem is a Greeley site (PBD) at the Bellvue diversion and will be identified in the new program as 010PBD.

Historically, Greeley and Fort Collins have sampled at different locations along the North Fork and its tributaries. Fort Collins sampled at two sites on the North Fork. The northernmost site is on the North Fork above Halligan Reservoir. The second site is downstream of Halligan Reservoir at the USGS gage. Sampling at these two sites began in 2006, and the two sites are now included in the new monitoring program with site names 280NDC and 270NBH. The site above Halligan Reservoir (280NDC) has historically been sampled below the confluence with Dale Creek. However, the site has been moved upstream of the Dale Creek confluence because the high water level for the proposed Halligan Reservoir expansion will extend to Dale Creek.

Greeley has sampled at eight locations on the North Fork and its tributaries, from Rabbit Creek downstream to the confluence with the main stem. In the new monitoring program, there are three sampling locations on the tributaries: Rabbit Creek (RCM), Stonewall Creek (SCM), and Lone Pine Creek (PCM). The new site names are 250RCM, 240SCM, and 230PCM. Rabbit Creek and Stonewall Creek experience very low flows most of the year except during spring runoff and the start of summer. Lone Pine Creek drains the Red Feather

Lakes region and has more significant flows than the other tributaries, but still has minimal flows during the summer months. The monitoring program does not require sampling at these sites during periods of no flow or low flows.

On the North Fork itself, sampling has historically been conducted by Greeley on the North Fork above Rabbit Creek (NFRC), North Fork at Livermore (NFL), on Seaman Reservoir itself (MSR), at the outflow from the reservoir (SER), and below Seaman Reservoir near the Colorado Division of Water Resources gage (NFG). The North Fork above Rabbit Creek and the North Fork at Livermore sites will be retained for the new monitoring program with the site names changed to 260NRC and 220NFL, respectively. Sampling will also be continued at one location on Seaman Reservoir, with the site name changed to 210SER. The outflow site (SER) was removed from the new design because it was considered redundant with the successive site just downstream at the gage (NFG). The new site name at the gage on the North Fork below Seaman Reservoir is 200NFG.

5.3 Parameter List

An initial parameter list was developed to encompass all of the current parameters being monitored by both parties (Appendix B). Specific parameters were discussed for removal from the list based on analysis of the historic data. A finalized list was developed to meet funding constraints and informational needs, and is shown in Table 5.2.

The parameter list in Table 5.2 will be monitored at all locations within the system, with the few exceptions noted. Additional parameters not included in Table 5.2 may be monitored on a site specific basis if needed. These parameters include but are not limited to low level mercury, BTEX, geosmin, and antibiotics, personal care products, and other emerging contaminants.

Geosmin is not included as a routine parameter due to cost. The existing geosmin data presented in Section 3.7.3 have provided an adequate understanding of its concentrations and occurrence in the watershed and the potential implications for water treatment. A limited number of samples may be collected during the late summer and fall from Halligan and Seaman Reservoirs, and more intensive sampling may be conducted as part of a future special study.

Continuous discharge measurements are currently taken at the five gages listed in Table 2.1. Discharge has also been measured by current meter when water quality samples were taken within the existing Greeley network. Current meter measurements will continue with the new monitoring program when and where water levels permit wading the stream. However, additional continuous discharge measurements are needed to provide for load estimation and study of flow versus quality relationships. The recommended new locations for continuous discharge measurement stations are 050PBR on the main stem below Rustic, 040SFM on the South Fork, and 280NDC on the North Fork above Halligan Reservoir.

Table 5.2. Upper CLP collaborative water quality monitoring program parameter list.

	Rationale	Notes
Field Parameters		
Conductance	Indicator of total dissolved solids.	Profile at Seaman Reservoir
Dissolved Oxygen	Profile indicates stratification, importance for aquatic life and chemical processes.	Profile at Seaman Reservoir
Secchi Disk	Measure of transparency.	Seaman Reservoir only
Temperature	Reflects seasonality; affects biological and chemical processes; water quality standard.	Profile at Seaman Reservoir
pH	Measure of acidity. Many biological and chemical processes are pH dependent.	
General & Miscellaneous Parameters		
Alkalinity	Indicator of carbonate species concentrations; Acid neutralizing capacity of water; treatment implications.	
Chlorophyll-a	Reflects algal biomass.	Seaman Reservoir only
Discharge	Necessary for flow dependant analysis and load estimation; will only be taken at specific sites.	Measured during sampling at NRC, RCM, SCM, PCM, PJW
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; water quality standard.	
Nitrate	Primary source of nitrogen to algae; indicator of pollution by sewage, septic tanks, agriculture; water quality standard.	
Nitrite	Toxic inorganic nitrogen species; rarely encountered at significant concentrations; water quality standard.	
Total Kjeldahl Nitrogen	Sum of organic nitrogen and ammonia.	
Ortho-Phosphorus (Soluble Reactive Phosphorus)	Form of phosphorous (dissolved PO_4^{-3}) most available to algae; indicator of pollution by sewage, septic tanks, agriculture.	
Total Phosphorus	Includes dissolved and adsorbed, organic and inorganic forms of phosphorus, indicator of pollution by sewage, septic tanks, agriculture.	

		Table 5.2 continued
Major Ions		
Calcium	Major ion.	Monitor for two years at half frequency (6x/yr)
Chloride	Major ion.	Monitor for two years at half frequency (6x/yr)
Magnesium	Major ion.	Monitor for two years at half frequency (6x/yr)
Potassium	Major ion, minor importance as a nutrient.	Monitor for two years at half frequency (6x/yr)
Sodium	Major ion.	Monitor for two years at half frequency (6x/yr)
Sulfate	Major ion.	Monitor for two years at half frequency (6x/yr)
Microbiological Constituents		
E. Coli	Indicator of human or animal waste contamination; water quality standard.	Only from Rustic downstream, NFG, SER, and SFM
Total Coliform	Indicator of human or animal waste contamination.	Only from Rustic downstream, NFG, SER, and SFM
Cryptosporidium	Pathogen, indicator of human or animal waste contamination.	Above and below Halligan Reservoir, and below Seaman Reservoir
Giardia	Pathogen, Indicator of human or animal waste contamination.	Above and below Halligan Reservoir, and below Seaman Res
Algal Species Composition	Shows presence of nuisance species and trophic state.	Seaman Reservoir surface sample only
Metals		
Cadmium, dissolved	Indicator of pollution from mining activity at elevated levels; water quality standard.	Only PNF & NFG (2x/yr)
Chromium, dissolved	Water quality standard.	Only PNF & NFG (2x/yr)
Copper, dissolved	Water quality standard.	Only PNF & NFG (2x/yr)
Iron, Total	Affects aesthetic quality of treated water.	Only PNF & NFG (2x/yr)
Iron, dissolved	Affects aesthetic quality of treated water.	Only PNF & NFG (2x/yr)
Lead, dissolved	Indicator of pollution from mining activity at elevated levels; water quality standard.	Only PNF & NFG (2x/yr)
Nickel, dissolved	Indicator of pollution from mining activity at elevated levels; water quality standard.	Only PNF & NFG (2x/yr)
Silver, dissolved	Indicator of pollution from mining activity at elevated levels.	Only PNF & NFG (2x/yr)
Zinc, dissolved	Indicator of pollution from mining activity at elevated levels.	Only PNF & NFG (2x/yr)
Mercury, Low Level	Accumulates in fish tissue even when present in very low concentrations.	Sample every 3 to 5 yrs.

5.4 Designation of Seasons and Sampling Frequencies

Greeley's historic temperature and flow data were used to identify the four seasons described earlier and shown below in Table 5.3. Seasonal average water temperatures are shown for three selected sites in Figure 5.3 below. Those three sites are Poudre above Joe Wright Creek, PJW; Poudre below South Fork, PSF; and Poudre at Bellvue Diversion, PBD. The temperature varies spatially and temporally. As expected, the Poudre below Joe Wright Creek (PJW) has on average the lowest temperatures, and the Poudre at the Bellvue Diversion (PBD) has the highest temperatures. Obviously, the lowest temperatures annually occur during the winter and spring seasons (seasons 4 and 1, respectively), and the highest temperatures occur during the summer and fall (seasons 2 and 3, respectively).

Table 5.3. Designation of seasons and recommended number of samples per season.

Season	Month	Flow and Temperature	No. of samples
1	Mid April - June	High flow, moderate temperature	5
2	July - August	Moderate flow, high temperature	2
3	September - October	Low flow, moderate temperature	2
4	November – Mid April	Low flow, low temperature	2
Total samples per year			**11**

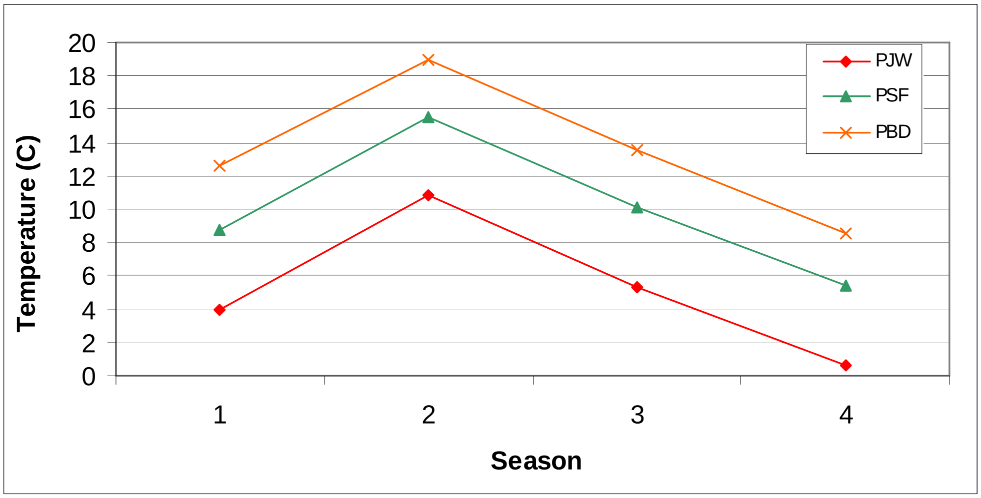


Figure 5.3. Average seasonal water temperatures, 2000-2006, at three stations on the Upper CLP and tributaries. PJW = Poudre below Joe Wright Creek, PSF = Poudre below South Fork, PBD = Poudre at Bellvue Diversion.

Seasonal average discharges are shown for three sites in Figure 5.4 below. The three sites are Poudre above Joe Wright Creek, PJW; South Fork on Pingree Park Road, SFM; and Poudre below South Fork, PSF. The graphs demonstrate the typical flow pattern, with high flows in the spring and low flows throughout the autumn and winter seasons. The greatest variation among the sites occurs during the spring runoff, with the highest flows occurring at the lower main stem site and the lowest flows at the South Fork site.

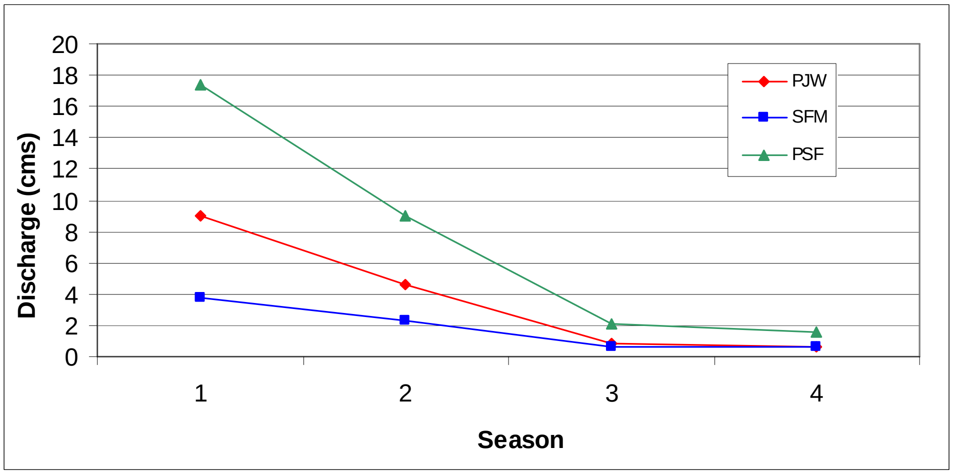


Figure 5.4. Average seasonal discharge measurements, 2000-2006, at three stations on the Upper CLP and tributaries. PJW = Poudre below Joe Wright Creek, SFM = South Fork on Pingree Park Road, PSF = Poudre below South Fork.

Design sampling frequencies were determined to provide the best tradeoff between statistical performance and cost. The design approach involved evaluating a range of feasible annual sample sizes and allocations across the four seasons, using the stratified random approach described in section 4.5. The alternative sample sizes were compared, primarily in terms of their resulting precision in estimating annual and seasonal mean concentrations. The alternative sampling frequencies ranged from bi-weekly to once every three months. The results of the calculations are shown in Appendix F. In general the higher sampling frequencies did not offer a great improvement in statistical performance compared to the lower frequencies. Therefore, only a modest number of total samples per year (eleven) was selected for the design. The allocation of samples across seasons is shown in Table 5.3. To provide the best statistical performance, the greatest number of samples is allocated to the season with the greatest temporal variability. Thus, season 1 has the highest sampling frequency with five samples during the two month period. Seasons 2, 3, and 4 each will have two sampling events per season.

The calculations of detectable trend for various sample sizes were described in section 4.5, and the results of those calculations are shown in Appendix G. The calculations described in section 4.5 determine the magnitude of the trend that can be detected for a given sample size with a power of either 75% or 90% and a confidence level of 90%. The power is the probability of detecting a real trend, and the confidence level is the probability of concluding that there is no trend when none actually exists. For a fixed power and confidence level, the magnitude of the trend that can be detected decreases with increasing sample size -- it takes more samples to detect smaller trends.

The figures presented in Appendix G give the size of the detectable trend for a range of sample sizes. To aid in the interpretation of the figures, let us consider as an example Figure G.1. “Linear trend detection performance for TOC at 90% power and 90% confidence for selected Greeley sites.” The total number of samples collected is shown on the horizontal axis, and the detectable trend is presented on the vertical axis as a percent of the historical mean. The total number of samples is the number of samples per year times the number of years in the study period. For our design sampling frequency of 11 samples per year, the total number of samples is 55 for a five-year period, and 110 for a ten-year period. For all of the stations presented in Figure G.1 except station PSF, the detectable trend in TOC after five-years (55 samples) is about 30% of the historical mean and drops to about 20 percent of the historical mean after ten years (110 samples). However for station PSF the detectable trend is much larger, roughly 175% of the historical mean after five years and 110% of the historical mean after 10 years. The detectable trend is larger at station PSF because the background variance, relative to the mean, is larger at that station, making the trend harder to discern through the noise.

Results for the other variables presented in Appendix G are similar. For 90% power and 90% confidence, the detectable trend for total phosphorus ranges (across stations) roughly from 50% to 150% of the historical mean after five years (55 samples) and roughly from 20% to 100% of the historical mean after ten years (110 samples). The detectable trend for specific conductance ranges (across stations) roughly from less than 10% to 80% of the historical mean after five years (55 samples) and roughly from 5% to 60% of the historical mean after ten years of monitoring (110 samples).

The results for 75% power, keeping the confidence level at 90%, are very nearly the same as for 90% power. The detectable trends are very slightly smaller. An overall conclusion of this analysis is that trend detection is fairly difficult. It will take at least five to ten years of monitoring at 11 samples per year to detect even fairly substantial trends.

Exceptions to design sampling frequencies. Several exceptions to the sampling frequencies shown in Table 5.3 were developed in order to reduce program costs:

- Small tributaries such as Rabbit Creek, Stonewall Creek, and Lone Pine Creek are to be sampled only when significant flow exists.
- Sampling frequencies were cut in half for the South Fork site 040SFM.
- Coliform sampling was limited to the four main stem sites at and downstream of Rustic: 050PBR, 030PSF, 020PNF, and 010 PBD; North Fork sites 200NFG, 210SER; and South Fork site 040SFM.
- *Cryptosporidium* and *Giardia* sampling is done only above and below Halligan Reservoir at 280NDC and 270NBH, and below Seaman Reservoir at 200NFG.
- The major ions have a reduced frequency of six samples per year for the first two years of the monitoring program. At the end of the two year period, continued sampling for major ions will be re-assessed.
- Metals will be sampled only at 020PNF and 200NFG and only twice per year.

