Geotechnical
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Ecological

Cherry Creek Reservoir 2013 Water Year Aquatic Biological Nutrient Monitoring Study and Cottonwood Creek Pollutant Reduction Facilities Monitoring

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Table of Contents

List of Tables

List of Figures

List of Appendices

List of Acronyms & Abbreviations

ac-ft	acre-feet
ANOVA	analysis of variance
APHA	American Public Health Association
CCBWQA	Cherry Creek Basin Water Quality Authority
CDPHE	Colorado Department of Public Health and Environment
CEC	Chadwick Ecological Consultants, Inc.
cfs	cubic feet per second
CPW	Colorado Parks and Wildlife
CWQCC	Colorado Water Quality Control Commission
CY	calendar year
DM	daily maximum
DRCOG	Denver Regional Council of Governments
ed.(s)	editor(s)
ft	feet
GEI	GEI Consultants, Inc.
ha	hectare
JCHA	John C. Halepaska & Associates, Inc.
KAPA	Denver/Centennial Airport
km	kilometer
lb	pound
m	meter
mg	milligram
mg/L	milligrams per liter
mL	milliliter
mo	month
mph	miles per hour
mV	millivolt
MWAT	maximum weekly average temperature
ORP	oxidation reduction potential
PAR	photosynthetically active radiation
PRF	pollutant reduction facilities
Reservoir	Cherry Creek Reservoir
TDP	total dissolved phosphorus
TMAL	total maximum annual load
TMDL	total maximum daily load
TN	total nitrogen
TP	total phosphorus
TSS	total suspended solids
SRP	soluble reactive phosphorus
µg/L	micrograms per liter
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
WY	water year
yr	year

Executive Summary

The purpose of this report is to present the 2013 water year (WY) data collected by GEI Consultants, Inc. (GEI), on behalf of the Cherry Creek Basin Water Quality Authority (CCBWQA). The data were collected to evaluate Cherry Creek Reservoir (Reservoir) water quality conditions with respect to selected standards identified in Regulations No. 31 & 38 and goals identified in the Cherry Creek Reservoir Control Regulation No. 72, as well as to evaluate the effectiveness of the CCBWQA's pollutant reduction facilities (PRFs) on Cottonwood Creek and other stream reclamation projects within the Cherry Creek Basin. Additionally, this report provides analysis of trends observed in the long-term monitoring data collected on behalf of the CCBWQA since 1987.

ES 1.1. Flow-weighted Phosphorus Concentrations and Loads

The 2013 WY total normalized inflow for Cherry Creek, Cottonwood Creek, and the ungaged residual inflow was 13,402 acre-feet per year (ac-ft/yr), contributing a total of 8,918 pounds (lbs) of phosphorus to the Reservoir. The annual precipitation falling directly on the Reservoir accounted for 1,206 ac-ft of water and contributed 381 lbs of phosphorus, while the normalized alluvial inflow was 1,998 ac-ft/yr, and contributed 1,033 lbs of phosphorus to the Reservoir. These three primary sources of inflow—streams, precipitation, and alluvium—accounted for a total inflow of 16,606 ac-ft/yr to the Reservoir, contributing a total of 10,332 lbs of phosphorus to the Reservoir. The 2013 WY flow-weighted total phosphorus concentration for all sources of inflow was 229 micrograms per liter (µg/L) which is greater than the flow-weighted total phosphorus goal of 200 µg/L for the Reservoir. However, the September storm events greatly affected the inflow and phosphorus conditions to the Reservoir. From October 2012 to August 2013, the flow-weighted total phosphorus concentration was 175 µg/L for all external sources to the Reservoir, whereas the flow-weighted total phosphorus concentration in September 2013 was 301 µg/L. The long-term (1992 to 2013) WY median flow-weighted total phosphorus concentration for the Reservoir is 205 µg/L. The total Reservoir outflow was 10,359 ac-ft/yr, exporting 3,378 lbs of phosphorus from the Reservoir with 2013 WY flow-weighted total phosphorus concentration of 120 µg/L. The long-term (1992 to 2013) WY median export flow-weighted total phosphorus concentration from the Reservoir is 103 µg/L. The net external total phosphorus load to the Reservoir was 6,954 lbs.

ES 1.2. Total Phosphorus

Total phosphorus concentrations in the upper 3 meter (m) layer of the Reservoir ranged from 92 to 156 µg/L during the July to September sampling events, with a seasonal mean of 125 µg/L. The long-term (1992 to 2013) seasonal median total phosphorus concentration for the Reservoir is 87 µg/L, whereas the seasonal median total phosphorus concentration for the last five years is 124 µg/L.

ES 1.3. Chlorophyll *a*

The annual pattern of chlorophyll a concentrations was quite variable with chlorophyll *a* less than 18 µg/L only in mid-May and considerably greater during a majority of the 2013 WY. From October 2012 through September 2013, chlorophyll *a* concentrations ranged from 15.8 µg/L to 35.5 µg/L with a 2013 WY mean chlorophyll *a* concentration of 24.8 µg/L (Figure 19). The July through September seasonal mean chlorophyll a level was 26.8 µg/L, with a peak seasonal reservoir mean concentration of 35.5 µg/L. This is the fourth consecutive year when the seasonal mean chlorophyll *a* value exceeded the site-specific standard of 18 µg/L. As a result, the Reservoir is not attaining the site-specific chlorophyll *a* standard. The long-term (1992 to 2013) seasonal median chlorophyll *a* concentration for the Reservoir is 18.3 µg/L, whereas the seasonal median chlorophyll *a* concentration for the last five years is 25.0 µg/L.

ES 1.4. Phytoplankton

Phytoplankton density in the photic zone ranged from 1,750 #/milliliter (mL) to 5,613 #/mL. The number of algal taxa present in the Reservoir ranged from 11 to 24 taxa. Based on the calendar year, the assemblage was dominated in terms of density by green algae (39%), with diatoms and cryptomonads being the next most abundant taxonomic groups at 30% and 15%, respectively. Similar to 2012, the relative density of large filamentous cyanobacteria (1%) was extremely low in 2013. Green algae were abundant throughout the year, and diatoms were relatively abundant throughout most of the year with exception to the months of February and March. During the 2013 winter ice-covered conditions, cryptophytes were the most abundant algal group in terms of biomass. These algae are similarly well-adapted to growing during low light and low temperature conditions during ice-covered periods. In February 2013, the majority of the algal assemblage was comprised of golden algae (84%) which was the only month that this group was the dominant algal group. After February 2013, golden algae densities continued to decrease and the algal assemblage began to be dominated by green algae.

When the size (i.e., biovolume) of each algae is considered, diatoms were the most dominant algal group (30%) observed over the course of the year, followed by green algae (26%), cryptomonads (14%) and euglenoids (13%). The dinoflagellates only accounted for approximately 6% of the total algal biovolume and cyanobacteria only accounted for only 5%

of algal biovolume. Patterns in algal biovolume show typical seasonal succession patterns of many temperate lakes and reservoirs with cryptomonads and diatoms being most abundant in the spring, cyanobacteria becoming evident in mid to late summer as well as dinoflagellates in late summer, then diatoms comprising most of the assemblage during the fall. In fall 2013, diatoms were abundant and green algae biovolume decreased compared to summer 2013.

ES 1.5. Temperature and Dissolved Oxygen

Seasonal water temperatures during routine profile measurements in the Reservoir ranged from 1.7°C at the surface in mid-January to 24.9°C at the surface in late June 2013. Temperature loggers were installed on April 29th and showed an early spring stratification period due to the seasonably warm ambient air temperatures that warmed the upper mixed layer. In mid-May, the Reservoir began showing signs of storm-induced thermal stratification. During this time, the large pulse of inflow from the May 8th-9th storm event flowed along the bottom of the Reservoir creating a temperature gradient. During May, the dissolved oxygen concentrations generally remained greater than 5 milligrams per liter (mg/L) throughout the water column, except for the deeper 5-7 m layers and water/sediment interface where dissolved oxygen concentrations averaged 2.9 mg/L.

By the first sampling event in June 2013, dissolved oxygen concentrations began decreasing at depths greater than 5 m with values less than the upper threshold (2 mg/L) conducive for internal loading at the sediment boundary. These conditions in the deep layers of the Reservoir may pose relatively little harm to the warm water biological community, because the mixed layer remained well oxygenated. However, deep water anoxia (< 2 mg/L) at the sediment boundary created favorable conditions for internal nutrient loading for several weeks during the summer period.

On August 13th, dissolved oxygen profiles indicated that the water column had become mixed with dissolved oxygen concentrations ranging from 7.8 mg/L at the surface to 5.5 mg/L at the sediment boundary. Storm events and cooler than average air temperatures resulted in a slight decrease in water temperatures (~2°C decrease) in mid-August. In late August, water temperatures increased to approximately 22°C throughout the water column facilitating the microbial driven anoxic conditions in the deeper water layers. On September 10th-15th, 2013 a large storm event occurred and resulted in anoxic conditions once again in the lower levels of the Reservoir.

Reservoir profiles were also evaluated to determine the attainment of the dissolved oxygen standard. Over the course of the monitoring year, 80 vertical water column profiles were collected in the Reservoir. For each profile, the 1 m and 2 m dissolved oxygen values were averaged and evaluated for attainment of the Class 1 Warm Water table value standard (5 mg/L) for lakes and reservoirs that are greater than 5 m deep. The Reservoir was in attainment of the dissolved oxygen standard for 79 of 80 profiles. The single low value of 4.8 mg/L occurred on September 11, 2013 at Site CCR-2 following the September storm events. Based on the assessment methodology, the September data are not representative of the Reservoir because the storm events temporarily influenced conditions. Therefore, the low value does not indicate an exceedance of the warm water dissolved oxygen standard. During the July to September growing season, the average dissolved oxygen concentration of the upper layer was 7.3 mg/L for all vertical profiles.

ES 1.6. Destratification System Effectiveness

The 2013 summer season represented the sixth full seasonal operation of the destratification system. The additional temperature monitoring continues to show that storm events greatly influence water temperatures and reservoir conditions, despite the constant mixing by the aeration system. However, based on the past seven years of temperature monitoring data, the Reservoir has shown a substantial reduction in the number of days it was thermally stratified during the summer season. Prior to the operation of the destratification system, the Reservoir was thermally stratified for approximately 60 days during the summer season, whereas during the 2013 WY, the Reservoir was thermally stratified for approximately 21 days. These results continue to support the observation that the destratification system has reduced the number of thermally stratified days by approximately 65% of pre-operating conditions.

To date, given the relative change in algal composition and the reduction in thermal stratification, the operation of the destratification system appears to be effective in attaining two of the key objectives that the system was designed to achieve – reduction of cyanobacteria habitat as well as thermal stratification. Low dissolved oxygen conditions still persist in the bottom waters at the sediment interface, which continues to facilitate internal nutrient loading.

ES 1.7. Pollutant Reduction Facility Effectiveness

The Cottonwood Creek Peoria Wetland PRF was effective in reducing the flow-weighted phosphorus concentration from 267 µg/L upstream to 113 µg/L downstream of the wetland system for a removal efficiency of approximately 58%. Over the life of the project, the PRF shows approximately an average 19% reduction in the flow weighted total phosphorus concentration at the downstream site. Also, the total suspended solids were reduced by the PRF by approximately 64% in 2013, with the long-term average showing a 27% reduction.

The Cottonwood Creek Perimeter Wetland PRF was also effective at reducing the flow-weighted total phosphorus concentration from 119 µg/L upstream to 57 µg/ downstream of the PRF, which indicates a high efficiency in removing phosphorus. Over the life of the project, the PRF shows approximately an average 23% reduction in the flow-weighted total phosphorus concentration at the downstream site. Also, the total suspended solids were reduced by approximately 63% in 2013, with the long-term average showing a 30% reduction.

Overall, the Cottonwood Creek Stream Reclamation project has shown to be very effective in reducing the amount of suspended solids in the downstream reach, as well as being effective in reducing the flow-weighted total phosphorus concentration. Since the completion of the Cottonwood Creek Stream Reclamation, the combination of these three PRFs has effectively reduced the flow-weighted total phosphorus concentration entering the Reservoir, via Cottonwood Creek, from a pre-project WY average of 143 µg/L to a post-project WY average of approximately 80 µg/L.

Water quality monitoring of the McMurdo Gulch Stream Reclamation PRF began in January 2012 and serves to provide information on a tributary to Cherry Creek planned for future development. The upstream – downstream monitoring regime showed that total suspended solids concentrations were very similar between the two monitoring locations, yet mean total phosphorus concentrations greatly decreased from the upstream (373 µg/L) to the downstream (262 µg/L) monitoring location even though remaining above a level considered as background (200 µg/L) for the area. Because Site MCM-1 is located upstream of the McMurdo Gulch Stream Reclamation Project Boundary and Site MCM-2 is located downstream of the PRF, the reduction in phosphorous from Site MCM-1 to Site MCM-2 indicates that the PRF is effectively reducing total phosphorous concentrations in McMurdo Gulch. To better assess the effectiveness of the Stream Reclamation Project, GEI will continue to monitor these two sites during the 2014 WY.

In an effort to identify the sources of elevated nutrient concentrations observed at Site MCM-1, background nutrient data was collected during a single sampling event in May 2013 at sites MCM-0.25, MCM-0.5 and MCM-Trib A. The elevated total phosphorous and total nitrogen levels observed at Site MCM-1 are likely due to higher nutrient input from an unnamed tributary that is located 225 m upstream of this site. This unnamed tributary receives drainage from a small sub-watershed containing two large residential lots to the east of McMurdo Gulch, but the source of elevated nutrient concentrations is not clearly apparent.

1.0 Historical Perspective

An inter-governmental agreement was executed in 1985 by several local governmental entities within the Cherry Creek basin to form the Cherry Creek Basin Water Quality Authority (CCBWQA). The CCBWQA was created for the purpose of coordinating and implementing the investigations necessary to maintain the quality of water resources of the Cherry Creek basin while allowing for further economic development. Based on a clean lakes water study (Denver Regional Council of Governments [DRCOG] 1984), the Colorado Water Quality Control Commission (CWQCC) set standards for phosphorus, and a total maximum daily load (TMDL) for phosphorus. The Reservoir was classified as Class 1 Warm Water for aquatic life, with an in-lake phosphorus standard of 35 micrograms per liter (µg/L) and seasonal mean chlorophyll *a* goal of 15 µg/L. Subsequently, a phosphorus TMDL was prepared for Cherry Creek Reservoir (Reservoir) allocating loads among point sources, background sources, and nonpoint sources with a total maximum annual load (TMAL) of 14,270 pounds (lbs) total phosphorus.

The Cherry Creek Basin Master Plan (DRCOG 1985), approved by the CWQCC in 1985, was adopted in part as the "Regulations for Control of Water Quality in Cherry Creek Reservoir" (Section 4.2.0, 5C.C.R.3.8.11). An annual monitoring program (In-Situ, Inc. 1986, as amended, Advanced Sciences, Inc., 1994a and 1994b) was implemented at the end of April 1987 to assist in the assessment of several aspects of the Master Plan. These monitoring studies have included long-term monitoring of: 1) nutrient levels within the Reservoir and from tributary streams during base flows and storm flows; 2) nutrient levels in precipitation; and 3) chlorophyll *a* levels within the Reservoir.

In September 2000, following a hearing before the CWQCC, the standard for Cherry Creek Reservoir (Regulation #38) was changed to a seasonal July to September mean value of 15 µg/L of chlorophyll *a* to be met 9 out of 10 years, with an underlying total phosphorus goal of 40 µg/L, also as a July to September mean value. In addition, the limit for wastewater effluent total phosphorus concentration was set at 50 µg/L, to be met as a 30-day mean value. In May 2001 at the CWQCC hearing, the Control Regulation (#72) was adopted for the Cherry Creek Reservoir, which maintained the annual TMAL of 14,270 lbs/year as part of a phased TMDL for the Reservoir. During the March 2009 Rulemaking Hearing, Regulations 38 and 72 were again refined to reflect the most current feasibility-based chlorophyll *a* standard and flow-weighted inflow total phosphorus goal for Cherry Creek Reservoir. The current chlorophyll *a* standard is 18 µg/L with an exceedance frequency of once in 5 years. The control regulation changed from a phosphorus load-based TMAL to a flow-weighted concentration such that the annual flow-weighted total phosphorus concentration goal is 200 µg/L for all combined sources of inflow to the Reservoir.

From 1993 to 1998, Dr. John Jones of the University of Missouri contributed greatly to the Cherry Creek Reservoir annual monitoring program (Jones 1994 to 1999, 2001), and assisted with the transition of the program to Chadwick Ecological Consultants, Inc. (CEC) in 1994. Results of the aquatic biological and nutrient analyses have been summarized in annual monitoring reports (CEC 1995 to 2006). In 2006, CEC merged with GEI Consultants, Inc. (GEI), and continues to perform the annual monitoring duties of Cherry Creek Reservoir (GEI 2007, 2008b, 2009 to 2013). The present study was designed to continue the characterization of the relationships between nutrient loading (both in-lake and external) and Reservoir productivity. The specific objectives of this annual monitoring study include the following:

- Determine baseflow and stormflow concentrations for nitrogen and phosphorus fractions in tributary inflows, as well as concentrations in Cherry Creek Reservoir and the outflow.
- Determine the hydrological inflows and nutrient loads entering Cherry Creek Reservoir, including Reservoir exports. These data provide the necessary information to calculate flow-weighted nutrient concentrations for the Reservoir.
- Determine biological productivity in Cherry Creek Reservoir, as measured by algal biomass (chlorophyll *a* concentration) and algal densities. In addition, determine species composition of the algal and zooplankton assemblages.
- Evaluate relationships between the biological productivity and nutrient concentrations within Cherry Creek Reservoir and total inflows.
- Assess the effectiveness of pollutant reduction facilities (PRFs) on Cottonwood Creek, McMurdo Gulch and Cherry Creek to reduce phosphorus loads into the Reservoir.
- Assess the effectiveness of the destratification system in controlling nuisance algae and minimizing periods of thermal stratification.

In 2010, the CCBWQA changed the reporting year to be representative of the water year (WY, October to September) rather than the normal calendar year. Tables and figures presenting historical data have been recalculated to appropriately reflect the water year summary values, although the 1992 WY only contains data from January 1992 to September 1992 due to the change in annual calculations.

2.0 Study Area

Cherry Creek was impounded in 1948 and the dam was completely finished in 1950 by the U.S. Army Corps of Engineers (USACE) to protect the City of Denver from flash floods that originated in the 995 square kilometers (km^2) (385 square miles) drainage basin. The Reservoir has maintained a surface area of approximately 345 hectares (ha) (approximately 850 acres) since 1959. The Reservoir and surrounding state park has also become an important recreational site, providing activities that include fishing, boating, swimming, bicycling, bird watching, and walking.

2.1 Sampling Sites

Sampling during the 2013 WY was routinely conducted at 13 sites, including three sites in Cherry Creek Reservoir, nine sites on tributary streams, and one site on Cherry Creek downstream of the Reservoir (Figures 1 and 2). In addition to these routine monitoring sites, 10 transect sites (D1 to D10) were established from the approximate mid-point of the dam face extending perpendicular across the destratification zone in the Reservoir, as well as three continuous temperature logging sites near routine reservoir monitoring sites. The routine sampling sites are summarized below.

2.1.1 Cherry Creek Reservoir

CCR-1 This site is also called the Dam site, and was established in 1987. Site CCR-1 corresponds to the northwest area within the lake (Knowlton and Jones 1993). Sampling was discontinued at this site in 1996 following determination that this site exhibited similar characteristics to the other two sites in this polymictic Reservoir. Sampling recommenced in July 1998 at the request of consultants for Greenwood Village.

CCR-2 This site is also called the Swim Beach site, and was established in 1987. Site CCR-2 corresponds to the northeast area within the lake (Knowlton and Jones 1993).

CCR-3 This site is also called the Inlet site and was established in 1987, corresponding to the south area within the lake (Knowlton and Jones 1993).

2.1.2 Shop Creek

SC-3 This site was established on Shop Creek in 1990 upstream of the Perimeter Road and downstream of the Shop Creek detention pond and wetland system. In 1994, this site was moved just downstream of the Perimeter Road and again moved farther downstream to a location just upstream of its confluence with Cherry Creek in 1997. This site serves to monitor the water quality of Shop Creek as it enters Cherry Creek.

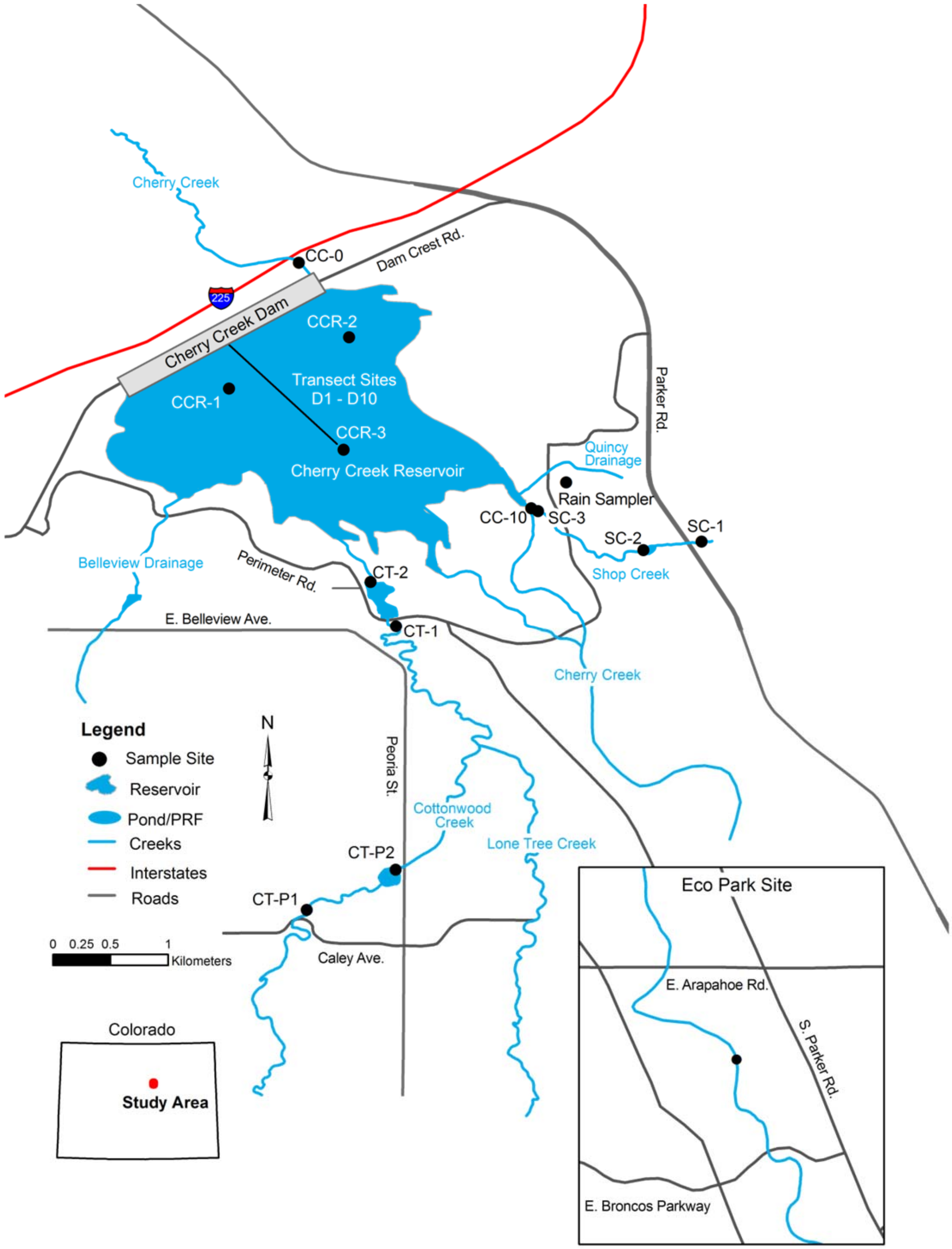

Figure 1: Sampling sites on Cherry Creek Reservoir and selected streams, 2013.

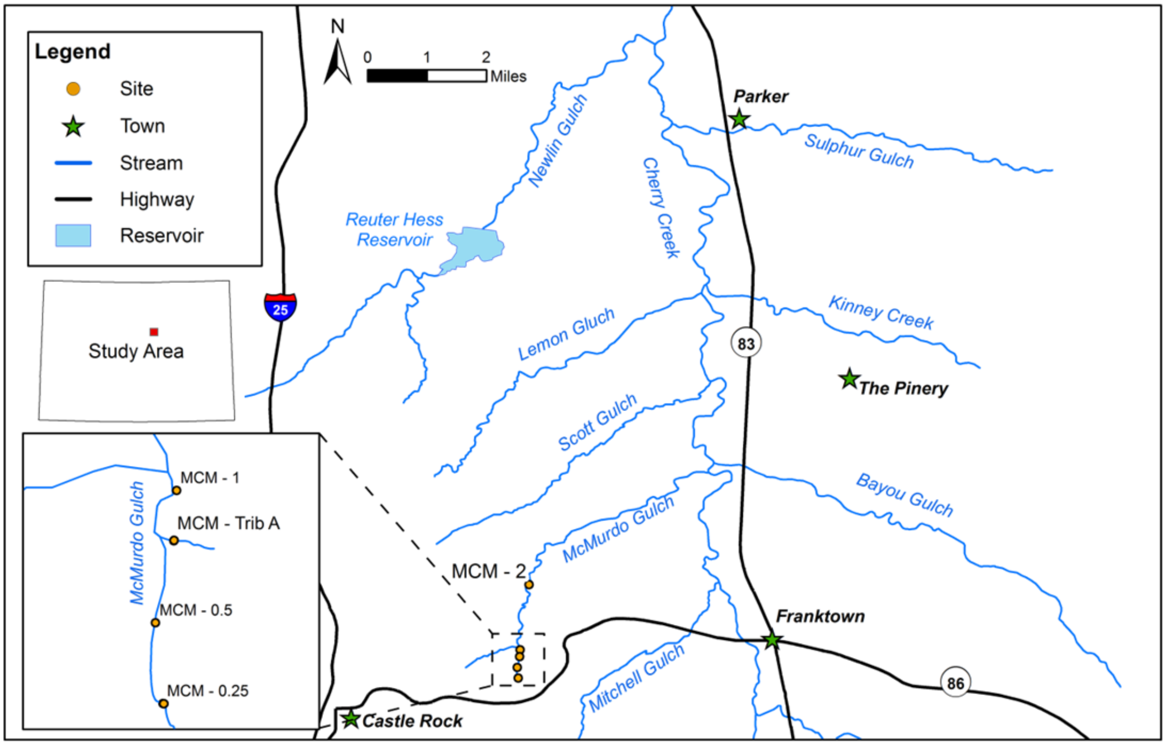

Figure 2: Sampling sites on McMurdo Gulch, 2013.

2.1.3 Cherry Creek

EcoPark — This site was established in 2013 on Cherry Creek at the downstream boundary of Cherry Creek Valley Ecological Park (EcoPark). This site is approximately 1.7 kilometers (km) upstream of Arapahoe Road, and serves to monitor water quality conditions downstream of the EcoPark Stream Reclamation Project (PRF). This site also provides more accurate flow estimates in this reach of Cherry Creek.

CC-10 — This site was originally established in 1987 on Cherry Creek near the historic U.S. Geological Survey (USGS) Melvin gage, approximately 3.5 km upstream of the Reservoir (roughly due west of the intersection of Parker Road and Orchard Road). This location is in an area of Cherry Creek that frequently becomes dry during summer months as a result of the natural geomorphology and alluvial pumping for domestic water supply (John C. Halepaska & Associates, Inc. [JCHA] 1999 and 2000).

In 1995, this site was relocated farther downstream between the Perimeter Road and the Reservoir, approximately 800 meters (m) upstream of the Reservoir. This site was moved still farther downstream in 1996, just upstream of the confluence with Shop Creek and closer to the Reservoir. In 1999, it was moved below the confluence with Shop Creek to eliminate the effect of a stream crossing on the site's hydrograph. Since 1995, Cherry Creek has been monitored in a reach with perennial flow, allowing for more accurate monitoring of water quality and surface flow in Cherry Creek before entering the Reservoir. Historically, this site has been referred to as CC or CC-I (i.e., CC-Inflow), but was renamed Site CC-10 in 1997 to place it in context with concurrent monitoring in Cherry Creek mainstem upstream of the Reservoir (JCHA 1999 to 2007).

CC-O This site was established in 1987 on Cherry Creek downstream of Cherry Creek Reservoir and upstream of the Hampden Avenue-Havana Street junction in the Kennedy Golf Course near the historical USGS gage (06713000). In 2007, Site CC-O (also identified as Site CC-Out @ I225) was relocated immediately downstream of the dam outlet structure and serves to monitor the water quality of the Reservoir outflow.

2.1.4 Cottonwood Creek

CT-P1 This site was established in 2002 and is located just north of where Caley Avenue crosses Cottonwood Creek, and west of Peoria Street. This site monitors the water quality of Cottonwood Creek before it enters the Peoria Pond PRF, also created in 2001/2002 on the west side of Peoria Street.

CT-P2 This site was established in 2002 and is located at the outfall of the PRF, on the west side of Peoria Street. The ISCO stormwater sampler and pressure transducer is located inside the outlet structure. This site monitors the effectiveness of the PRF on water quality.

CT-1 This site was established in 1987 where the Cherry Creek Park Perimeter Road crosses Cottonwood Creek. It was chosen to monitor the water quality of Cottonwood Creek before it enters the Reservoir. During the fall/winter of 1996, a PRF, consisting of a water quality/detention pond and wetland system, was constructed downstream of this site. As a result of the back-flow from this pond inundating this site, this site was relocated approximately 250 m upstream near Belleview Avenue in 1997. In 2009, this site was relocated approximately 75 m upstream of the Perimeter Road as it crosses Cottonwood Creek, due to the stream reclamation project. This site is now approximately 200 m upstream of the PRF.

CT-2 This site was established in 1996 and was originally located downstream of the Perimeter Pond on Cottonwood Creek. The ISCO pressure transducer and staff gage was located in a section of the stream relatively unobstructed by vegetation, and approximately 50 m downstream of the PRF. However, over the years the growth of vegetation considerably increased along the channel, creating problems with accurately determining stream flow. Eventually, when no accurate and reliable streamflow measurements could be performed in 2003, other locations were evaluated. In August 2004, the pressure transducer and staff gage were relocated inside of the outlet structure for the PRF to mitigate problems associated with streamflow measurements by providing a reliable multilevel weir equation. In 2013, modifications to the PRF overflow elevation and internal weir structure changed the relationship of the multilevel weir equation, resulting in unreliable stream flow estimates. In 2014, the weir elevations will be resurveyed to adjust the equations accordingly. Water quality samples are collected from the outlet structure as well. This site monitors the effectiveness of the PRF on Cottonwood Creek water quality and provides information on the stream before it enters the Reservoir.

2.1.5 McMurdo Gulch

MCM-0.25 This site was established in 2013 on McMurdo Gulch, approximately 860 m upstream of Site MCM-1 and 50 m downstream of North Valley View Road crossing. This site served as the furthest upstream location exhibiting surface flow and represents background conditions in McMurdo Gulch.

MCM-0.5 This site was established in 2013 on McMurdo Gulch, approximately 570 m upstream of Site MCM-1. This site serves as a background condition site for McMurdo Gulch.

MCM-Trib A This site was established in 2013 in the unnamed tributary that receives drainage from large lot residential areas to the east of McMurdo Gulch. The confluence of the unnamed tributary is 225 m upstream of Site MCM-1, and the site is located 50 m upstream of the confluence. This site serves as background conditions to McMurdo Gulch.

MCM-1 This site was established in 2012 on McMurdo Gulch, approximately 150 m upstream of the McMurdo Gulch Stream Reclamation Project boundary. This site is also 120 m upstream of the confluence with an unnamed tributary that receives runoff from the Castle Oaks Subdivision. This site serves as the upstream monitoring location for the McMurdo Gulch Stream Reclamation Project.

MCM-2 This site was established in 2012 on McMurdo Gulch, approximately 80 m upstream of the Castle Oaks Drive Bridge crossing of McMurdo Gulch, near the North Rocky View Road intersection. This site serves as the downstream monitoring location for the McMurdo Gulch Stream Reclamation Project. This site is located within the project boundary, and consistently maintained base flows, whereas the reach further downstream was often dry due to surface flow becoming subsurface.

3.0 Methods

3.1 Sampling Methodologies

Field sampling protocols and analytical methods used for monitoring the Reservoir and stream sites as outlined in the Cherry Creek Reservoir Sampling and Analysis Plan (GEI 2008a; Appendix A).

3.1.1 Reservoir Sampling

The general sampling schedule included regular sampling trips to the Reservoir at varying frequencies over the annual sampling period, as outlined below, with increased sampling frequency during the summer growing season (Table 1). A total of 16 reservoir sampling events were conducted during the 2013 WY. The December 2012 sampling event was not performed due to unsafe ice conditions. During each sampling event on the Reservoir, three main tasks were conducted, including: 1) determining water clarity, 2) collecting physicochemical depth profiles, and 3) collecting water samples for chemical and biological analyses.

Table 1: Sampling trips per sampling period, 2013 WY.

Sampling Period	Frequency	Planned Trips/Period	Actual Trips/Period
Oct - Apr	Monthly	7	6
May - Sept	Bi-Monthly	10	10
Total		**17**	**16**

3.1.1.1 Water Clarity

Transparency was determined using a Secchi disk and LI-COR quantum sensors (ambient and underwater). Detailed methods of both instruments can be found in the Sampling and Analysis Plan (Appendix A).

3.1.1.2 Profile Measurements

A Hydrolab MS5 Surveyor and Sonde was used for the collection of dissolved oxygen, temperature, conductivity, pH, and oxidation reduction potential (ORP) profile measurements from the surface to the bottom of the Reservoir.

3.1.1.3 Water Sampling

Water samples for nutrient, phytoplankton, zooplankton, chlorophyll *a*, and suspended solids analyses were collected at the three Reservoir sites. Data collected from each site during a single sampling event (i.e., three replicate samples), are averaged to provide a whole-reservoir mean estimate for each parameter. Sample event means are then used to calculate annual or seasonal mean values for key parameters such as chlorophyll *a* and total phosphorus and to facilitate comparison with regulatory standards and goals that apply to the Reservoir. Depending upon the distributional characteristics of each parameter, annual values may be compared to either the long-term mean or median value. Secchi depth and chlorophyll *a* are two parameters that reveal normal distributions, thus it is more appropriate to compare annual values with the long-term mean. Conversely, the total phosphorus data exhibit a log normal distribution; therefore it is more appropriate to compare annual values to the long-term median value. The Sampling and Analysis Plan (Appendix A) outlines the detailed methods used to collect lake water samples, as well as the laboratory methods in sample handling and preparation.

3.1.1.4 Fish Population Data

Historically, this monitoring study has also reviewed fish stocking and population data collected by the Colorado Parks and Wildlife (CPW). The most recent fish population survey was conducted in the late summer 2013 by the CPW (personal communication with Paul Winkle, CPW). Unfortunately, these data were not available to GEI at the time of finalizing the 2013 Cherry Creek Monitoring Report.

3.1.1.5 Sediment Core Sampling

To characterize the source of internal nutrient loading in the Reservoir, sediment core samples were collected from sites CCR-1, CCR-2 and CCR-3 in June 2013. Based on site-specific factors (water depth, sediment particle size, sample depth, and sample volume), a Kajak-Brinkhurst sediment corer was selected to collect sediment cores at these sites (USEPA 2001). Three replicate samples were collected from each site for a total of 12 sediment core samples. The top 15 cm of each core was analyzed for nutrients including total phosphorous, total extractable phosphorous, nitrate, nitrite, ammonia and total iron.

3.1.2 Stream Sampling

3.1.2.1 Base Flow Sampling

Base flow stream sampling was conducted on a monthly basis (12 events) in coordination with the routine Reservoir sampling trips to Cherry Creek Reservoir. This sampling was performed to characterize base flow conditions, which corresponds to the low-flow ambient samples collected in past studies. Monthly samples are assumed to be representative of non-storm, base flow periods on Cherry Creek, Cottonwood Creek, Shop Creek, and McMurdo Gulch.

3.1.2.2 Storm Sampling

Storm events sampled at the inflow sites on Cherry Creek, Cottonwood Creek, and Shop Creek characterize non-base flow conditions during the sampling season (Table 2). A detailed outline of storm sampling protocols can be found in the Sampling and Analysis Plan (Appendix A). Storm samples were not collected on McMurdo Gulch.

Table 2: Number of storm samples collected from tributary streams to Cherry Creek Reservoir, 2013 WY. See Appendix C for sample dates.

	Sites						
	EcoPark	CC-10	SC-3	CT-P1	CT-P2	CT-1	CT-2
Number of Storm Samples	7	5	6	7	7	7	7

3.1.3 Surface Hydrology

Pressure transducers attached to ISCO Series 6700 or 6712 flowmeters measured and recorded water levels (stage) at seven sites on the three tributaries to Cherry Creek Reservoir (Figure 1). These flow meters are programmed to record water level data on 15-minute intervals year round. Streamflow (discharge) was estimated at sites CC-10, SC-3, CT-1, CT-P1 using stage-discharge relationships developed for each stream site. For sites CT-2 and CT-P2, where the flow meters are located inside the concrete outlet structure, multi-level orifice and weir equations were used to estimate discharge. Periodic stream discharge measurements were collected during a range of flow conditions using a Marsh McBirney Model 2000 flowmeter. For a complete description of streamflow determination, see Appendix D.

In 2012, a modification to the Site CT-2 outlet works structure and dam embankment occurred during maintenance to the PRF system which altered the flow characteristics inside the weir. Subsequently in 2013, flow conditions still indicate a change in the multi-level weir equations which is under further investigation. As a result, the Site CT-2 flow estimates are not reliable, thus Site CT-1 flow and CT-2 phosphorus data were used to estimate inflow and flow-weighted concentrations entering the Reservoir.

3.2 Laboratory Procedures

3.2.1 Nutrient Laboratory Analysis

Physicochemical and biological analyses from the Reservoir and stream water quality samples were performed by the GEI analytical laboratory (Table 3). Quality Assurance/ Quality Control protocols for the low level nutrient analyses were performed by the GEI Laboratory, with all results being reported in Appendix B.

3.2.2 Biological Laboratory Analysis

Biological analyses of the Reservoir phytoplankton samples were conducted by Aquatic Analysts, Friday Harbor, Washington. Aquatic Analysts performed phytoplankton identification and enumeration and provided the number of phytoplankton per unit volume (#/milliliter (mL)) and taxa richness, while GEI performed the chlorophyll *a* concentrations (µg/L). Zooplankton samples were analyzed by Water's Edge Scientific LLC, Baraboo, Wisconsin. The methods for these analyses, with appropriate QA/QC procedures, are available from GEI. In 2013, the total nitrogen, total dissolved nitrogen, and ammonium ion methods changed slightly because the Lachat QuikChem auto-analyzer was replaced. The new methods slightly increased the extraction efficiency for nitrogen but the changes were not significant when compared with the older methods.

Table 3: Parameter list, method number, and detection limits for chemical and biological analyses of water collected from Cherry Creek Reservoir and tributaries.

Parameter	Method	Detection Limit
Total Phosphorus	QC 10-115-01-4-B	2 µg/L
Total Dissolved Phosphorus	QC 10-115-01-4-B	2 µg/L
Soluble Reactive Phosphorus	QC 10-115-01-1-T	2 µg/L
Total Nitrogen	QC 10-107-04-4-B	2 µg/L
Total Dissolved Nitrogen	QC 10-107-04-4-B	2 µg/L
Ammonium Ion	QC 10-107-06-2-A	3 µg/L
Nitrate and Nitrite	QC 10-107-04-1-C	2 µg/L
TSS	APHA 2540D	4 mg/L
TVSS	APHA 2540E	4 mg/L
Chlorophyll *a*	APHA 10200 H (modified)	0.1 µg/L

APHA = American Public Health Association, 1998.

3.3 Evaluation of Long-Term Trends in Cherry Creek Reservoir

Long-term seasonal trends were evaluated for Secchi depth, chlorophyll *a*, and total phosphorus using whole-reservoir mean values from 1987 to 2013 and linear regression analysis (described below). Additionally, 95% confidence intervals provided information on data dispersal around the mean annual values. These analyses were used to determine whether there was significant increasing or decreasing trends in Secchi depth, total phosphorus, and chlorophyll *a* levels over time.

Comparisons of biological and physical parameters for each site were conducted using NCSS 2007 statistical software (Hintze 2009). Basic descriptive statistics were used to evaluate the distributional characteristics of the data, and to determine whether a variable required transformation to meet the basic assumptions of normality. Logarithmic transformations were used to increase the symmetry of the data about the mean, approximating a normal distribution. If the transformation did not improve normality, the untransformed data were used in subsequent analyses.

The least-squares linear regression was used to estimate slope, with analysis of variance (ANOVA) being used to determine if the slope was significantly different than zero. A probability of < 0.05 was used to indicate statistical significance. In the cases of the linear regressions, the R^2 value provided a measure of how well the variance is explained by the regression equation. R^2 values measure the proportion of total variation that is explained or accounted for by the fitted regression line (i.e., it is a measure of the strength of the relationship with the observed data).

4.0 Results and Discussion

4.1 Reservoir Water Quality

4.1.1 2013 WY Transparency

The whole-reservoir mean Secchi depth varied from 0.44 m in late September to 0.97 m in late March (Figure 3). The seasonal (July through September) whole-reservoir mean Secchi depth was 0.65 m (Figure 4). The depth at which 1% of photosynthetically active radiation (PAR) penetrated the water column (i.e., photic zone depth) ranged from 1.45 m in mid-September to a maximum depth 3.48 m in April (Figure 3). The greatest level of whole-reservoir chlorophyll *a* of 35.5 µg/L was observed in mid-September which also coincided with some of the poorest water clarity values (Figure 3).

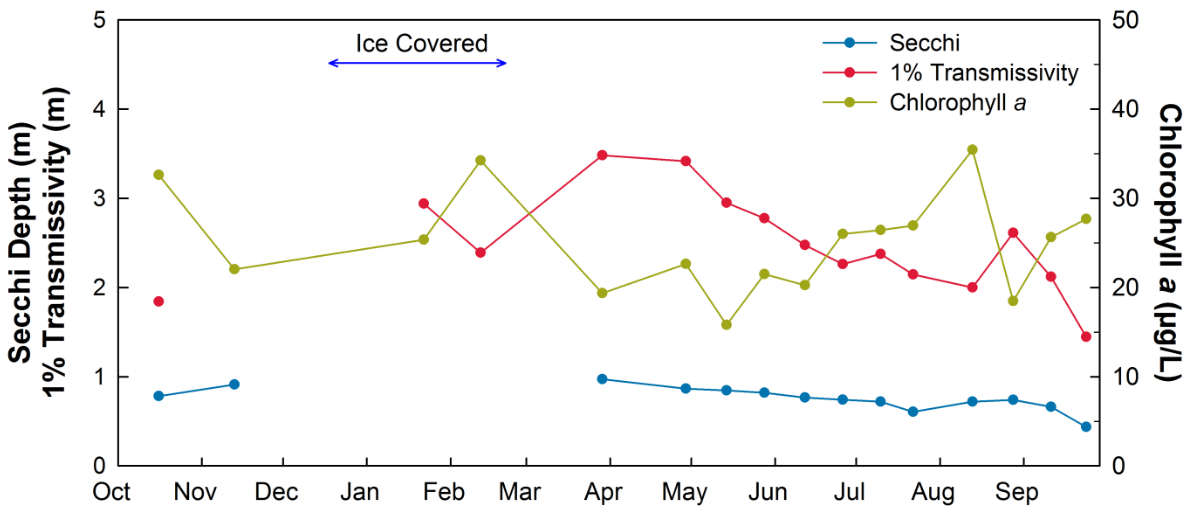

Figure 3: Patterns for mean whole-reservoir Secchi depth, 1% transmissivity, and chlorophyll *a* in Cherry Creek Reservoir, 2013 WY.

4.1.2 Long-Term Secchi Transparency Trends in Cherry Creek Reservoir

In general, seasonal mean (July through September) Secchi depths increased from 1987 to 1996, then decreased in 1997 at which time they have been relatively stable until the past few years (Figure 4). The 2013 seasonal whole-reservoir mean Secchi depth was 0.65 m, which is less than the present long-term (1987 to present) mean value of 0.94 m.

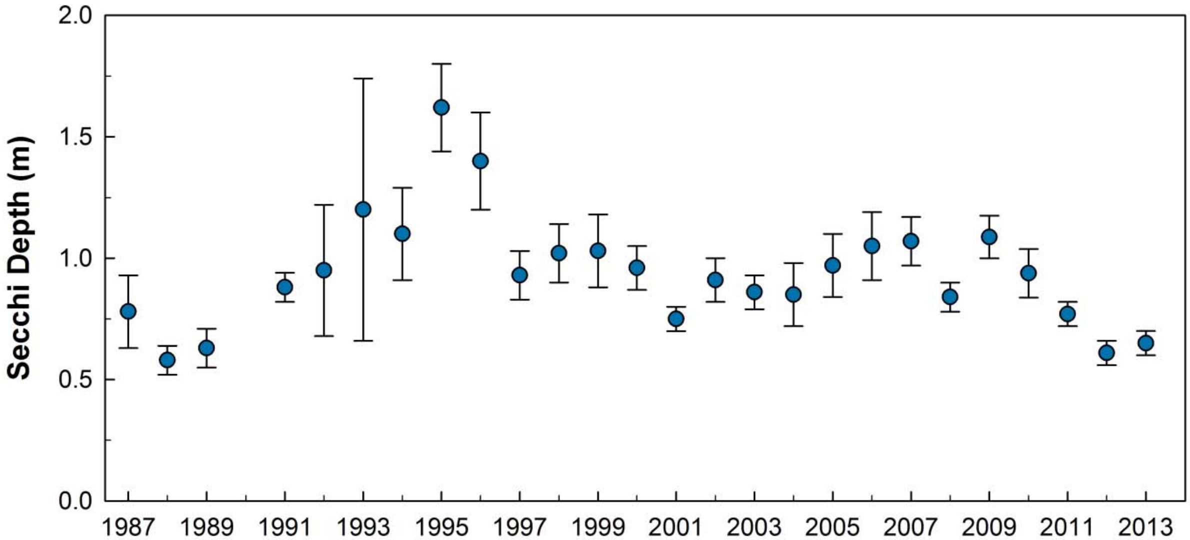

Figure 4: Whole-reservoir seasonal mean (July through September) Secchi depth (m) measured in Cherry Creek Reservoir. Error bars represent a 95% confidence interval for each mean.

4.1.3 2013 WY Temperature and Dissolved Oxygen

Analysis of past Cherry Creek Reservoir temperature profiles indicates that stratification typically occurs when there is greater than 2°Celsius (C) difference between the surface and bottom water temperatures (Jones 1998). Differences of less than 1°C between the surface and bottom waters indicate mixing (Jones 1998). This criterion is generally supported by the classical definition of a thermocline, as being the layer with the greatest rate of change in temperature or dt/dz greater than 1°C/m. However, given the relatively shallow nature of the Reservoir and the temperature-density relationships, the Reservoir can become stratified even though the greatest rate of change may be less than 1°C. In addition, relative thermal resistance to mixing (RTRM) can be used to evaluate stratification as a function of temperature differentials in the water column (Wetzel 2001). Dissolved oxygen profiles are also used to evaluate periods of stratification when temperature differences are less than 1°C.

Under the current reservoir management regime, the physical location of the aeration heads in relation to the water column and bottom sediments (~ 0.75 m off of the bottom) has changed the location of the typical temperature-density boundary in the Reservoir and made the water temperatures more consistent. This boundary, as well as the oxygen boundary, typically align with the bubble plume rising upward from the aerators, thus density gradients can be established at this water level throughout the year. Using the above criteria, the multiple profiles and transect data for the Reservoir were evaluated for periods of potential stratification and low dissolved oxygen levels.

Seasonal water temperatures during routine profile measurements in the Reservoir ranged from 1.7°C at the surface in mid-January to 24.9°C at the surface in late June 2013 (Figure 5, Figure 7, and Figure 9). Temperature loggers were installed on April 29th and showed an early spring stratification period due to the seasonably warm ambient air temperatures that warmed the upper mixed layer. In mid-May, the Reservoir began showing signs of storm-induced thermal stratification. During this time, the large pulse of inflow from the May 8th-9th storm event flowed along the bottom of the Reservoir creating a temperature gradient (i.e., *dt*/*dz* greater than 1°C at the 6 m depth). During May, the dissolved oxygen concentrations generally remained greater than 5 milligrams per liter (mg/L) throughout the water column, except for the deeper 5-7 m layers and water/sediment interface where dissolved oxygen concentrations averaged 3.1 mg/L (Figures 6, 8, and 10).

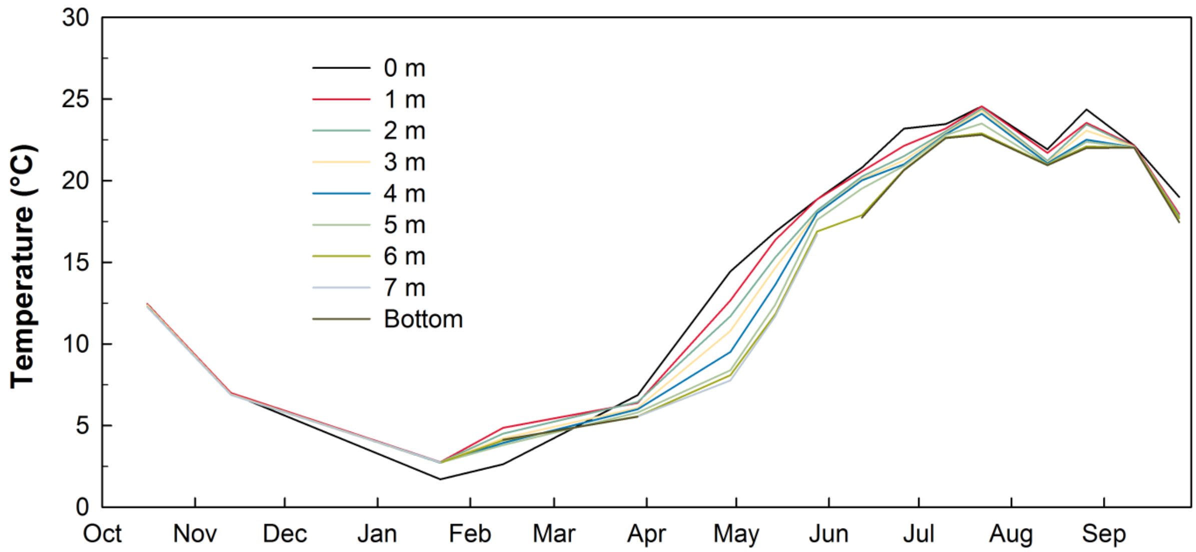

Figure 5: Temperature (°C) recorded at depth during routine monitoring at CCR-1 during the 2013 WY.

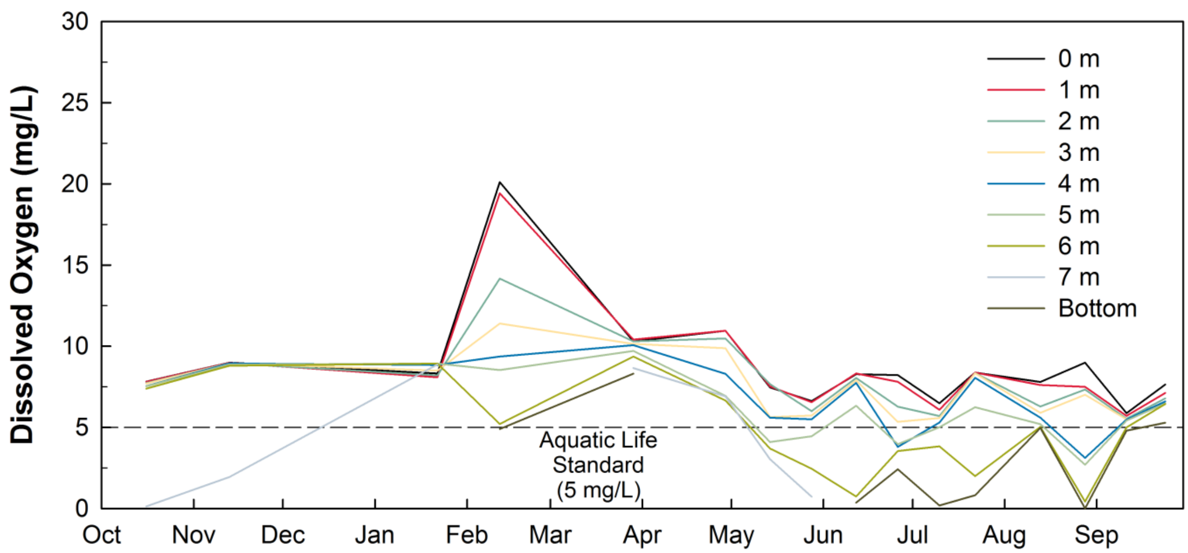

Figure 6: Dissolved oxygen (mg/L) recorded at depth during routine monitoring at CCR-1 during the 2013 WY. The dissolved oxygen basic standards table value for Class 1 warm water lakes and reservoirs is provided for comparison (5 mg/L).

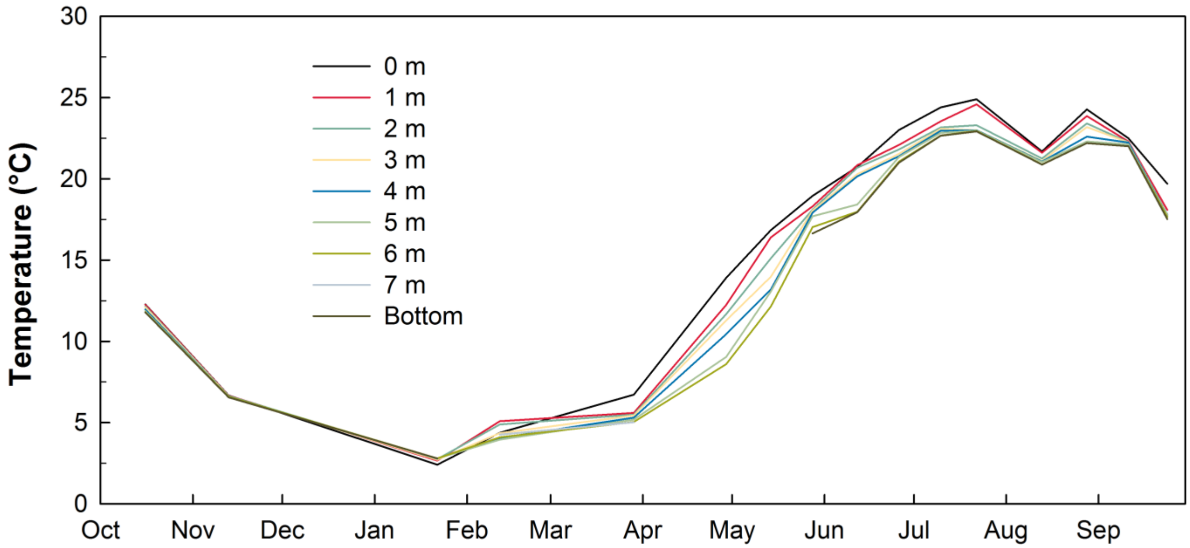

Figure 7: Temperature (°C) recorded at depth during routine monitoring at CCR-2 during the 2013 WY.

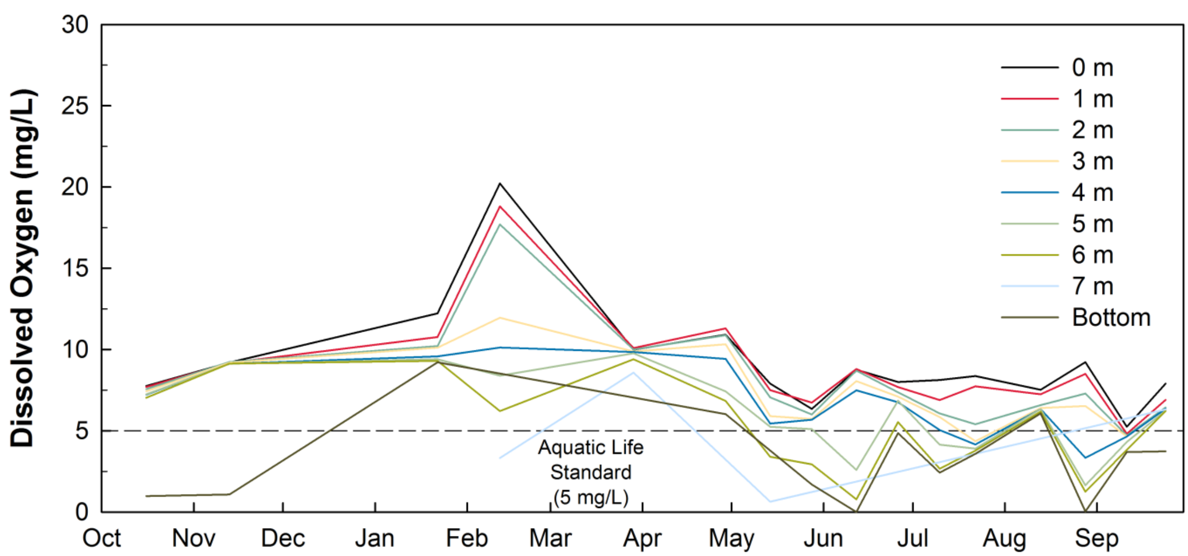

Figure 8: Dissolved oxygen (mg/L) recorded at depth during routine monitoring at CCR-2 during the 2013 WY. The dissolved oxygen basic standards table value for Class 1 warm water lakes and reservoirs is provided for comparison (5 mg/L).

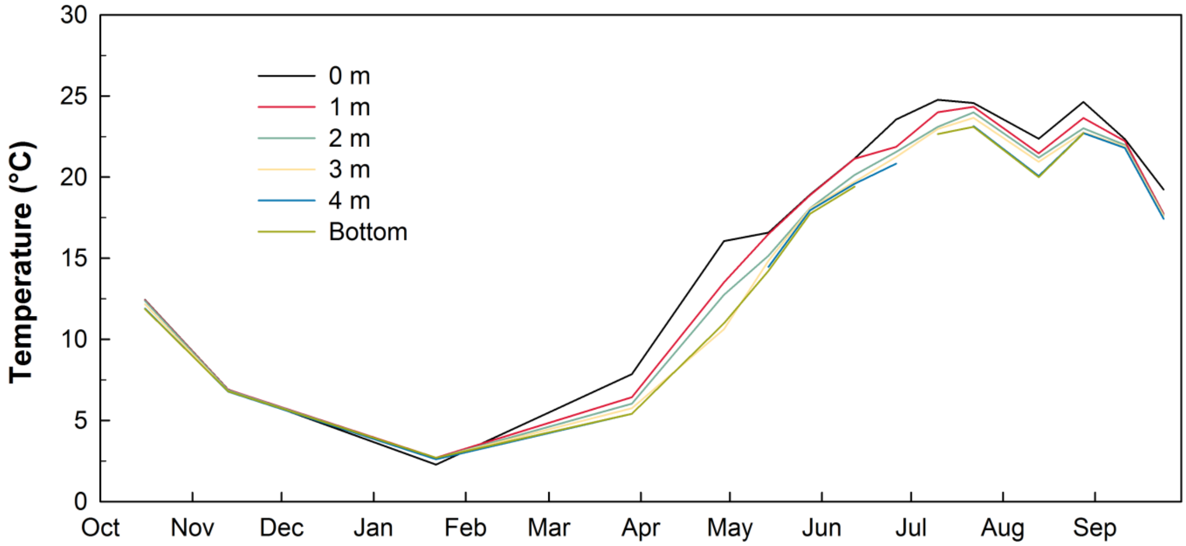

Figure 9: Temperature (°C) recorded at depth during routine monitoring at CCR-3 during the 2013 WY.

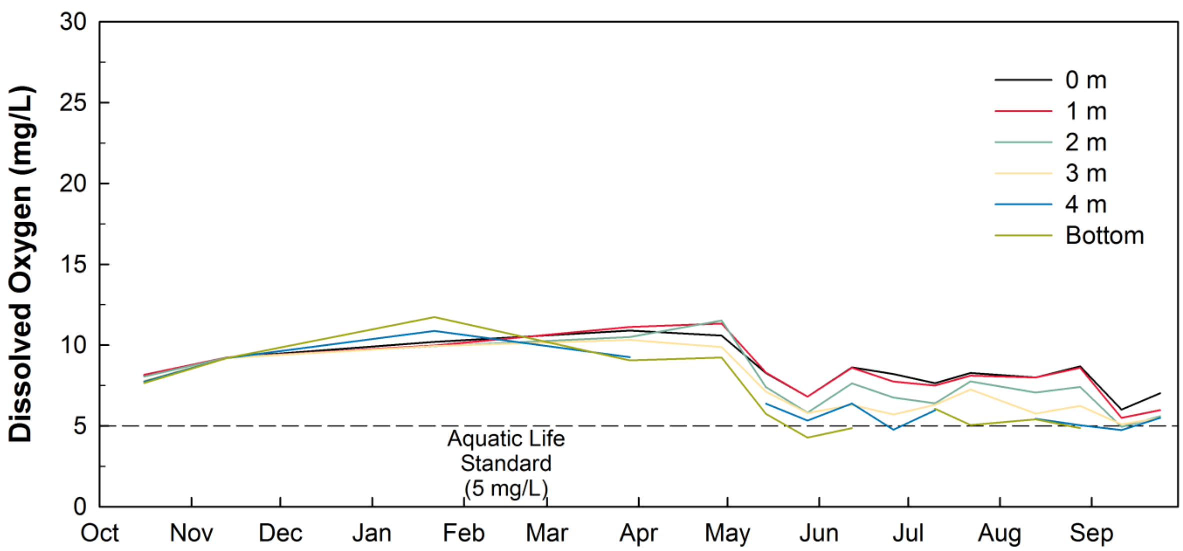

Figure 10: Dissolved oxygen (mg/L) recorded at depth during routine monitoring at CCR-3 during the 2013 WY. The dissolved oxygen basic standards table value for Class 1 warm water lakes and reservoirs is provided for comparison (5 mg/L).