Sampling on Seaman Reservoir will occur at a single location near the outlet and will have the same frequency and constituents as the stream sites, with the addition of algal species composition, chlorophyll-a, and Secchi disk measurements. Grab samples from Seaman Reservoir will be collected at the top and bottom of the water column. Additionally, dissolved oxygen, conductance, and temperature profiles will be taken at 1 meter intervals.

The 2008 sampling plan, including the sampling schedule is shown in Table 5.4.

	2008 Sampling Date										
	Apr 8- 9	Apr 29- 30	May 13-14	May 27-28	June 10-11	June 24-25	July 22-23	Aug 19-20	Sept 17-18	Oct 15-16	Nov 12-13
Station											
North Fork											
280NDC[3]	F,G,P	F,G,I	F,G,P	F,G,I	F,G,P	F,G,I	F,G,P	F,G,I,P	F,G,P	F,G,I,P	F,G,I
270NBH[3]	F,G,P	F,G,I	F,G,P	F,G,I	F,G,P	F,G,I	F,G,P	F,G,I,P	F,G,P	F,G,I,P	F,G,I
260NRC	F,G,D	F,G,I,D	F,G,D	F,G,I,D	F,G,D	F,G,I,D	F,G,D	F,G,I,D	F,G,D	F,G,I,D	F,G,I,D
250RCM	G,D	F,G,I,D	F,G,D	F,G,I,D	F,G,D	F,G,I,D					
240SCM	G,D	F,G,I,D	F,G,D	F,G,I,D	F,G,D	F,G,I,D					
230PCM	G,D	F,G,I,D	F,G,D	F,G,I,D	F,G,D	F,G,I,D					
220NFL	F,G	F,G,I	F,G	F,G,I	F,G	F,G,I	F,G	F,G,I	F,G	F,G,I	F,G,I
200NFG	F,G,E,P[4]	F,G,I,E	F,G,E,P	F,G,I,M,E	F,G,E,P	F,G,I,E	F,G,E,P	F,G,I,E,P	F,G,E,P	F,G,I,M,E,P	F,G,I,E
Main Stem											
100CHR	F,G	F,G,I	F,G	F,G,I	F,G	F,G,I	F,G	F,G,I	F,G	F,G,I	F,G,I
090BMR[2]	F,G	F,G,I	F,G	F,G,I	F,G	F,G,I	F,G	F,G,I	F,G	F,G,I	F,G,I
080JWC	F,G	F,G,I	F,G	F,G,I	F,G	F,G,I	F,G	F,G,I	F,G	F,G,I	F,G,I
070PJW	F,G,D	F,G,I,D	F,G,D	F,G,I,D	F,G,D	F,G,I,D	F,G,D	F,G,I,D	F,G,D	F,G,I,D	F,G,I,D
060LRT	F,G	F,G,I	F,G	F,G,I	F,G	F,G,I	F,G	F,G,I	F,G	F,G,I	F,G,I
050PBR	F,G,E	F,G,I,E	F,G,E	F,G,I,E	F,G,E	F,G,I,E	F,G,E	F,G,I,E	F,G,E	F,G,I,E	F,G,I,E
040SFM		F,G,I,D		F,G,I,D		F,G,I,D		F,G,I,D		F,G,I,D	F,G,I,D
030PSF	F,G,E	F,G,I,E	F,G,E	F,G,I,E	F,G,E	F,G,I,E	F,G,E	F,G,I,E	F,G,E	F,G,I,E	F,G,I,E
020PNF	F,G,E	F,G,I,E	F,G,E	F,G,I,E,M	F,G,E	F,G,I,E	F,G,E	F,G,I,E	F,G,E	F,G,I,E,M	F,G,I,E
010PBD	F,G,E	F,G,I,E	F,G,E	F,G,I,E	F,G,E	F,G,I,E	F,G,E	F,G,I,E	F,G,E	F,G,I,E	F,G,I,E
Reservoir											
210SER[1]	F,G,A,C,E	F,G,I,A,C,E	F,G,A,C,E	F,G,I,A,C,E	F,G,A,C,E	F,G,I,A,C,E	F,G,A,C,E	F,G,I,A,C,E	F,G,A,C,E	F,G,I,A,C,E	F,G,I,A,C,E

[1] Grab samples taken at two depths (Top & Bottom); meter samples at 1-m intervals.
[2] Call commissioner to find out if water is flowing. If not flowing, skip sample.
[3] To be sampled by Fort Collins personnel; all other stations to be sampled by Dr. Bill Lewis' Team.
[4] Giardia/Cryptosporidium sampling to be conducted bv Fort Collins personnel.

Table 5. 4. Upper CLP Collaborative Water Quality Monitoring Program 2008 Sampling Plan: A = Algae (Lugol's); C = Chlorophyll (500 mL sample); D = Flow; F = Field data (Temp, pH, conductance streams + Secchi, DO for lake); G = 1 liter sample for general, nutrients, TOC; E = *E. coli*, coliform (500 mL sterile bottle); I = Major ions; M = Metals; P = *Giardia/Cryptosporidium*.

5.5 Sampling Methods and Protocol

The standardization of sampling methods and protocols is critical to obtaining high quality data. The sampling protocol for the Upper CLP Collaborative Water Quality Monitoring Program is presented in this section.

In order to provide continuity between historic data records and future monitoring, the sampling methods will be similar to old methods unless stated otherwise in the annual report. A written field methodology will assure that all sampling teams and efforts are using the same protocol. It is important that all sampling personnel be trained consistently, and that they review the protocol before sampling begins each year.

The sample collection methods to be applied to this program will adhere to standard protocols for the collection of water quality samples. The field sampling protocol will consist of the following:

- Samples will be collected in clean bottles appropriate for the specified analysis.
- Appropriate sample preservation methods and holding times, as shown on Table 5.5, will be adhered to.
- Approximately 10 percent of the total sample load will consist of field quality control samples (field blanks and field duplicate samples).
- At a given field site, the (clean) bottle will be filled three times with water from the site to be sampled and rinsed with that water.
- The sample will be collected by immersion of the bottle in the stream at the collection site, with the bottle pointed upstream of the individual who is doing the sampling. The point of sampling in each case will be the center of the main flow, or as near as practical. Sampling the center of the flow avoids potentially confusing influences from small amounts of seepage or ungaged flow coming into the shallower water near the sides of the stream.
- The bottles will be capped and stored in insulated containers to keep the sample cool and minimize exposure to sunlight.
- The samples will be delivered to the laboratory on the day of collection.
- Fractions requiring filtration should be filtered on the day of collection.
- Bottles to be reused will be cleaned and dried by the laboratory for use in collection of future samples.

Table 5.5 Analytical methods, sample preservation, and sample 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	none	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		none	28 days
	Total Dissolved Solids	SM 2540 C	10 mg/L	cool, 4C	7 days
	Turbidity (NTU)	SM2130B,EPA180.1	0.01 units	none	48 hrs
Nutrients	Ammonia - N	Lachat 10-107-06-2C	0.02 mg/L	H_2SO_4	28 days
	Nitrate + Nitrite	EPA 300 (IC)	0.2 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 as CaCO3	SM 3500-Ca D	2.0 mg/L	none	28 days
	Chloride	EPA 300 (IC)	1.0 mg/L	none (eda)	28 days
	Magnesium, flame	SM 3111 B	0.2 mg/L	HNO_3 pH <2	6 mos
	Potassium	SM 3111 B	0.2 mg/L	HNO_3 pH <2	6 mos
	Sodium, flame	SM 3111 B	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	SM 3113 B	0.1 ug/L	HNO_3 pH <2	6 mos
	Chromium	SM 3113 B	0.5 ug/L	HNO_3 pH <2	6 mos
	Copper, GFAA	SM 3113 B	3 ug/L	HNO_3 pH <2	6 mos
	Iron, GFAA (total & dissolved)	SM 3113 B	5 ug/L	HNO_3 pH <2	6 mos
	Lead	SM 3113 B	1 ug/L	HNO_3 pH <2	6 mos
	Nickel	SM 3113 B	3 ug/L	HNO_3 pH <2	6 mos
	Silver	SM 3113 B	0.5 ug/L	HNO_3 pH <2	6 mos
	Zinc, flame	SM 3111 B	100 ug/L	HNO_3 pH <2	6 mos
TOC	TOC	SM 5310 C	0.5 mg/L	HCl 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.					

- Temperature, pH and specific conductance measurements will be obtained at each site by placing the Hach Hydrolab (or equivalent) probe directly in the stream flow, at or as near as possible to the site where samples are collected. Due to extremely low flows from Barnes Meadow Reservoir and the frequent build-up of attached algae on the bottom of the flume, the reservoir outflow will be collected in a bucket and the Hydrolab probe will be submerged in the bucket to measure field parameters.

- Flow measurements will be recorded using a FlowMate (or equivalent) flow meter at 1m intervals in larger streams. In the smaller streams, flow measurements will be taken at 0.5m intervals. In the event that high velocity flows inhibit a complete flow transect, measurements will be taken as far along the transect as possible from each side of the stream bank.

- Grab samples from Seaman Reservoir will be collected using a Van Dorn Sampler at the top and bottom of the water column. Dissolved oxygen, conductance, and temperature profiles will be taken at 1 meter intervals using a Hach Hydrolab (or equivalent) multi-parameter probe.

- Field notes will be made during each sampling event and will consist of sample identification numbers for a given date (same as shown on labels attached to sample bottles), indication of any unusual conditions or problems, other potentially relevant observations, weather conditions, time of day for each sample collected, and records of the field measurements of temperature, specific conductance, and pH. A field data sheet will be prepared to help ensure consistent documentation of all required field information. The numeric information will be transferred to a spreadsheet that will hold the cumulative data across all sampling dates.

- Field probes for measurement of temperature, dissolved oxygen, specific conductance and pH will undergo calibration and verification prior to each sampling event. The membrane-style dissolved oxygen probe will be calibrated in the lab using barometric pressure and a half-saturated oxygen gas.

5.5.1 Sample Timing

The design sampling frequency specifies how many samples are needed for each season but does not specify what day of the week and time of day to sample. Choosing the best date and time depends on the characteristics of the watershed, the resources of the monitoring program and requirements of the laboratory for sample delivery.

For rigorous statistical analysis, samples must be collected at random, with each potential sampling unit (for example a 1 liter sample) having an equal chance of being collected. In practice, truly random sampling is almost impossible to achieve. However, several steps can be taken to minimize aliasing of the data by non-random sampling. By “aliasing,” we mean an interaction between the sampling pattern and natural patterns in water quality, such as daily, weekly, or annual cycles, that cause estimated means or other statistics to be shifted higher or lower than their true values.

A number of factors can cause aliasing of the data. Some of these factors can easily be reduced, whereas others may need to be acknowledged and the potential effects understood. Common causes for aliasing are periodic discharges, diurnal fluctuations, and sampling personnel work schedules. In order to reduce the occurrence of sampling during periodic discharges, sampling should rotate among different days of the week. Aliasing from diurnal variation can be minimized by varying the start time or sampling the sites in reverse order during alternate sampling events. Aliasing caused by work schedules may be the most difficult to reduce. Generally weekend samples are never taken due to crew scheduling and laboratory personnel availability. Aliasing of discharge measurements can result from scheduling if the weekend flows are never measured. However, the use of continuous streamflow monitoring stations effectively solves this problem.

5.5.2 Sampling Locations

Each specific monitoring site has already been identified. Sampling protocols should stress the importance of sampling at the same exact location each time. Detailed directions to each site, GPS coordinates, and site photos are important so that someone who might be going to the site for the first time can find its exact location on the river or reservoir. Descriptions and photographs for each of the 19 sites of the Upper CLP Collaborative Water Quality Monitoring Program are included in Appendix H.

5.5.3 Field and Laboratory Quality Assurance/ Quality Control

Quality control in the field is essential for high quality data. Sampling personnel must be trained to properly use all field equipment. Equipment must be maintained and calibrated on a standard basis. The protocols outlined in Section 5.5 will be followed to assure standardization and consistency for each sampling event.

The City of Fort Collins Water Quality Laboratory has an established QA/QC protocol that is applied to all samples received by the lab for analysis. The primary features of their QA/QC protocol include:

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

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

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

Any laboratory that is contracted to conduct the water quality analyses for the Upper CLP Monitoring Program should have standard QA/QC procedures that include the features outlined above.

5.6 Reporting

The regular production of reports is an essential feature of a meaningful monitoring program. Data analysis and reporting turn data into useful information. Annual and five year reports will be produced for this monitoring program and will be designed with the informational goals in mind. Annual reports will briefly describe water quality, hydrology and any special features of the most recent year (such as floods, droughts, fires, or contaminant spills) in comparison to the previous three years. The five-year reports will provide a more in-depth review and analysis, including analysis of temporal trends. Proposed outlines for both annual and five-years reports are included in Appendix I. Routine data analysis and reporting may reveal water quality issues or information gaps that need to be addressed by modification of the monitoring program or by one-time special studies.

6.0 SUMMARY

This report documents the Upper CLP Collaborative Water Quality Monitoring Program designed for the City of Fort Collins, the City of Greeley and the Tri-Districts. The primary focus of this monitoring program is the collection and assessment of water quality data to provide information that will help the collaborating entities meet present and future drinking water treatment goals.

A significant amount of information related to watershed features, existing water quality, and the results of the monitoring program design is documented in this report. A summary of the information presented for each of these general topics, as well as recommendations for the future, is provided below:

Watershed Features

- The Upper CLP watershed originates at the Continental Divide, drains 1,016 square miles with an elevation drop of 5,100 feet, and receives water from neighboring watersheds via trans-mountain and trans-basin diversions.

- The Upper CLP watershed consists of two primary sub-basins, the main stem (including the South Fork), and the North Fork. The North Fork sub-basin extends into Wyoming, and includes about 54% of the total watershed area.

- The North Fork sub-basin includes somewhat more intensive land use (with more agricultural and grazed lands and slightly more developed land) than the main stem sub-basin, which is primarily forest.

- Destruction of lodgepole and ponderosa pine trees from pine beetle infestations, along with the related increased threat of wildfires, will impact the quantity and quality of runoff within the watershed.

- Recreation draws many people to the Upper CLP, and increasing recreational pressures will likely impact water quality.

- The CDPH&E Source Water Assessment and Protection (SWAP) report and associated databases indicate that potential sources of contaminants in the Upper CLP include sites within the “existing/abandoned mine site” category and the “aboveground, underground and leaking storage tank sites” category. None of this information has been verified by site visits or other field evaluations.

Existing Water Quality

- The Upper CLP provides a high-quality source of water for domestic and other uses.

- Most of the Upper CLP flow is provided by snowmelt, and the dominant feature of CLP hydrology is the dramatic annual cycle in flow rates and associated water quality parameters.

- The spring snowmelt and runoff peak is accompanied by high TOC and turbidity and low alkalinity. This combination provides special challenges for water treatment, which are generally met by blending Poudre River water with Horsetooth Reservoir water during the peak snowmelt runoff period.

- Water quality of the North Fork is significantly different from that of the main stem and South Fork. North Fork water tends to contain higher nutrient concentrations and higher TOC during most of the year. TOC concentrations on the main stem are higher than those on the North Fork only during peak runoff.

- Milton Seaman Reservoir on the North Fork is subject to algal blooms and anoxic conditions below the thermocline during much of the summer. Anoxic conditions can lead to the release of phosphorus, manganese, and iron from the bottom sediments. Nutrient enrichment of Seaman Reservoir has resulted in algal blooms, including blue-green algae which are known sources of geosmin and other taste and odor compounds.

- Geosmin has been seasonally detected in Halligan and Seaman Reservoirs at concentrations over 100 ng/L. Geosmin imparts an earthy odor to water, is very difficult to remove during treatment, and can be detected by the most sensitive noses at extremely low concentrations (5 to 10 ng/L).