Relative thermal resistance to mixing (RTRM) was calculated to evaluate stratification as a function of density gradients in the water column. From June through September 2013 the RTRM gradients are minimal, with the exception of June 12th and July 22nd (Figure 11). Despite the RTRM values indicating an elevated resistance to mixing between the 4 and 6 m layers on these dates, the level of resistance indicates the water column was only weakly stratified. Greater RTRM values were observed in the upper layers of the Reservoir on June 26th, August 28th, and September 24th (Figure 11). However, these values are limited to the upper layers and indicate solar heating in the top portion of the water column and are not indicative of typical stratification in the water column. Despite the low levels of thermal stratification and low RTRM which indicate a well-mixed Reservoir, the sediment oxygen demand (SOD) remains very high. This indicates that even a few centimeters of anoxic bottom water is sufficient for creating a reducing environment and internal load release of nutrients. The placement of the Reservoir aerator heads and circulation pattern are not sufficient to overcome the SOD despite the low levels of thermal stratification throughout the water column.

By the first sampling event in June 2013, dissolved oxygen concentrations began decreasing at depths greater than 5 m with values less than the upper threshold (2 mg/L) conducive for internal loading at the sediment boundary. These conditions in the deep layers of the Reservoir may pose relatively little harm to the warm water biological community, because the mixed layer remained well oxygenated. However, deep water anoxia (< 2 mg/L) at the sediment boundary created favorable conditions for internal nutrient loading for several weeks during the summer period.

On August 13th, dissolved oxygen profiles indicated that the water column had become mixed with dissolved oxygen concentrations ranging from 7.8 mg/L at the surface to 5.5 mg/L at the sediment boundary (Figure 6, Figure 8, and Figure 10). Storm events and cooler than average air temperatures resulted in a slight decrease in water temperatures (~2°C decrease) in mid-August (Figures 5, 7, and 9). In late August, water temperatures increased to approximately 22°C throughout the water column facilitating the microbial driven anoxic conditions in the deeper water layers. In addition, lake levels had decreased by 1.2 m from the management pool elevation (5,550 ft = 1,692 m) which also affected the relative depth of poor oxygen conditions at the 4 m water level. At this time, the Reservoir was approximately 6 m deep. On September 10th-15th, 2013 a large storm event occurred and resulted in anoxic conditions once again in the lower levels of the Reservoir (Figure 6, Figure 8, and Figure 10).

Reservoir profiles were also evaluated to determine the attainment of the dissolved oxygen standard. Over the course of the monitoring year, 83 vertical water column profiles were collected in the Reservoir. For each profile, the 1 m and 2 m dissolved oxygen values were averaged and evaluated for attainment of the Class 1 Warm Water table value standard (5 mg/L) for lakes and reservoirs that are greater than 5 m deep (CDPHE 2011). The Reservoir was in attainment of the dissolved oxygen standard for 82 of 83 profiles. The single exceedance occurred on September 11, 2013 with a minimum average dissolved oxygen value of 4.8 mg/L which occurred at Site CCR-2, following the early September storm event. During the July to September growing season, the average dissolved oxygen concentration of the upper layer was 7.3 mg/L for all vertical profiles.

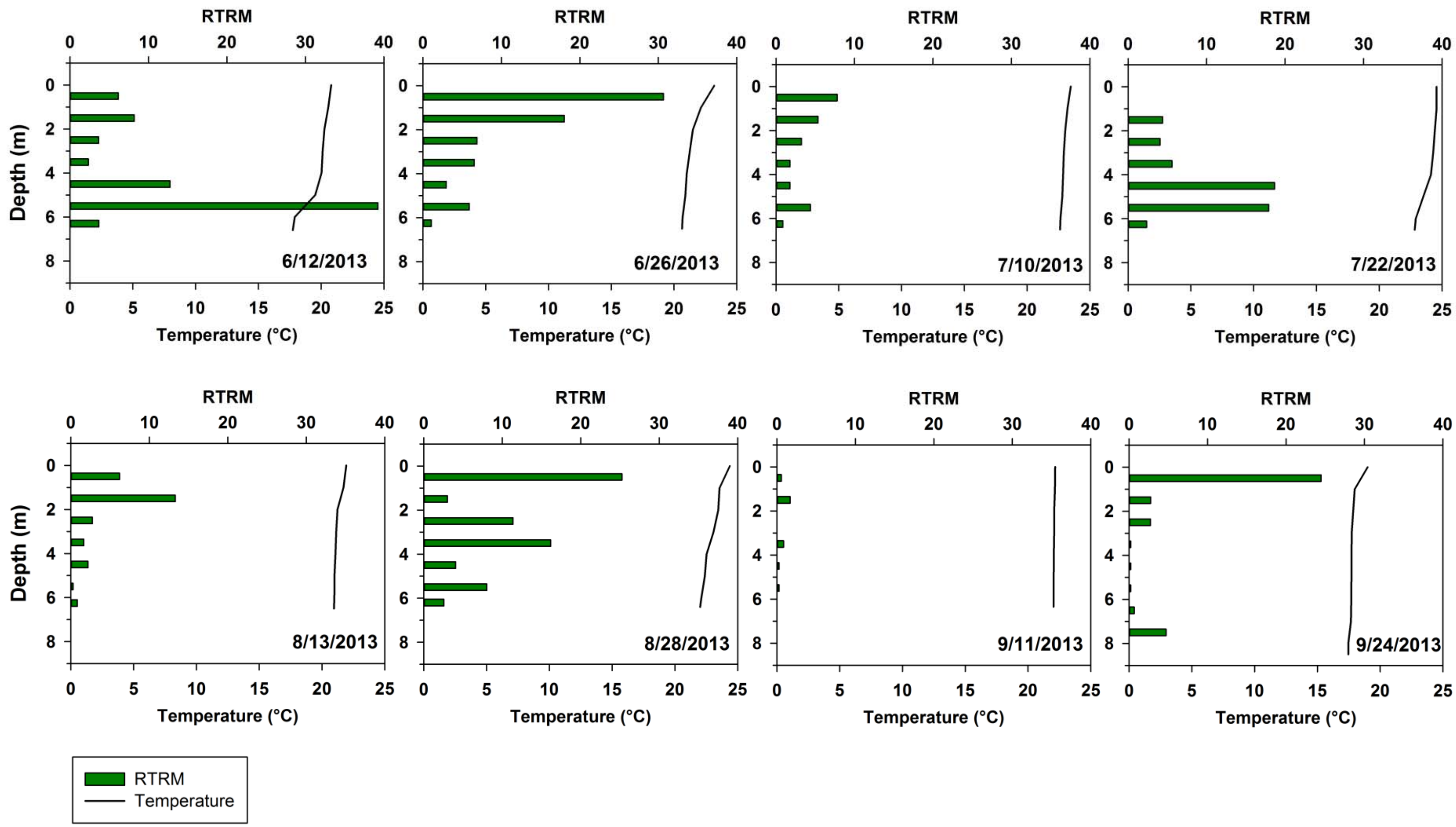

Figure 11: Relative thermal resistance to mixing gradients and temperature profiles for Cherry Creek Reservoir, June – September, 2013.

4.1.3.1 Continuous Temperature Monitoring

On April 29, 2013, temperature loggers were deployed for monitoring the efficiency of the destratification system at mixing the water column. Using the > 2°C difference criteria from the surface to the bottom, Cherry Creek Reservoir was evaluated for periods of stratification using the continuous temperature record at depths for all three Reservoir sites from April 29th to November 18th (Figure 12, Figure 13, and Figure 14). In mid May 2013, the Reservoir showed a brief period of storm-induced stratification (Figure 12, Figure 13, and Figure 14). By mid-July the continuous temperature profiles indicated the Reservoir was more thermally consistent with little temperature variation from the surface to the bottom; however, a large storm event occurred from September 10th-15th (total rainfall at KAPA station: 5.49 in) resulted in a large inflow into the Reservoir (Figure 12, Figure 13, and Figure 14). This inflow of cooler water resulted in thermal stratification throughout the Reservoir.

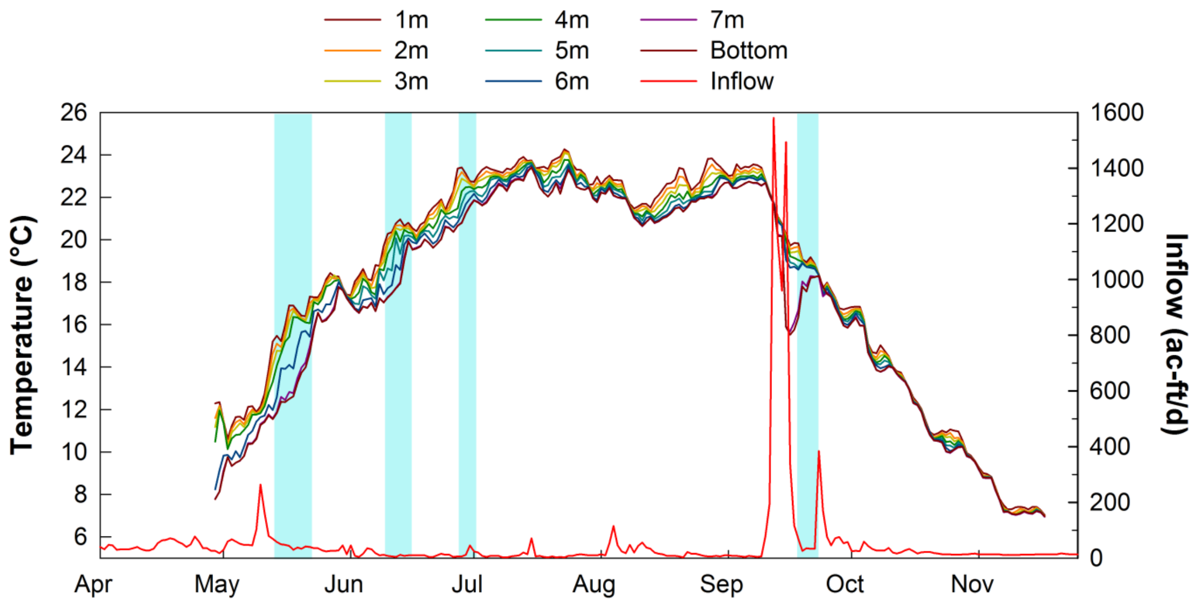

Figure 12: Daily mean temperature (°C) recorded at depth for CCR-1 based on 15-minute interval data collected by temperature loggers, with USACE inflow in 2013. Shaded areas denote periods of thermal stratification.

On April 29, 2013, the Reservoir showed signs of brief thermal stratification lasting between 2 to 11 days for each event: April 29th - May 1st, May 4th -5th, May 12th- 22nd, June 7th-13th, June 27th-28th, and September 15th-18th. During the June stratification periods, the deeper water layers of the Reservoir revealed low dissolved oxygen concentrations resulting from the higher sediment oxygen demand. The low dissolved oxygen levels were not as persistent in the deeper waters throughout the summer period, as observed in previous years. The thermally stratified conditions are more closely linked to storm events that facilitate the onset of stratification. However, natural warming of the water column also promoted thermal stratification despite the evidence of the destratification system's effectiveness at circulating the upper water layers (0 to 6 m).

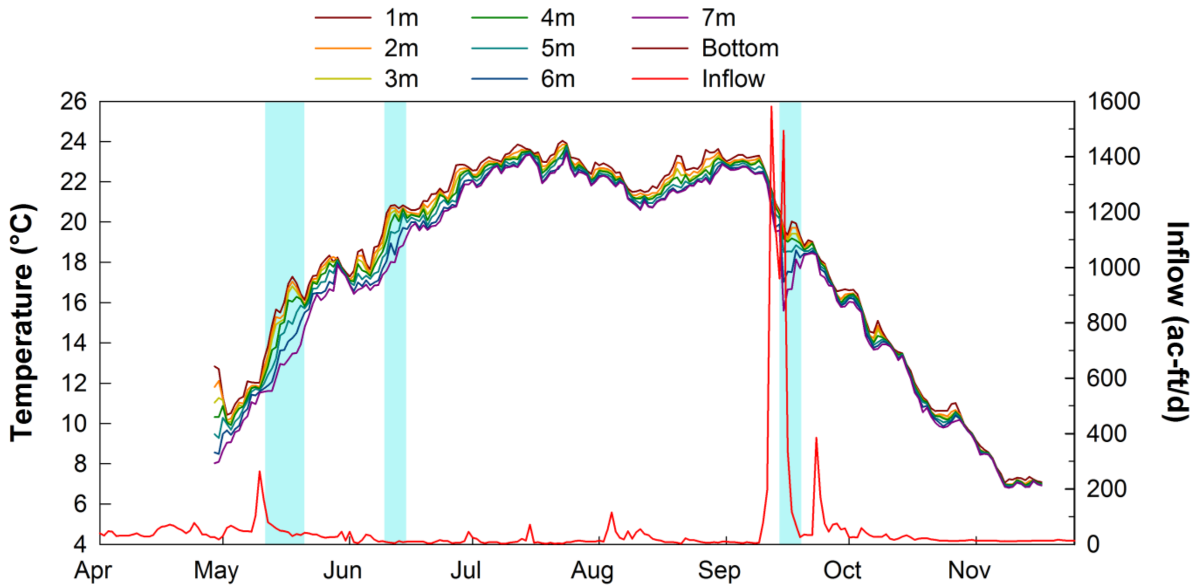

Figure 13: Daily mean temperature (°C) recorded at depth for CCR-2 based on 15-minute interval data collected by temperature loggers, with USACE inflow in 2013. Shaded areas denote periods of thermal stratification.

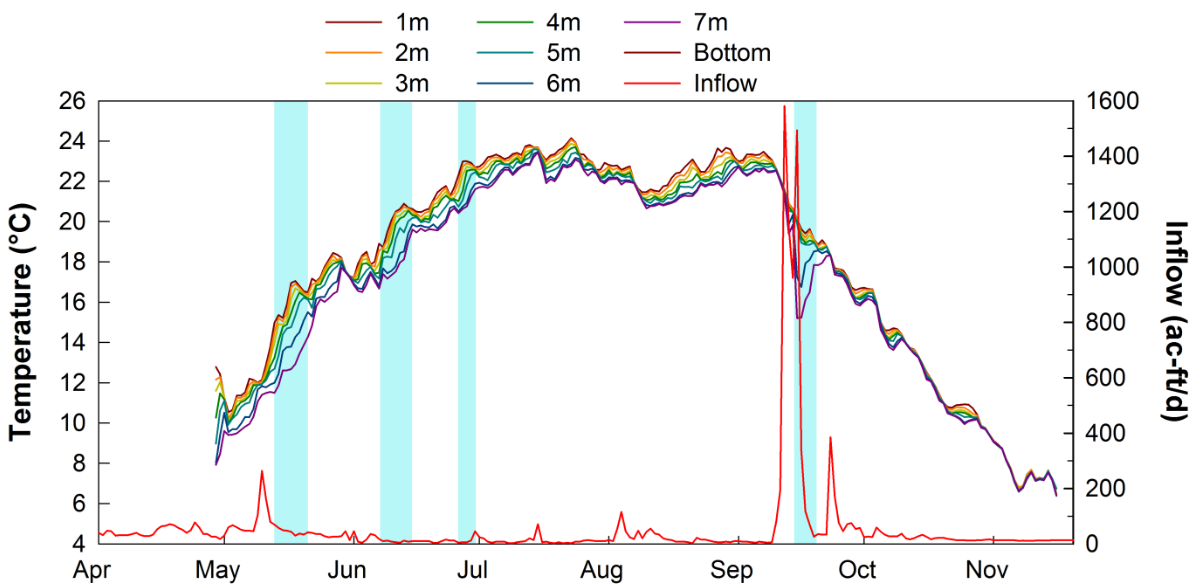

Figure 14: Daily mean temperature (°C) recorded at depth for CCR-3 based on 15-minute interval data collected by temperature loggers, with USACE inflow in 2013. Shaded areas denote periods of thermal stratification.

4.1.3.2 Dissolved Oxygen and Oxidation-Reduction Potential Transect

The water quality transect was established in the Reservoir originating from approximately the mid-point of the dam and extending southward across the Reservoir, towards the inlet region (see Figure 1). As part of the destratification monitoring program, water column dissolved oxygen and oxidation reduction potential profiles were collected at twelve locations along the transect and the nearby Site CCR-3 location, on three sample dates (Figure 15). These data help document the areal extent of low dissolved oxygen and reducing conditions near the water/sediment interface. Low dissolved oxygen conditions (i.e., < 2 mg/L) facilitate the internal release of soluble nutrients that promotes algae growth during the summer. In late June, low dissolved oxygen conditions began manifesting in the Reservoir, but were not evident in mid-July. The darker blue colors during the August sampling event represent the extent of the deep water low dissolved oxygen conditions that covered a substantial portion of the transect sites (Figure 15).

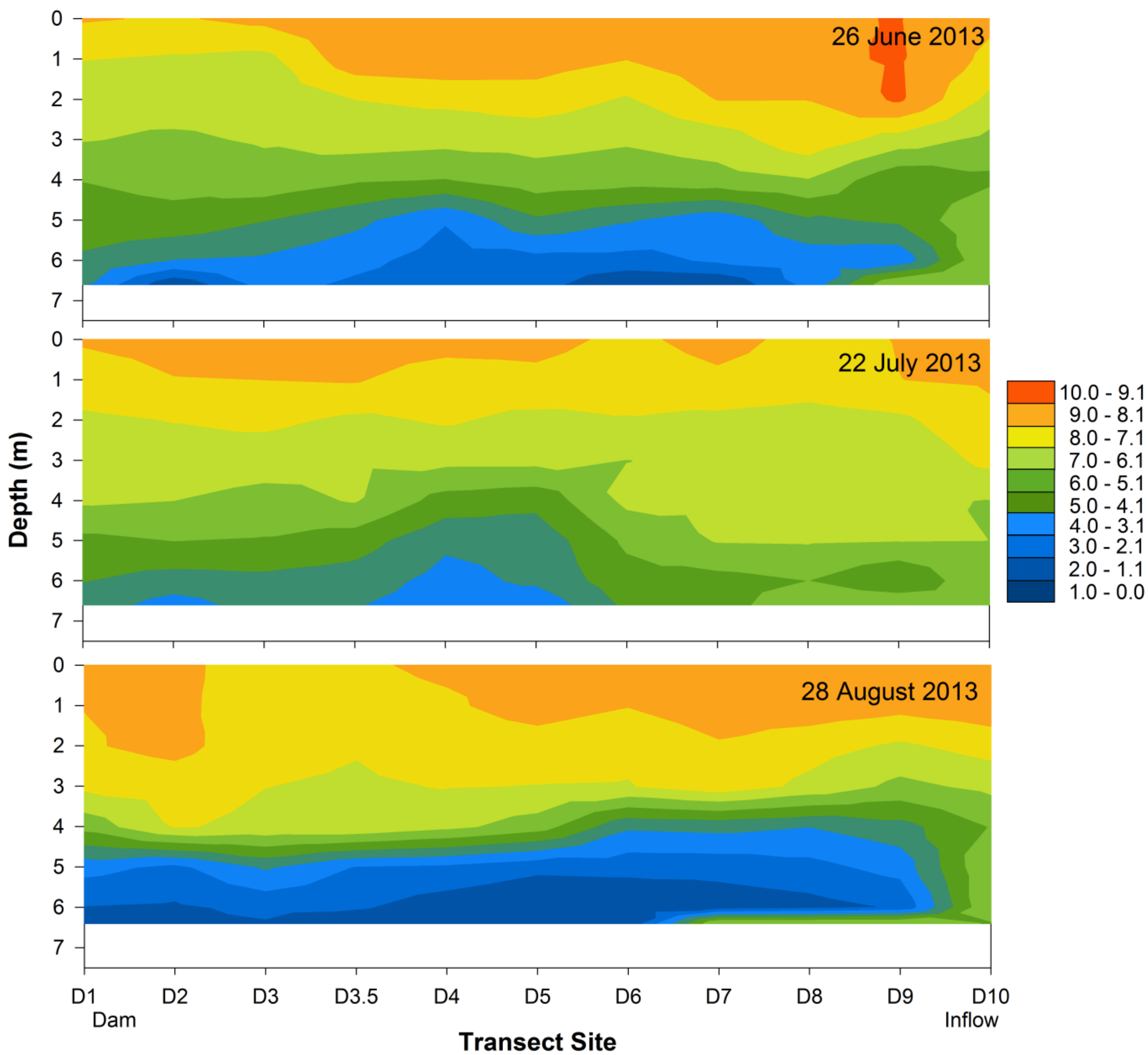

Figure 15: Dissolved oxygen conditions in Cherry Creek Reservoir for three dates based on transect profile data during the 2013 WY.

Oxidation reduction potential (ORP) measurements are used to quantify the exchange of electrons that occur during oxidation-reduction reactions (redox reactions), with electrical activity being reported in millivolts (mV), very similar to a pH probe. At the water-sediment boundary layer, microbial organisms facilitate the chemical reactions but do not actually oxidize or reduce the compounds. The redox reactions provide energy for microbial cells to carry out their metabolic processes (Wetzel 2001). The combination of microbial organisms and redox reactions are responsible for the breakdown of organic matter and development of anoxic conditions near the sediment boundary in reservoirs during the summer, and as a result soluble nutrients (nitrogen and phosphorus) are released as well as other forms of iron, manganese and sulfur.

In Cherry Creek Reservoir, the water column ORP measurements will often range between 100 to 300 mV depending upon the seasonal conditions. On any given date, the water column ORP conditions, from the surface waters down to approximately the 6 m layer, will be fairly uniform because there is sufficient dissolved oxygen in the water column to maintain compounds in their most oxidized state. However, when anoxic conditions exist at depths greater than 6 m or near the water-sediment interface, the redox potential will sharply decrease, often ranging from -200 to 0 mV, indicating conditions that facilitate internal nutrient loading as well as other elemental releases. When reviewing ORP profile measurements (Figure 16), the occurrence of a sharp inflection point (i.e., low or negative values) in the profile indicates where conditions are favorable for redox reactions to occur.

During the first sample date on June 26th, the Reservoir was well oxygenated (dissolved oxygen values of 5 to 9 mg/L) from the surface down to a depth of approximately 3 m (Figure 15). This pattern was consistent from D1 near the dam to D10, at which point the maximum Reservoir depth became shallower (4 m to 5 m). The average dissolved oxygen concentration for the 1 m and 2 m depths along the transect was 7.6 mg/L indicating the Reservoir was in attainment of the dissolved oxygen standard. The average dissolved oxygen concentration at the 4 m and 5 m layers was 5.2 mg/L and 3.6 mg/L, respectively. The dissolved oxygen concentration at the 6 m layer and the water-sediment interface (~6.4 m) was 2.3 mg/L and 1.4 mg/L (Figure 15; Appendix B).

The July 22nd transect profiles documented the extent of the anoxic zone as discussed above (Figure 15). The average dissolved oxygen concentration of the 1 m and 2 m layer values along the transect was 7.5 mg/L which indicated the Reservoir was in attainment of the standard. The average dissolved oxygen concentration at the 4 m and 5 m layers was 5.8 mg/L and 4.9 mg/L, respectively. The dissolved oxygen concentration at the 6 m layer and at the water-sediment interface (~6.4 m) was 3.9 mg/L and 3.2 mg/L, respectively. Similarly, the oxidation-reduction potentials at the water/sediment interface revealed favorable conditions for a reducing environment (Figure 16).

The last transect profile was collected on August 28th and showed similar conditions in the dissolved oxygen concentrations in the Reservoir in the upper layer (1 m and 2 m); however, the water-sediment interface was more anoxic versus the previous sampling events. The average concentration in the upper layer was 7.8 mg/L and in attainment of the standard, while the dissolved oxygen concentration in the 4 m and 5 m layers was 5.1 mg/L and 1.9 mg/L, respectively. The dissolved oxygen concentration at the 6 m layer and at depths greater than 6 m near the water-sediment interface (~6.2 m) was 0.7 mg/L and 0.4 mg/L, respectively.

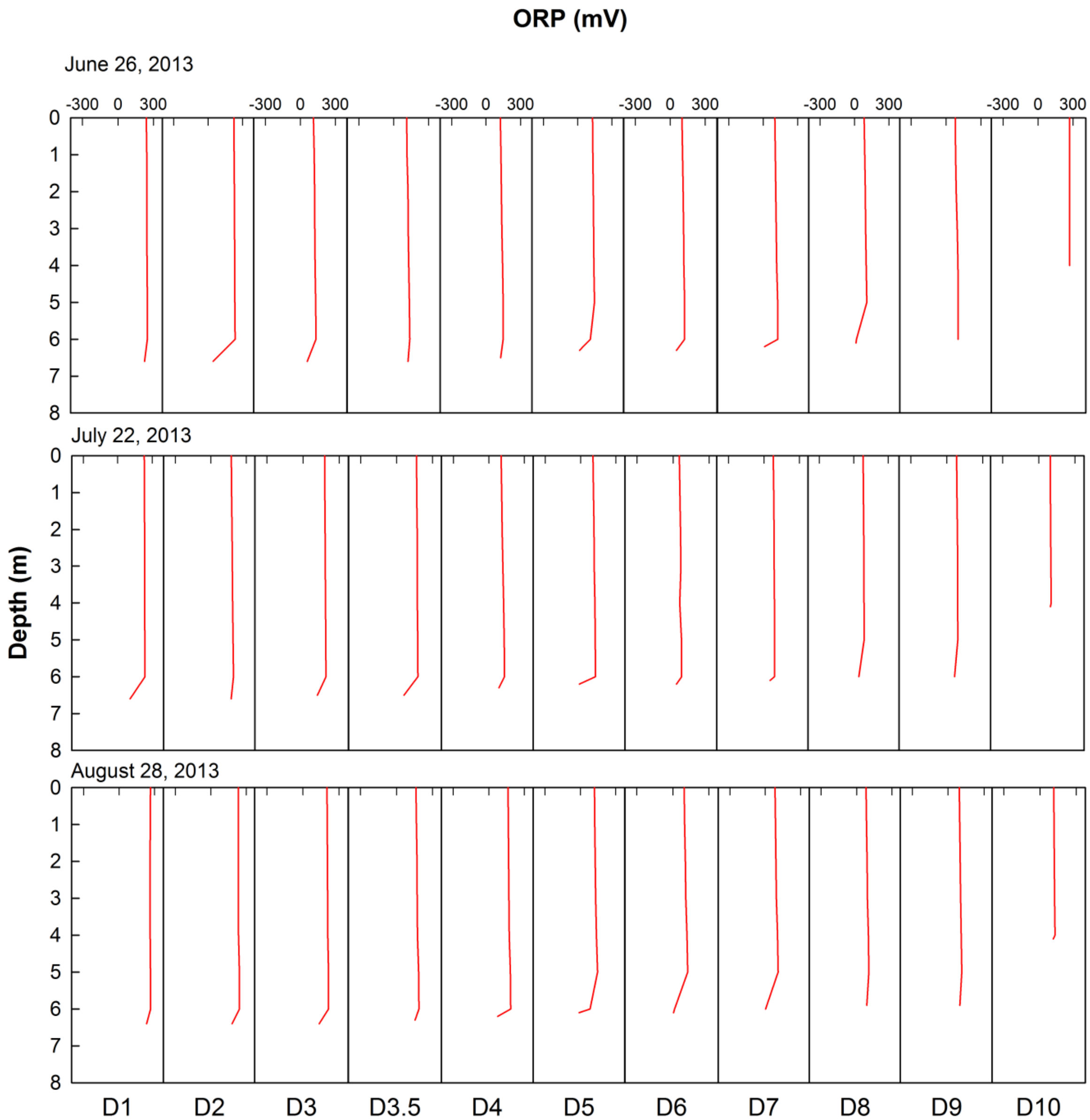

Figure 16: Oxidation reduction potentials (ORP) in Cherry Creek Reservoir for three dates based on transect profile data during the 2013 WY. The ORP scales for each transect are all relative to each other within and among sampling events.

The oxidation-reduction potential profiles on June 26th, July 22nd, and August 28th also indicate that conditions were favorable for a reducing environment at the water-sediment interface (Figure 16). This interface acts as a barrier to the free exchange of soluble phosphorus between water and sediment, and when conditions are favorable (e.g., anoxic-reducing environment) phosphorus is released (i.e., internal load) at rates as much as 1,000 times faster than during well oxygenated conditions (Horne and Goldman 1994). Although the rate of exchange of nutrients (mainly phosphorus) at this interface remains unknown for Cherry Creek Reservoir, the internal loading component of the Reservoir has been estimated to account for approximately 25% of the cumulative total phosphorus load from 1992 to 2006 (Nürnberg and LaZerte 2008).

4.1.4 2013 WY Nutrients

Monitoring at Cherry Creek Reservoir has focused on the concentrations of phosphorus and nitrogen, because these inorganic nutrients are often the limiting factor in the growth of algae (Cole 1979; Horne and Goldman 1994; Wetzel 2001; Cooke et al. 1993). Excessive amounts of these nutrients in aquatic systems often result in algal blooms that create aesthetic problems as well as potentially unsuitable conditions for aquatic life.

During the 2013 WY, the photic zone mean concentration of total phosphorus ranged from 67 to 156 µg/L with an overall water year mean of 101 µg/L. The seasonal (July through September) photic zone mean concentrations ranged from 92 to 156 µg/L (Figure 17), with a seasonal mean of 125 µg/L. Reservoir internal loading contributed substantially to the higher seasonal mean total phosphorous concentrations. In September, the storm-induced external load sharply increased photic zone total phosphorous concentrations (Figure 17).