- The City of Greeley Bellvue Water Treatment Plant receives water from the main stem Upper CLP below the North Fork and Seaman Reservoir. There is concern over the quality of water in Seaman Reservoir compared to other Poudre water that reaches the Bellvue Water Treatment Plant intake. However, the flows on the North Fork below Seaman Reservoir are relatively small compared to the main stem Upper CLP flows. Poudre water at the Bellvue Water Treatment Plant can be blended with water from Horsetooth Reservoir to minimize water quality problems.

- Both Halligan and Seaman Reservoirs are under consideration for possible major expansion. Thus North Fork water quality issues may become more important in the future.

Upper CLP Monitoring Program Design

- Monitoring program objectives: objectives address water treatment process information needs, temporal and spatial trends, standards compliance, watershed protection, mass loads of specified variables, and the health of reservoirs.

- Monitoring network: a total of 19 sites, including nine on the main stem, eight on the North Fork and North Fork tributaries, one on the South Fork, and one on Seaman Reservoir.

- Sampling frequency: 11 times per year, including five events during spring runoff (mid-April – June), two during summer (July – August), two in fall (September – October), and two in winter (November – mid-April).

- Routine monitoring parameters: flow, field data, general parameters, nutrients, TOC, major ions, metals, and pathogens.

- In order to reduce program costs, not all sites will be sampled 11 times/year, and not all sites will be sampled for the whole suite of routine parameters.

- Additional parameters may be monitored on a site specific basis during future special studies, including low level mercury, BTEX (benzene, toluene, ethylbenzene, and xylenes), geosmin, and antibiotics, personal care products, and other emerging contaminants.

- Annual and five year reports will be produced as part of this monitoring program.

Recommendations for the Future

- Installation and maintenance of flow gaging stations by the USGS is recommended; recommended sites include the South Fork, the main stem below Rustic, and the North Fork above Halligan Reservoir.

- Low level mercury sampling and analysis should be conducted every three to five years across the watershed.

- A cooperative study with the USGS should be conducted to update the USGS/Collins & Sprague (2005) study on the presence of pesticides, personal care products and other wastewater compounds (emerging contaminants) in Upper CLP waters. Depending on the findings, such monitoring should continue to be conducted every five years.

- Field verification of the CDPH&E SWAP reports and associated databases should be performed to better assess the identified potential point and non-point sources of contamination.

The CLP is a high quality drinking water source for the City of Fort Collins, City of Greeley, and the Tri-Districts. The monitoring program described in this document will allow for the identification of water quality changes or trends that are occurring in the watershed over space and time. The monitoring program design was developed through discussion and agreement among the three participating drinking water providers. Information generated from the monitoring program will be documented in the annual and five year reports, and the program will be re-assessed every three to five years to ensure that it meets changing needs and conditions.

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APPENDIX A

Stream Classifications & Water Quality Standards

STREAM CLASSIFICATIONS and WATER QUALITY STANDARDS

REGION: 2 BASIN: CACHE LA POUDRE RIVER Stream Segment Description	DESIG	CLASSIFICATIONS	NUMERIC STANDARDS PHYSICAL and BIOLOGICAL	INORGANIC mg/l		METALS ug/l			TEMPORARY MODIFICATIONS AND QUALIFIERS
1. Mainstem of the Cache La Poudre River, and all tributaries, including lakes, reservoirs and wetlands, within Rocky Mountain National Park and the Rawah, Neota, Comanche Peak, and Cache La Poudre Wilderness Areas.	OW	Aq Life Cold 1 Recreation 1a Water Supply Agriculture	D.O.=6.0 mg/l D.O.(sp)=7.0 mg/l pH=6.5-9.0 F.Coli=200/100ml E.Coli=126/100ml	NH_3(ac/ch)=TVS Cl_2(c)=0.019 Cl_2(ch)=0.011 CN=0.005	S=0.002 B=0.75 NO_2=0.05 NO_3=10 Cl=250 SO_4=WS	As(ac)=50(Trec) Cd(ac)=TVS(tr) Cd(ch)=TVS CrIII(ac)=50(Trec) CrVI(ac/ch)=TVS Cu(ac/ch)=TVS	Fe(ch)=WS(dis) Fe(ch)=1000(Trec) Pb(ac/ch)=TVS Mn(ac/ch)=TVS Mn(ch)=WS(dis) Hg(ch)=0.01(Tot)	Ni(ac/ch)=TVS Se(ac/ch)=TVS Ag(ac)=TVS Ag(ch)=TVS(tr) Zn(ac/ch)=TVS	
2. Mainstem of the Cache La Poudre River and all tributaries, including lakes, reservoirs and wetlands from the boundaries of Rocky Mountain National Park, and the Rawah, Neota, Comanche Peak, and Cache La Poudre Wilderness Areas to the Monroe Gravity Canal/North Poudre Supply canal diversion.		Aq Life Cold 1 Recreation 1a Water Supply Agriculture	D.O.=6.0 mg/l D.O.(sp)=7.0 mg/l pH=6.5-9.0 F.Coli=200/100ml E.Coli=126/100ml	NH_3(ac/ch)=TVS Cl_2(ac)=0.019 Cl_2(ch)=0.011 CN=0.005	S=0.002 B=0.75 NO_2=0.05 NO_3=10 Cl=250 SO_4=WS	As(ac)=50(Trec) Cd(ac)=TVS(tr) Cd(ch)=TVS CrIII(ac)=50(Trec) CrVI(ac/ch)=TVS Cu(ac/ch)=TVS	Fe(ch)=WS(dis) Fe(ch)=1000(Trec) Pb(ac/ch)=TVS Mn(ac/ch)=TVS Mn(ch)=WS(dis) Hg(ch)=0.01(Tot)	Ni(ac/ch)=TVS Se(ac/ch)=TVS Ag(ac)=TVS Ag(ch)=TVS(tr) Zn(ac/ch)=TVS	
3. Deleted.									
4. Deleted.									
5. Deleted.									
6. Mainstem of the North Fork of the Cache La Poudre River, including all tributaries, lakes, reservoirs and wetlands, from the source to the inlet of Halligan Reservoir.		Aq Life Cold 1 Recreation 1a Water Supply Agriculture	D.O.=6.0 mg/l D.O.(sp)=7.0 mg/l pH=6.5-9.0 F.Coli=200/100ml E.Coli=126/100ml	NH_3(ac/ch)=TVS Cl_2(ac)=0.019 Cl_2(ch)=0.011 CN=0.005	S=0.002 B=0.75 NO_2=0.05 NO_3=10 Cl=250 SO_4=WS	As(ac)=50(Trec) Cd(ac)=TVS(tr) Cd(ch)=TVS CrIII(ac)=50(Trec) CrVI(ac/ch)=TVS Cu(ac/ch)=TVS	Fe(ch)=WS(dis) Fe(ch)=1000(Trec) Pb(ac/ch)=TVS Mn(ac/ch)=TVS Mn(ch)=WS(dis) Hg(ch)=0.01(Tot)	Ni(ac/ch)=TVS Se(ac/ch)=TVS Ag(ac)=TVS Ag(ch)=TVS(tr) Zn(ac/ch)=TVS	
7. Mainstem of the North Fork of the Cache La Poudre River from the inlet of Halligan Reservoir to the confluence with the Cache La Poudre River.	UP	Aq Life Cold 2 Recreation 1a Water Supply Agriculture	D.O.=6.0 mg/l D.O.(sp)=7.0 mg/l pH=6.5-9.0 F.Coli=200/100ml E.Coli=126/100ml	NH_3(ac/ch)=TVS Cl_2(ac)=0.019 Cl_2(ch)=0.011 CN=0.005	S=0.002 B=0.75 NO_2=0.05 NO_3=10 Cl=250 SO_4=WS	As(ac)=50(Trec) Cd(ac)=TVS(tr) Cd(ch)=TVS CrIII(ac)=50(Trec) CrVI(ac/ch)=TVS Cu(ac/ch)=TVS	Fe(ch)=WS(dis) Fe(ch)=1000(Trec) Pb(ac/ch)=TVS Mn(ac/ch)=TVS Mn(ch)=WS(dis) Hg(ch)=0.01(Tot)	Ni(ac/ch)=TVS Se(ac/ch)=TVS Ag(ac)=TVS Ag(ch)=TVS(tr) Zn(ac/ch)=TVS	Water + Fish Organics
8. All tributaries to the North Fork of the Cache La Poudre River, including all lakes, reservoirs and wetlands from, the inlet of Halligan Reservoir to the confluence with the Cache La Poudre River, except for specific listings in Segment 9.	UP	Aq Life Cold 2 Recreation 1a Water Supply Agriculture	D.O.=6.0 mg/l D.O.(sp)=7.0 mg/l pH=6.5-9.0 F.Coli=200/100ml E.Coli=126/100ml	NH_3(ac/ch)=TVS Cl_2(ac)=0.019 Cl_2(ch)=0.011 CN=0.005	S=0.002 B=0.75 NO_2=0.05 NO_3=10 Cl=250 SO_4=WS	As(ac)=50(Trec) Cd(ac)=TVS(tr) Cd(ch)=TVS CrIII(ac)=50(Trec) CrVI(ac/ch)=TVS Cu(ac/ch)=TVS	Fe(ch)=WS(dis) Fe(ch)=1000(Trec) Pb(ac/ch)=TVS Mn(ac/ch)=TVS Mn(ch)=WS(dis) Hg(ch)=0.01(Tot)	Ni(ac/ch)=TVS Se(ac/ch)=TVS Ag(ac)=TVS Ag(ch)=TVS(tr) Zn(ac/ch)=TVS	Water + Fish Organics
9. Mainstem of Rabbit Creek and Lone Pine Creek from the source to the confluence with the North Fork of the Cache La Poudre River.		Aq Life Cold 1 Recreation 1a Water Supply Agriculture	D.O.=6.0 mg/l D.O.(sp)=7.0 mg/l pH=6.5-9.0 F.Coli=200/100ml E.Coli=126/100ml	NH_3(ac/ch)=TVS Cl_2(ac)=0.019 Cl_2(ch)=0.011 CN=0.005	S=0.002 B=0.75 NO_2=0.05 NO_3=10 Cl=250 SO_4=WS	As(ac)=50(Trec) Cd(ac)=TVS(tr) Cd(ch)=TVS CrIII(ac)=50(Trec) CrVI(ac/ch)=TVS Cu(ac/ch)=TVS	Fe(ch)=WS(dis) Fe(ch)=1000(Trec) Pb(ac/ch)=TVS Mn(ac/ch)=TVS Mn(ch)=WS(dis) Hg(ch)=0.01(Tot)	Ni(ac/ch)=TVS Se(ac/ch)=TVS Ag(ac)=TVS Ag(ch)=TVS(tr) Zn(ac/ch)=TVS	
10. Mainstem of the Cache La Poudre River from the Monroe Gravity Canal/North Poudre Supply Canal diversion to Shields Street in Ft. Collins, Colorado.	UP	Aq Life Cold 2 Recreation 1a Water Supply Agriculture	D.O.=6.0 mg/l D.O.(sp)=7.0 mg/l pH=6.5-9.0 F.Coli=200/100ml E.Coli=126/100ml	NH_3(ac/ch)=TVS Cl_2(ac)=0.019 Cl_2(ch)=0.011 CN=0.005	S=0.002 B=0.75 NO_2=0.05 NO_3=10 Cl=250 SO_4=WS	As(ac)=50(Trec) Cd(ac)=TVS(tr) Cd(ch)=TVS CrIII(ac)=50(Trec) CrVI(ac/ch)=TVS Cu(ac/ch)=TVS	Fe(ch)=WS(dis) Fe(ch)=1000(Trec) Pb(ac/ch)=TVS Mn(ac/ch)=TVS Mn(ch)=WS(dis) Hg(ch)=0.01(Tot)	Ni(ac/ch)=TVS Se(ac/ch)=TVS Ag(ac)=TVS Ag(ch)=TVS(tr) Zn(ac/ch)=TVS	Water + Fish Organics
11. Mainstem of the Cache La Poudre River from Shields Street in Ft. Collins to a point immediately above the confluence with Boxelder Creek.	UP	Aq Life Warm 2 Recreation 1a Agriculture	D.O.=5.0 mg/l pH=6.5-9.0 F.Coli=200/100ml E.Coli=126/100ml	NH_3(ac/ch)=TVS Cl_2(ac)=0.019 Cl_2(ch)=0.011 CN=0.005	S=0.002 B=0.75 NO_2=2.7	As(ch)=100(Trec) Cd(ac/ch)=TVS CrIII(ac/ch)=TVS CrVI(ac/ch)=TVS Cu(ac/ch)=TVS	Fe(ch)=1000(Trec) Pb(ac/ch)=TVS Mn(ac/ch)=TVS Hg(ch)=0.01(Tot) Ni(ac/ch)=TVS	Se(ac/ch)=TVS Ag(ac/ch)=TVS Zn(ac/ch)=TVS	Nitrite as a 30 day average. Fish Ingestion Organics Temporary Modifications: type (iii) Cu (ac/ch)=Current Condition. Expiration date of 12/31/2009. NH_3(ac/ch)=TVS(old) (Type i). Expiration date of 12/31/2011.

APPENDIX B

Background Information for the

Historic City of Greeley and City of Fort Collins

Upper CLP Water Quality Monitoring Programs

Table B.1. Initial combined variable list

Inorganic Constituents	Fort Collins	Greeley	Descriptor	Rationale
Alkalinity	x		General	Indicator of carbonate species concentrations; Acid neutralizing capacity of water. Drinking water standard.
Discharge		x	General	Necessary for flow dependant analysis and load estimations.
Hardness	x	x	General	Treatment implications; Hard water causes scaling and soft water is considered corrosive.
Nitrate	x	x	Nutrients	Primary source of nitrogen to algae, potential health risk to infants. Drinking water and water quality standard.
Nitrite	x	x	Nutrients	Toxic inorganic nitrogen, indicator of microbiological quality of water. Drinking water and water quality standard.
Nitrogen, Ammonia	x	x	Nutrients	Primary source of nitrogen to algae, indicator of organic pollution by sewage or industrial effluent, agriculture waste or fertilizers. Water quality standard.
Total Kjeldahl Nitrogen	x		Nutrients	Sum of organic nitrogen and ammonia, increased levels of organic nitrogen indicate pollution of water.
pH	x	x	General	Measure of acidity, important variable in WQ as many biological and chemical processes are pH dependent. Drinking water and water quality standard.
Potassium	x		Major Ion	Indicator of pollution from runoff and discharge.
Sodium	x		Major Ion	Indicator of sewage, industrial effluents and road salts.
Specific Conductance	x	x	General	Presence of dissolved ions; provides a relationship to concentrations of total dissolved solids in water and major ions. Drinking water standard.
Sulfate	x		Major Ion	Indicator of industrial air/water pollution or mine drainage; treatment implications (taste and odor).
Temperature	x	x	General	Reflects seasonality; affects biological and chemical processes. Drinking water and water quality standard.
Ortho-Phosphate (Soluble Reactive Phosphorus)	x	x	Nutrients	Dissolved P available to algae.

Table B.1 continued

Total Dissolved Phosphorus		x	Nutrients	P available to algae.
Total Particulate Phosphorus		x	Nutrients	P potentially available to algae.
Total Phosphorus	x	x	Nutrients	Total phosphorus available to algae.
Total Organic Carbon	x	x	Nutrients	Arises from living material and waste materials and effluents; precursor of disinfection byproducts potential.
Total Suspended Solids	x	x	General	Reflects inorganic and organic contributions to suspended material; implications for water treatment, stream habitat, and reservoir life.
Turbidity	x		General	Important for water treatment; indicator of biological activity in the water column. Drinking water standard.

Organic Constituents	**Fort Collins**	**Greeley**	**Descriptor**	**Rationale**
VOCs	x		Organics	Presence of gasoline compounds and industrial solvents.
THMs	x		Organics	Indicates presence of chlorination disinfection by-products .
BTEX	x		Organics	Presence of gasoline compounds and industrial solvents.

Microbiological Constituents				
E. Coli	x	x	Microorganism	Indicator of human or animal waste contamination.
Heterotrophic Plate Count	x		Microorganism	Indicator of live heterotrophic bacteria.
Fecal Coliform		x	Microorganism	Indicator of human or animal waste contamination.
Total Coliform	x	x	Microorganism	Indicator of human or animal waste contamination. Drinking water standard.
Fecal Strep	x		Microorganism	Indicator of human or animal waste contamination.