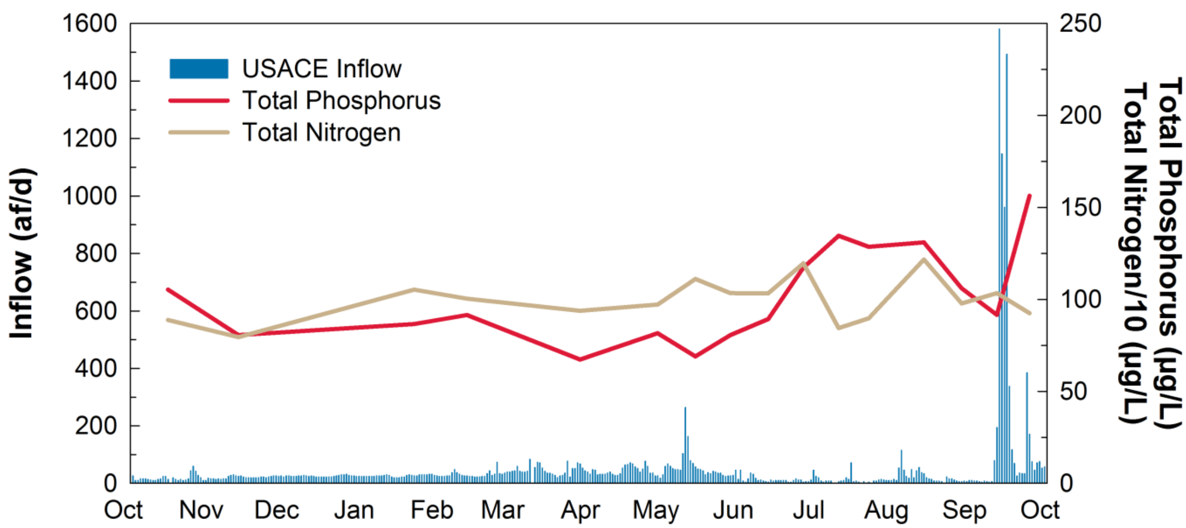

Figure 17: Annual pattern of photic zone total phosphorus, total nitrogen and USACE inflow in Cherry Creek Reservoir, 2013 WY.

Patterns in soluble reactive phosphorus concentrations collected during profile sampling at Site CCR-2 showed a well-mixed Reservoir from October to May (Figure 18). In early February, there was a small increase in soluble reactive phosphorous at the water-sediment interface. This occurrence is not uncommon during winter because ice-covered conditions combined with the previous summer's decaying organic matter at the sediment interface may result in nutrient release. There was an extended period of nutrient release from bottom sediments from May through early September as revealed by the pattern of increasing total phosphorus concentrations for 7 m layer as compared with concentrations observed at the same layers during the spring and late fall periods (Figure 18). The period of internal phosphorous loading shows a substantial increase in phosphorus at the 6 m and 7 m depths from May to mid-June. Despite a storm-induced mixing event in late June, phosphorous concentrations at the 6 and 7 m layers remained greater than the upper layers (Figure 18). The consistency within the upper layers is due to the upward diffusion of phosphorus from the sediment layer at approximately 7 m, and the eventual circulation within the upper layers by the aeration system. In terms of nutrient concentrations, the aeration system creates a well-mixed layer from the surface down to approximately 6 m, which is slightly above the aerator heads (approximately 0.75 m above the sediment). During the June and July period, the soluble reactive phosphorus fraction in the 7 m water layer accounted for approximately 31 to 68% of the total phosphorus content, also supporting evidence that phosphorus was being released from the sediment during that time.

Photic zone total nitrogen mean concentrations ranged from 795 to 1,217 µg/L, with a 2013 WY average of 995 µg/L. During the July through September period, the photic zone total nitrogen concentration also ranged from 844 to 1,217 µg/L, with a mean concentration of 983 µg/L.

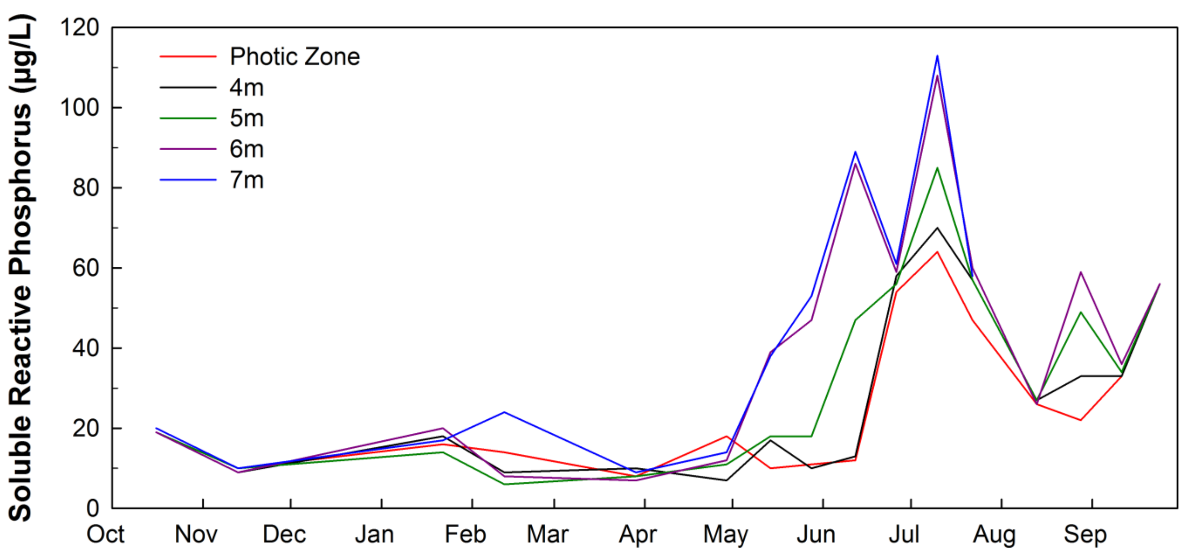

Figure 18: Soluble phosphorus concentrations recorded for the photic zone and at depth during routine monitoring during the 2013 WY at CCR-2.

4.1.5 Long-Term Phosphorus Trends in Cherry Creek Reservoir

In any long-term database, consistency in data analysis (i.e., analytical chemistry) is paramount, especially when evaluating long-term trends. Differences in methodologies or analytical laboratories may bias the data, which hinders the evaluation of potential trends. This is particularly evident in the total phosphorus and chlorophyll *a* database for Cherry Creek Reservoir. This database represents a variety of data produced by different analytical laboratories, and while the same standard method may have been utilized, subtle differences are apparent in the database. Over the monitoring period, analytical method detection limits varied and the precision of the analyses have increased with time. During the late 1990s, a transition from Metro Wastewater analytical services to GEI occurred, with the period from 1999 to 2013 representing the most consistent data processing methodologies. Furthermore, 1999 represents a time when a concerted effort started to implement best management practices throughout the basin, along with PRFs being established along Shop Creek and Cottonwood Creek to control storm flow and reduce the amount of phosphorus entering the Reservoir. In 2013, an equipment upgrade at GEI Laboratories resulted in minor changes to the nitrogen analysis; however, long term data comparison and laboratory QA procedures indicate consistency in the data analysis.

Routine monitoring data collected since 1987 indicates a general increasing pattern in summer mean concentrations of total phosphorus (Figure 19). In 2013, the July through September mean concentration of total phosphorus was 125 μg/L. This value is less than last year's 141 μg/L concentration, and it is greater than the long-term median value of 87 μg/L (Table 4). Regression analyses performed on 1987 to 2013 seasonal mean total phosphorous data indicates a significant ($p < 0.001$) increasing trend.

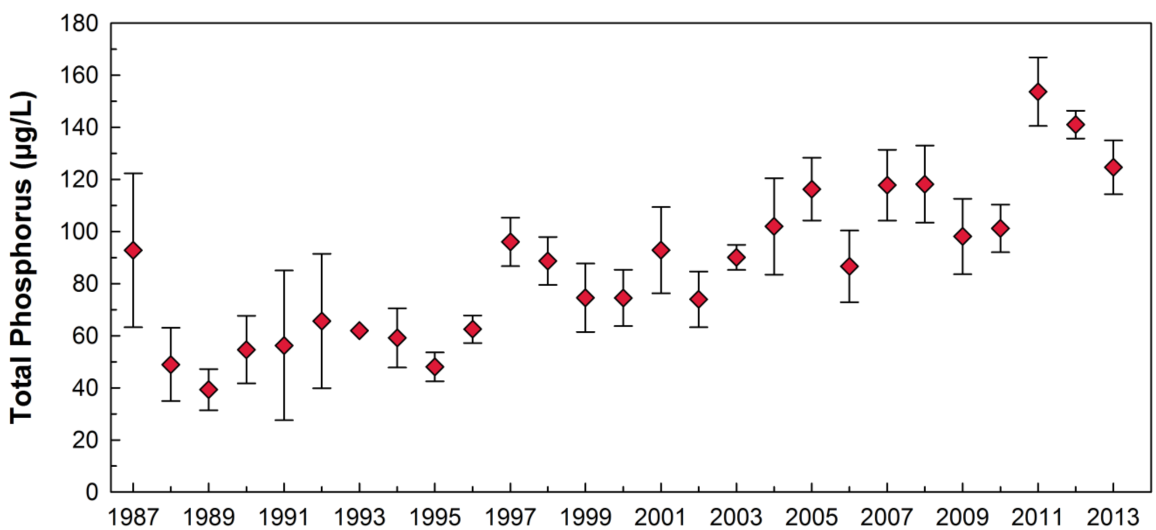

Figure 19: Seasonal mean (July through September) total phosphorus concentrations (µg/L) measured in Cherry Creek Reservoir, 1987 to 2013. Error bars represent a 95% confidence interval for each mean.

Table 4: Comparison of water year mean and July through September mean phosphorus, nitrogen, and chlorophyll *a* levels in Cherry Creek Reservoir, 1988 to 2013.

Year	Total Nitrogen (µg/L)		Total Phosphorus (µg/L)		Mean Chlorophyll *a* (µg/L)	
	WY	Jul-Sep	WY	Jul-Sep	WY	Jul-Sep
1988	902	1,053	52	49	21.8	31.8
1989	803	828	45	39	8.5	5.6
1990	600	--	58	55	2.3	8.6
1991	1,067	1,237	86	56	9.7	9.8
1992	931	970	52	66	12.2	17.4
1993	790	826	55	62	12.6	14.8
1994	1,134	1,144	53	59	11.4	15.4
1995	910	913	46	48	12.7	15.6
1996	889	944	35	62	13.4	18.2
1997	981	1,120	70	96	16.4	22.2
1998	763	880	77	89	18.4	26.6
1999	709	753	76	81	21.6	28.9
2000	774	802	80	81	22.3	25.1
2001	764	741	84	87	26.0	26.1
2002	825	858	70	74	21.7	18.8
2003	987	1,121	83	90	22.7	25.8
2004	929	977	85	102	19.1	18.4
2005	916	990	93	116	16.3	17.1
2006	874	914	96	87	13.7	14.7
2007	880	716	108	118	21.4	12.6
2008	795	800	92	118	15.8	16.6
2009	1,173	1,236	85	98	12.4	13.2
2010	925	974	92	101	23.6	31.0
2011	904	987	110	154	25.6	26.7
2012	891	923	114	141	24.0	27.1
2013	995	983	101	125	24.8	26.8
Mean	**889**	**948**	**77**	**87**	**17.3**	**19.8**
Median	**897**	**944**	**82**	**87**	**17.4**	**18.3**

4.1.6 2013 WY Chlorophyll a Levels

The annual pattern of chlorophyll *a* concentrations was quite variable with chlorophyll *a* less than 18 µg/L only in mid-May, and considerably greater during a majority of the 2013 WY (Figure 20). From October 2012 through September 2013, chlorophyll *a* concentrations ranged from 15.8 µg/L to 35.5 µg/L with a 2013 WY mean chlorophyll *a* concentration of 24.8 µg/L (Figure 20). Algal production is typically the lowest during the spring time of year, when the reservoir experiences flushing flows from spring runoff and seasonal storms along with the seasonal succession of the phytoplankton community. The July through September seasonal mean chlorophyll *a* level was 26.8 µg/L, with a peak seasonal reservoir mean concentration of 35.5 µg/L.

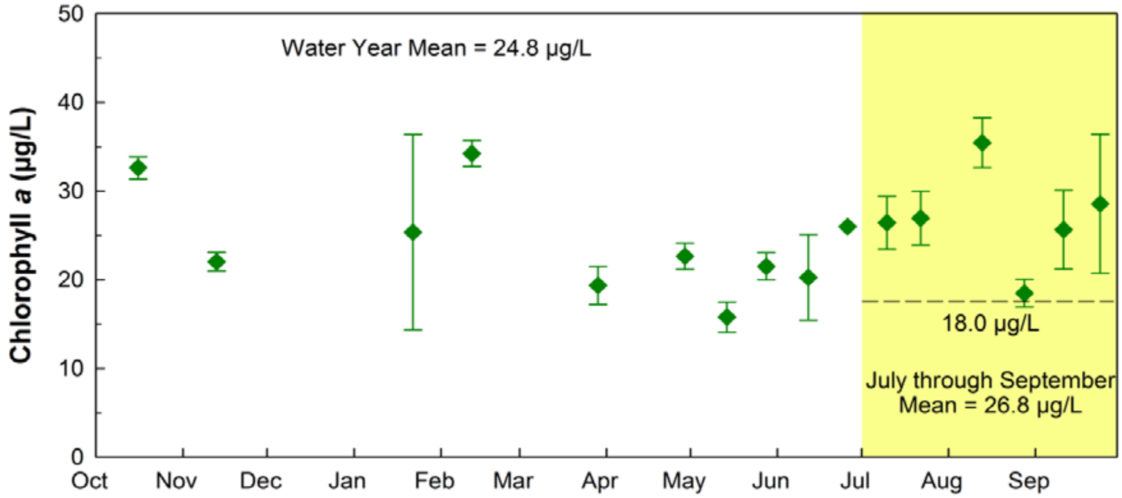

Figure 20: Concentration of chlorophyll *a* (µg/L) in Cherry Creek Reservoir, 2013 WY. Error bars represent a 95% confidence interval around each mean. Highlighted area denotes the seasonal period for the chlorophyll *a* standard.

4.1.7 Long-term Chlorophyll a Trends in Cherry Creek Reservoir

Since 1987, there is no significant trend in the seasonal mean chlorophyll *a* concentration (Figure 21). However, the 2010 seasonal mean chlorophyll *a* concentration represented the highest seasonal level observed for the Reservoir since the CCBWQA's monitoring program began, and highlights the propensity of algae to respond to optimal growing conditions. The 2011 through 2013 seasonal mean chlorophyll *a* levels were not as high as 2010, but were considerably greater than the 18 µg/L chlorophyll *a* standard. The 2013 chlorophyll *a* conditions represent the fourth consecutive year the Reservoir has exceeded the seasonal chlorophyll standard, as well as the allowable exceedance frequency of once in five years (Figure 21).

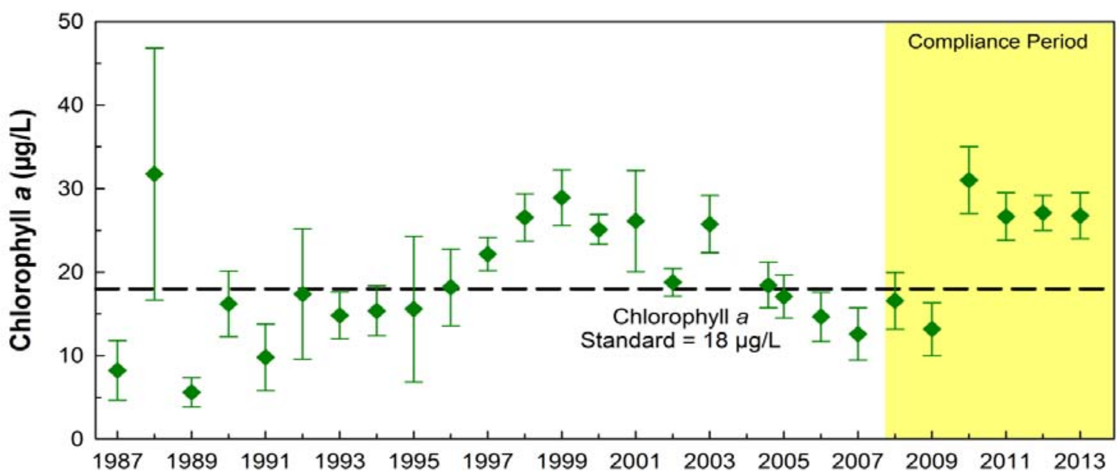

Figure 21: Seasonal mean (July through September) concentrations of chlorophyll *a* (µg/L) measured in Cherry Creek Reservoir, 1987 to 2013. Error bars represent a 95% confidence interval around each mean.

4.2 Reservoir Biology

4.2.1 2013 Phytoplankton

Phytoplankton density in the photic zone ranged from 1,750 #/mL on March 29th to 5,613 #/mL on August 13th (Table 5). The number of algal taxa present in the Reservoir ranged from 11 on February 12th, to 24 on September 11th. Based on the calendar year, the assemblage was dominated in terms of density by chlorophytes (green algae, 39%), with diatoms and cryptophytes (cryptomonads) being the next most abundant taxonomic groups at 30% and 15%, respectively (Figure 22). Similar to 2012, the relative density of large filamentous cyanobacteria (1.4%) was extremely low in 2013. Green algae were abundant throughout the year, and diatoms were relatively abundant throughout most of the year with exception to the months of February and March (Table 5). During the 2013 winter ice-covered conditions, cryptomonads were the most abundant algal group in terms of biomass. This group was able to respond to the release of nutrients during January. These algae are similarly well-adapted to growing during low light and low temperature conditions during ice-covered periods (Wright 1964). In February 2013, the majority of the algal assemblage was comprised of chrysophytes (golden algae, 84%) which was the only month that this group was the dominant algal group. After February 2013, golden algae densities continued to decrease and the algal assemblage began to be dominated by green algae (Figure 22).

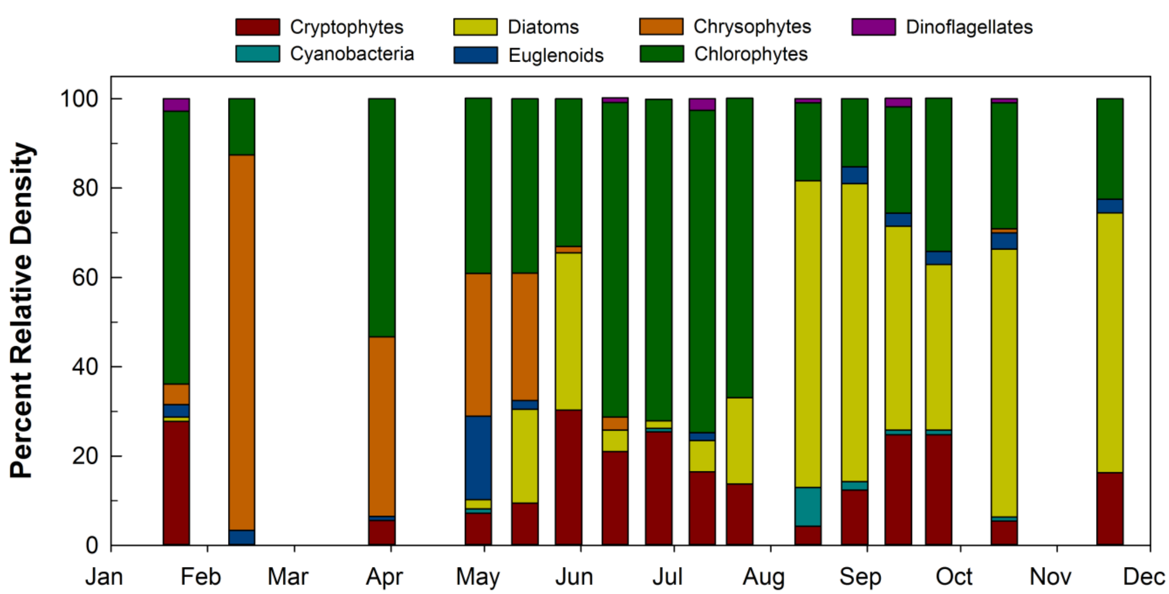

Figure 22: Percent relative density of algal groups by sample date in Cherry Creek Reservoir, 2013 CY.

Table 5: Density (#/mL) of phytoplankton and total number of taxa collected from all three sites on Cherry Creek Reservoir, 2013 CY.

Sample Date	Taxonomic Group								
	Diatoms	Green Algae	Cyano-bacteria	Golden Algae	Euglenoid	Dino-flagellate	Crypto-monads	Total Density	Total Taxa
1/22/2013	17	1,154	--	87	52	52	524	1,888	15
2/12/2013	--	604	--	4,027	161	--	--	4,792	11
3/29/2013	--	932	--	703	16	--	98	1,750	15
4/29/2013	41	782	21	638	370	--	144	1,996	19
5/14/2013	574	1,070	--	783	52	--	261	2,740	20
5/28/2013	949	892	--	38	--	--	816	2,695	16
6/12/2013	103	1,520	--	62	--	21	452	2,156	17
6/26/2013	79	3,375	40	--	--	--	1,191	4,685	16
7/10/2013	260	2,701	--	--	65	98	618	3,742	21
7/22/2013	815	2,833	--	--	--	--	582	4,231	22
8/13/2013	3,856	976	488	--	--	49	244	5,613	18
8/28/2013	2,769	633	79	--	158	--	514	4,154	16
9/11/2013	1,760	917	37	--	110	73	953	3,850	24
9/24/2013	1,313	1,212	34	--	101	--	875	3,534	21
10/15/2013	2,221	1,043	34	34	135	34	202	3,702	21
11/18/2013	1,622	627	--	--	86	--	454	2,789	19

When the size (e.g., biovolume) of each algae is considered, diatoms were the most dominant algal group (30%) observed over the course of the year, followed by green algae (26%), cryptomonads (14%) and euglenoids (13%) (Figure 23). The dinoflagellates only accounted for approximately 6% of the total algal biovolume and cyanobacteria only accounted for only 5% of algal biovolume. Patterns in algal biovolume show typical seasonal succession patterns of many temperate lakes and reservoirs with cryptomonads and diatoms being most abundant in the spring and fall, green algae being the most abundant throughout the summer with cyanobacteria becoming evident in mid to late summer as well as dinoflagellates in late summer. In fall 2013, diatoms were abundant and green algae biovolume decreased compared to summer 2013 (Figure 23). These observed successional patterns of algal dominance are closely coupled with reservoir conditions such as cooler water temperature during the spring followed by the warmer water and longer photoperiod conditions of the summer and the cool down during the fall.

In January 2013, the flagellated cryptomonad algae (*Cryptomonas erosa*), and euglenoid (*Trachelomonas scabra*) were the most abundant in terms of biovolume; *Cryptomonas erosa* and the nonmotile green algae (*Ankistrodesmus falcatus*) were the most dominant algae in terms of density. In February, *Chrysococcus rufescens* (golden algae) accounted for 80% of the total algal density and 47% of the total biovolume. These golden algae and green algae species remained the most abundant through the spring, although a flagellated euglenoid (*Trachelomonas crebea*) was the most dominant in terms of total algal biovolume. During June and July, *Scenedesmus quadricauda* (green algae) was the most dominant species in terms of both total density and biovolume. *Cryptomonas erosa* continued to be a large component of the assemblage in early summer. In early August, a diatom – *Stephanodiscus astraea minutula* – was the most abundant species in terms of total biovolume, followed by a dinoflagellate and cyanobacterium (*Anabaena flos-aquae*). *Cryptomonas erosa* again became the most dominant species in terms of total algal biovolume in September. The diatoms – *S. astraea minutula and S. hantzschii* and euglenoid – *T. scabra* were the most dominant species in terms of total algal biovolume for October and November.

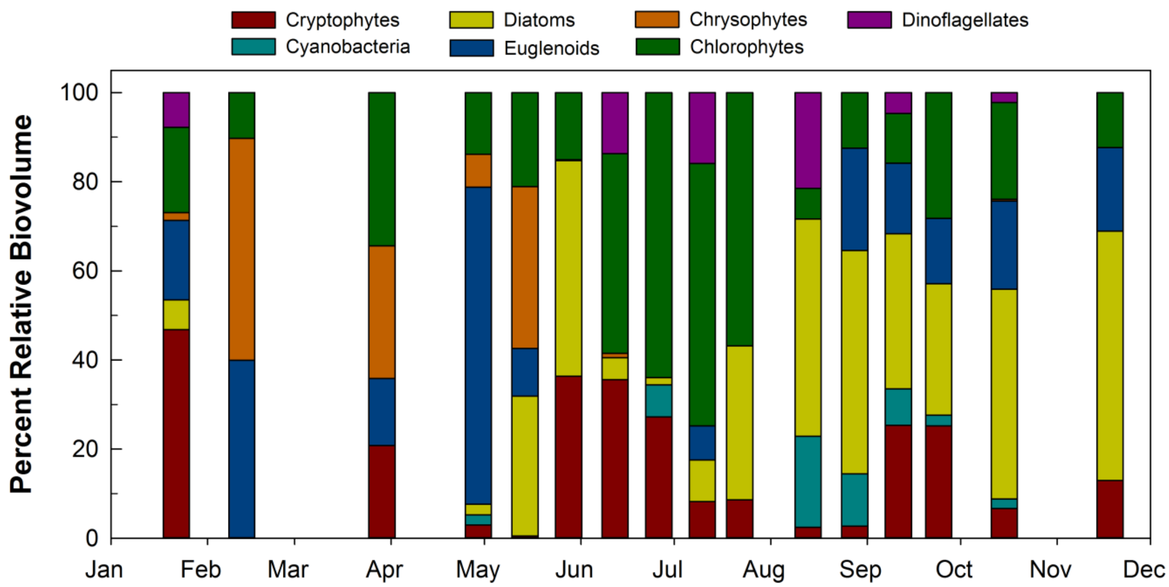

Figure 23: Percent relative biovolume of algal groups by sample date in Cherry Creek Reservoir, 2013 CY.

In the Rocky Mountain region, cryptomonads appear to prefer colder water (Kugrens and Clay 2003) which explains their abundance in late winter and spring. Cryptomonads also prefer moderate turbulence when they are circulated through the water column and mixed with higher nutrient rich waters (Reynolds 1984). This could partially explain the increased density of cryptomonads during the sampling events. Cyanobacteria were again rare in terms of annual density, although this group did have an early August bloom that comprised approximately 9% of the total density, and 20% of the total biovolume of the algal assemblage. This early August cyanobacteria bloom was primarily comprised of *Anabaena flos-aquae and Aphanizomenon flos-aquae*, both filamentous nitrogen fixing cyanobacteria whose trichome is composed of many individual cells to form one physiological entity (Komárek et al. 2003). The cyanobacteria (e.g., *Aphanizomenon flos-aquae* and *Anabaena flos-aquae)* typically dominate late summer algal assemblages (Whitton and Potts 2000; James et al. 1992; Padisák 1985, Konopka and Brock 1978; Pollingher 1987).

A key aspect in the algal successional patterns is that cyanobacteria were only dominant during a few weeks in August (Figures 22 and 23). Only 15 days after the cyanobacteria bloom was observed on August 13th, this group comprised less than 2% of the assemblage in terms of density and approximately 12% in terms of biovolume.

The relative density and biovolume of algae is largely a response to bottom-up factors that promote growth such as inorganic nutrients, light, temperature, and pH which are closely coupled with top-downs factors such as predation (i.e., zooplankton grazing), life history traits (i.e., cyst production) and outflow (Pollingher 1987). The bottom-up factors were clearly evident during the summer season when internal phosphorus loading was evident in late May and phosphorus was quickly mixed throughout the water column by the destratification system. Following the mid-May storm event and onset of internal phosphorous loading, there was a decrease in algae biomass in the reservoir. By early July there was a peak in the summer internal phosphorous loading event, which facilitated the growth of the summer algal assemblage comprised mainly of green algae and cryptomonads (Table 5). The constant mixing by the destratification system also enhances the bottom-up factors by providing a soluble phosphorus-rich photic zone environment that allows algae to maximize their production during the summer which accounts for the increased algal biomass from June through August 2013.

In the event of reduced top-down pressure such as low zooplankton grazing, the algal assemblage can maximize their relative density given the influence of the bottom-up factors. It is unlikely that the zooplankton population was able to effectively exert top-down controls on the algal population during the summer 2013 conditions. The large gizzard shad (forage fish) population in the Reservoir appear to be over-grazing the zooplankton population such that algae growth remained unchecked during their peak growing period. Communities dominated by large zooplankton populations tend to show reduced algal biomass yields as these herbivores effectively reduce the number of algae in the water column (Sarnelle 1992; Mazumder 1994; Mazumder and Lean 1994). These patterns are not observed in the Reservoir. However, this relationship can be affected by the relative biomass (e.g., size) of the individual algae. For example, if the algal assemblage is dominated by filamentous or colonial cyanobacteria, zooplankton will preferentially graze on more palatable and preferred algae such as diatoms, cryptomonads, and green algae (Vanni and Temte 1990).

In 2013 the Reservoir exhibited high biomass levels (i.e., chlorophyll *a*) at various periods throughout the year. In February 2013, the high chlorophyll *a* concentration of 34.3 µg/L was associated with primarily with *Chrysococcus rufescens* (golden algae). In early August 2013, the high chlorophyll *a* concentration of 35.5 µg/L was associated with the relatively higher biovolume of *Stephanodiscus astraea minutula* (diatom, 40%), Ceratium hirundinella (dinoflagellate, 22%), *Anabaena flos-aquae* (cyanobacteria, 13%), and *Aphanizomenon flos-aquae* (cyanobacteria, 7%). During the late August sampling event, chlorophyll *a* concentrations decreased by 48% compared to concentrations measured only two weeks prior. This decrease in chlorophyll *a* levels was associated with a decrease in the density of diatoms (3,856 to 2,769 #/mL), cyanobacteria (488 to 79 #/mL) and green algae density (976 to 633 #/mL) which followed an early August storm event and cooler reservoir water temperatures.

4.2.2 Long-Term Phytoplankton

Historically, the cyanobacteria have been the most abundant algae in the Reservoir, especially during the late summer season. One of the primary objectives of the destratification system was to reduce the suitable habitat conditions for filamentous cyanobacteria by vertical mixing which would disrupt the ability of cyanobacteria to efficiently grow in the upper water layers. Historically, the nuisance chlorophyll *a* levels (i.e., > 30 µg/L) during the summer were always associated with filamentous cyanobacteria blooms. However, during the past four years the reservoir has exhibited a shift in the algal species composition such that cyanobacteria have become a smaller component of the assemblage (Figure 24). Prior to the operation of the destratification system, cyanobacteria represented between 40 and 80% of assemblage in terms of density (#/mL). During the first season of operation in 2008, green algae and cyanobacteria were still the dominant types of algae, with cyanobacteria dominating the summer assemblage. However, since 2009, the cyanobacteria population has been greatly reduced, representing between 1 and 7% of the algal assemblage in terms of density (Figure 24). Cryptomonads, diatoms, and green algae have become the dominant algal types, all of which are a better food source for zooplankton and fish. In 2013, the percent density of golden algae increased compared to previous years (Figure 24).