Biological Constituents				
Chlorophyll-a	x			Reflects algal biomass.

Table B.2. Initial metals parameter list monitored by FCWTF

Metals	Method	units	Method Reporting Limit
Aluminum	SM 3113 B	ug/L	10 (1993-2006)
Aluminum Reactive	SM 3500- Al E	ug/L	10 (1987) 15 (1988-1996)
Antimony	SM 3113 B	ug/L	2.0 (1989-2006)
Arsenic	SM 3113 B	ug/L	0.5 (1987-1990) 1.0 (1991-1997) 2.0 (1998-2006)
Barium	SM 3113 B	ug/L	100 (1987-1992) 20 (1993-1997) 30 (1998-2000, 2003) 20 (2001-2002) 3.0 (2004-2006)
Beryllium	SM 3113 B	ug/L	0.5 (1989-2006)
Cadmium	SM 3113 B	ug/L	0.5 (1987-1988) 0.1 (1989-2006)
Calcium-flame	SM 3111 D	mg/L as	0.5 (1989-2006)
Chromium	SM 3113 B	ug/L	0.2 (1987-1992) 0.5 (1993-2006)
Copper	SM 3113 B	ug/L	1.0 (1987-1996) 3.0 (1997-2006)
Iron	SM 3113 B	ug/L	10 (1987-2006)
Lead	SM 3113 B	ug/L	0.5 (1987-1992) 1.0 (1993-2006)
Magnesium	SM 3111 B	mg/L	0.2 (1987-2006)
Manganese	SM 3113 B	ug/L	10 (1987) 1.0 (1988-2006)
Mercury	EPA 245.2	ug/L	0.5 (1987-1993) 1.0 (1994-2006)
Molybdenum	SM 3113 B	ug/L	1.0 (1993-1995) 2.0 (1996)
Nickel	SM 3113 B	ug/L	50 (1987) 0.1 (1988-1990) 0.5 (1991) 1.0 (1992-1993) 2.0 (1994-1997,2004) 3.0 (1998-2003,2005-2006)
Selenium	SM 3113 B	ug/L	0.25 (1987-1988) 0.3 (1989-1990) 1.0 (1991,2004) 2.0 (1992-2003,2005-2006)
Silver	SM 3113 B	ug/L	0.1 (1987-1993) 0.2 (1994) 0.5 (1995-2006)
Sodium	SM 3111 B	mg/L	0.5 (1987-2006)
Strontium	SM 3113 B	ug/L	5.0 (1992-1999)
Thallium	EPA 200.9	ug/L	1.0 (1989,1992-1997) 0.1 (1990-1991) 2.0 (1998-2000) 1.0 (2001-2006)
Vanadium	SM 3113 B	ug/L	2.0 (1993-1996)
Zinc	SM 3111 B	ug/L	10 (1987-1988) 20 (1989-1994) 30 (1995-1997) 100 (1998-2006)

Table B.3. Description of original CLP monitoring site locations

	Main stem	Site ID	Description	Rationale
1	Greeley A	CHR	Chambers Lake Outflow	Outflow Chambers Lake
2	Greeley A	BMR	Barnes Meadow Reservoir outflow	High TOC and nutrients compared to CHR
3	Greeley A	PJW	Poudre above Joe Wright Creek	Same as FCWTF 9
4	FCWTF	10	Joe Wright Creek at Aspen Glen Campground	Joe Wright Creek
5	FCWTF	9	Poudre at Hwy14 crossing (Keal Bridge)	Above Joe Wright Creek
6	FCWTF	7	Laramie River at Tunnel at Hwy 14 crossing	Laramie River diversion water
7	FCWTF	8	Poudre above Laramie Poudre Tunnel	Above Laramie diversion confluence
8	FCWTF	6	Poudre above Sheep Cr. near sleeping Elephant campground	Below Laramie diversion confluence
9	FCWTF	5	Poudre below Sheep Cr. at camp near Williams Gulch	Below Sheep Creek confluence
10	FCWTF	4	Poudre above confluence South Fork	Poudre above South Fork confluence
11	Greeley A	PSF	Poudre above South Fork	Redundant site with FCWTF 4
12	Greeley A	SFM	South Fork Cache la Poudre	Redundant site with FCWTF 3
13	FCWTF	3	South Fork at bridge on Pingree Park Rd	South Fork
14	FCWTF	2	Poudre below confluence South Fork mile 101	Below confluence S Fork
15	FCWTF	1	Poudre at Intake 1/2 mile upstream from Old WTP#1	Fort Collins intake
16	Greeley A	PNF	Poudre above North Fork	Redundant site with FCWTF 1
17	Greeley B	PBD	Poudre at Bellvue Diversion	Greeley intake

	North Fork	Site ID	Description	Rationale
18	FCWTF		Confluence of Dale Creek and North Fork above Halligan	Inflow to Halligan
19	FCWTF		Halligan Reservoir	Algae samples
20	FCWTF		North Fork at the USGS gage below Halligan	Halligan Reservoir outflow
21	Greeley A	NFG	North Fork Cache la Poudre at gage below Seaman Res	Below Seaman R
22	Greeley A	MSR	Seaman Reservoir	Water quality on reservoir
23	Greeley A	SER	Seaman Res Outflow (bottom release, not spillway flow)	Release from Seaman R
24	Greeley B	SCM	Stonewall Creek Mouth	Low flows most of the year
25	Greeley B	NFRC	North Fork of Poudre above Rabbit Creek	Above Rabbit Creek Confluence
26	Greeley B	RCM	Rabbit Creek Mouth	Low flows most of the year
27	Greeley B	PCM	Lone Pine Creek Mouth	Drains Red Feather Lakes
28	Greeley B	NFL	North Fork at Livermore	North Fork below RCM,PCM,SCM

APPENDIX C

Comparison of Water Quality data at redundant sites

sampled by the City of Fort Collins and City of Greeley

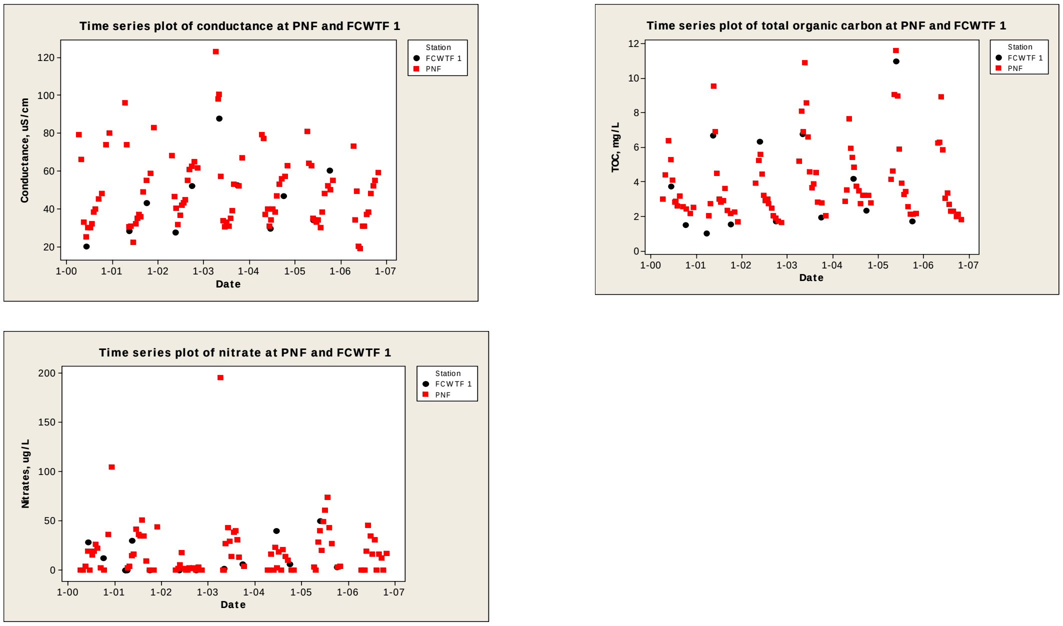


Figure C.1.Comparison of time series data for conductance, total organic carbon, and nitrates at PNF and FCWTF 1 (main stem Poudre above the North Fork confluence)

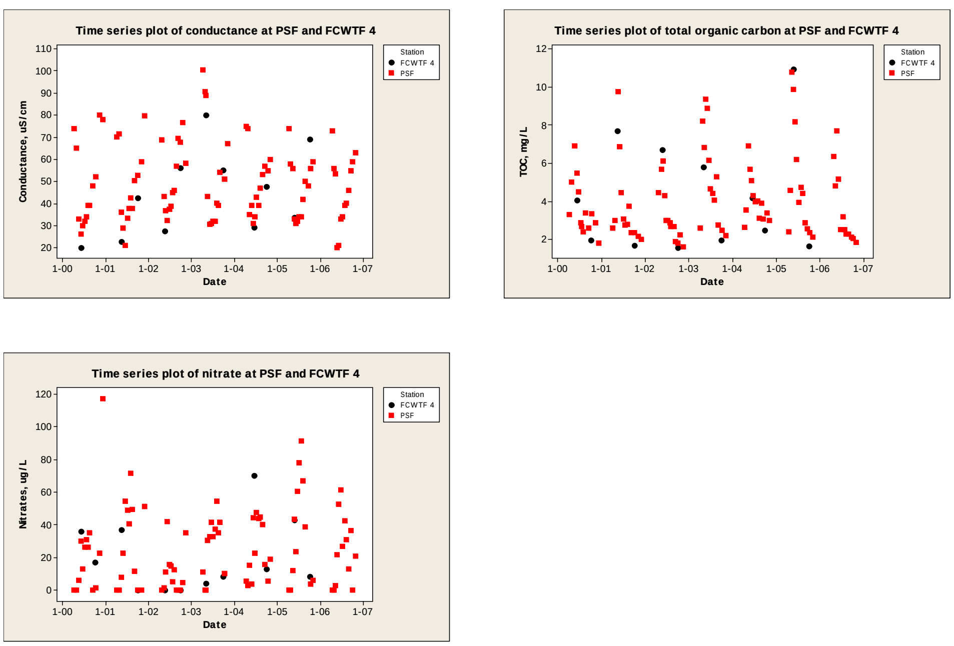


Figure C.2. Comparison of time series data for conductance, total organic carbon, and nitrates at PSF and FCWTF 4 (main stem Poudre above the South Fork confluence)

APPENDIX D

Flow versus Quality Relationships

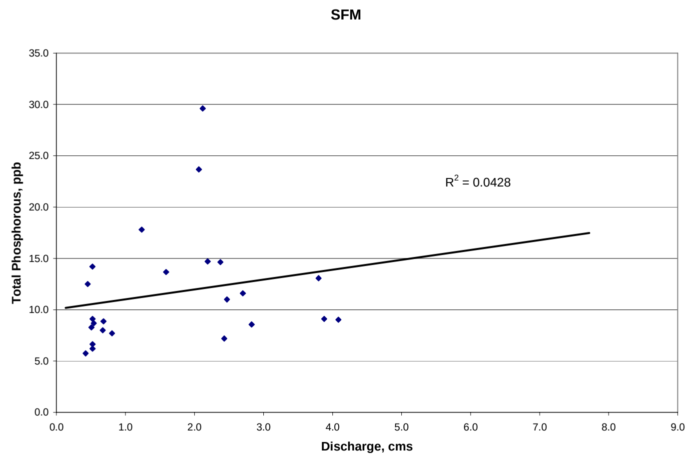


Figure D.1. Total Phosphorous versus flow at SFM

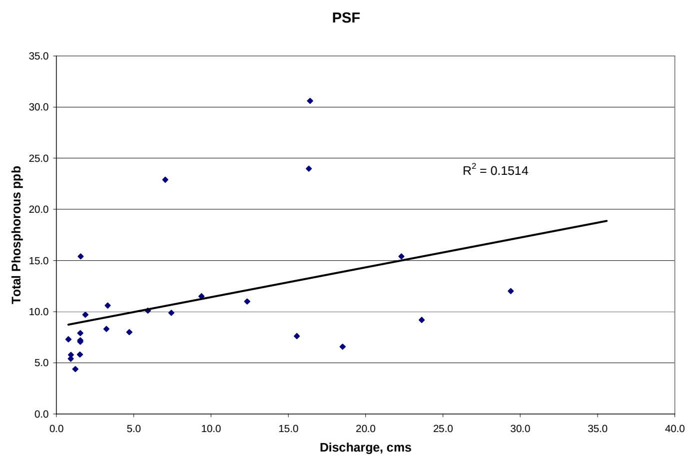


Figure D.2. Total Phosphorous versus flow at PSF

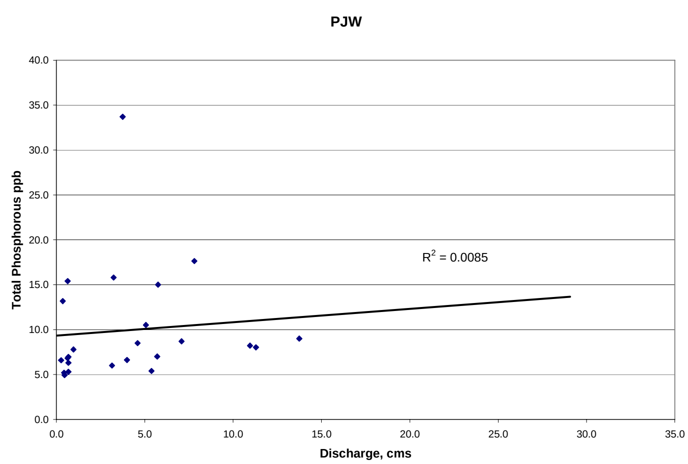


Figure D.3. Total Phosphorous versus flow at PJW

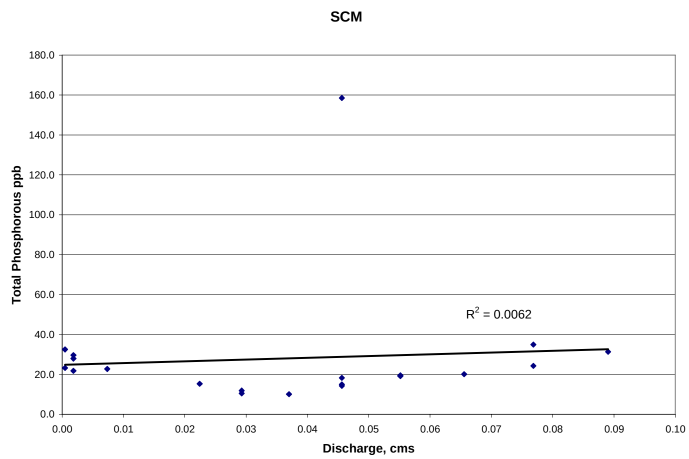


Figure D.4. Total Phosphorous versus flow at SCM

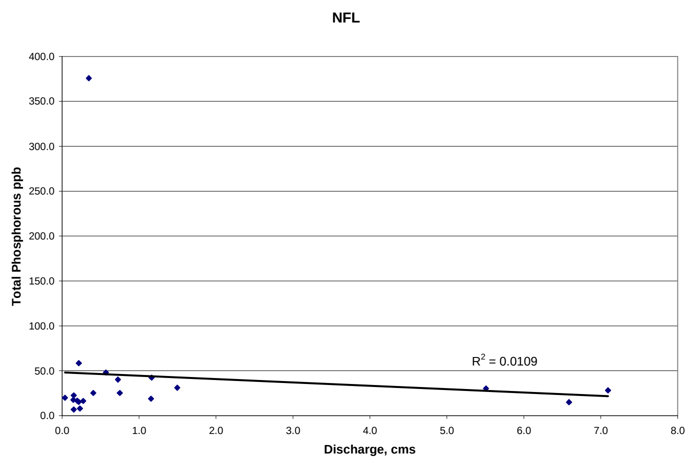


Figure D.5. Total Phosphorous versus flow at NFL

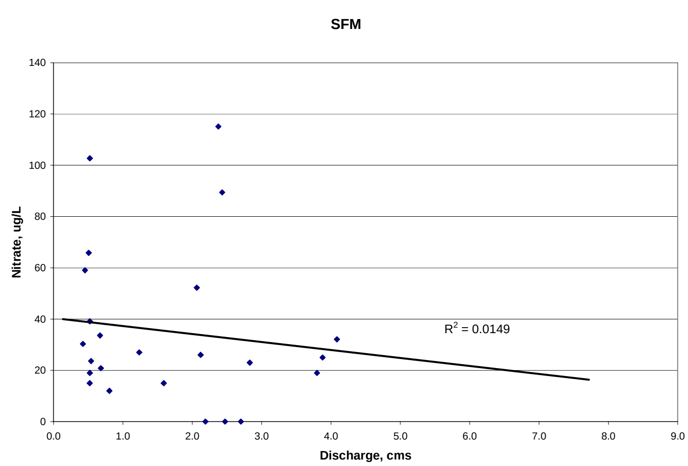


Figure D.6. Nitrate versus flow at SFM

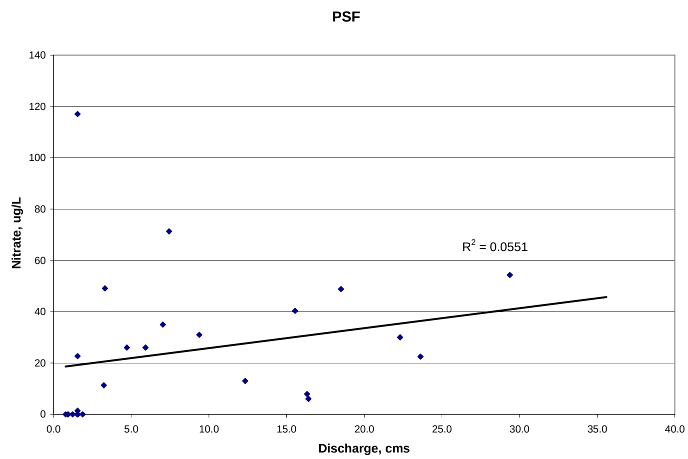


Figure D.7. Nitrate versus flow at PSF

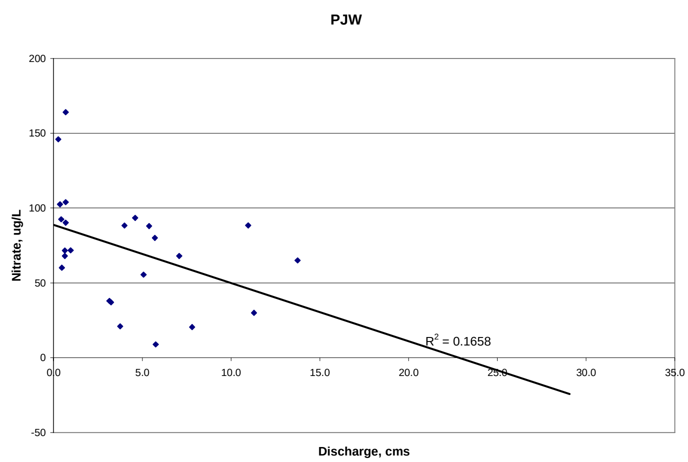


Figure D.8. Nitrate versus flow at PJW

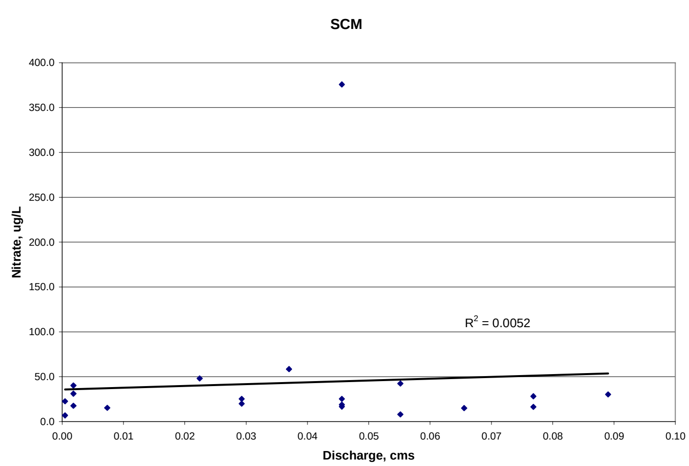


Figure D.9. Nitrate versus flow at SCM

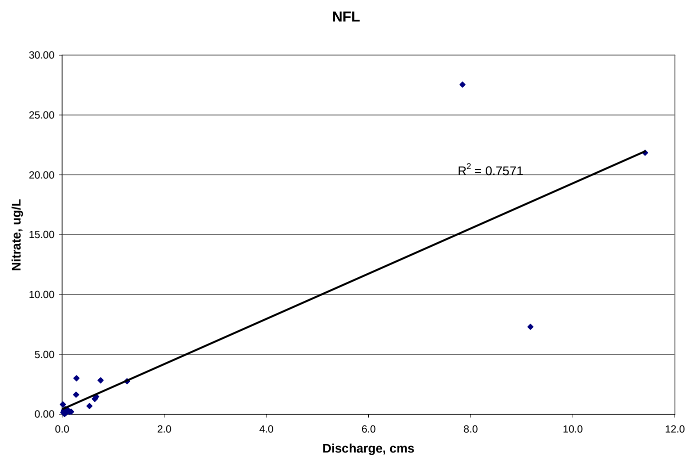


Figure D.10. Nitrate versus flow at NFL

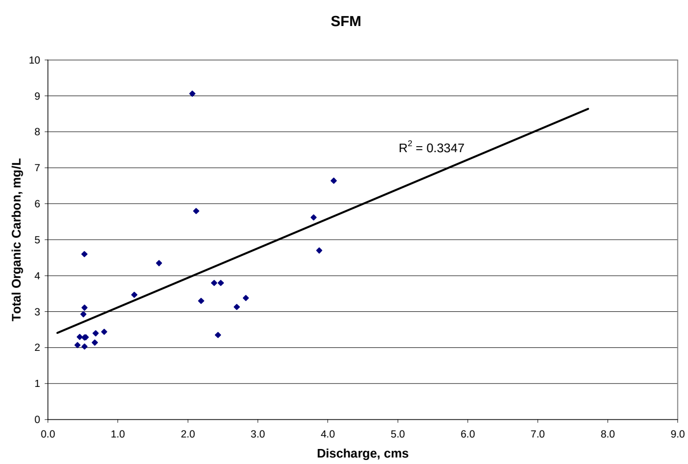


Figure D.11. Total Organic Carbon versus flow at SFM

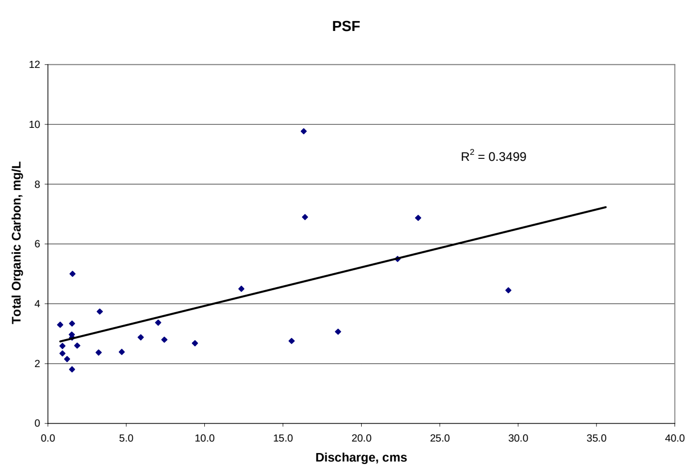


Figure D.12. Total Organic Carbon versus flow at PSF

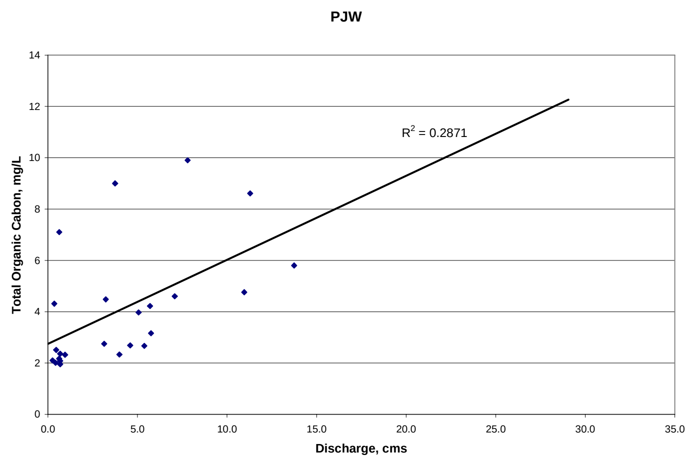


Figure D.13. Total Organic Carbon versus flow at PJW

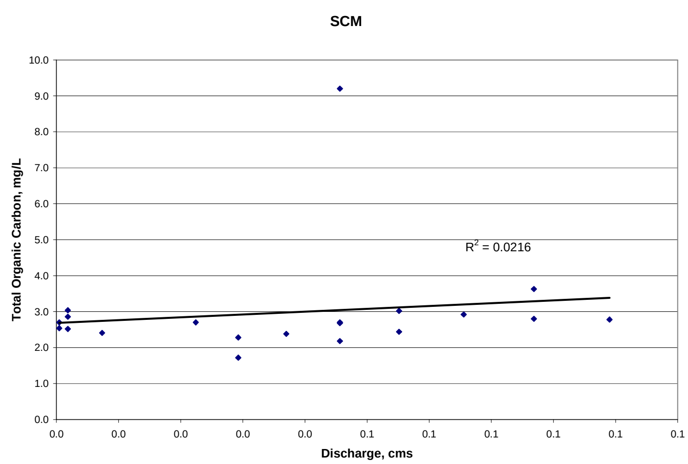


Figure D.14. Total Organic Carbon versus flow at SCM

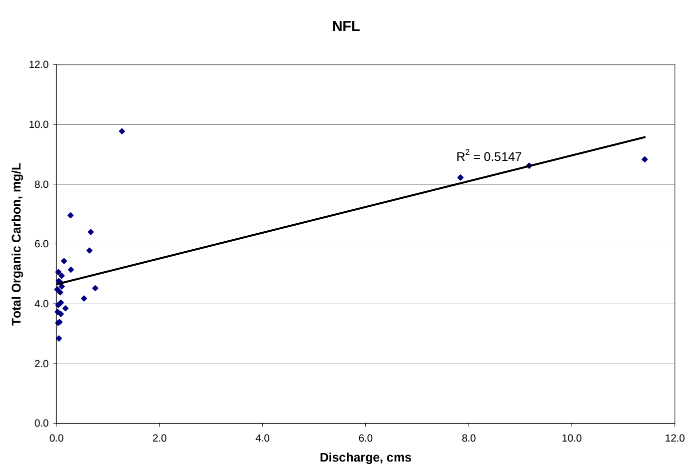


Figure D.15. Total Organic Carbon versus flow at NFL

APPENDIX E

Load Estimation for Greeley A and Greeley B sites

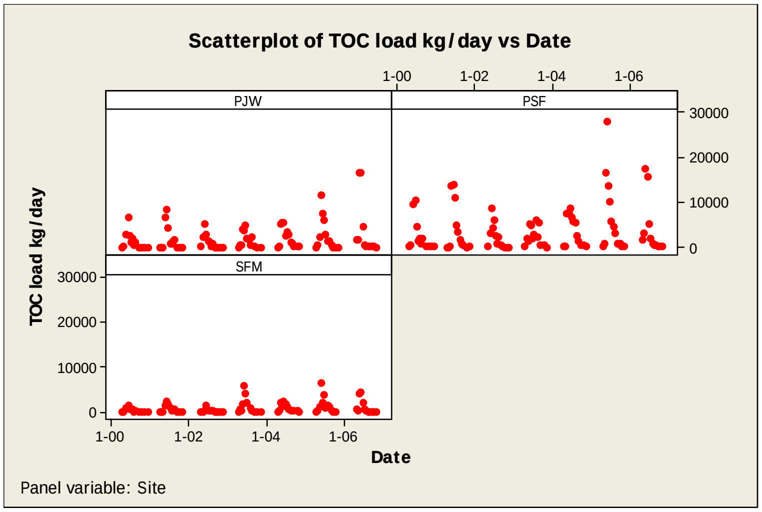


Figure E.1 Total Organic Carbon load Greeley A sites

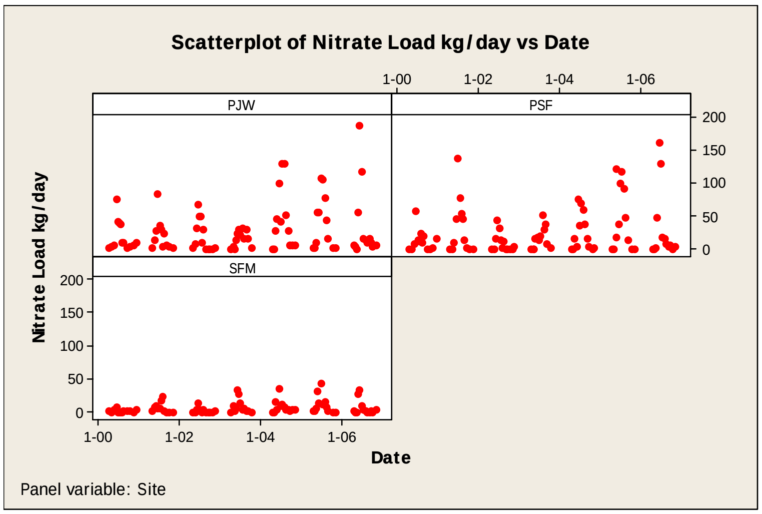


Figure E.2 Nitrate load Greeley A sites

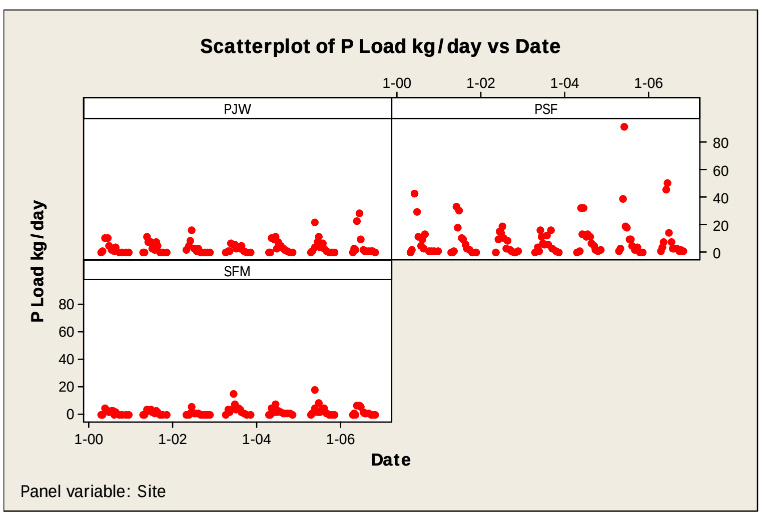


Figure E.3 Phosphorous load Greeley A sites

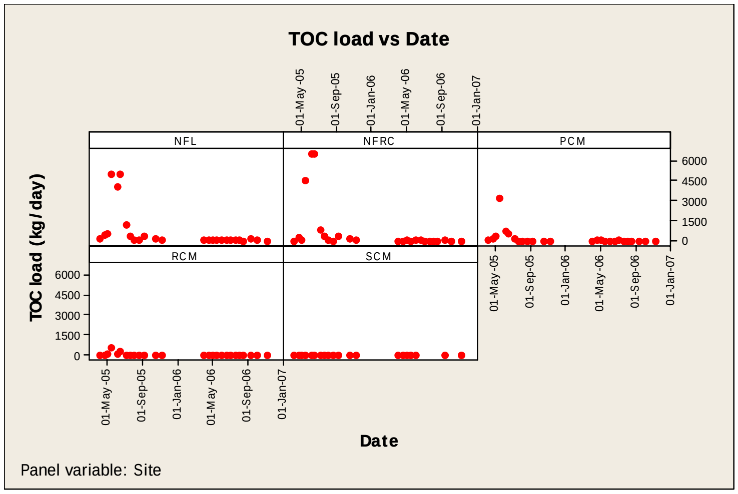


Figure E.4 Total Organic Carbon load Greeley B sites

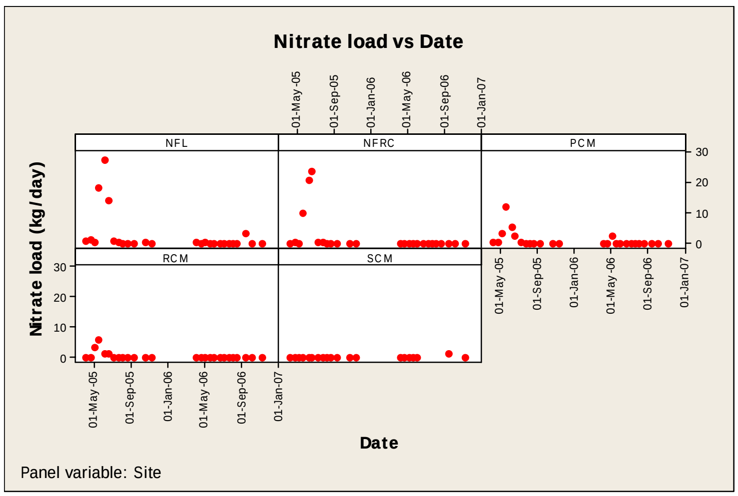


Figure E.5 Nitrate load Greeley B sites

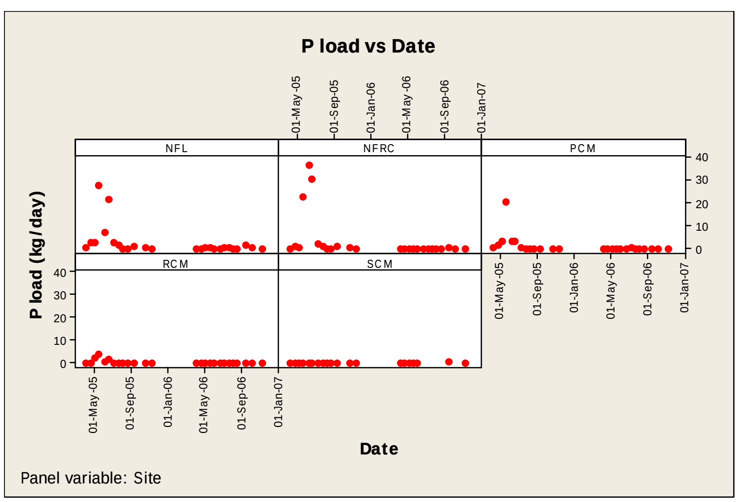


Figure E.6 Phosphorous load Greeley B sites

APPENDIX F

Sample size calculations

Table F.1. Main stem sample size calculations represented as standard errors as a percent of the mean

Main stem Flow weighted		**Standard Error as Percent of Mean**			
Total	**Sample size**	**Ammonia**	**Conductance**	**TOC**	**Total P**
10	4 2 2 2	48.22	9.34	11.24	18.83
11	5 2 2 2	48.02	9.06	10.59	17.92
12	4 4 2 2	47.96	9.28	11.19	18.67
13	5 4 2 2	47.75	8.99	10.54	17.75
13	4 4 2 3	45.56	8.63	10.47	18.10
14	6 4 2 2	47.61	8.80	10.08	17.11
15	4 4 4 3	36.18	7.89	10.30	16.38
15	6 4 2 3	45.18	8.11	9.28	16.49
16	6 6 2 2	47.52	8.77	10.07	17.05
16	6 4 4 2	38.28	8.08	9.91	15.31
18	6 6 4 2	38.18	8.06	9.89	15.25
19	6 6 4 3	35.66	7.30	9.08	14.58
20	8 8 2 2	47.28	8.51	9.45	16.17
22	8 8 4 2	37.93	7.77	9.27	14.29
Main stem Seasonally weighted		**Standard Error as Percent of Mean**			
Total	**Sample size**	**Ammonia**	**Conductance**	**TOC**	**Total P**
10	4 2 2 2	50.49	12.15	16.94	21.13
11	5 2 2 2	50.45	12.10	16.78	20.85
12	4 4 2 2	50.12	12.04	16.86	20.72
13	5 4 2 2	50.08	11.99	16.69	20.44
13	4 4 2 3	44.99	10.11	14.16	18.21
14	6 4 2 2	50.05	11.95	16.58	20.24
15	4 4 4 3	38.89	9.94	14.11	17.34
15	6 4 2 3	44.91	10.00	13.83	17.67
16	6 6 2 2	49.92	11.91	16.55	20.10
16	6 4 4 2	44.02	11.80	16.53	19.41
18	6 6 4 2	43.89	11.76	16.50	19.25
19	6 6 4 3	38.65	9.78	13.75	16.60
20	8 8 2 2	49.82	11.84	16.39	19.78
22	8 8 4 2	43.79	11.69	16.34	18.91
Main stem Weight 0.4 spring and 0.2's other		**Standard Error as Percent of Mean**			
Total	**Sample size**	**Ammonia**	**Conductance**	**TOC**	**Total P**