This shift in algal composition is notable as it provides some initial results that validate the effectiveness of the destratification system at achieving one of the primary objectives—reducing suitable habitat conditions for cyanobacteria. The destratification system's efficient vertical mixing allows the more beneficial algal types (e.g., cryptomonads, diatoms, and green algae) a competitive advantage over cyanobacteria, in terms of nutrient and light resources. However, as a consequence of the efficient mixing, the relatively constant supply of soluble reactive phosphorus to algal community allows the beneficial cells to maximize their productivity. As a result, the reservoir exhibited extremely high chlorophyll *a* levels in 2013 that exceeded the chlorophyll threshold of 18 µg/L. This greater productivity in the Reservoir has also resulted in the exceedance of the chlorophyll *a* standard, despite being associated with more beneficial types of algae in terms of zooplankton and fish food resources.

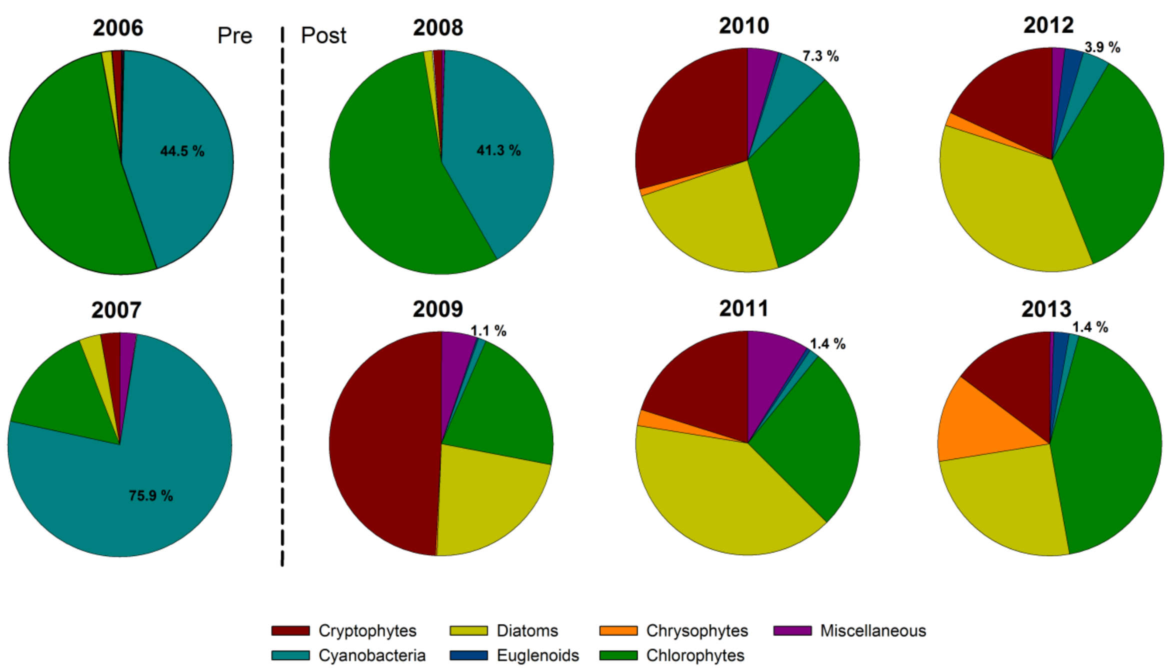

Figure 24: Percent algal density of major taxonomic groups in Cherry Creek Reservoir, pre- and post-operation of the destratification system. For comparative purposes, diagrams are based on the calendar year composition rather than water year.

4.2.3 2013 Zooplankton

Zooplankton density ranged from 183 organisms/L in late March to 562 organisms/L which occurred in late May 2013 (Figure 25). A total of seven zooplankton crustacean species—four cladocerans and three copepods with immature copepodids and nauplius—and six species of rotifers were collected during the 16 sampling events (Appendix E). There were two species that were collected during all 16 sampling events: one relatively smaller cladoceran (*Bosmina longirostris*) and a copepod *(Diacyclops thomasi*). One rotifer (*Keratella cochlearis*) was collected during 13 of the 16 sampling events and one cladoceran (*Skistodiaptomus pallidus*) was collected during 9 sampling events (Appendix E). The other cladoceran taxa, mainly larger daphnia, were observed to occur over shorter time periods (i.e., 1 to 8 weeks) and were more common in July and late September 2013. The immature copepods (copepodids and nauplius) were also observed during 15 of the 16 sampling events. *Bosmina longirostris* have been found to be the dominant cladoceran in other eutrophic lakes (Harman et al. 1995).

Cladocera were low in abundance throughout the spring and early summer 2013; however, they became relatively abundant during early August through mid-September cladocerans and comprised the majority of the zooplankton assemblage (Figure 25). The total density of zooplankton generally follows the pattern of chlorophyll *a* concentration (Figure 25); however there is no statistical correlation between the zooplankton density and chlorophyll *a* (surrogate for algal biomass). Similarly, there was no correlation between zooplankton density and algal density or algal biomass.

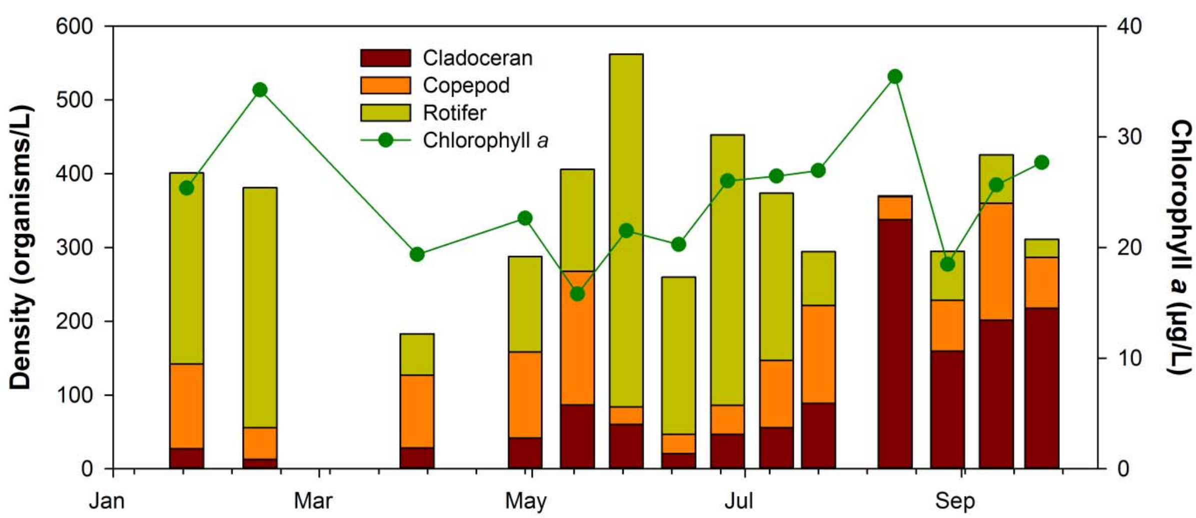

Figure 25: Total density of zooplankton groups and chlorophyll *a* concentration by sample date in Cherry Creek Reservoir, 2013.

Ideally, the pattern between zooplankton density and chlorophyll *a* (algal biomass) should be inversely related, as herbivorous zooplankton could theoretically affect algal biomass via grazing pressure, provided planktivorous fish are not suppressing the zooplankton populations (Harman et al. 1995). However, in Cherry Creek Reservoir, the increased abundance of gizzard shad has likely increased the grazing pressure on the zooplankton assemblage, thereby reducing the zooplankton density and reducing their ability to effectively control the algal assemblage. Notably, the cladoceran – Daphnia lumholtzi – was not observed in the Reservoir during 2013. This species is considered an Aquatic Nuisance Species (ANS) and was observed in 2011 and 2012. This species has two relatively long spines on the head and tail which may affect fish that feed on zooplankton, plus this species may outcompete other native cladocera for resources.

4.3 Stream Water Quality

4.3.1 2013 WY Phosphorus Concentrations in Streams

The median annual total phosphorus concentration for base flow conditions ranged from 41 µg/L at Site CT-P1 to 181 µg/L at Site CC-10 (Table 6). The median seasonal (July through September) base flow total phosphorous concentration was greater than the annual median concentration at both Cherry Creek sites (sites CC-10 and CC-Out @ I225) and three of the four Cottonwood Creek sites (sites CT-P1, CT-P2 and CT-2; Table 6). The seasonal median concentration of total phosphorous was equal to the median annual phosphorous concentration at Site CT-1 (Table 6). The seasonal median concentration of total phosphorus ranged from 67 µg/L at Site CT-2 to 289 µg/L at Site CC-10. At all stream sites, the storm flow total phosphorous concentration was greater than concentrations during base flow conditions. The annual median storm flow total phosphorous concentrations ranged from 60 µg/L at Site CT-2 to 414 µg/L at Site CC-10 (Table 6).

Total suspended solids were generally consistent across all sites during base flow conditions during the 2013 WY. The annual median annual total suspended solids concentrations for base flow conditions ranged from 12 mg/L at Site CT-P1 to 35 mg/L at CT-1 (Table 6). The median seasonal (July through September) base flow total suspended solids concentrations were similar at most sites compared to the annual median concentrations. At all stream sites, the storm flow total suspended solids concentration was greater than concentrations during base flow conditions. The annual median storm flow total suspended solids concentrations ranged from 7 mg/L at Site SC-3 to 211 mg/L at Site CT-P1 (Table 6). Annual median storm flow total suspended solids concentration at Site CT-P1 was significantly greater than all other sites (Table 6).

Table 6: Comparison of median base flow and median storm flow concentrations of total phosphorus (TP) and total suspended solids (TSS) in tributaries to Cherry Creek Reservoir, 2013 WY.

Stream/Site	Base Flow				Storm Flow	
	July - September		Annual		Annual	
	TP (µg/L)	TSS (mg/L)	TP (µg/L)	TSS (mg/L)	TP (µg/L)	TSS (mg/L)
Cherry Creek						
CC-10	289	10	181	15	414	63
CC-Out @ I225	123	27	113	24	--	--
Cottonwood Creek						
CT-P1	91	26	41	12	364	211
CT-P2	80	25	44	19	145	42
CT-1	73	30	73	35	172	47
CT-2	67	17	53	19	60	25
Shop Creek						
SC-3	DRY	DRY	71	21	109	7

4.3.2 Long-Term Trends in Phosphorus Concentrations in Cherry Creek Reservoir Tributaries

Long-term patterns (1995 to 2013) in total phosphorus and soluble reactive phosphorus concentrations were evaluated for the three main tributary sites (CC-10, SC-3, and CT-2) to Cherry Creek Reservoir, for both base flow and storm flow conditions. The long-term median annual base flow total phosphorus concentration for Cherry Creek (Site CC-10) and Shop Creek (Site SC-3) are 213 µg/L and 85 µg/L, respectively (Table 7), with storm flow concentrations being approximately 71 to 96% greater (Table 8). In Cottonwood Creek (Site CT-2), the long-term median annual base flow total phosphorus concentration is 69 µg/L; however, the long-term median storm flow concentration is approximately three times greater (190 µg/L). Soluble reactive phosphorus fractions in base flows for Cherry Creek and Shop Creek were approximately 77% and 71%, respectively, of the total phosphorus concentrations, while soluble reactive phosphorus fractions in Cottonwood Creek (Site CT-2) have been approximately 16% of total phosphorus concentrations.

In the Colorado regulatory proceedings there is precedence for only considering the last five years of data in the hearing for standard levels because conditions may change. In the case of Cherry Creek Reservoir tributaries, total phosphorous concentrations have decreased due to the Authority's efforts in stream reclamation to reduce erosion, reductions in nutrient discharges from point sources and other storm management practices implemented within the watershed. Therefore, median values for the most recent 5-year period have been provided for comparison to long-term statistics (2009 through 2013, Tables 7 and 8).

Table 7: Comparison of base flow median WY total phosphorus (TP) and soluble reactive phosphorus (SRP) concentrations for CC-10, SC-3, and CT-2 from 1995 to 2013.

Water Year	CC-10		SC-3		CT-2	
	TP (µg/L)	SRP (µg/L)	TP (µg/L)	SRP (µg/L)	TP (µg/L)	SRP (µg/L)
1995	218	169	85	75	--	--
1996	145[a]	153[a]	77	68	97	77
1997	176	170	91	71	108	64
1998	291	231	80	76	108	66
1999	258	200	93	60	94	39
2000	247	195	156	134	83	24
2001	239	168	173	116	84	22
2002	191	144	160	125	69	13
2003	213	158	81	59	83	13
2004	214	164	139	105	92	8
2005	200	163	142	76	66	10
2006	162	134	101	59	67	7
2007	217	160	103	47	65	11
2008	200	143	49	27	69	5
2009	176	129	58	23	50	6
2010	217	168	74	30	61	7
2011	226	165	46	25	56	7
2012	181	147	61	46	56	6
2013	181	141	71	34	53	7
Median (1995-2013)	**213**	**163**	**85**	**60**	**69**	**11**
Median (2009-2013)	**181**	**147**	**61**	**30**	**56**	**7**

[a] Results for total phosphorus and soluble reactive phosphorus are obtained independently and are within the 10% analytical error rate for all data used to calculate the median annual value.

Table 8: Comparison of storm flow median WY total phosphorus (TP) and soluble reactive phosphorus (SRP) concentrations for CC-10, SC-3, and CT-2 from 1995 to 2013.

Water Year	CC-10		SC-3		CT-2	
	TP (µg/L)	SRP (µg/L)	TP (µg/L)	SRP (µg/L)	TP (µg/L)	SRP (µg/L)
1995	181	161	122	95	--	--
1996	323	270	132	85	336	160
1997	402	316	175	74	391	221
1998	378	277	155	124	314	108
1999	348	247	141	112	118	58
2000	673	274	407	166	277	93
2001	293	172	227	84	209	33
2002	251	171	207	110	175	21
2003	365	171	197	134	204	35
2004	285	237	208	100	208	35
2005	354	187	190	129	175	26
2006	477	221	161	122	259	74
2007	366	195	167	78	230	27
2008	271	207	175	101	79	14
2009	378	180	111	80	78	24
2010	307	178	130	101	97	24
2011	409	197	142	56	113	29
2012	471	210	231	118	110	19
2013	414	197	109	100	60	16
Median (1995-2013)	**365**	**197**	**167**	**101**	**190**	**31**
Median (2009-2013)	**409**	**197**	**130**	**100**	**97**	**24**

Base flow total phosphorus and soluble reactive phosphorus concentrations revealed no trends over time at both sites CC-10 and SC-3 (Figures 26 through 29). However, at Site CT-2, both the total phosphorus and soluble reactive phosphorus concentrations reveal a significant ($p < 0.001$) decreasing trend (Figures 30 and 31) during base flow conditions. The observed decreasing trend and greatly reduced variability in soluble reactive phosphorus concentrations at Site CT-2 from 1995 to 2013 is the result of the effectiveness of the PRFs near the Perimeter Road and Peoria Street, along with the stream reclamation project along Cottonwood Creek. There is a seasonal pattern in phosphorus concentration at all sites, which is not specifically addressed in the trend analysis.

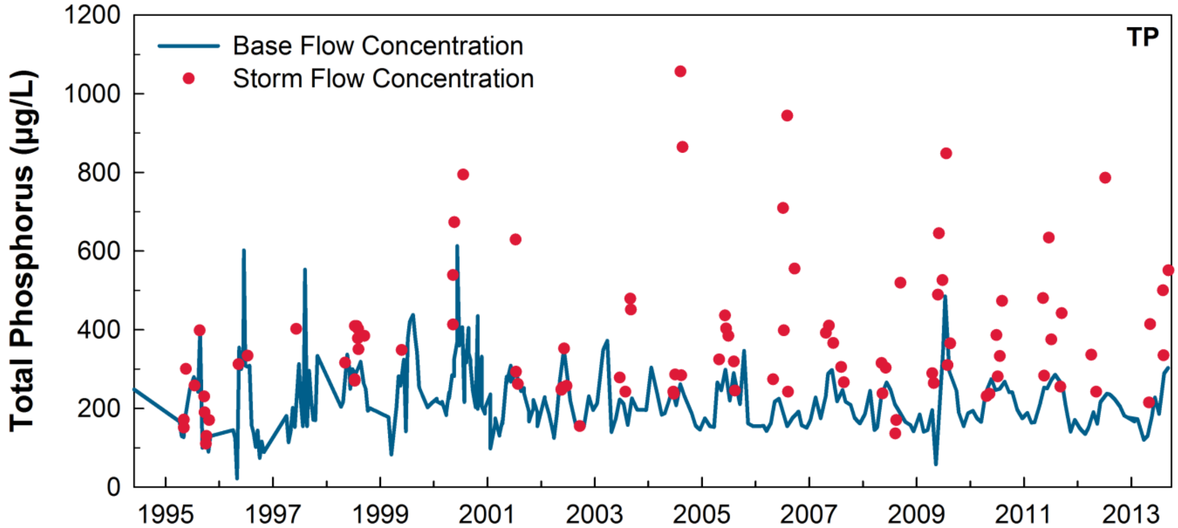

Figure 26: Base flow and storm flow total phosphorus concentrations measured at CC-10, 1994 to 2013.

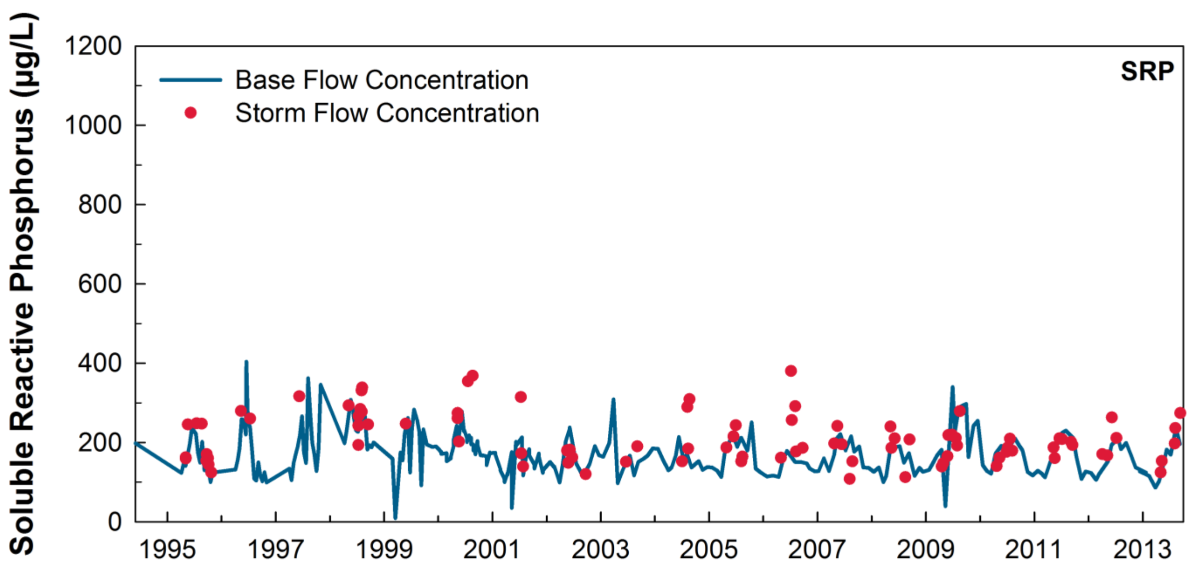

Figure 27: Base flow and storm flow soluble reactive phosphorus concentrations measured at CC-10, 1994 to 2013.

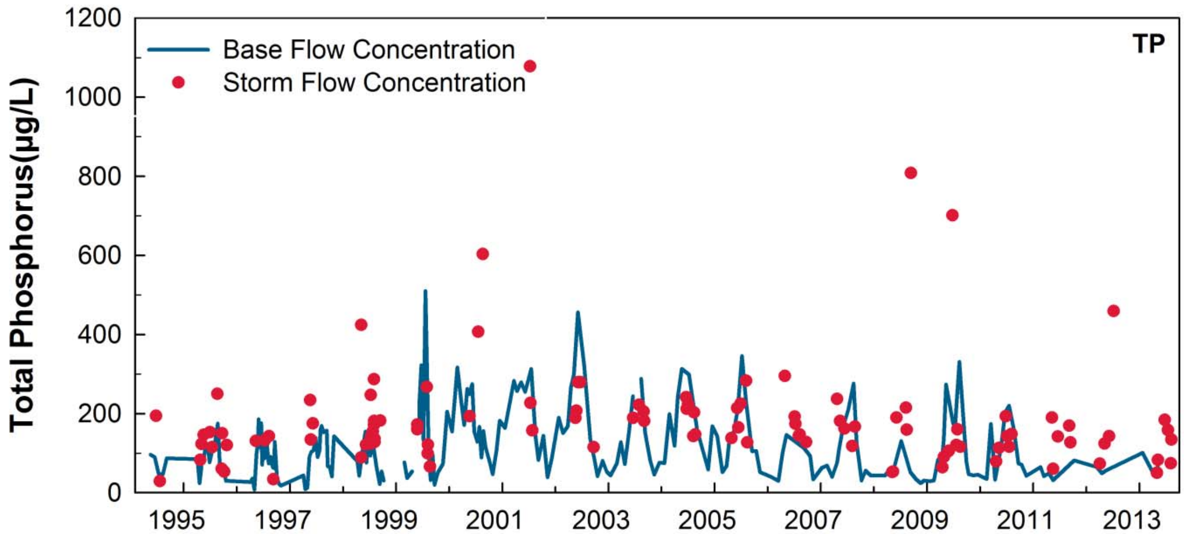

Figure 28: Base flow and storm flow total phosphorus concentrations measured at SC-3, 1994 to 2013.

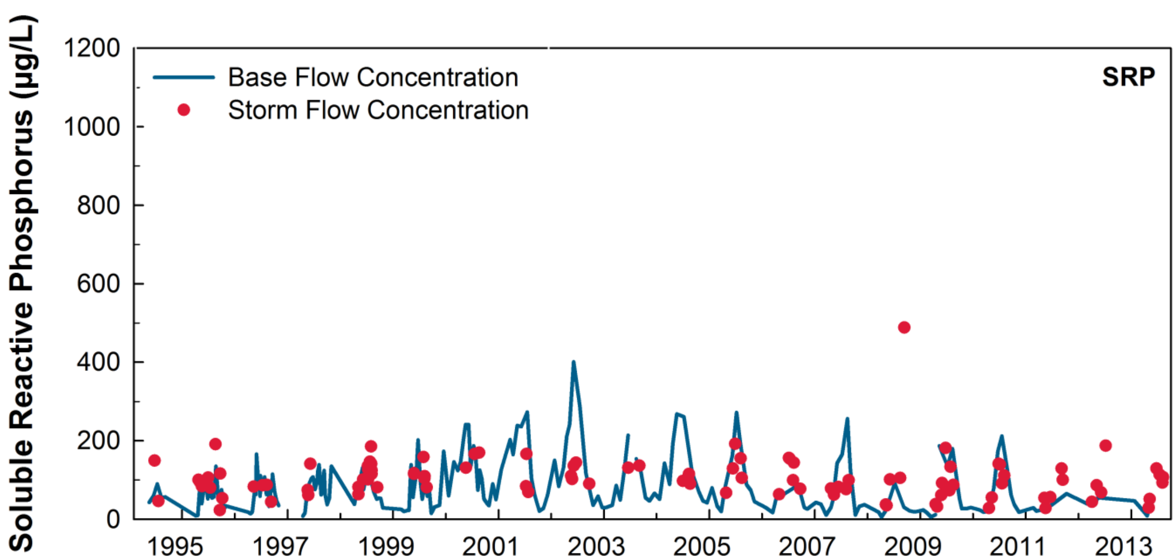

Figure 29: Base flow and storm flow soluble reactive phosphorus concentrations measured at SC-3, 1994 to 2013.

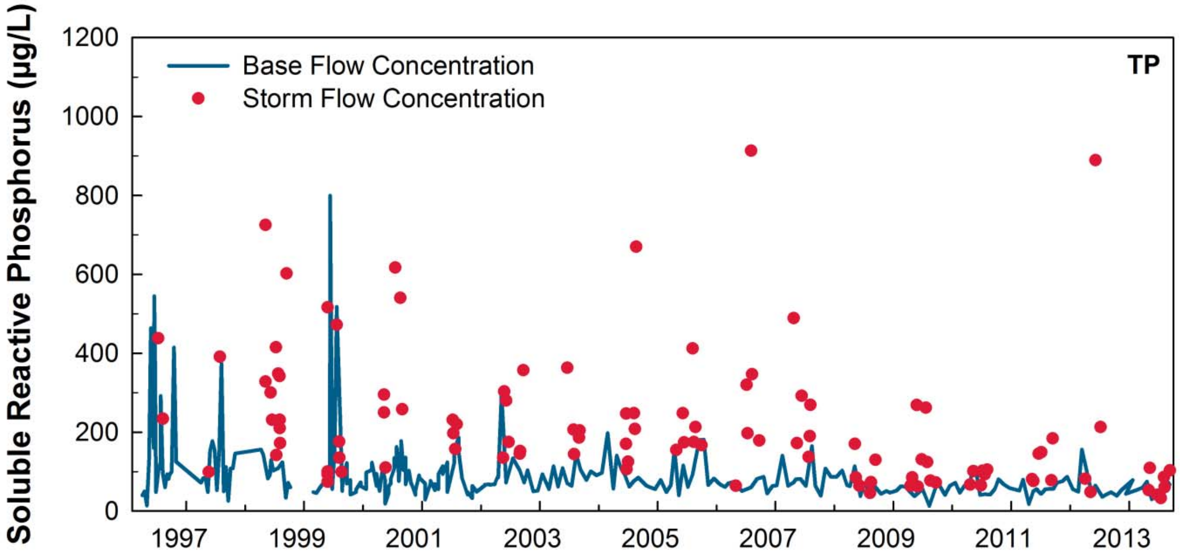

Figure 30: Base flow and storm flow total phosphorus concentrations measured at CT-2, 1996 to 2013.

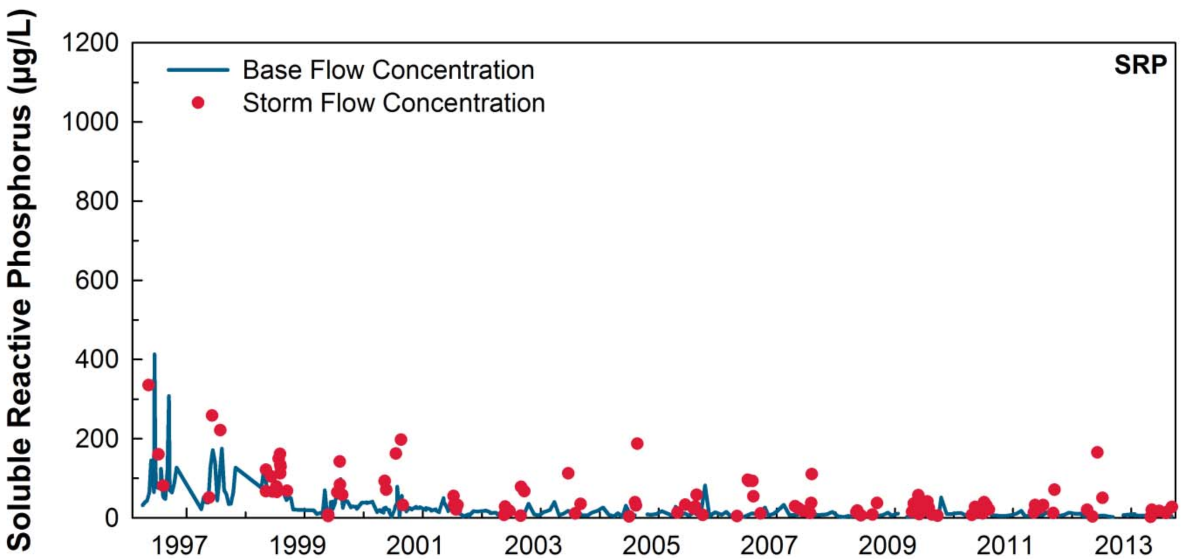

Figure 31: Base flow and storm flow soluble reactive phosphorus concentrations measured at CT-2, 1996 to 2013.

4.3.3 *Long-Term Trends in Phosphorus Concentrations in Cherry Creek Reservoir Alluvium*

Alluvial phosphorus data for Site MW-9 were used to estimate the alluvial phosphorus load component, as summarized in Appendix D (JCHA 2001 through 2010; GEI 2012 - 2013). Given the ability of alluvium to filter out particulates, total dissolved phosphorus was used as a surrogate to total phosphorus. Alluvial total dissolved phosphorus concentrations show a significant ($p < 0.001$), increasing trend over time (1994 to 2013) at Site MW-9 (Figure 32).

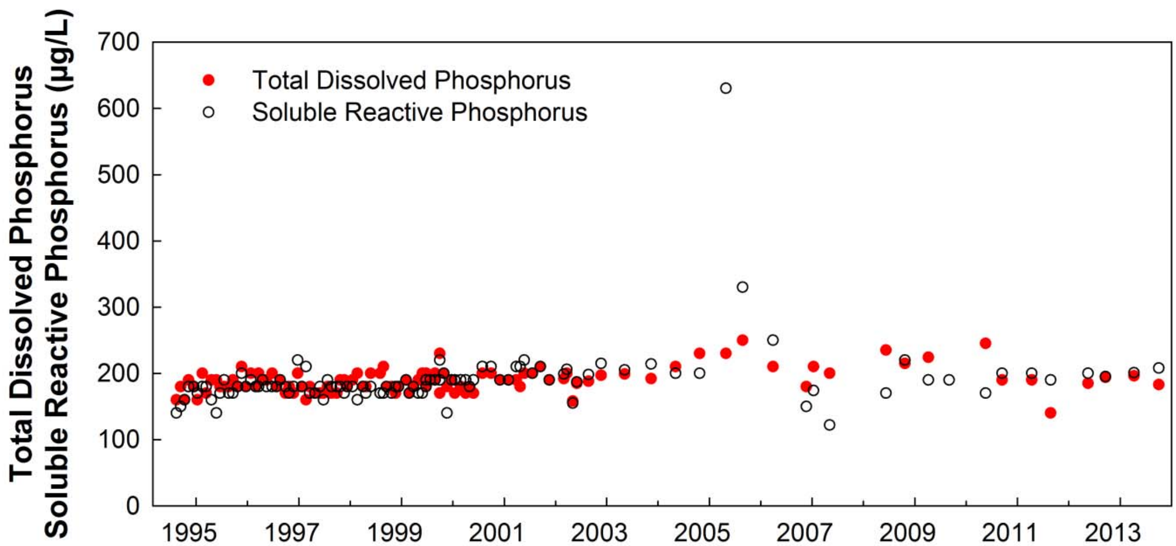

Figure 32: Total dissolved phosphorus and soluble reactive phosphorus concentrations measured at MW-9, 1994 to 2013.