10	4 2 2 2	39.90	8.52	11.66	18.99
11	5 2 2 2	39.61	8.11	10.77	17.69
12	4 4 2 2	39.23	8.38	11.54	18.54
13	5 4 2 2	38.91	7.96	10.64	17.21
13	4 4 2 3	37.46	7.92	11.13	18.23
14	6 4 2 2	38.70	7.67	10.00	16.25
15	4 4 4 3	30.18	7.53	11.06	17.44
15	6 4 2 3	36.90	7.18	9.52	15.90
16	6 6 2 2	38.45	7.62	9.95	16.08
16	6 4 4 2	31.42	7.28	9.93	15.39

18	6 6 4 2	31.16	7.23	9.88	15.20
19	6 6 4 3	29.31	6.69	9.40	14.83
20	8 8 2 2	38.02	7.20	9.05	14.69
22	8 8 4 2	30.72	6.79	8.97	13.74

Table F.2. North Fork sample size calculations standard error represented as a percent of the mean

North Fork Seasonally weighted		Standard Error as Percent of Mean			
Total	**Sample size**	**Ammonia**	**Conductance**	**TOC**	**Total P**
10	4 2 2 2	26.04	46.79	14.84	20.28
11	5 2 2 2	25.96	46.65	14.76	20.14
12	4 4 2 2	25.07	46.69	14.68	19.80
13	5 4 2 2	25.00	46.55	14.60	19.66
13	4 4 2 3	21.21	38.48	12.29	16.84
14	6 4 2 2	24.94	46.46	14.55	19.57
15	4 4 4 3	20.93	38.40	12.18	16.55
15	6 4 2 3	21.06	38.21	12.13	16.56
16	6 6 2 2	24.61	46.43	14.49	19.40
16	6 4 4 2	24.70	46.40	14.46	19.31
18	6 6 4 2	24.36	46.36	14.40	19.15
19	6 6 4 3	20.37	38.09	11.95	16.07
20	8 8 2 2	24.37	46.30	14.40	19.20
22	8 8 4 2	24.12	46.23	14.31	18.94
North Fork Weights 0.4 and 0.2's		**Standard Error as Percent of Mean**			
Total	**Sample size**	**Ammonia**	**Conductance**	**TOC**	**Total P**
10	4 2 2 2	19.24	29.54	9.98	15.32
11	5 2 2 2	18.69	28.21	9.41	14.50
12	4 4 2 2	17.33	29.36	9.68	14.59
13	5 4 2 2	16.72	28.01	9.10	13.73
13	4 4 2 3	16.40	26.64	9.21	14.06
14	6 4 2 2	16.30	27.08	8.69	13.12
15	4 4 4 3	15.90	26.53	9.04	13.62
15	6 4 2 3	15.31	24.13	8.16	12.54
16	6 6 2 2	15.57	27.01	8.58	12.84
16	6 4 4 2	15.78	26.96	8.51	12.65
18	6 6 4 2	15.03	26.89	8.39	12.36
19	6 6 4 3	13.96	23.93	7.84	11.74
20	8 8 2 2	14.60	25.75	7.97	11.86
22	8 8 4 2	14.02	25.61	7.77	11.35

Table F.3. South Fork at Pingree Park road sample size calculations

South Fork Flow weighted		Standard Error as percent of mean			
Station	**Sample size**	**Ammonia**	**Conductance**	**TOC**	**Total P**
SFM	4 2 2 2	12.21	6.92	13.99	16.01
	5 2 2 2	11.73	6.43	12.84	14.83
	4 4 2 2	11.57	6.74	13.87	15.58
	5 4 2 2	11.06	6.22	12.72	14.38
	4 4 2 3	10.84	6.56	13.46	15.09
	6 4 2 2	10.71	5.86	11.89	13.51
	4 4 4 3	10.55	6.46	13.42	15.04
	6 4 2 3	9.93	5.66	11.40	12.94
	6 6 2 2	10.47	5.78	11.85	13.34
	6 4 4 2	10.41	5.74	11.85	13.45
	6 6 4 2	10.16	5.67	11.81	13.29
	6 6 4 3	9.33	5.46	11.31	12.70
	8 8 2 2	9.87	5.24	10.69	12.07
	8 8 4 2	9.55	5.11	10.64	12.01

Table F.4. South Fork at Pingree Park road sample size calculations at half frequency

South Fork Flow weighted		Standard Error as percent of mean			
Station	**Sample size**	**Ammonia**	**Conductance**	**TOC**	**Total P**
SFM	2 1 1 1	56.42	12.04	16.49	26.86
	3 1 1 1	55.73	11.07	14.33	23.69
	2 2 1 1	55.47	11.85	16.32	26.23
	3 2 1 1	54.73	10.85	14.14	22.99
	2 2 1 2	51.56	10.87	15.43	25.56
	3 2 1 1	54.73	10.85	14.14	22.99
	2 2 2 2	41.23	10.28	15.34	24.44
	3 2 1 2	50.73	9.78	13.11	22.22
	3 3 1 1	54.37	10.78	14.07	22.75
	3 2 2 1	44.44	10.30	14.04	21.76
	3 3 2 1	44.07	10.22	13.97	21.50
	3 3 2 2	39.94	9.06	12.93	20.70
	4 4 1 1	53.77	10.19	12.80	20.77
	4 4 2 1	43.44	9.61	12.69	19.43

APPENDIX G

Linear Trend Detection

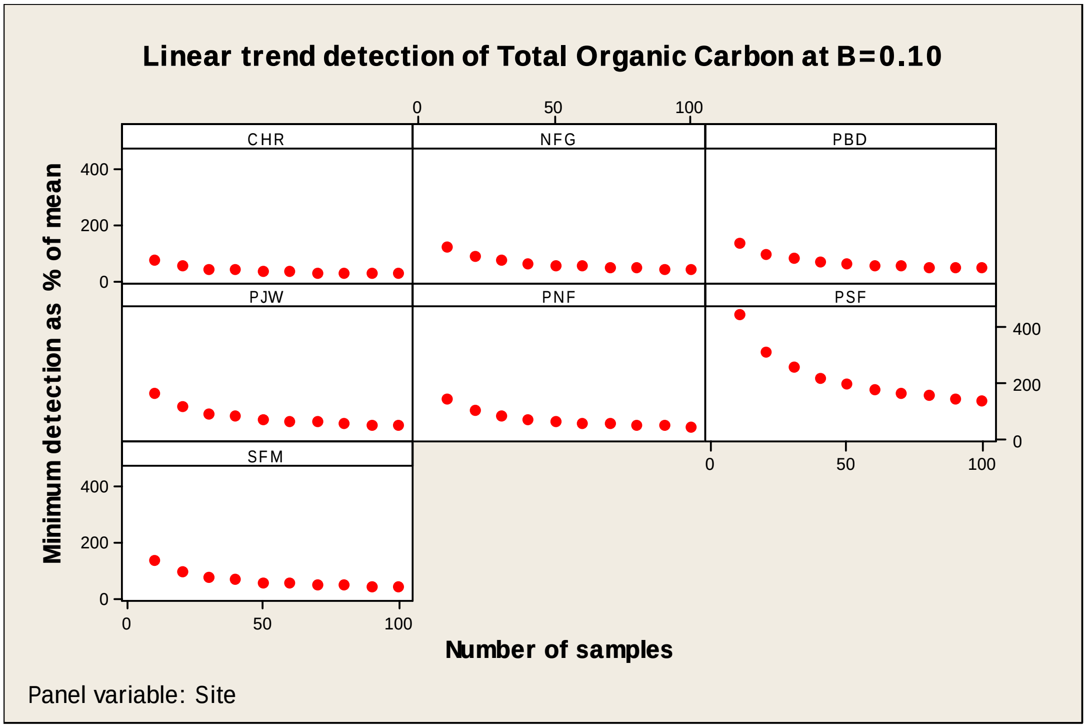


Figure G.1. **Linear trend detection performance for TOC at 90% power and 90% confidence for selected Greeley sites**

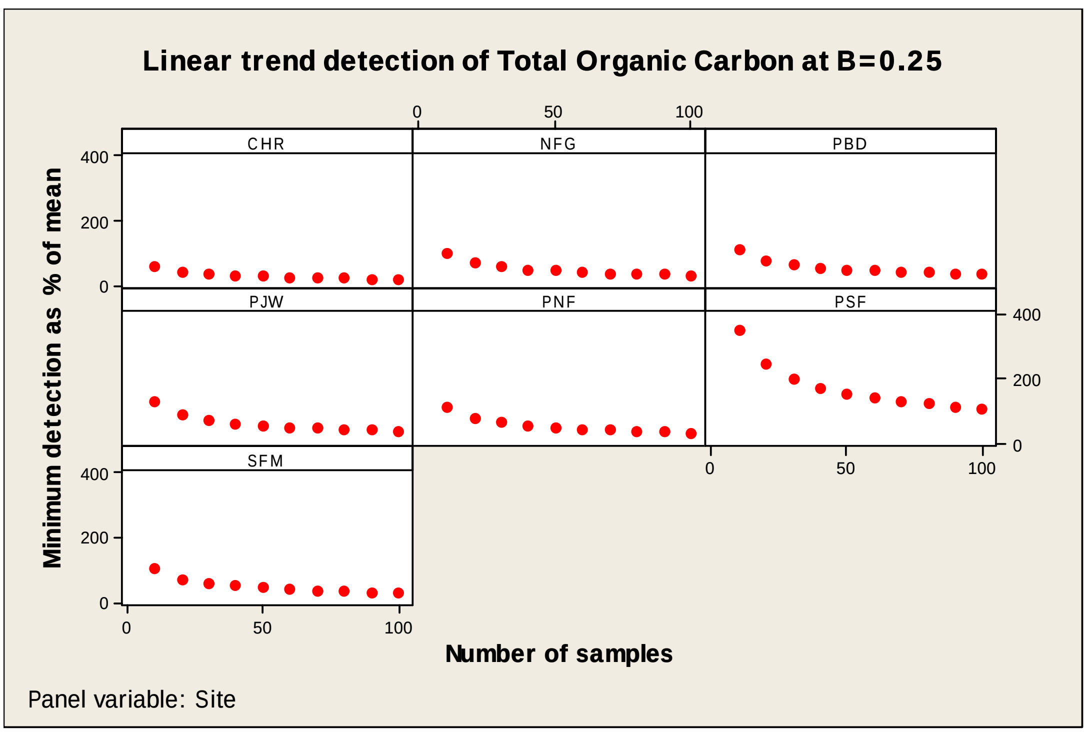


Figure G.2. **Linear trend detection performance for TOC at 75% power and 90% confidence for selected Greeley sites**