4.4 Reservoir Phosphorus Loads and Export

Nutrients that limit or enhance algal growth in Cherry Creek Reservoir have many sources, both within the Reservoir (internal loading) or from outside the Reservoir (external loading). The direct release of nutrients from sediment, fish and plankton excrement, and the decay of organic matter are all internal sources of nutrients in a reservoir (Horne and Goldman 1994). However, the release of phosphorus from sediment during anoxic water conditions is the most substantial component of internal loading and is approximately 2,000 pounds per year (lbs/yr) in Cherry Creek Reservoir (Nürnberg and LaZerte 2008). Other studies evaluating internal loading from the sediments suggest lower estimates of internal phosphorus loading ranging between 810 lbs/yr and 1,590 lbs/yr (AMEC et al. 2005).

External sources of nutrients include flow from streams, direct precipitation and the alluvium, which carry nutrients from soil erosion, agricultural and residential runoff, treated wastewater, and airborne particulates. While both phosphorus and nitrogen are potentially important, past studies have concluded that Cherry Creek Reservoir was generally phosphorus limited (DRCOG 1985). However, a more recent nutrient enrichment study by Lewis et al. (2004)

indicated that nitrogen was often the primary limiting nutrient in Cherry Creek Reservoir during the growing season.

Phosphorus (unlike nitrogen) does not have a gas phase. Thus, phosphorus concentrations cannot be reduced by interactions with the atmosphere or gases within the water column. For these reasons, efforts in past years and during the present study have focused on phosphorus loading and flow-weighted phosphorus concentrations. Total phosphorus loads were determined for several primary sources, including the tributary streams Cherry Creek, Shop Creek, and Cottonwood Creek, as well as from precipitation and alluvium, as summarized in Appendix D. The flow-weighted concentrations represent the relationship between the total annual phosphorus load divided by total annual flow at a site.

4.4.1 Phosphorus Load from Tributary Streams

Monthly base flow phosphorus concentrations, along with the annual storm flow median concentration were applied to their respective flow to estimate loads for each stream site. Stream flows that were greater than the 90th percentile of all flows measured during the respective year and for that site were categorized as storm flows. The greatest proportion (63%) of the normalized total phosphorus load to the Reservoir was from Cherry Creek mainstem flows (6,052 lbs). Because Cherry Creek is monitored downstream of Shop Creek, the 305 lbs (<1%) contributed by Shop Creek has been subtracted from the normalized total load calculated for Site CC-10. Cottonwood Creek accounted for 13% of the phosphorus load, or 1,300 lbs. During the 2013 WY, the total phosphorus load to Cherry Creek Reservoir from tributary streams was 8,670 lbs and includes 1,012 lbs of ungaged residual phosphorus load (Table 9).

4.4.2 Phosphorus Export from Reservoir Outflow

The total outflow from Cherry Creek Reservoir as measured by the USACE was 10,359 acre-feet (ac-ft) in 2013 (Appendix D). Monthly total phosphorus data collected from Site CC-Out @ I225 near the dam outlet was used to estimate the phosphorus export at 3,378 lbs/yr for the Reservoir in 2013 (Table 9).

Table 9: Normalized phosphorus loads and export (lbs/year) for Cherry Creek Reservoir, 1992 to 2013 WY.

Water Year	Cherry Creek Load	Cottonwood Creek Load	Stream & Ungaged Residual Load	Cherry Creek Alluvial Load	Direct Precipitation Load	External Load	Cherry Creek Export	Net External Load
1992*	3,007	344	3,700	750	350	4,800	1,376	3,424
1993	1,534	233	1,854	1,026	305	3,185	995	2,190
1994	2,524	169	2,788	876	264	3,929	1,016	2,912
1995	2,081	1,400	3,989	996	592	5,576	1,377	4,200
1996	2,587	602	3,287	941	343	4,571	1,418	3,153
1997	2,159	622	2,894	1,008	436	4,338	1,140	3,198
1998	10,107	1,827	12,203	1,033	437	13,673	4,100	9,572
1999	10,606	1,279	14,950	1,033	526	16,508	6,363	10,145
2000	11,822	1,384	13,206	1,034	358	14,598	4,113	10,485
2001	6,293	2,108	8,647	1,033	397	10,077	5,524	4,553
2002	2,098	443	2,540	916	295	3,751	1,971	1,781
2003	6,215	1,055	7,894	1,033	445	9,372	4,774	4,598
2004	4,316	1,643	5,983	1,034	369	7,386	2,682	4,703
2005	8,770	1,351	10,121	1,033	372	11,526	3,964	7,562
2006	3,580	1,230	4,810	1,033	340	6,184	3,251	2,932
2007	15,999	2,075	18,209	1,033	369	19,611	7,891	11,721
2008	7,263	833	8,096	1,016	276	9,388	4,785	4,603
2009	13,608	937	14,607	1,033	424	16,063	9,483	6,581
2010	12,065	1,039	13,104	1,003	389	14,496	7,880	6,616
2011	7,354	655	8,009	1,025	278	9,312	4,113	5,199
2012	5,545	592	6,137	1,023	315	7,475	3,477	3,998
2013	6,357	1,300	8,670	1,033	381	10,083	3,378	6,705
Median (1992-2013)	6,254	1,047	7,776	1,030	369	9,192	3,721	4,601
Median (2009-2013)	7,354	937	8,009	1,025	381	9,312	4,113	5,693

* 1992 WY totals are calculated using January through September data.

4.4.3 Phosphorus Load from Precipitation

During the 2013 WY, a total of 17.0 inches of precipitation was recorded at the KAPA meteorological station located at Centennial Airport. When scaled to the areal extent of the Reservoir (852 acres), precipitation accounted for a total of 1,206 ac-ft of inflow to the Reservoir. The long-term (1995 to 2005) median total phosphorus concentration of 116 µg/L was used to calculate the 2013 WY total phosphorus load of 381 lbs/yr. This long-term median total phosphorous concentration represents a combination of dry fall and precipitation as measured near the Reservoir. The long-term median total phosphorus load from precipitation events collected from 1992 to 2013 is 369 lbs (Table 9).

4.4.4 Phosphorus Load from Alluvium

During the 2013 WY, the alluvial inflow constant was 1,998 ac-ft/yr (see Appendix D). The long-term (1994 to 2013) median total dissolved phosphorus concentration of alluvial flows from Site MW-9 is 190 µg/L. The alluvial phosphorus load to the Reservoir was estimated to be 1,033 lbs in 2013 (Table 9).

4.4.5 Mass Balance/Net Loading of Phosphorus to the Reservoir

The USACE calculates daily inflow to Cherry Creek Reservoir as a function of change in storage (i.e., reservoir volume) based on: 1) changes in reservoir level; 2) measured outflow; 3) precipitation; and 4) evaporation. This method for calculating reservoir volume accounts for groundwater inflow via alluvium, but does not directly quantify the flow. GEI monitors surface water inflow to the Reservoir using gaged stations on the three main surface inflows, Cherry Creek, Cottonwood Creek, and Shop Creek. Given the differences in the two methods for determining inflow, combined with the potential for unmonitored multiple Cherry Creek channels in the wetlands adjacent to the Reservoir, unmonitored surface flow (i.e., Belleview and Quincy drainages), and the potential for the USACE calculations to underestimate dam leakage (Lewis and Saunders 2002), an exact match between USACE and GEI calculated inflows is not expected.

During the 2013 WY, the USACE calculated inflow was 16,606 ac-ft/yr, while GEI calculated stream inflow was 12,230 ac-ft/yr (Appendix D). To compare these two inflow values, the USACE inflow was adjusted for precipitation (1,206 ac-ft/yr) and alluvial inflows (1,998 ac-ft/yr), which resulted in an adjusted USACE inflow of 13,401 ac-ft/yr. The difference between the adjusted USACE inflow and the GEI stream inflow was 1,171 ac-ft of water. This water volume difference was reapportioned between Cherry Creek (63%), Cottonwood Creek (37%), while 1,678 ac-ft was allocated to ungaged inflows during the September 2013 storm events. Flow-weighted total phosphorus concentrations for Cherry Creek and Cottonwood Creek were used to calculate the combined reapportioned load of 179 lbs.

Following the water balance normalization process, flow from Cherry Creek and Cottonwood Creek accounted for a total phosphorus load of 7,657 lbs to the Reservoir during the 2013 WY (Figure 33). The alluvial inflow contributed 1,033 lbs of phosphorus, with precipitation events contributing 381 lbs to the Reservoir. The total external load of phosphorus to the Reservoir in 2013 WY was 10,083 lbs (Figure 33).

The Reservoir outflow phosphorus load was estimated to be 3,378 lbs. The flow-weighted total phosphorus concentration for all external sources of inflow to the Reservoir is 223 µg/L and the flow-weighted export concentration for the Reservoir is 120 µg/L (Table 10). The difference of 103 µg/L was retained by the Reservoir. The net external phosphorus load to the Reservoir was 6,705 lbs during the 2013 WY.

The effectiveness of the CCBWQA's efforts in reducing flow-weighted phosphorus concentrations entering the Reservoir is illustrated by the concentrations observed along Cottonwood Creek (Table 10). During the past few years, the effectiveness of the Cottonwood Reclamation Project combined with the effectiveness of sediment removal at the Peoria Pond appear to have greatly reduced the amount of phosphorus mobilized within this system. At the most upstream monitoring location (Site CT-P1), the annual flow-weighted total phosphorus concentration was 267 µg/L. The phosphorus level in Cottonwood Creek flow was greatly reduced by the Cottonwood Creek Peoria Wetland System, and was further reduced through the stream restoration reach before the flow entered the Perimeter Pond PRF. The normalized flow-weighted concentration of 119 µg/L at Site CT-1 is still on the low end of the observed inflow concentrations for Cottonwood Creek since 1992.

Table 10: Flow-weighted phosphorus concentrations (µg/L) for Cherry Creek Reservoir, 1992 to 2013 WY.

Water Year	Cherry Creek Flow-weighted Concentration	Cottonwood Creek Flow-weighted Concentration	Inflow Flow-weighted Concentration	Outflow Flow-weighted Concentration
1992	268	172	220	95
1993	251	189	199	91
1994	247	88	196	77
1995	190	203	179	63
1996	234	331	211	89
1997	266	184	201	89
1998	282	176	238	81
1999	271	134	235	101
2000	312	159	265	83
2001	257	130	198	127
2002	221	88	171	107
2003	287	138	229	140
2004	247	157	201	96
2005	247	120	208	78
2006	231	132	187	115
2007	295	149	254	115
2008	205	84	177	104
2009	276	62	218	148
2010	239	78	200	115
2011	263	81	212	108
2012	244	91	200	118
2013	294	127	229	120
Median (1992-2013)	254	133	205	103
Median (2009-2013)	263	81	212	118

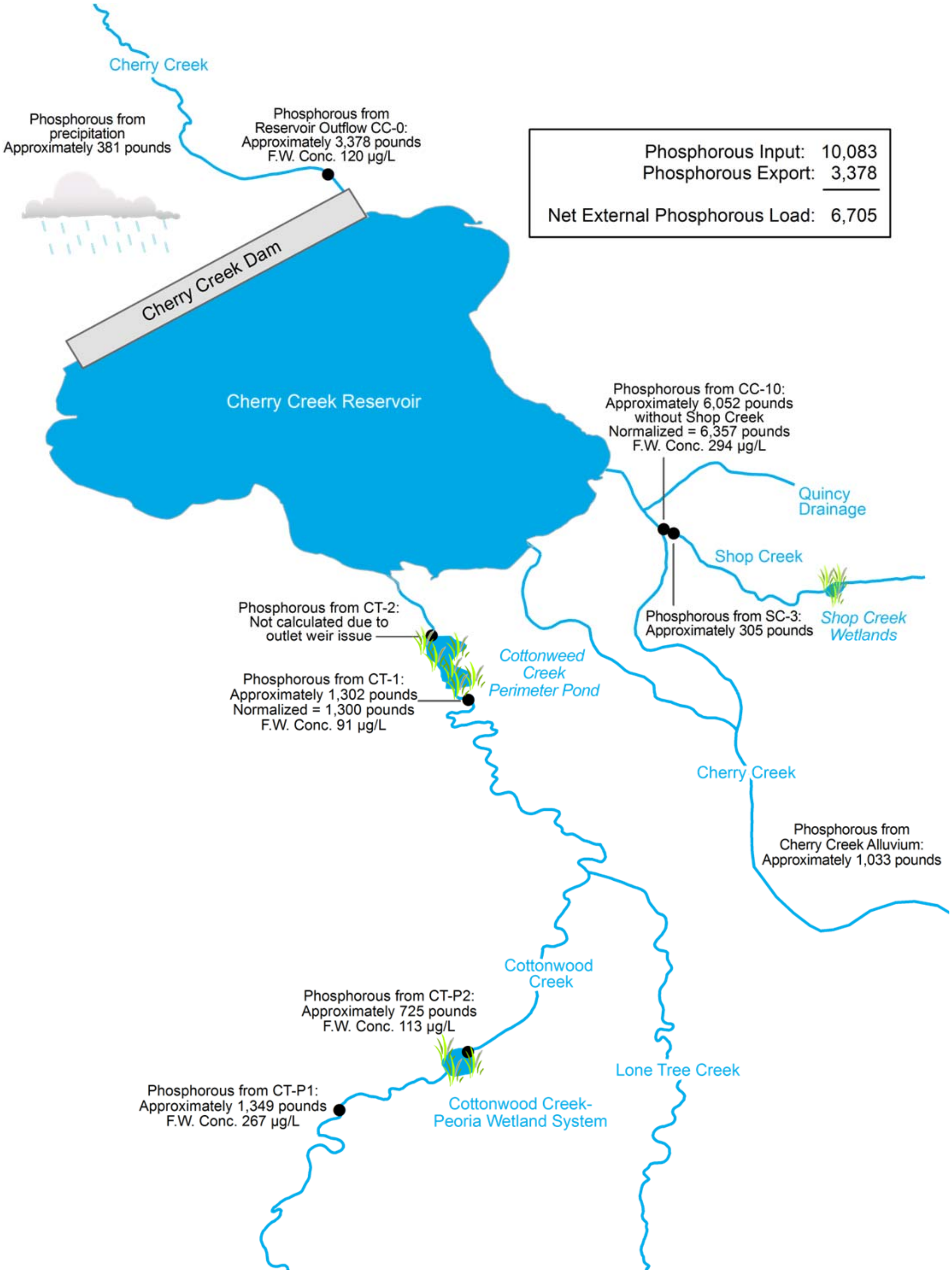

Figure 33: Mass balance diagram of phosphorus loading in Cherry Creek Reservoir, 2013 WY.

4.5 2013 Reservoir Sediment Sampling

To characterize the source of internal nutrient loading in the Reservoir, sediment core samples were collected from sites CCR-1, CCR-2 and CCR-3 in June 2013. These sediment samples were collected using a Kajak-Brinkhurst sediment corer. Three replicate samples were collected from each site for a total of 12 sediment core samples. The top 15 cm each core was analyzed for nutrients including total phosphorous, total extractable phosphorous, nitrate, nitrite, ammonia and total iron. Total phosphorous ranged from 3.9 to 9.7% with a Reservoir-wide average of 7.3% total phosphorous (Figure 34). Total extractable phosphorous ranged from 12 to 24 mg/kg, and the Reservoir-wide average was 16 mg/kg (Figure 34). The percent total phosphorous was lower at Site CCR-3 compared to sites CCR-1 and CCR-2. This pattern can be explained by the differences in organic matter within the sediment layer at these sites. Site CCR-3 is relatively close to the inflow of Cherry Creek and is shallower compared to sites CCR-1 and CCR-2. As the inflow from Cherry Creek enters the reservoir, organic matter is likely moved towards the deeper portion of the Reservoir which results in a reduced amount of organic matter at Site CCR-3 compared to the other two sites. This reduction in organic matter decreases the likelihood of internal phosphorous loading at Site CCR-3, and accounts for the lower percent total phosphorous.

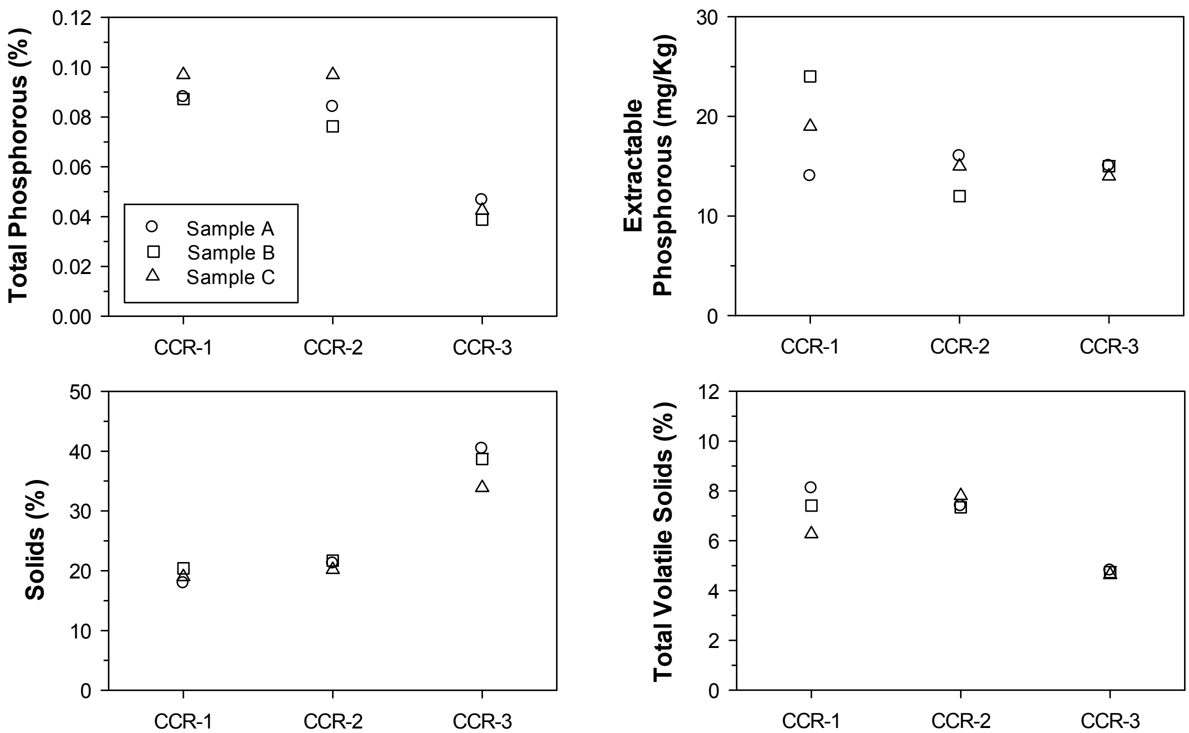

Figure 34: Percent phosphorous, total extractable phosphorous, percent solids and percent total volatile solids data from sediment cores collected from Cherry Creek Reservoir, June 2013.

When the percent total phosphorus content is converted to mg/kg basis, the mean concentration for sites CCR-1 and CCR-2 is 907 mg/kg and 857 mg/kg, respectively, and 426 mg/kg for Site CCR-3. As such, the extractable phosphorus content is between 1.5 and 3.9% of the total phosphorus content in the Reservoir sediment.

Percent solids ranged from 17.9 to 40.4% among the replicate samples with a Reservoir-wide average of 25.9% (Figure 34). Percent solids were similar at sites CCR-1 and CCR-2 and approximately double at Site CCR-3. The average percent solids content was approximately 20% for sites CCR-1 and CCR-2, and 38% at Site CCR-3. Total volatile solids ranged from 4.6 to 8.1% among the replicate samples with a Reservoir-wide average of 6.5% (Figure 34). Total volatile solids comprised approximately 37% of the total solids fractions at sites CCR-1 and CCR-2. In contrast, combustible organic matter comprised 12% of the total solids fraction at Site CCR-3.

4.6 Effectiveness of Pollutant Reduction Facilities

4.6.1 Cottonwood Creek Peoria Pond

The effectiveness of the Cottonwood Creek Peoria Pond is gaged by monitoring the concentrations of phosphorus and total suspended solids, and determining the flow-weighted phosphorus concentrations upstream and downstream of the facility. Notably, the loads and flows used to evaluate the effectiveness of the PRF are not affected by the “normalization” of GEI inflow to USACE inflow values for Cherry Creek Reservoir.

This PRF continues to be effective in reducing the amount of total suspended solids and total phosphorus as stream flow passes through this system. The total suspended solids were reduced by approximately 64% in 2013, with the long-term average showing a 27% reduction. The flow-weighted total phosphorus concentration upstream and downstream of the PRF was 267 µg/L and 113 µg/L, respectively, which indicates a high efficiency in removing phosphorus from flow (Table 11). Over the life of the project, the PRF shows approximately an average 19% reduction in the flow-weighted total phosphorus concentration at the downstream site.

This PRF was particularly effective at reducing the total suspended solids and total phosphorous load during multiple storm events during the 2013 WY. During the August 5, 2013 storm event, the inflow total suspended solids concentration at Site CT-P1 was approximately 327 mg/L while the outflow total suspended solids concentration at Site CT-P2 was approximately 22.7 mg/L. Similarly, the total phosphorous concentration entering the PRF during the storm event was 513 µg/L while the outflow concentration was 130 µg/L. During the event the PRF removed approximately 93% of the total suspended solids and 75% of the total phosphorous in Cottonwood Creek flows. During the storm event on September 11, 2013, the inflow total suspended solids concentration at Site CT-P1 was 468 mg/L while the outflow total suspended solids concentration at Site CT-P2 was 202 mg/L. The total phosphorous concentration entering the PRF during this storm event was 485 µg/L while the outflow concentration was 370 µg/L. Overall, the PRF was less efficient at removing total suspended solids and total phosphorous during the September 11, 2013 storm event versus the August 5, 2013 storm event. This decrease in efficiency can be explained by the fact that the September storm event was larger, and high discharge rates did not allow for sufficient holding time in the PRF necessary for nutrient reduction.

Table 11: Historical total phosphorus and total suspended solids concentrations and total phosphorus loads upstream and downstream of the Cottonwood Creek – Peoria Pond, 2002 to 2013 WY.

Parameter	Water Year	Sampling Sites		Difference	Percent Change Downstream
		CT-P1	CT-P2		
Mean Total Suspended Solids (mg/L)	2002	81	74	-7	-9
	2003	30	33	3	10
	2004	104	51	-53	-51
	2005	50	53	3	6
	2006	13	13	0	0
	2007	78	41	-37	-47
	2008*	36	34	-2	-6
	2009	48	27	-21	-44
	2010	34	26	-8	-24
	2011	48	30	-18	-38
	2012	121	55	-66	-55
	2013	97	35	-62	-64
	Mean	**62**	**39**	**-22**	**-27**
Flow-weighted Total Phosphorus Concentration (µg/L)	2002	142	118	-24	-17
	2003	117	109	-8	-7
	2004	132	132	0	0
	2005	129	119	-10	-8
	2006	146	140	-6	-4
	2007	156	120	-36	-23
	2008*	128	92	-36	-28
	2009	114	83	-31	-27
	2010	106	96	-10	-9
	2011	153	131	-22	-14
	2012	193	127	-66	-34
	2013	267	113	-154	-58
	Mean	**149**	**115**	**-34**	**-19**

* Eight months of operation.

Based on this significant storm event that occurred in September 2013, flow-weighted total phosphorous concentrations were evaluated pre-storm (October 2012 through August 2013) and post-storm (September 2013 only). During the pre-storm period, the flow-weighted total phosphorous concentration upstream and downstream of the PRF was 197 µg/L and 94 µg/L, respectively. These values are slightly reduced from the annual flow-weighted total phosphorous concentrations (267 µg/L and 113 µg/L), but they are fairly similar. During the post-storm period, the flow-weighted total phosphorous concentration upstream and downstream of the PRF was 352 µg/L and 142 µg/L, respectively. These values are well above the pre-storm period and are greater than the annual flow-weighted total phosphorous concentrations. The PRF efficiencies were similar during the pre- and post-storm periods.

4.6.2 Cottonwood Creek Perimeter Pond

The effectiveness of the Cottonwood Creek storm water Perimeter Pond in reducing phosphorus loads to the Reservoir is similarly gaged by comparing data from sites upstream and downstream of the PRF (Table 12). The total suspended solids were reduced by approximately 63% in 2013, with the long-term average showing a 30% reduction. The flow-weighted total phosphorus concentration upstream and downstream of the PRF was 119 µg/L and 57 µg/L, respectively, which indicates a high efficiency in removing phosphorus from flow (Table 12). Over the life of the project, the PRF shows approximately an average 23% reduction in the flow-weighted total phosphorus concentration at the downstream site.

Similar to Cottonwood Creek Peoria Pond, flow-weighted total phosphorous concentrations were evaluated pre-storm (October 2012 through August 2013) and post-storm (September 2013 only). During the pre-storm period, the flow-weighted total phosphorous concentration upstream and downstream of the PRF was 101 µg/L and 55 µg/L, respectively. Once again these values are slightly reduced from the annual flow-weighted total phosphorous concentrations (119 µg/L and 57 µg/L), but they are fairly similar. During the post-storm period, the flow-weighted total phosphorous concentration upstream and downstream of the PRF was 162 µg/L and 62 µg/L, respectively. These values are greater than the pre-storm period and the annual flow-weighted total phosphorous concentrations. Like the Cottonwood Creek Peoria Pond, the PRF efficiencies were similar during the pre- and post-storm periods.

Table 12: Historical total phosphorus and total suspended solids concentrations and total phosphorus loads upstream and downstream of the Cottonwood Creek Perimeter Pond, 1997 to 2013 WY.

Parameter	Water Year	Sampling Sites		Difference	Percent Change Downstream
		CT-1	CT-2		
Average Total Suspended Solids (mg/L)	1997	207	87	-120	-58
	1998	311	129	-182	-59
	1999	267	68	-199	-75
	2000	96	64	-32	-33
	2001	79	43	-36	-46
	2002	150	86	-64	-43
	2003	83	58	-25	-30
	2004	156	128	-28	-18
	2005	123	65	-58	-47
	2006	31	20	-11	-35
	2007	93	64	-29	-31
	2008*	31	59	28	90
	2009	31	32	1	3
	2010	33	33	0	0
	2011	48	30	-18	-38
	2012	NA	NA	NA	NA
	2013	57	21	-36	-63
	Mean	**112**	**62**	**-51**	**-30**
Flow-weighted Total Phosphorus Concentration (µg/L)	1997	485	183	-302	-62
	1998	311	176	-135	-43
	1999	143	129	-14	-10
	2000	266	161	-105	-39
	2001	163	146	-17	-10
	2002	124	105	-19	-15
	2003	193	124	-69	-36
	2004	194	149	-45	-23
	2005	141	120	-21	-15
	2006	165	135	-30	-18
	2007	170	148	-22	-13
	2008*	87	86	-1	-1
	2009	70	61	-9	-13
	2010	77	77	0	0
	2011	101	81	-20	-20
	2012	NA	NA	NA	NA
	2013	119	57	-62	-52
	Mean	**176**	**121**	**-54**	**-23**

* Nine months of operation.

4.6.3 McMurdo Stream Reclamation

Using a proactive approach to control stream erosion along McMurdo Gulch, before extensive land use development occurs along McMurdo Gulch, the town of Castle Rock and the CCBWQA implemented a stream reclamation project along three miles of stream between the Cobblestone Ranch and Castle Oaks subdivisions. Once the reclamation activities were completed in fall 2011, two water quality monitoring sites were established by CCBWQA. Site MCM-1 was established in January 2012 on McMurdo Gulch, approximately 150 m upstream of the McMurdo Gulch Stream Reclamation Project Boundary. This site is also 120 m upstream of the confluence with an unnamed tributary that receives runoff from the Castle Oaks Subdivision. This site serves as the upstream monitoring location for the McMurdo Gulch Stream Reclamation Project. Site MCM-2 was also established in January 2012 on McMurdo Gulch, approximately 80 m upstream of the Castle Oaks Drive Bridge crossing of McMurdo Gulch, near the North Rocky View Road intersection. This site serves as the downstream monitoring location for the McMurdo Gulch Stream Reclamation Project. This site is located within the project boundary, and consistently maintained base flows, whereas reaches further downstream were dry due to flow going subsurface.

In addition, three new sites were sampled in 2013 to characterize background nutrient concentrations in McMurdo Gulch (sites MCM-0.25, MCM-0.5, and MCM-Trib A). Site MCM-0.25 is located approximately 860 m upstream of Site MCM-1 and 50 m downstream of North Valley View Road crossing and served as the furthest upstream location exhibiting surface flow. Site MCM-0.5 is located approximately 570 m upstream of Site MCM-1. Site MCM-Trib A is located along the unnamed tributary that is located approximately 225 m upstream of Site MCM-1, and the confluence of the site is located 50 m upstream of the confluence.

Base flow water quality samples were collected on a monthly basis at sites MCM-1 and MCM-2) during the 2013 WY. Total phosphorous concentrations at Site MCM-1 ranged from 258 to 581 µg/L with a yearly mean concentration of 373 µg/L. Total phosphorous concentrations at Site MCM-2 were reduced compared to Site MCM-1 and ranged from 172 to 511 µg/L with a yearly mean concentration of 262 µg/L. Total suspended solids were similar throughout the year at both sites and had similar WY mean values (9.5 mg/L at Site MCM-1 and 11.2 mg/L at Site MCM-2). Total phosphorous and total suspended solids values were similar compared to data collected during the 2012 WY.

Because Site MCM-1 is located upstream of the McMurdo Gulch Stream Reclamation Project Boundary and Site MCM-2 is located downstream of the PRF, the reduction in phosphorous from Site MCM-1 to Site MCM-2 indicates that the PRF is effectively reducing total phosphorous concentrations in McMurdo Gulch. To better assess the effectiveness of the Stream Reclamation Project, GEI will continue to monitor these two sites during the 2014 WY.

Background nutrient data was only collected at sites MCM-0.25, MCM-0.5, and MCM-Trib A in May 2013. Total phosphorous concentrations ranged from 277 µg/L at Site MCM-0.25 to 418 µg/L at Site MCM-Trib A (Table 13). Total nitrogen values were similar at sites MCM-0.25 and MCM-0.5 (428 µg/L and 399 µg/L, respectively), but nearly double at Site MCM-Trib A (1,073 µg/L). Total suspended solids ranged from non-detect at Site MCM-0.5 to 27.6 mg/L at Site MCM-Trib A (Table 13). Overall, Site MCM-Trib A had greater nutrient concentrations compared to sites MCM-0.25 and MCM-0.5. In addition, the nutrient values at Site MCM-Trib A were greater than the annual mean total phosphorous and total suspended solids concentrations at sites MCM-1 and MCM-2. These background nutrient data suggest that this unnamed tributary contributes a larger nutrient load to McMurdo Gulch than activities on the upstream portion of McMurdo Gulch. This unnamed tributary receives drainage from large lot residential areas to the east of McMurdo Gulch.

Table 13: Total phosphorous, total nitrogen and total suspended solids data along McMurdo Gulch, May 2013.

Site	Total Phosphorous (µg/L)	Total Nitrogen (µg/L)	Total Suspended Solids (mg/L)
MCM-0.25	277	438	9.4
MCM-0.5	336	399	ND
MCM-Trib A	418	1,073	27.6
MCM-1	357	445	6.2
MCM-2	246	544	6.0

ND = below detection limit

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Appendix A

Cherry Creek Reservoir Sampling and Analysis Plan

Geotechnical
Water Resources
Environmental and
Ecological Services

Cherry Creek Reservoir Aquatic Biological and Nutrient Sampling and Laboratory Analysis Sampling, Analysis, and Quality Assurance Work Plan

Submitted to:
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April 2008
Project 062450

Table of Contents

List of Tables

List of Figures

1.0 Introduction

An inter-governmental agreement was executed in 1985 by several local governmental entities within the Cherry Creek basin to form the Cherry Creek Basin Water Quality Authority (Authority). The Authority, initially created by an intergovernmental agreement, was specially authorized by legislation adopted in 1988. The Authority develops and implements the means to protect the water quality of Cherry Creek Basin and Reservoir. Following legislation in 2001, the Board was reconstituted to include Arapahoe and Douglas County, seven municipalities (Aurora, Castle Rock, Centennial, Foxfield, Greenwood Village, Lone Tree, and Parker), one member representing the seven special districts (Arapahoe, Cottonwood, Inverness, Meridian, Parker, Pinery, and Stonegate Village), and seven citizens appointed by the governor. The Authority was created for the purpose of coordinating and implementing the investigations necessary to protect and to preserve the quality of water resources of the Cherry Creek basin while allowing for further economic development.

The Cherry Creek Basin Master Plan (DRCOG 1985), approved by the Colorado Water Quality Control Commission (CWQCC) in 1985, was adopted in part as the "Regulations for Control of Water Quality in Cherry Creek Reservoir" (Section 4.2.0, 5C.C.R.3.8.11). An annual monitoring program was implemented at the end of April 1987 to assist in the assessment of several aspects of the Master Plan. These monitoring studies have included long-term monitoring of 1) nutrient levels within the reservoir and from tributary streams during base flows and storm flows, 2) nutrient levels in precipitation, and 3) chlorophyll *a* levels within the reservoir. This monitoring program has been modified over the years in response to changes in the Control Regulation, various research goals, and suggestions from outside reviewers, including input from the Water Quality Control Division (WQCD).

2.0 Project Description

The Authority has prepared this Sampling, Analysis, and Quality Assurance Work Plan (Sampling and Analysis Plan) for aquatic biological nutrient analyses to be conducted on Cherry Creek Reservoir and selected off-lake sampling sites in 2008. This Sampling and Analysis Plan identifies field and laboratory protocols necessary to achieve quality data designed to help characterize the potential relationships between nutrient loading (both in-lake and external) and reservoir productivity. The specific objectives of the Sampling and Analysis Plan study are:

1. Determine the concentrations of selected nutrients, primarily phosphorus and nitrogen species, in Cherry Creek Reservoir as well as in various streams flowing into the reservoir and measure nutrients in the reservoir outflow.

2. Determine the annual phosphorus load entering Cherry Creek Reservoir from streams and precipitation and the phosphorus export from the reservoir via the outlet structure.

3. Determine biological productivity in Cherry Creek Reservoir, as measured by chlorophyll *a* concentrations and algal densities.

4. Provide data on the effectiveness of pollutant removal from Pollutant Removal Facilities (PRF) constructed by the Authority.

5. Provide data on the effectiveness of the destratification system at mixing the reservoir water column.

This Sampling and Analysis Plan presents the proposed 2008 sampling and analyses requirements for Cherry Creek Reservoir and includes discussions of: 1) project organization and responsibilities; 2) quality assurance objectives for the measurement of data in terms of accuracy, representativeness, comparability, and completeness; 3) field sampling and sample preservation procedures; 4) laboratory processing and analytical procedures; and 5) guidelines for data verification and reporting, quality control checks, corrective actions, and quality assurance reporting.

3.0 Project Organization and Responsibilities

All personnel involved in the investigation and in the generation of data are implicitly a part of the overall project and quality assurance program. Certain individuals have specifically delegated responsibilities, as described below.

3.1 Project Manager

Steven Canton is the Project Manager who is responsible for fiscal oversight and management of the project and for ensuring that all work is conducted in accordance with the Scope of Service, Sampling and Analysis Plan, and approved procedures. Tasks include:

- Maintain routine contact with the project's progress, regularly review the project schedule, and review all work products.
- Evaluate impacts on project objectives and the need for corrective actions based on quality control checks.
- Review and update of this Sampling and Analysis Plan as needed.

3.2 Quality Assurance Manager

Craig Wolf is the Quality Assurance Manager who is responsible for the aquatic biological and field sampling portions of the study as well as the technical management of the monitoring program and reporting. The Quality Assurance Manager shall be responsible for evaluation and review of all data reports relevant to the project and perform data verification. The Quality Assurance Manager shall work with the Project Manager to determine the need for corrective actions and, together, will make recommendations for any needed changes to either sampling methodologies or laboratory analytical procedures. Tasks include:

- Ensure data collection is in accordance with the Sampling and Analysis Plan.
- Maintain a central file, which contains or indicates the location of all documents relating to this project.
- Coordinate with the Authority, the WQCD, and the Authority's other consultants to ensure compliance with the Cherry Creek Reservoir Control Regulation No. 72.

3.3 Analytical and Biological Laboratory Managers

Suzanne Pargee is the Analytical Laboratory Manager who will ensure that all water quality and chlorophyll *a* samples are analyzed in a technically sound and timely manner. The Analytical Laboratory Manager shall be responsible for ensuring all laboratory quality assurance procedures associated with the project are followed, including proper sample entry, sample handling procedures, and quality control records for samples delivered to the laboratory. The Analytical Laboratory Manager will be responsible for all data reduction and verification and ensure that the data is provided in a format agreed upon between the Project Manager, the Analytical Laboratory Manager, and the Authority.

GEI subcontracts the phytoplankton identification and enumeration to the University of Colorado, Center for Limnology. This Center for Limnology shall be responsible for ensuring all laboratory quality assurance procedures associated with the project are followed, including proper sample entry, sample handling procedures, and quality control records for samples delivered to the laboratory.

3.4 Sampling Crew

The field sampling efforts shall be conducted by individuals qualified in the collection of chemical, physical, and biological surface water samples. Field tasks and sampling oversight will be provided by the Quality Assurance Manager. The Sampling Crew shall be responsible for following all procedures for sample collection, including complete and accurate documentation.

4.0 Aquatic Biological and Nutrient Sampling

4.1 Reservoir Monitoring Sites

Sampling would be conducted at sites established during past sampling efforts, as modified herein (see Figure 1 for location of all sites).

4.1.1 Cherry Creek Reservoir

CCR-1 This site is also called the Dam site, and was established in 1987. CCR-1 corresponds to the northwest area within the lake (Knowlton and Jones, 1993). Sampling was discontinued at this site in 1996 and 1997 following determination that this site exhibited similar characteristics to the other two sites. Sampling recommenced in July 1998 at the request of consultants for Greenwood Village.

CCR-2 This site is also called the Swim Beach site, and was established in 1987. Site CCR-2 corresponds to the northeast area within the lake (Knowlton and Jones, 1993).

CCR-3 This site is also called the Inlet site and was established in 1987, corresponding to the south area within the lake (Knowlton and Jones, 1993).

4.2 Stream Monitoring Sites

4.2.1 Cherry Creek

CC-10 This site is on Cherry Creek immediately downstream of the Shop Creek confluence, approximately 0.5 km upstream of Cherry Creek Reservoir. This site provides data to estimate phosphorus loads to the Reservoir from Cherry Creek and Shop Creek.

CC-O In 2007, this site was relocated further upstream on Cherry Creek to a location approximately 75 m downstream of the reservoir outflow gates. Site CC-O (i.e., CC-Outflow) provides data to evaluate the water quality of the Reservoir outlet.

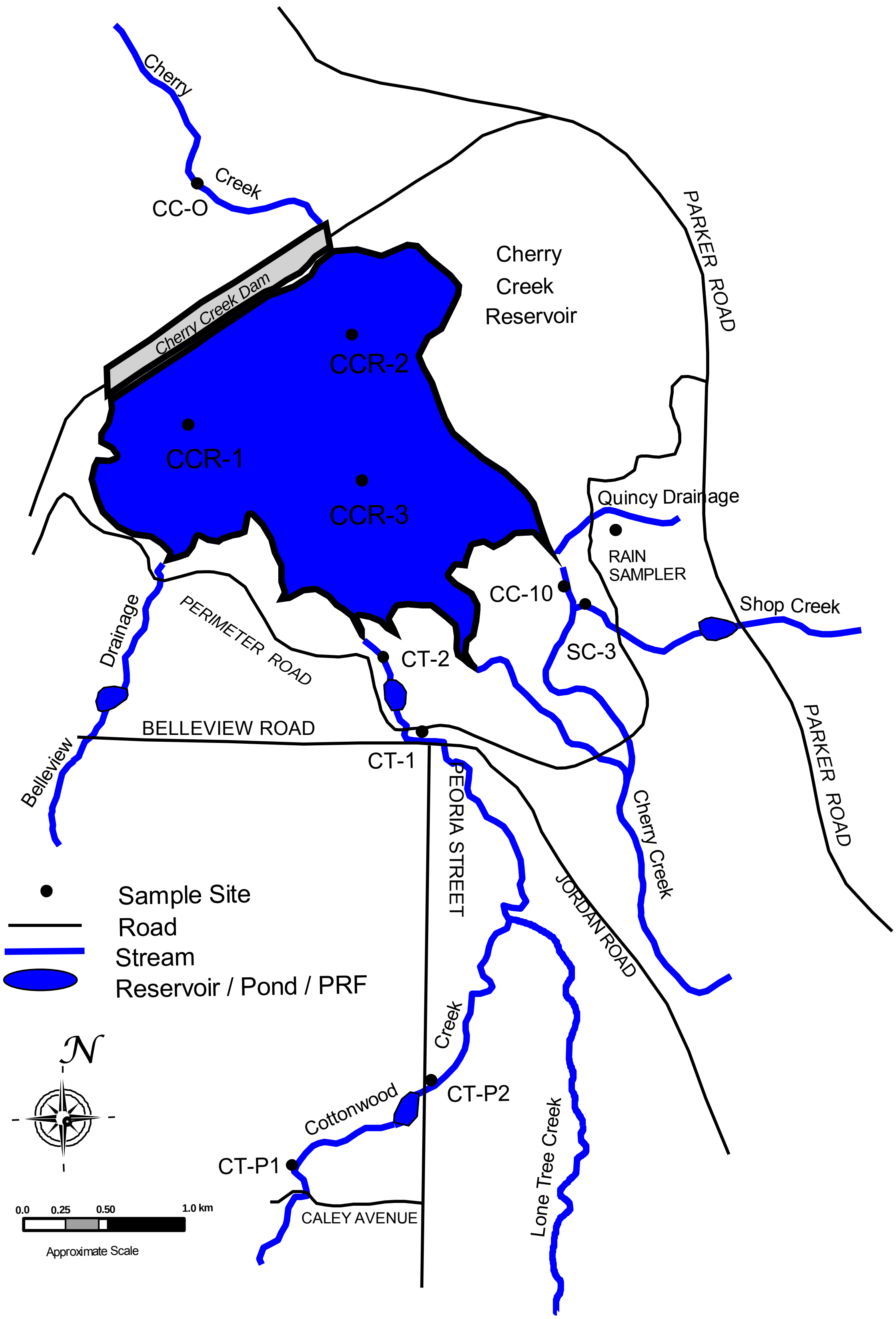


Figure 1: Sampling sites on Cherry Creek Reservoir and selected streams.

4.2.2 Cottonwood Creek

CT-2 This site is contained within the outflow weir structure for the Perimeter Pond PRF, upstream of Cherry Creek Reservoir. This site is included in the reservoir portion of the effort because the data is used to estimate phosphorus loads to the Reservoir from Cottonwood Creek. This site is also used to evaluate the performance of the Perimeter Pond PRF.

4.3 PRF Monitoring Sites

4.3.1 Shop Creek

SC-3 This site is located 35 m upstream of its confluence with Cherry Creek, and is used to monitor the water quality of Shop Creek before it joins Cherry Creek.

4.3.2 Cottonwood Creek

CT-P1 This site is located just north of where Caley Avenue crosses Cottonwood Creek, and west of Peoria Street. This site is used to monitor the water quality of Cottonwood Creek before it enters the Peoria Pond PRF.

CT-P2 This site is located at the outfall of the Peoria Pond PRF, on the west side of Peoria Street. The ISCO stormwater sampler and pressure transducer is located inside the outlet structure. This site is used to evaluate the performance of the PRF on water quality.

CT-1 This site is located 250 m upstream of the Cherry Creek Park Perimeter Road. The Cottonwood Creek Phase II Project will require the relocation of this site in 2008. Note that Site CT-2 is included in the reservoir monitoring requirements.

4.3.3 Precipitation Sampling Site

This site is located near the Quincy Drainage, upstream of the Perimeter Road. The sampler consists of a clean, inverted trash can lid used to funnel rainfall into a one-gallon container. While this collection vessel is maintained and cleaned on a routine basis, precipitation will wash any atmospheric dry fall that has accumulated between cleanings, into the one-gallon container. Therefore, these data more appropriately represent a “bulk” atmospheric deposition component for the Reservoir.

4.4 Analyte List

The sampling and analyses shall be conducted in accordance with the methods and detection limits provided in Table 1.

Table 1: Standard methods for sample analysis.

Parameter	Abbreviation	Analytical Method*	Recommended Hold Times	Detection Limit
Physicochemical				
Total Nitrogen	TN	4500-N B (modified)	< 24 hrs before digestion; < 7 days after digestion	2 µg/L
Total Dissolved Nitrogen	TDN	4500-N B (modified)	48 hrs	2 µg/L
Nitrate/Nitrite Nitrogen	NO_3+NO_2	4500-NO31	48 hrs	2 µg/L
Ammonium Ion Nitrogen	NH_4	QuickChem 10-107-06	24 hrs	3 µg/L
Total Phosphorus	TP	4500-P G	< 24 hrs before digestion	2 µg/L
Total Dissolved Phosphorus	TDP	4500-P G	48 hrs	2 µg/L
Soluble Reactive Phosphorus	SRP	4500-P G	48 hrs	2 µg/L
Total Suspended Solids	TSS	2540 D	7 days	4 mg/L
Total Volatile Suspended Solids	TVSS	2540 E	7 days	4 mg/L
Biological				
Chlorophyll *a*	Chl	10200 H (modified)	< 24 hrs before filtration	0.1 µg/L
Phytoplankton	--	Standard methods	NA	NA

* Analytical Methods are from American Public Health Association (APHA) 2005, unless otherwise noted.

4.5 Sampling Schedule

4.5.1 Reservoir Sampling

The Reservoir monitoring program includes collecting water quality data from three locations within the Reservoir, CCR-1, CCR-2, and CCR-3, as well as three stream sites, CC-10, CT-2 and CC-O that are important for characterizing the hydrological and mass balance budgets for the Reservoir. The Reservoir sampling schedule generally consists of monthly sampling from January to April and from October to December, with bimonthly reservoir samples collected from May to September (Table 2). Sampling during the winter months (November – February) will depend on ice conditions and safety concerns. The tributary inflow/outflow sites are sampled on a monthly basis from January to December and represent base flow conditions during each month. The sampling schedule for the reservoir and streams sites is summarized below:

Table 2: Cherry Creek reservoir and tributary inflow/outflow sampling.

	Sampling Period	Frequency	Trips/Period
Reservoir Sites CCR-1, CCR-2, and CCR-3	Jan – April	Monthly	4
	May – Sept	Bi-monthly	10
	Oct – Dec	Monthly	3
		Total	**17**
Stream Sites CC-10, CT-2, and CC-O	Jan – Dec	Monthly	12
		Total	**12**

4.5.2 PRF Sampling

The PRF sampling is conducted on a monthly basis, often concurrent with the regular reservoir sampling trips, to represent base flow conditions during each month (Table 3). These samples correspond to the low-flow ambient samples collected during earlier studies.

Table 3: PRF sampling.

Stream Sites CT-P1, CT-P2, CT-1, SC-3	Sampling Period	Frequency	Trips/Period
	Jan – Dec	Monthly	12
		Total	**12**

4.5.3 Storm Flow Sampling

To characterize storm flows, six stream sites are sampled during storm events (i.e., S-3, CC-10, CT-1, CT-2, CT-P1, and CT-P2). Automated samplers collect sequential storm flow samples when a threshold stream level is exceeded for each site. Storm samples are not collected at Site CC-O downstream of the reservoir, unless the Army Corps of Engineers (Corps) alerts the Consultant to an outflow event that could be tied to a storm-related inflow. Up to five storm events shall be collected over the summer for Cherry Creek (Site CC-10) and on Shop Creek (Site S-3). Up to seven storm events shall be collected at the four sites on Cottonwood Creek (CT-1, CT-2, CT-P1, and CT-P2). The actual number of storm events for which samples are obtained will be subject to weather patterns. The recommended storm sampling period is April through September to attempt to capture some of the late spring snowmelt events as well as the summer "monsoon" season.

4.5.4 Precipitation Sampling

Precipitation samples are to be collected after substantial rainfall events, defined as 0.5 inches or more. The sampler shall be inspected weekly and emptied of any accumulations of insignificant precipitation and the collector (inverted trash can lid) cleaned. This procedure is required to minimize small amounts of precipitation contaminating the sample between larger precipitation events.

4.6 Field Methodologies

4.6.1 Reservoir Sampling

4.6.1.1 Transparency

Transparency shall be determined using a Secchi disk and Licor quantum sensors. The Secchi reading shall be slowly lowered on the shady side of the boat, until the white quadrants disappear, at which point the depth is recorded to the nearest tenth of a meter. The disk is then lowered roughly 1 m further and slowly brought back up until the white quadrants reappear and again the depth is recorded. The Secchi disk depth is recorded as the average of these two readings.

Licor quantum sensors provide a quantitative approach to determine the depth at which 1 percent of the light penetrates the water column. This is considered the point at which light no longer can sustain photosynthesis in excess of oxygen consumption from respiration (Goldman and Horne 1983) and represents the deepest portion of the photic zone. This is accomplished by using an ambient and underwater quantum sensor attached to a Licor-1400 data logger. The ambient quantum sensor remains on the surface, while the underwater sensor is lowered into the water on the sunny side of the boat. The underwater sensor is lowered until the value displayed on the data logger is 1 percent of the value of the ambient sensor, and the depth is recorded.

4.6.1.2 Depth Profile Measurements

Measurements for dissolved oxygen, temperature, conductivity, pH, and oxidation/reduction potential (ORP) shall be collected at 1 m intervals, including the surface and near the water/sediment interface, using a YSI 600XL Multiparameter Sonde. The sonde shall be calibrated at the GEI Laboratory prior to each sampling episode to ensure accurate readings. In an effort to minimize probe contamination at the water/sediment interface, a depth sounding line is used to determine maximum depth. The bottom profile measurement is collected approximately 10 cm from the benthos.

4.6.1.3 Continuous Temperature Monitoring

The effectiveness of the destratification system at mixing the entire water column would be evaluated by deploying Onset HOBO® Water Temp Pro data loggers at three locations in the Reservoir (CCR-1, CCR-2, and CCR-3). At each site, temperature loggers would be deployed at 1 m increments, including the 0.5 m and bottom depths and configured to collect 15-minute interval temperature data.

The temperature arrays would be deployed using the State Park’s buoy system, beginning in March/April and operated through October, with periodic downloading of data to minimize potential loss of data. This deployment schedule would overlap with the proposed operational schedule of the destratification system.

In addition to the temperature loggers at the three monitoring sites, GEI will also perform three monthly ORP profiles during the July to September period at up to ten sample locations along a single transect through the deep-water zone. The sample locations and transect will be consistent with locations previously established by AMEC during their destratification feasibility study. Measurements of ORP will be performed from the waters surface to the sediment interface using the YSI 600XL Multiparameter Sonde.

4.6.1.4 Water Samples

A primary task of the monitoring program is to characterize the chemical and biological constituents of the upper 3m layers of the reservoir. This layer represents the most active layer for algal production (photic zone), and represents approximately 54 percent of the total lake volume given the typical lake level of 5550 ft. At each reservoir site, water from the surface, 1 m, 2 m, and 3 m depths is sampled individually using a 2-liter vertical Van Dorn water sampler and combined into a clean 5-gallon container to create a composite photic zone sample (Table 4). The vertical Van Dorn sampler is lowered to the appropriate depth, such that the middle of the sampler is centered on the selected depth. The “messenger” is sent to activate the sampler and the water is retrieved. Three one-liter aliquots are collected from the composite photic zone sample and stored on ice, until transferred to the laboratory for chemical and biological analyses.

At Site CCR-2, profile water samples are also collected on one-meter increments, starting from 4 m and continuing down to the 7 m depth. Given the recent lowering of the reservoir level by the USACE, in preparation for a 100-year flood event, the 7 m sample often represents a bottom water sample at Site CCR-2. This sample is collected as close to the water/sediment interface as possible, without disturbing the sediment. The sampler and 5-gallon container are rinsed thoroughly with lake water between sites.

Based on this sampling scheme, the number of samples collected at each site is as below:

Table 4: Number of reservoir samples collected.

Reservoir Site	Upper 3m Composite (Photic zone)	1-m Depth Profiles	Number of Samples
CCR-1	1	0	1
CCR-2	1	4	5
CCR-3	1	0	1
Total Samples/Sample Event	**3**	**4**	**7**

4.6.2 Water Quality Analyses

1. Nutrient analyses shall be performed on all reservoir water samples.
2. Chlorophyll analyses shall be performed on all photic zone composite samples.
3. Phytoplankton analyses shall be performed on all photic zone composite samples.

See Table 1 for the list of analytes, laboratory methods, and detection limits.

4.7 Stream Sampling

One sample shall be collected from each stream site on a monthly basis, when there is sufficient flow. Samples shall be collected as mid-stream mid-depth grab sample using a 5-gallon container. Two one-liter aliquots are collected from this grab sample and stored on ice, until transferred to the GEI laboratory for chemical analyses (Table 5).

4.7.1 Automatic Sampler

Each stream sampling station upstream of the reservoir also contains an Authority-owned ISCO flow meter and sampling device. The flow meter is a pressure transducer that measures stream water level. Rating curves are developed for each sampling site by measuring stream discharge (ft^3/sec) with a Marsh McBirney Model # 2000 flowmeter, and recording the water level at the staff gage (ft) and ISCO flowmeter (ft). Discharge is measured using methods outlined in Harrelson *et al.* 1994. To determine flow rate, the level must be translated into flow rate using a "stage-discharge" relationship. Since stage-discharge relationships can change over the years, the relationship is calibrated annually using a flow meter to record stream flow measurements three to four times per year at a range of flows. These data are combined with historical data, as long as stream geomorphology conditions are similar, to validate and modify the stage-discharge relationship for that site. If the staff gage is reset, moved to a new location, or geomorphology conditions have changed, then a new stage-discharge relationship is created for that site.

Water level data are collected on 15-minute intervals and stored in the ISCO sampler. These data are downloaded on a monthly basis to minimize the risk of data loss due to power failure or ISCO failure. The flow data and stage-discharge rating curves shall be checked throughout the year by comparing calculated flow estimates to actual flow measurements recorded in the field with a flowmeter.

The USACE also reports daily inflow to Cherry Creek Reservoir as a function of storage, based on changes in reservoir level. This daily inflow value incorporates information regarding measured outflow, precipitation, and evaporation. GEI monitors inflow to the Reservoir using gaging stations on Cherry Creek, Cottonwood Creek, and Shop Creek (the three main surface inflows) to provide a daily surface inflow record. Given the differences in the two methods for determining inflow, combined with the potential of unmonitored alluvial and surface flows that may result in greater seepage through the adjacent wetlands during storm events, and other unmonitored surface inflows (i.e., Belleview and Quincy drainages) an exact match between USACE and GEI calculated inflows is not expected. Therefore, GEI normalizes their streamflow data to match the USACE computed inflow value.

4.7.2 Storm Event Sampling

Samples from storm flow events are collected using ISCO automatic samplers, which are programmed to collect samples when the flow reaches a threshold level. The threshold level is determined by analyzing annual hydrographs from each stream and determining storm levels. When the threshold is reached, the ISCO collects a sample every 15 minutes for approximately 2.5 hours (i.e., a timed composite) or until the water recedes below the threshold level. This sampling procedure occurs at Sites S-3, CC-10, CT-1, CT-2, CT-P1, and CT-P2. Following the storm event, water collected by the automatic samplers is combined (timed composite) into a clean 5-gallon container, with two 1-liter aliquots collected from the composited sample and stored on ice until transferred to the laboratory for analysis. Approximately 4 L would be collected from the 24 bottles, with each bottle contributing a sample amount representative of the flow at which it was collected. During the seasons in which no storm samples are collected, the storm samplers are disabled.

4.8 Precipitation Sampling

After each substantial storm, the sample bottle shall be removed, stored on ice, and transferred to the laboratory for analysis of phosphorus and nitrogen fractions. The sampler shall be inspected and cleaned of any accumulations of unimportant precipitation on a weekly basis. This will minimize extraneous “dry fall” from being washed into the sampler between substantial storm events.

5.0 Laboratory Procedures

5.1 Chemical Laboratory Analysis

Chemical analyses for the water collected in the study (Table 1) will be conducted by a qualified laboratory. Water samples will be analyzed for the parameters listed in Table 5.

Table 5: List of Analytes performed on each type of sample.

Parameter	Reservoir Photic Zone Composite	Reservoir 1 m Interval	Stream Base Flow	Stream Storm Flow	Rain Fall
Physicochemical					
Total Nitrogen	X	X	X	X	X
Total Dissolved Nitrogen	X	X	X	X	X
Nitrate/Nitrite Nitrogen	X	X	X	X	X
Ammonium Ion Nitrogen	X	X	X	X	X
Total Phosphorus	X	X	X	X	X
Total Dissolved Phosphorus	X	X	X	X	X
Soluble Reactive Phosphorus	X	X	X	X	X
Total Suspended Solids	--	--	X	X	--
Total Volatile Suspended Solids	--	--	X	X	--
Biological					
Chlorophyll *a*	X	--	--	--	--
Phytoplankton	X	--	--	--	--

5.2 Biological Laboratory Analysis

Biological analyses for the samples collected in the study, include chlorophyll *a*, phytoplankton identification and enumeration. The methods of these analyses, with appropriate QA/QC procedures shall be in accordance with the methods provided in Table 1. Chlorophyll *a* samples are analyzed by the GEI Analytical Laboratory, while phytoplankton samples are analyzed by the University of Colorado, Center for Limnology.

5.3 Laboratory Quality Assurance/Quality Control Protocols

Analytical equipment calibrations are performed every time new standards are prepared (minimum of once per week). Instrument values are compared to known standard concentration and if the correlation coefficient of the standard curve is less than 0.999, the instrument is recalibrated or standards are remade, with the process being completed until the instrument passes the test. Pseudo-replicate analyses are performed on each sample analyzed (i.e., sample analyzed twice) and the percent difference must be within 10 percent, if the resultant concentration is above the minimum detection limit. If the difference of the pseudo-replicate analyses are >10 percent, a new analytical sample is placed in a clean test tube and analyzed. During a sample analysis run, check standards are analyzed between every 5 samples (or 10 replicates). The check standards consist of one high range standard, one mid range standard, and the control blank (zero). Check standards analyzed before and after each group of samples must be within 10 percent of the theoretical value. If standards are outside of this range, new analytical samples and standards are placed in clean test tubes and analyzed to try to determine the source of the error. Sample values are not accepted until the problem has been resolved and all check standards pass the QC criteria. One matrix spike is run for every 10 samples analyzed (or 20 replicates). The percent recovery for matrix spikes must be ± 20 percent.

Following sample analyses, a final QC check is performed to determine if all parameters measured are in agreement. Final analyses for each sample are compared to ensure that concentrations of total phosphorus ≥ total dissolved phosphorus ≥ orthophosphate and that the concentration of total nitrogen ≥ total dissolved nitrogen ≥ nitrate/nitrite and ammonia. If parameters are not in agreement samples are reanalyzed.

6.0 Data Verification, Reduction, and Reporting

Data verification shall be conducted to ensure that raw data are not altered. All field data, such as those generated during any field measurements and observations, will be entered directly into a bound Field Book. Sampling Crew members will be responsible for proof reading all data transfers, if necessary. At least 10 percent of all data transfers will be checked for accuracy.

The Quality Assurance Project Manager will conduct data verification activities to assess laboratory performance in meeting quality assurance requirements. Such reviews include a verification that: 1) the correct samples were analyzed and reported in the correct units; 2) the samples were properly preserved and not held beyond applicable holding times; 3) instruments are regularly calibrated and meeting performance criteria; and 4) laboratory QA objectives for precision and accuracy are being met.

Data reduction for laboratory analyses is conducted by Consultant's personnel in accordance with EPA procedures, as available, for each method. Analytical results and appropriate field measurements are input into a computer spreadsheet. No results will be changed in the spreadsheet unless the cause of the error is identified and documented.

A data control program will be followed to insure that all documents generated during the project are accounted for upon their completion. Accountable documents include: Field Books, Sample Chain of Custody, Sample Log, analytical reports, quality assurance reports, and interpretive reports.

Data shall be summarized and provided to the Authority's Technical Advisory Committee on a monthly basis and presented in an annual report.

7.0 References

American Public Health Association. 2005. *Standard Methods for Examination of Water and Wastewater*, 20th Edition. American Public Health Association, Washington, DC.

Denver Regional Council of Governments. 1985. *Cherry Creek Basin Water Quality Management Master Plan*. Prepared in Cooperation with Counties, Municipalities, and Water and Sanitation Districts in the Cherry Creek Basin and Colorado Department of Health.

Goldman, C.R., and A.J. Horne. 1983. *Limnology*. McGraw-Hill Company, NY.

Harrelson, Cheryl C., Rawlins, C.L., Potyondy, John P. 1994. *Stream channel reference sites: an illustrated guide to field technique.* Gen. Tech. Rep. RM-245. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 61p.