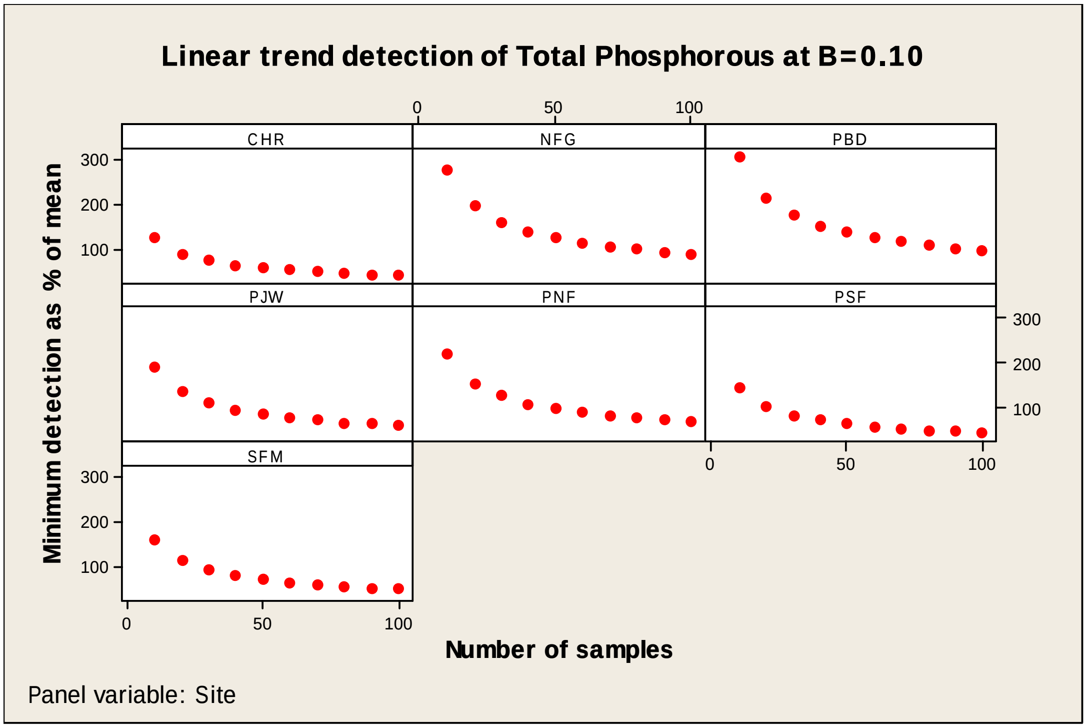


Figure G.3. Linear trend detection performance for total phosphorous at 90% power and 90% confidence for selected Greeley sites

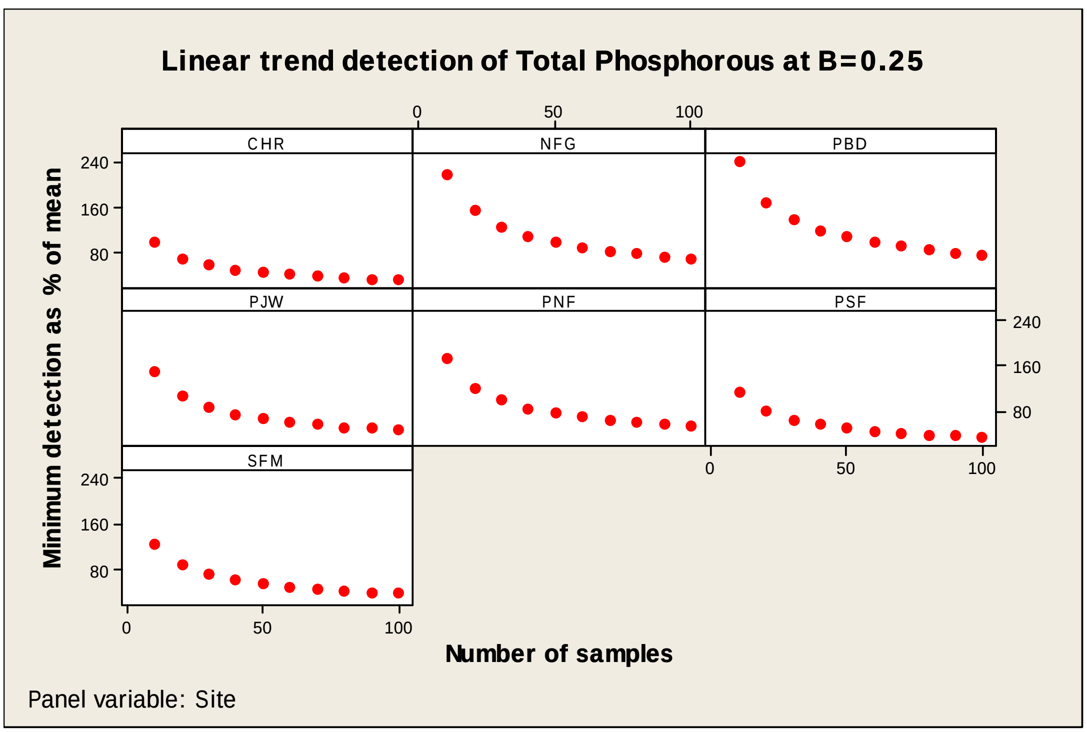


Figure G.4. Linear trend detection performance for total phosphorous at 75% power and 90% confidence for selected Greeley sites

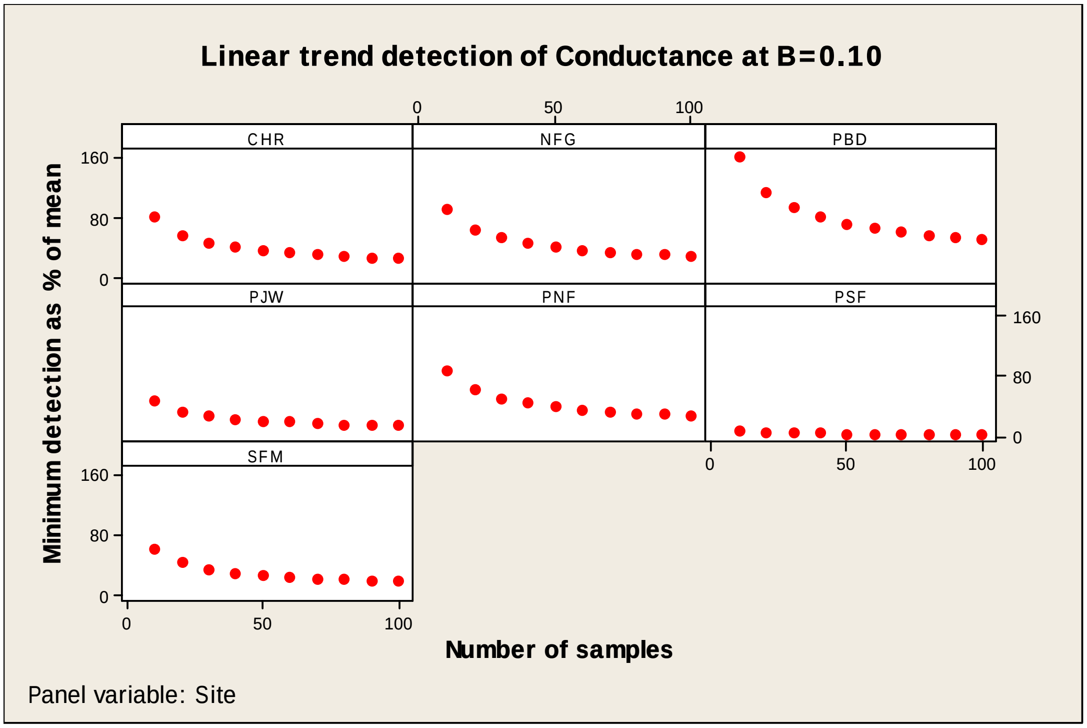


Figure G.5. Linear trend detection performance for conductance at 90% power and 90% confidence for selected Greeley sites

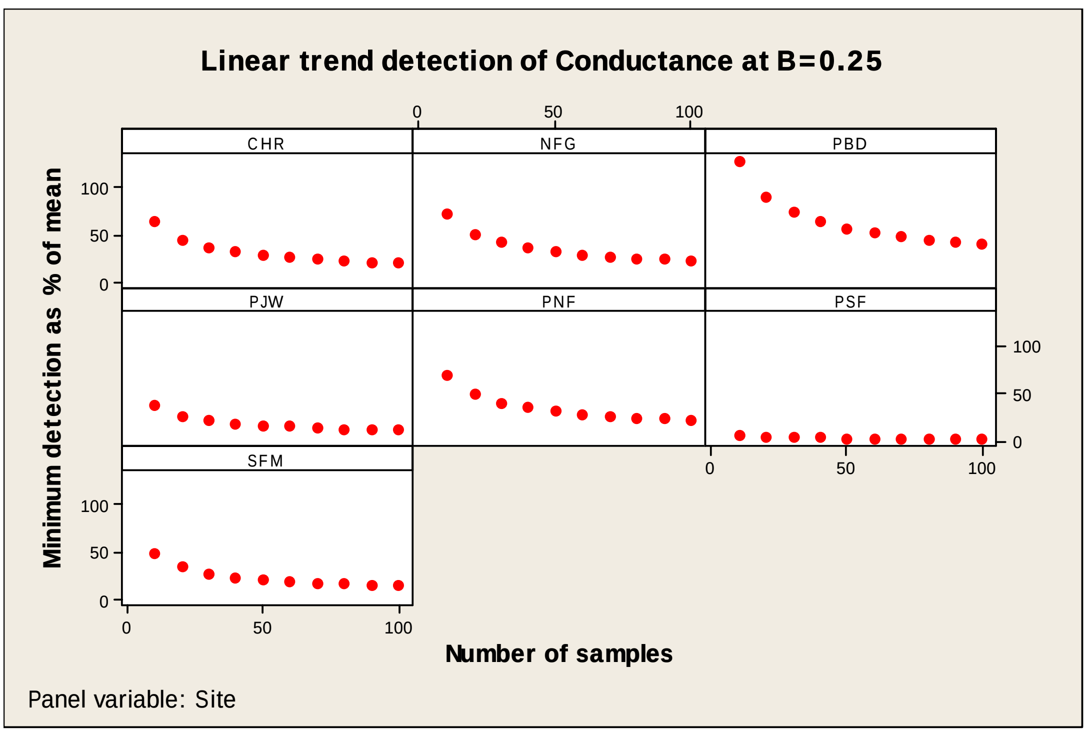


Figure G.6. Linear trend detection performance for conductance at 75% power and 90% confidence for selected Greeley sites

APPENDIX H

Description of Monitoring Site Locations

Site ID: 100CHR

Lat: N 40° 36.039
Long: W 105° 50.203
Location Description: Chambers Lake Outflow just upstream of Barnes Meadow outflow

Notes:
Sampling point is located on Joe Wright Creek, just upstream from BMR outflow. Access site by gravel pathway next to BMR outflow structure located North side of road, across from BMR dam.

Site ID: 090BMR

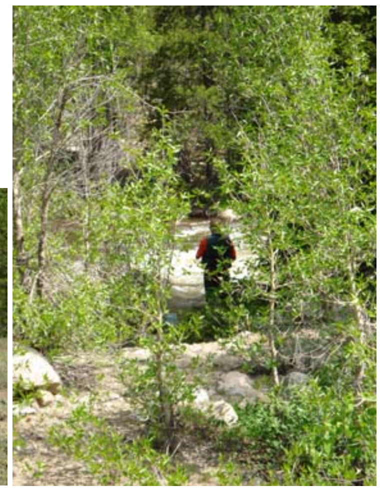
Latitude: N 40° 36.039
Longitude: W 105° 50.203
Location Description: Barnes Meadow Reservoir Outflow above confluence with Joe Wright Creek

Notes: Sample collected directly from outflow structure. Access site by gravel pathway next to BMR outflow structure located North side of road, across from BMR dam.

Site ID: 080JWC

Latitude: N 40° 37.233
Longitude: W 105° 49.098
Location Description: Joe Wright Creek at Aspen Glen Campground

Notes: Turn into the National Forest Service Aspen Glen Campground. Park near Campsite #3, just S of the bathrooms. Walk north along the gravel road past the bathrooms, approximately 30m. Follow the footpath to the left towards the creek. Sample site is located in small stream-side clearing in the willows and cottonwoods.

Site ID: 070PJW

Latitude: N 40° 38.074
Longitude: W 105° 48.421
Location Description: Poudre at Highway 14 crossing at Big South trailhead

Notes: Park in National Forest Service Big South trailhead parking lot. Sample site is located on W. side of HWY 14. Access site using footpath, located just beyond north end of guard rail.

Site ID: 060LRT

Latitude: N 40° 40.056
Longitude: W 105° 48.067
Location Description: Laramie River at tunnel and Highway 14 crossing

Notes: Gravel parking area located on west side of Hwy 14. Walk upstream approximately 20 meters to access flow. Flows are highly variable throughout the year.

Site ID: 050PBR

Latitude: N 40° 41.967
Longitude: W 105° 32.476
Location Description: Poudre below Rustic at Indian Meadows National Forest Service Parking Area

Notes: From parking lot, follow foot path past the bathrooms to the river. Sampling site is directly below large Ponderosa pine.

Site ID: 040SFM

Latitude: N 40° 37.095
Longitude: W 105° 31.535
Location Description: South Fork on bridge on Pingree Park Road

Notes: Sample on upstream side of the bridge. Access sample site from east stream bank.

Site ID: 030PSF

Latitude: N 40° 41.224
Longitude: W 105° 26.895
Location Description: Poudre main stem below confluence of South Fork at mile marker 101

Notes: Access sample site from National Forest Service Dutch George Campground. Park near the self-service pay station. Follow foot path to the right of the pay station kiosk to the river. Sample site is located to the left of the park bench.

Site ID: 020PNF

Latitude: N 40° 42.087
Longitude: W 105° 14.484
Location Description: Poudre main stem above confluence of North Fork.

Notes: Sample site located ½ mile downstream of FCWTF intake structure, across from FC Old WTP#1. Park next to the gate on the road that leads behind Old WTP#1 (not the gate at bridge). Follow the footpath beyond the wooden fence down to the river.

Site ID: 010PBD

Latitude: N 40° 39.882
Longitude: W 105° 12.995
Location Description: Greeley diversion

Notes: Road side parking for this site is limited to one vehicle.

Site ID: 280NDC

Latitude: N 40°53.852'
Longitude: W 105°22.556'
Location Description: North Fork above Halligan Reservoir and above Dale Cr.

Notes: From parking area, hike the old road down to the river. Pass through the State Wildlife Area gate and continue upstream along the trail next to the river. Sampling site is located above confluence of N. Fork and Dale creek at the fenced property line.

Site ID: 270NBH

Latitude: N 40°52'42"
Longitude: W 105°20'15"
Location Description: North Fork at USGS gage below Halligan Reservoir

Notes: Turn west off of main gravel road leading to Halligan Reservoir dam onto 4WD road. Continue to bottom of the road and collect samples next to the USGS gage site.

Site ID: 260NRC

Latitude: N 40° 49.640
Longitude: W 105° 16.776
Location Description: North Fork at Rabbit Creek

Notes: Park in pull off just west of bridge. Samples are collected on the upstream side of the bridge from the west stream bank.

Site ID: 250RCM

Latitude: N 40° 48.615
Longitude: W 105° 17.146
Location Description: Rabbit Creek mouth

Notes: Samples are collected on the downstream side of the bridge. Flows at this site are intermittent.

Site ID: 240SCM

Latitude: N 40° 48.458
Longitude: W 105° 15.195
Location Description: Stonewall Creek mouth

Notes: Park in pull-off on north side of CR76H. Sample from west culvert on south side of the road. Flows are intermittent.

Site ID: 230PCM

Latitude: N 40° 47.696
Longitude: W 105° 17.231
Location Description: Lone Pine Creek mouth

Notes: Samples collected upstream from bridge.

Site ID: 220NFL

Latitude: N 40° 47.269
Longitude: W 105° 15.130
Location Description: North Fork at USGS gage in Livermore

Notes: Pull-off located east of bridge on south side of Livermore road and accommodates only one vehicle. Use caution due to the high volume of fast moving traffic on this road.

Site ID: 210SER

Latitude: N 40° 42.274
Longitude: W 105° 14.210
Location Description: Seaman Reservoir

Notes:

Site ID: 200NFG

Latitude: N 40° 42.143
Longitude: W 105° 14.064
Location Description: North Fork below Seaman Reservoir

Notes: Samples are collected upstream of the stream gauge and bridge. Sample site is accessible from footpath along north stream bank.

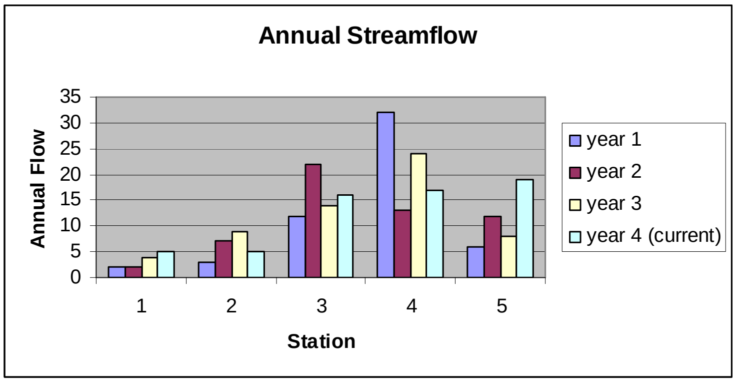
APPENDIX I

Data analysis report outlines for Annual and Five Year Reports

CLP Monitoring Program
Annual Report Format

I. Introduction and description of monitoring program
Map of locations
List of variables

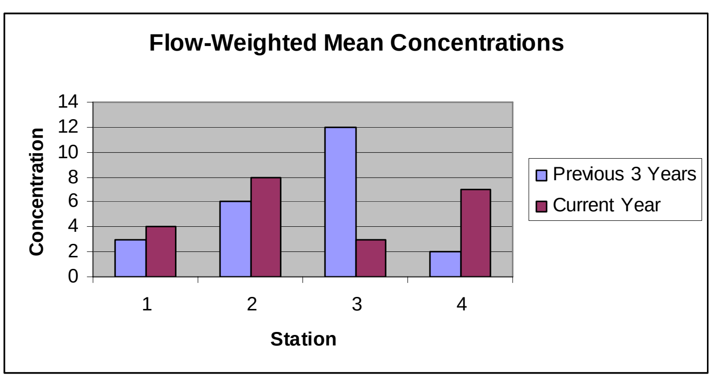
II. Discussion of hydrology of year, any special occurrences, such as fires
Plots of streamflow for last 4 years at 3-4 key locations on same graph
Bar graph of annual flow (not including winter) at key locations for last four years



The following two topics (III and IV) are organized into three sections for each:
1. Conductivity, hardness, TOC, 2. Nutrients, 3. Other variables.

III. Discussion of how current year concentrations differ from previous three years, including standards violations, if any
Time series of concentrations for each variable, 3-4 stations per graph--current year and 3 previous years
Water quality standards shown on graphs where applicable

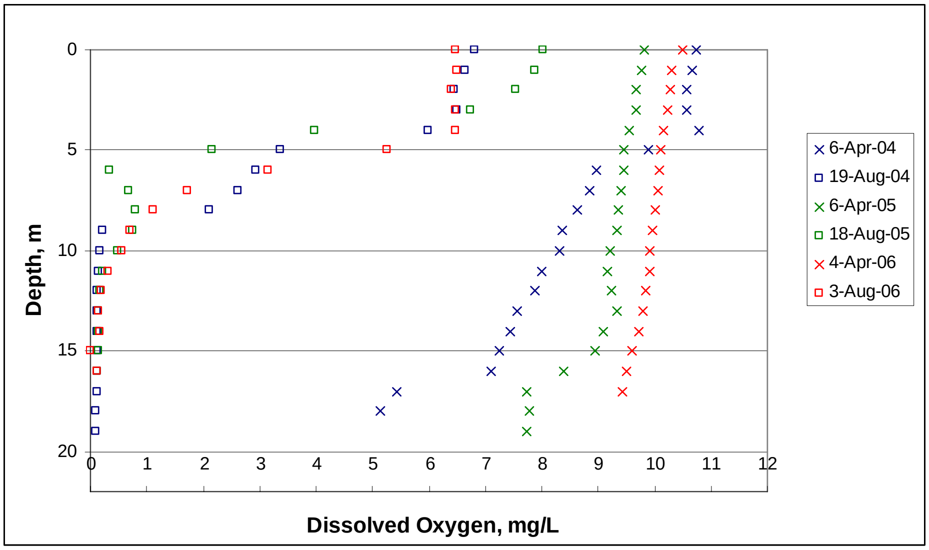
IV. Discussion of spatial patterns in concentration
Bar graph by station of flow-weighted mean concentration for each variable compared to average of 3 previous years



V. Discussion of Seaman Reservoir behavior compared to recent years

Top and bottom time series for most recent 4 years

Profiles for temp and DO, current year only.



VI. Conclusions

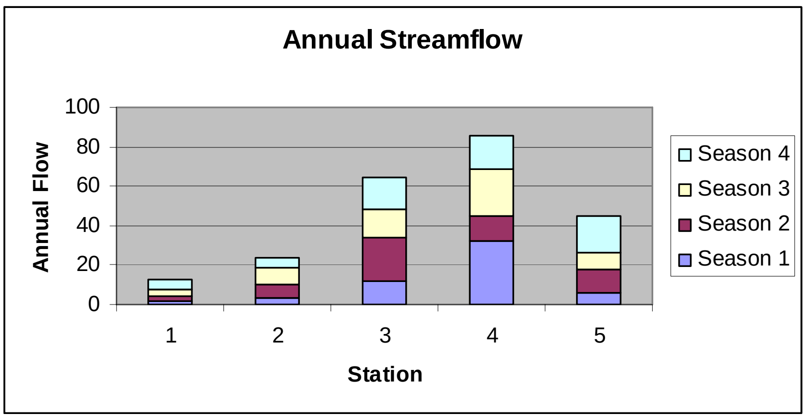
CLP Monitoring Program
Five Year Report Format

I. Introduction and description of monitoring program

Map of locations
List of variables

II. Discussion of hydrology for study period, any special occurrences, such as fires, trends over time

Plots of streamflow data for study period (five years) at 3-4 key locations on same graph
Bar graph of total annual flow (not including winter) at key locations for entire period of record, one graph per location
Bar graph (stacked seasons) of average annual flow by location



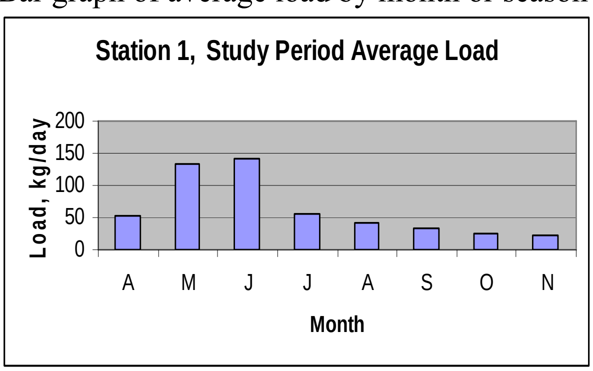
III. Discussion of flow versus quality relationships

Plots of concentration vs. flow (also logs) for nutrients, conductivity, TOC, at key stations, including r^2

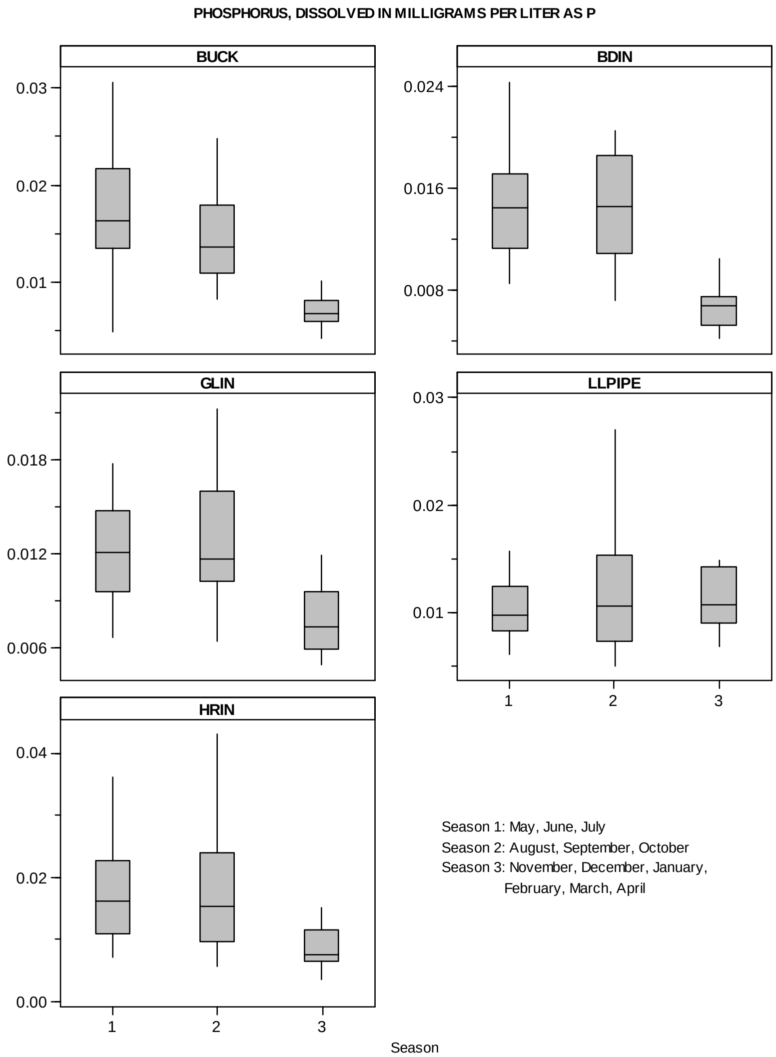
The following four topics (IV, V, VI, VII) are organized into three sections for each: 1. Conductivity, hardness, TOC, 2. Nutrients, 3. Other variables.

IV. Discussion of seasonal patterns in concentration, loads

Bar graph of average load by month or season for each key variable, location.



Boxplots of concentrations by month or season for each key variable and location for study period only

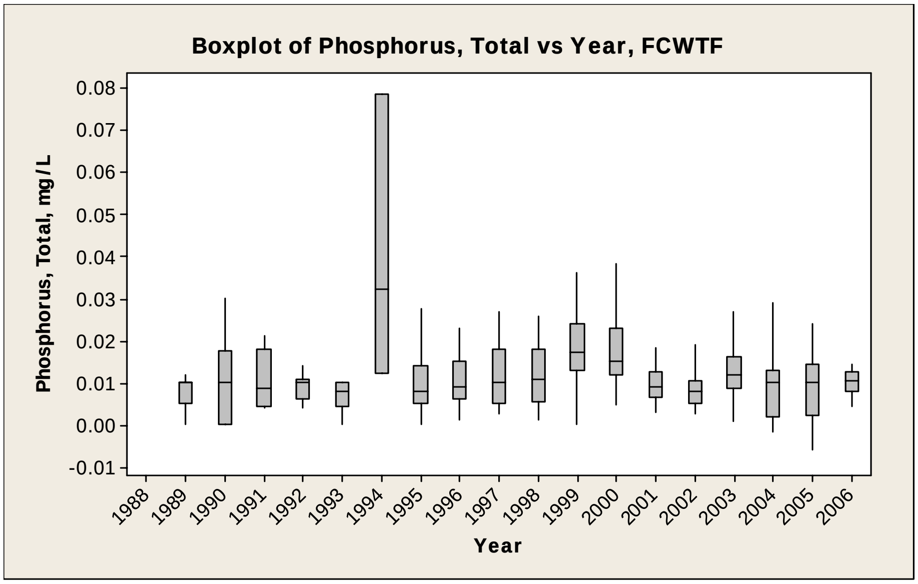


V. Discussion of trends over time

Annual boxplots and time series plots of each variable for period of record

Tests for significance of trend using seasonal regression on ranks, with and without flow adjustment

Regression estimates of the magnitude trend slope, using data not ranks



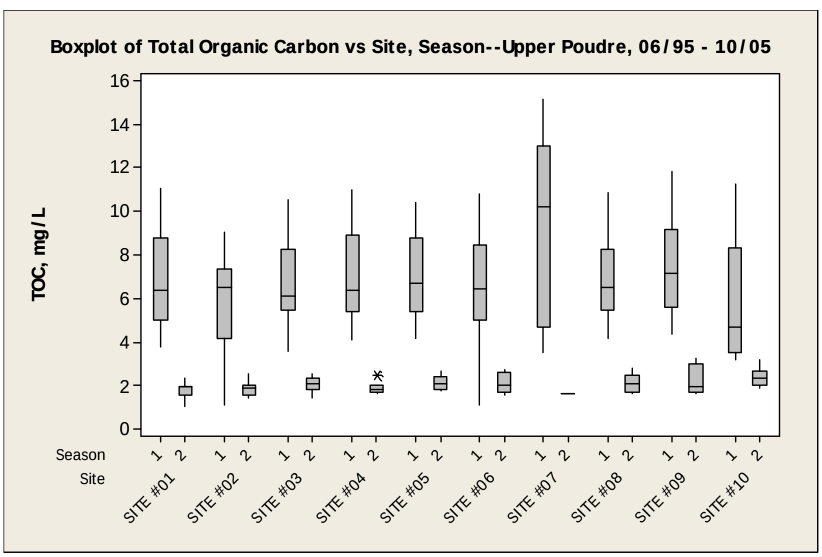
VI. Discusssion of standards compliance

Time series graphs, showing applicable water quality standards

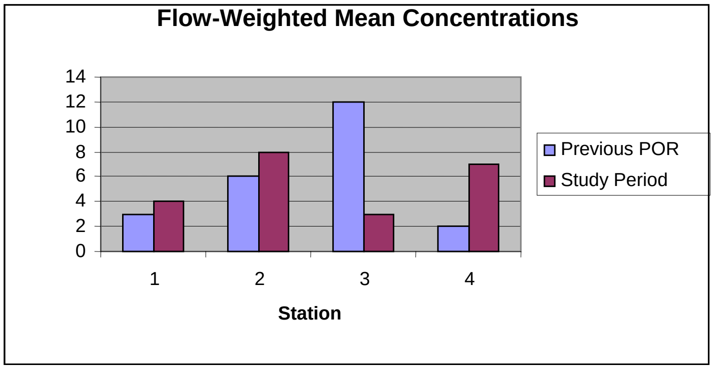
Table showing the number of standards violations for each variable for each year over study period (last five years)

VII. Discussion of spatial patterns in concentration

Boxplots of concentration by station for each variable



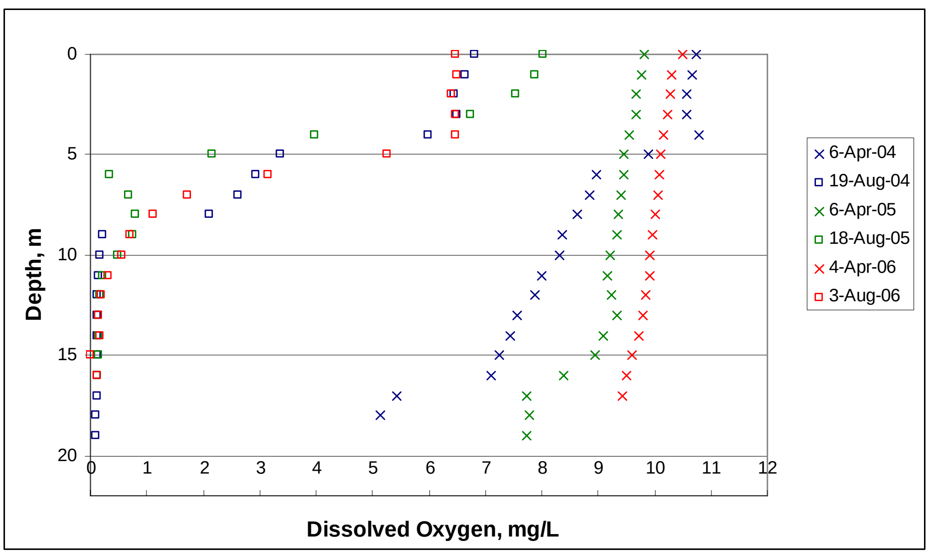
Bar graph of flow-weighted mean concentration for each variable for study period compared to previous period of record



Bar graph of total annual load for each variable for study period compared to previous period of record.

VIII. Discussion of Seaman Reservoir behavior

Top and bottom time series for period of record
Profiles for temp and DO, study period only



IX. Tables of summary statistics by variable, location, year

Minimum, maximum, median, mean, standard deviation, standard error or confidence interval for mean, annual load, standard error of load

X. Conclusions

APPENDIX J

Retrospective Analysis Report for City of Fort Collins

APPENDIX K

Retrospective Analysis Report for City of Greeley