Knowlton, M.R., and J.R. Jones. 1993. *Limnological Investigations of Cherry Creek Lake*. Final report to Cherry Creek Basin Water Quality Authority.

Appendix B

2013 WY Reservoir Water Quality Data

CCR-1 GEI Water Chemistry Data											
Analytical Detection Limits		**2**	**2**	**2**	**2**	**2**	**2**	**3**	**0.1**	**4**	**4**
Sample Date	**Sample Name/ Location**	**Total Phosphorous (µg/L)**	**Total Dissolved Phosphorous (µg/L)**	**Ortho-phosphate (µg/L)**	**Total Nitrogen (µg/L)**	**Total Dissolved Nitrogen (µg/L)**	**Nitrate+ Nitrite (µg/L)**	**Ammonia (µg/L)**	**Average Chlorophyll *a* (mg/m^3)**	**TSS (mg/L)**	**TVSS (mg/L)**
10/16/2012	CCR-1 Photic	114	29	17	863	491	6	23	32.2	15.8	6.2
11/13/2012	CCR-1 Photic	78	20	11	823	483	4	15	21.1	11.2	5.0
1/22/2013	CCR-1 Photic	74	34	31	1,033	807	61	112	14.5	6.2	ND
2/12/2013	CCR-1 Photic	85	36	13	980	538	10	13	33.5	12.3	6.7
3/29/2013	CCR-1 Photic	76	22	9	894	528	6	13	17.6	10.8	5.4
4/29/2013	CCR-1 Photic	73	21	8	957	598	12	13	21.2	16.6	7.0
5/14/2013	CCR-1 Photic	78	16	10	1,121	760	2	41	14.9	9.6	5.0
5/28/2013	CCR-1 Photic	79	31	11	1,044	859	5	33	22.7	14.2	4.0
6/12/2013	CCR-1 Photic	83	27	14	919	528	ND	49	16.0	18.0	7.0
6/26/2013	CCR-1 Photic	130	56	60	1,326	796	2	58	26.1	15.2	7.0
7/10/2013	CCR-1 Photic	136	68	68	818	555	4	33	24.8	11.0	5.4
7/22/2013	CCR-1 Photic	128	49	44	830	562	ND	27	29.8	14.8	7.4
8/13/2013	CCR-1 Photic	133	43	29	1,248	689	ND	50	38.3	17.4	6.8
8/28/2013	CCR-1 Photic	101	35	23	946	585	ND	48	18.0	10.6	5.2
9/11/2013	CCR-1 Photic	90	29	29	1,031	927	4	30	26.6	15.0	5.2
9/24/2013	CCR-1 Photic	170	62	59	996	509	ND	38	33.0	24.8	8.0

ND = below detection limit

CCR-2 GEI Water Chemistry Data											
Analytical Detection Limits		**2**	**2**	**2**	**2**	**2**	**2**	**3**	**0.1**	**4**	**4**
Sample Date	**Sample Name/ Location**	**Total Phosphorous (µg/L)**	**Total Dissolved Phosphorous (µg/L)**	**Ortho-phosphate (µg/L)**	**Total Nitrogen (µg/L)**	**Total Dissolved Nitrogen (µg/L)**	**Nitrate+ Nitrite (µg/L)**	**Ammonia (µg/L)**	**Average Chlorophyll *a* (mg/m^3)**	**TSS (mg/L)**	**TVSS (mg/L)**
10/16/2012	CCR-2 Photic	101	36	19	953	579	13	36	33.9	14.6	5.8
10/16/2012	CCR-2 4m	105	28	19	830	456	8	13	--	--	--
10/16/2012	CCR-2 5m	98	27	19	795	450	14	13	--	--	--
10/16/2012	CCR-2 6m	90	27	19	829	496	4	13	--	--	--
10/16/2012	CCR-2 7m	106	29	20	779	521	49	12	--	--	--
11/13/2012	CCR-2 Photic	84	18	10	785	481	4	14	22.3	10.6	4.6
11/13/2012	CCR-2 4m	79	17	9	810	463	4	11	--	--	--
11/13/2012	CCR-2 5m	78	17	10	812	476	4	12	--	--	--
11/13/2012	CCR-2 6m	81	19	9	757	495	4	11	--	--	--
11/13/2012	CCR-2 7m	87	20	10	786	503	5	13	--	--	--
1/22/2013	CCR-2 Photic	103	25	16	1,124	654	71	34	33.1	8.8	6.4
1/22/2013	CCR-2 4m	63	26	18	955	640	80	61	--	--	--
1/22/2013	CCR-2 5m	88	24	14	1,193	658	69	35	--	--	--
1/22/2013	CCR-2 6m	67	28	20	980	633	83	74	--	--	--
1/22/2013	CCR-2 7m	69	25	17	977	657	75	62	--	--	--
2/12/2013	CCR-2 Photic	98	34	14	1,028	579	24	14	35.0	4.7	7.0
2/12/2013	CCR-2 4m	69	25	9	813	540	8	13	--	--	--
2/12/2013	CCR-2 5m	54	21	6	712	484	5	16	--	--	--
2/12/2013	CCR-2 6m	53	28	8	676	515	9	15	--	--	--
2/12/2013	CCR-2 7m	75	35	24	848	536	17	96	--	--	--
3/29/2013	CCR-2 Photic	43	19	8	951	577	7	28	19.2	9.2	4.8
3/29/2013	CCR-2 4m	52	21	10	1,029	666	6	32	--	--	--
3/29/2013	CCR-2 5m	91	22	8	952	577	5	32	--	--	--
3/29/2013	CCR-2 6m	64	20	7	1,611	645	6	30	--	--	--
3/29/2013	CCR-2 7m	49	18	9	868	544	4	34	--	--	--
4/29/2013	CCR-2 Photic	79	23	18	983	595	50	15	23.3	15.4	7.0
4/29/2013	CCR-2 4m	115	21	7	905	514	11	12	--	--	--
4/29/2013	CCR-2 5m	115	24	11	997	550	11	14	--	--	--

CCR-2 GEI Water Chemistry Data											
Analytical Detection Limits		**2**	**2**	**2**	**2**	**2**	**2**	**3**	**0.1**	**4**	**4**
Sample Date	**Sample Name/ Location**	**Total Phosphorous (µg/L)**	**Total Dissolved Phosphorous (µg/L)**	**Ortho-phosphate (µg/L)**	**Total Nitrogen (µg/L)**	**Total Dissolved Nitrogen (µg/L)**	**Nitrate+ Nitrite (µg/L)**	**Ammonia (µg/L)**	**Average Chlorophyll *a* (mg/m^3)**	**TSS (mg/L)**	**TVSS (mg/L)**
4/29/2013	CCR-2 6m	101	25	12	945	565	10	12	--	--	--
4/29/2013	CCR-2 7m	115	33	14	1,045	522	11	11	--	--	--
5/14/2013	CCR-2 Photic	62	16	10	993	579	8	51	15.0	9.4	4.2
5/14/2013	CCR-2 4m	75	18	17	928	598	20	57	--	--	--
5/14/2013	CCR-2 5m	63	20	18	911	571	12	50	--	--	--
5/14/2013	CCR-2 6m	94	40	39	1,104	705	14	209	--	--	--
5/14/2013	CCR-2 7m	76	47	38	1,003	710	11	210	--	--	--
5/28/2013	CCR-2 Photic	79	24	11	1,120	731	3	35	21.8	16.4	4.7
5/28/2013	CCR-2 4m	71	21	10	817	551	3	28	--	--	--
5/28/2013	CCR-2 5m	75	27	18	737	564	4	34	--	--	--
5/28/2013	CCR-2 6m	114	54	47	868	658	6	143	--	--	--
5/28/2013	CCR-2 7m	143	69	53	933	778	7	183	--	--	--
6/12/2013	CCR-2 Photic	87	27	12	1,142	850	ND	55	24.5	15.8	7.0
6/12/2013	CCR-2 4m	89	35	13	930	536	ND	39	--	--	--
6/12/2013	CCR-2 5m	129	55	47	847	464	ND	47	--	--	--
6/12/2013	CCR-2 6m	223	95	86	890	566	ND	45	--	--	--
6/12/2013	CCR-2 7m	202	95	89	822	564	ND	48	--	--	--
6/26/2013	CCR-2 Photic	116	45	54	1,077	711	ND	42	26.0	16.6	8.2
6/26/2013	CCR-2 4m	117	61	58	874	553	ND	45	--	--	--
6/26/2013	CCR-2 5m	109	50	56	969	513	ND	40	--	--	--
6/26/2013	CCR-2 6m	115	52	59	960	539	ND	46	--	--	--
6/26/2013	CCR-2 7m	128	53	61	802	468	ND	57	--	--	--
7/10/2013	CCR-2 Photic	129	60	64	828	576	3	29	25.1	11.6	5.6
7/10/2013	CCR-2 4m	118	67	70	820	497	2	45	--	--	--
7/10/2013	CCR-2 5m	142	82	85	861	541	4	115	--	--	--
7/10/2013	CCR-2 6m	162	111	108	855	649	6	180	--	--	--
7/10/2013	CCR-2 7m	165	108	113	890	659	5	192	--	--	--
7/22/2013	CCR-2 Photic	122	49	47	826	492	2	22	24.5	15.0	7.0

CCR-2 GEI Water Chemistry Data											
Analytical Detection Limits		**2**	**2**	**2**	**2**	**2**	**2**	**3**	**0.1**	**4**	**4**
Sample Date	**Sample Name/ Location**	**Total Phosphorous (µg/L)**	**Total Dissolved Phosphorous (µg/L)**	**Ortho-phosphate (µg/L)**	**Total Nitrogen (µg/L)**	**Total Dissolved Nitrogen (µg/L)**	**Nitrate+ Nitrite (µg/L)**	**Ammonia (µg/L)**	**Average Chlorophyll *a* (mg/m^3)**	**TSS (mg/L)**	**TVSS (mg/L)**
7/22/2013	CCR-2 4m	157	48	57	906	495	4	53	--	--	--
7/22/2013	CCR-2 5m	164	54	57	838	559	3	41	--	--	--
7/22/2013	CCR-2 6m	157	59	60	801	622	3	61	--	--	--
7/22/2013	CCR-2 7m	186	50	58	937	704	6	64	--	--	--
8/13/2013	CCR-2 Photic	124	39	26	1,221	999	ND	44	33.6	20.2	7.4
8/13/2013	CCR-2 4m	142	41	27	1,162	936	ND	40	--	--	--
8/13/2013	CCR-2 5m	130	40	27	1,124	934	ND	32	--	--	--
8/13/2013	CCR-2 6m	200	33	26	1,244	898	ND	39	--	--	--
8/13/2013	CCR-2 7m	--	--	--	--	--	--	--	--	--	--
8/28/2013	CCR-2 Photic	105	38	22	919	490	ND	56	17.4	11.6	5.8
8/28/2013	CCR-2 4m	117	42	33	925	594	ND	67	--	--	--
8/28/2013	CCR-2 5m	140	63	49	976	710	ND	136	--	--	--
8/28/2013	CCR-2 6m	199	67	59	1,053	666	ND	173	--	--	--
8/28/2013	CCR-2 7m	--	--	--	--	--	--	--	--	--	--
9/11/2013	CCR-2 Photic	92	30	33	1,019	847	6	31	21.4	12.4	5.4
9/11/2013	CCR-2 4m	98	35	33	886	704	4	35	--	--	--
9/11/2013	CCR-2 5m	90	36	34	997	721	6	56	--	--	--
9/11/2013	CCR-2 6m	129	34	36	1,267	824	6	77	--	--	--
9/11/2013	CCR-2 7m	--	--	--	--	--	--	--	--	--	--
9/24/2013	CCR-2 Photic	158	62	56	965	549	3	40	32.1	23.6	6.2
9/24/2013	CCR-2 4m	156	60	56	802	449	2	47	--	--	--
9/24/2013	CCR-2 5m	159	58	56	800	451	2	49	--	--	--
9/24/2013	CCR-2 6m	163	62	56	828	515	3	51	--	--	--
9/24/2013	CCR-2 7m	170	60	57	811	476	ND	45	--	--	--
9/24/2013	CCR-2 8m	198	57	60	831	435	2	62	--	--	--

ND = below detection limit

CCR-3 GEI Water Chemistry Data

Analytical Detection Limits		2	2	2	2	2	2	3	0.1	4	4
Sample Date	**Sample Name/ Location**	**Total Phosphorous (µg/L)**	**Total Dissolved Phosphorous (µg/L)**	**Ortho-phosphate (µg/L)**	**Total Nitrogen (µg/L)**	**Total Dissolved Nitrogen (µg/L)**	**Nitrate+ Nitrite (µg/L)**	**Ammonia (µg/L)**	**Average Chlorophyll *a* (mg/m^3)**	**TSS (mg/L)**	**TVSS (mg/L)**
10/16/2012	CCR-3 Photic	101	24	14	850	492	6	19	31.9	17.2	7.2
11/13/2012	CCR-3 Photic	80	18	9	778	475	4	10	22.9	12.0	4.2
1/22/2013	CCR-3 Photic	83	25	16	1,004	641	79	50	28.6	9.0	5.2
3/29/2013	CCR-3 Photic	83	32	8	971	601	8	30	21.4	9.6	5.4
4/29/2013	CCR-3 Photic	93	22	7	977	570	11	13	23.6	18.2	7.4
5/14/2013	CCR-3 Photic	67	21	9	1,219	840	3	50	17.6	11.8	5.0
5/28/2013	CCR-3 Photic	84	21	10	940	633	ND	27	20.1	16.5	4.5
6/12/2013	CCR-3 Photic	98	29	15	1,038	531	ND	48	20.4	19.4	7.0
6/26/2013	CCR-3 Photic	106	35	56	1,186	737	ND	52	26.0	15.0	6.8
7/10/2013	CCR-3 Photic	139	64	63	886	610	2	25	29.5	12.4	5.6
7/22/2013	CCR-3 Photic	136	41	43	1,036	611	ND	33	26.6	16.2	7.2
8/13/2013	CCR-3 Photic	136	34	28	1,182	760	2	38	34.5	20.2	8.0
8/28/2013	CCR-3 Photic	112	33	22	1,070	568	ND	66	20.1	14.6	6.0
9/11/2013	CCR-3 Photic	93	36	32	1,053	767	2	29	29.1	12.0	4.6
9/24/2013	CCR-3 Photic	141	63	63	814	526	5	63	20.6	20.2	5.6

ND = below detection limit

Site CCR-1 Small Tables

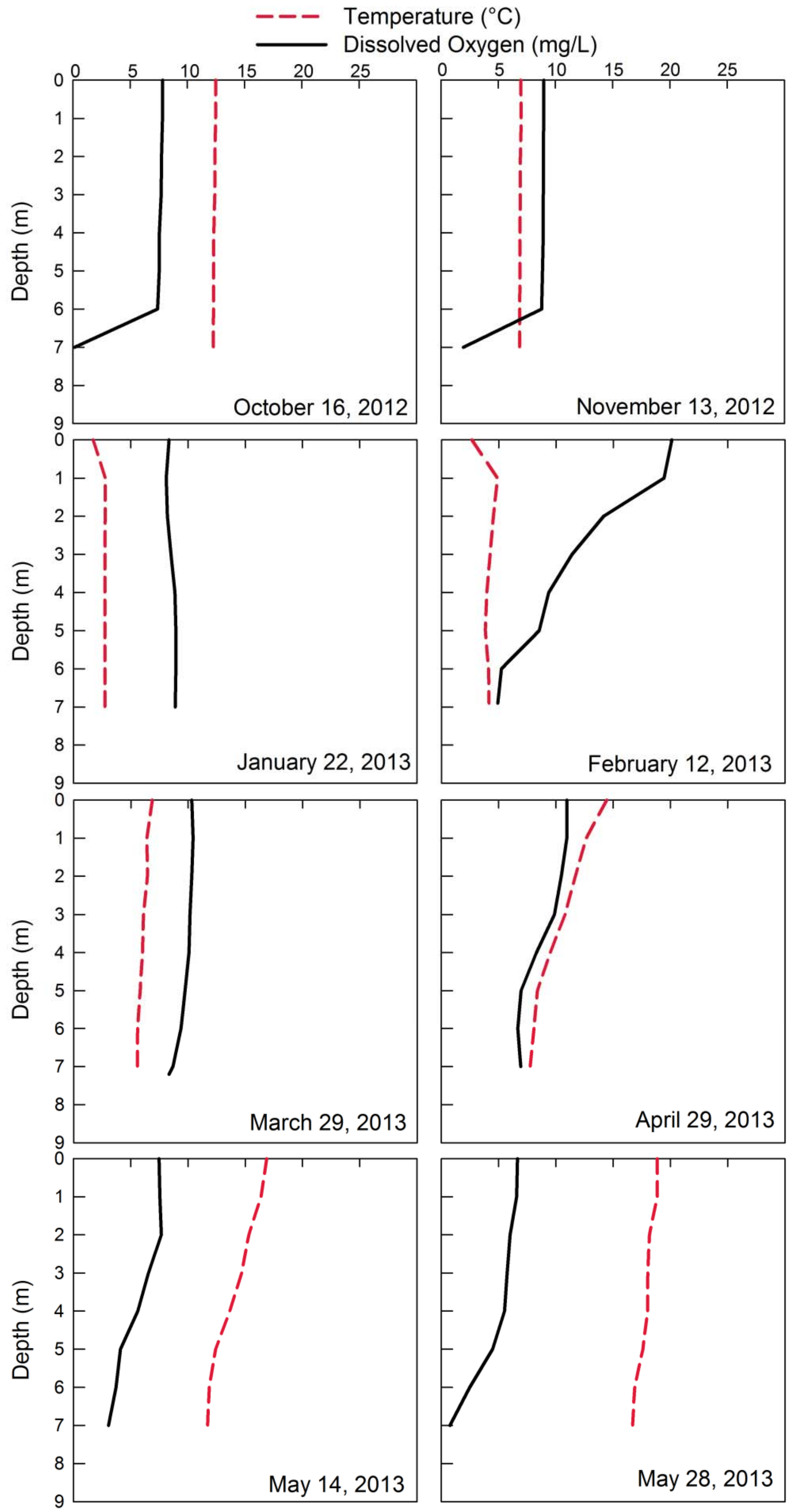
Sample Date	Depth (m)	Temperature (˚C)	Conductivity (µS/cm)	Dissolved Oxygen (mg/L)	pH	ORP (mV)	1% Transmittance (m)	Secchi Disk (m)
10/16/2012	0	12.46	1,150	7.83	7.99	214		
	1	12.45	1,150	7.82	8.02	213		
	2	12.39	1,148	7.74	8.03	213		
	3	12.38	1,150	7.71	8.04	213		
	4	12.29	1,149	7.55	8.01	214		
	5	12.28	1,148	7.54	8.07	213		
	6	12.26	1,149	7.39	8.03	214		
	7	12.26	1,149	0.14	7.72	76		
	--						2.25	0.78
11/13/2012	0	6.96	1,147	8.99	7.87	327		
	1	6.99	1,147	8.98	8.00	319		
	2	6.92	1,148	8.96	8.01	318		
	3	6.92	1,148	8.95	8.03	315		
	4	6.90	1,147	8.95	8.04	314		
	5	6.89	1,148	8.88	8.04	313		
	6	6.87	1,148	8.81	8.04	311		
	7	6.87	1,147	1.95	7.80	85		
	--						--	0.94
1/22/2013*	0	1.71	1,239	8.33	7.78	367		
	1	2.76	1,236	8.09	7.80	366		
	2	2.75	1,237	8.20	7.84	365		
	3	2.73	1,238	8.51	7.88	364		
	4	2.72	1,239	8.85	7.91	363		
	5	2.73	1,240	8.94	7.93	362		
	6	2.73	1,241	8.94	7.94	362		
	7	2.74	1,241	8.88	7.94	360		
	--							ICE
2/12/2012*	0	2.63	635	20.12	8.10	184		
	1	4.86	1,136	19.43	8.01	186		
	2	4.51	1,165	14.17	7.97	189		
	3	4.22	1,184	11.41	7.76	195		
	4	3.94	1,203	9.37	7.69	197		
	5	3.81	1,205	8.54	7.68	199		
	6	4.10	1,222	5.22	7.43	204		
	6.9	4.13	1,222	4.90	7.34	204		
	--						2.50	ICE
3/29/2013	0	6.86	1,130	10.31	7.93	315		
	1	6.38	1,126	10.42	7.93	312		
	2	6.44	1,119	10.31	7.93	312		
	3	6.08	1,125	10.15	7.92	312		
	4	6.00	1,127	10.07	7.83	309		
	5	5.79	1,125	9.72	7.81	308		
	6	5.56	1,126	9.37	7.74	307		
	7	5.55	1,125	8.66	7.72	305		
	7.2	5.54	1,124	8.32	7.11	83		
	--						3.51	0.97
4/29/2013	0	14.45	1,268	10.96	7.95	139		
	1	12.67	1,266	10.96	7.94	139		
	2	11.71	1,264	10.48	7.90	140		
	3	10.81	1,264	9.88	7.88	141		
	4	9.52	1,265	8.30	7.73	144		
	5	8.39	1,255	6.95	7.57	148		
	6	8.09	1,255	6.66	7.51	150		
	7	7.76	1,257	6.92	6.95	-44		
	--						3.50	0.87

Sample Date	Depth (m)	Temperature (˚C)	Conductivity (µS/cm)	Dissolved Oxygen (mg/L)	pH	ORP (mV)	1% Transmittance (m)	Secchi Disk (m)
5/14/2013	0	16.87	1,259	7.47	7.77	217		
	1	16.37	1,262	7.53	7.82	218		
	2	15.30	1,255	7.67	7.84	219		
	3	14.66	1,254	6.54	7.71	222		
	4	13.63	1,253	5.61	7.58	225		
	5	12.40	1,259	4.10	7.39	229		
	6	11.83	1,257	3.71	7.35	231		
	7	11.70	1,260	3.05	7.27	232		
	--						3.20	0.95
5/28/2013	0	18.86	1,270	6.63	7.96	238		
	1	18.86	1,272	6.56	7.98	236		
	2	18.18	1,269	6.00	7.92	236		
	3	18.04	1,271	5.74	7.89	236		
	4	18.02	1,271	5.51	7.88	236		
	5	17.60	1,271	4.46	7.76	238		
	6	16.90	1,272	2.46	7.54	243		
	7	16.70	1,274	0.74	7.40	146		
	--						2.90	0.83
6/12/2013	0	20.80	1,302	8.28	7.76	180		
	1	20.57	1,300	8.33	7.80	178		
	2	20.26	1,300	8.05	7.78	179		
	3	20.12	1,299	7.90	7.76	179		
	4	20.03	1,298	7.75	7.75	180		
	5	19.53	1,298	6.34	7.63	190		
	6	17.90	1,295	0.75	7.23	195		
	6.6	17.74	1,297	0.37	7.16	195		
	--						2.46	0.78
6/26/2013	0	23.19	1,328	8.23	8.30	279		
	1	22.14	1,326	7.82	8.29	274		
	2	21.50	1,327	6.28	8.16	275		
	3	21.25	1,328	5.35	8.06	275		
	4	21.01	1,329	3.80	7.93	277		
	5	20.90	1,326	3.97	7.94	277		
	6	20.68	1,328	3.55	7.88	277		
	6.5	20.64	1,328	2.43	7.83	266		
	--						2.37	0.73
7/10/2013	0	23.47	1,347	6.49	8.00	275		
	1	23.21	1,347	6.09	7.98	274		
	2	23.03	1,348	5.70	7.94	274		
	3	22.92	1,346	5.58	7.93	273		
	4	22.86	1,348	5.30	7.93	272		
	5	22.80	1,348	5.02	7.90	270		
	6	22.65	1,349	3.84	7.79	272		
	6.5	22.62	1,349	0.19	7.73	11		
	--						2.48	0.73
7/22/2013	0	24.56	1,418	8.38	8.25	99		
	1	24.56	1,418	8.38	8.22	101		
	2	24.42	1,417	8.35	8.22	104		
	3	24.29	1,418	8.34	8.22	106		
	4	24.11	1,417	8.06	8.23	107		
	5	23.50	1,416	6.25	8.10	112		
	6	22.90	1,419	2.01	7.72	124		
	6.5	22.82	1,420	0.83	7.62	27		
	--						2.20	0.64

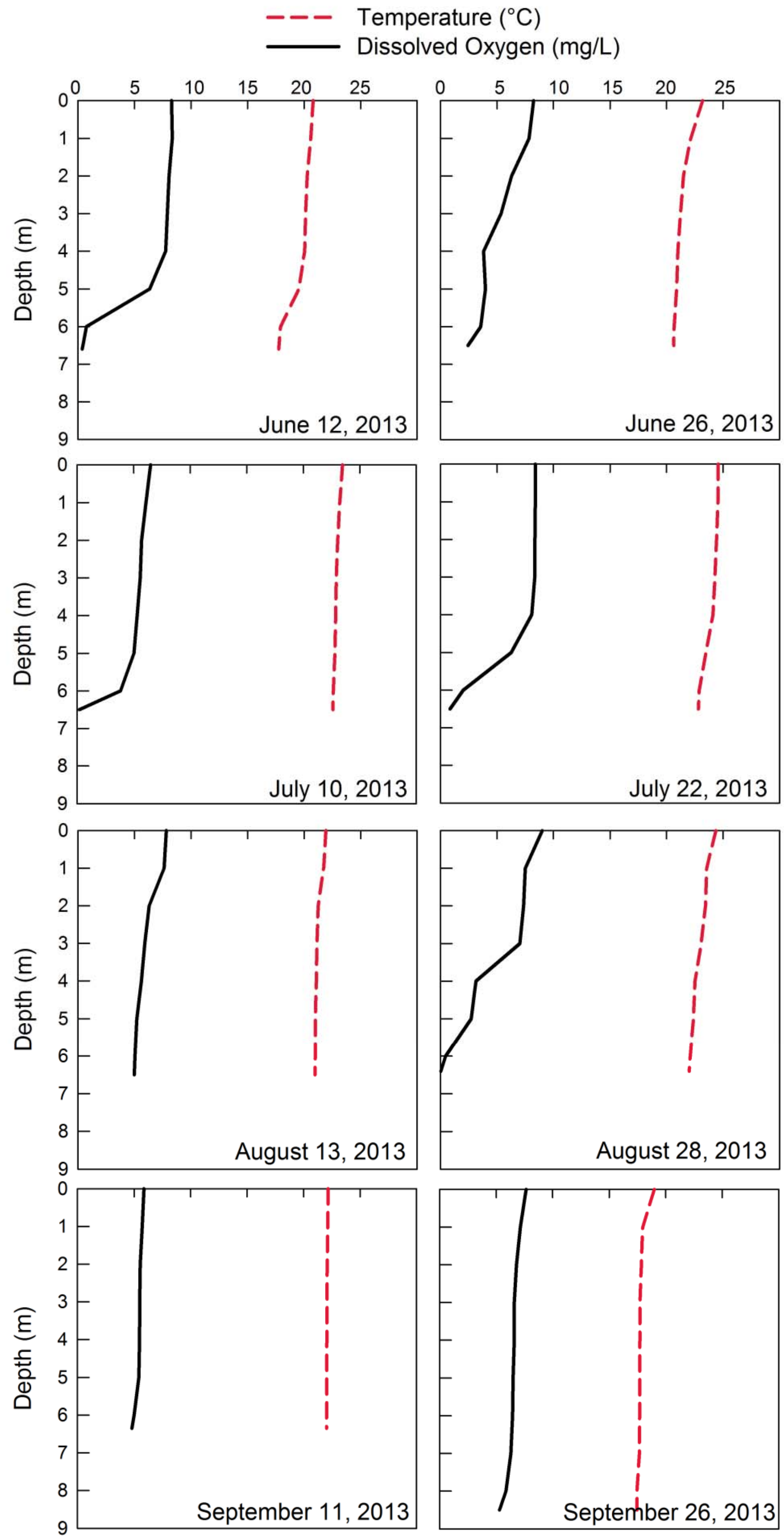
Sample Date	Depth (m)	Temperature (˚C)	Conductivity (µS/cm)	Dissolved Oxygen (mg/L)	pH	ORP (mV)	1% Transmittance (m)	Secchi Disk (m)
8/13/2013	0	21.93	1,275	7.81	8.53	190		
	1	21.71	1,274	7.62	8.52	190		
	2	21.23	1,275	6.29	8.42	193		
	3	21.13	1,274	5.91	8.39	194		
	4	21.07	1,274	5.61	8.40	195		
	5	20.99	1,274	5.20	8.33	195		
	6	20.98	1,275	5.04	8.32	195		
	6.5	20.95	1,275	4.97	8.29	127		
	--						2.00	0.63
8/28/2013	0	24.37	1,326	8.99	8.23	98		
	1	23.55	1,325	7.50	8.12	103		
	2	23.45	1,326	7.34	8.11	105		
	3	23.07	1,324	7.02	8.09	106		
	4	22.52	1,326	3.13	7.77	114		
	5	22.38	1,326	2.71	7.71	116		
	6	22.10	1,326	0.44	7.56	118		
	6.4	22.01	1,327	0.02	7.35	-150		
	--						2.64	0.75
9/11/2013	0	22.16	1,347	5.88	8.24	206		
	1	22.14	1,347	5.72	8.24	205		
	2	22.08	1,347	5.54	8.22	205		
	3	22.08	1,347	5.50	8.22	205		
	4	22.05	1,347	5.49	8.22	204		
	5	22.04	1,345	5.43	8.21	204		
	6	22.03	1,348	5.00	8.21	204		
	6.35	22.03	1,348	4.81	8.13	174		
	--						1.91	0.62
9/24/2013	0	19.00	988	7.65	8.09	314		
	1	17.97	985	7.13	8.02	313		
	2	17.85	985	6.79	7.98	312		
	3	17.73	986	6.60	7.95	311		
	4	17.72	987	6.60	7.95	309		
	5	17.71	987	6.48	7.95	309		
	6	17.70	988	6.45	7.95	308		
	7	17.67	993	6.29	7.93	308		
	8	17.46	993	5.86	7.91	307		
	8.5	17.46	993	5.29	7.87	62		
	--						1.41	0.39

* Denotes data collected when Reservoir was ice-covered (approximately 0.23 m thick).

CCR-1


Temperature (°C)
Dissolved Oxygen (mg/L)
0 5 10 15 20 25
Depth (m)
0 1 2 3 4 5 6 7 8 9
October 16, 2012
November 13, 2012
January 22, 2013
February 12, 2013
March 29, 2013
April 29, 2013
May 14, 2013
May 28, 2013

CCR-1


Temperature (°C)
Dissolved Oxygen (mg/L)
Depth (m)
0
5
10
15
20
25
June 12, 2013
June 26, 2013
July 10, 2013
July 22, 2013
August 13, 2013
August 28, 2013
September 11, 2013
September 26, 2013

CCR-2 Small Tables

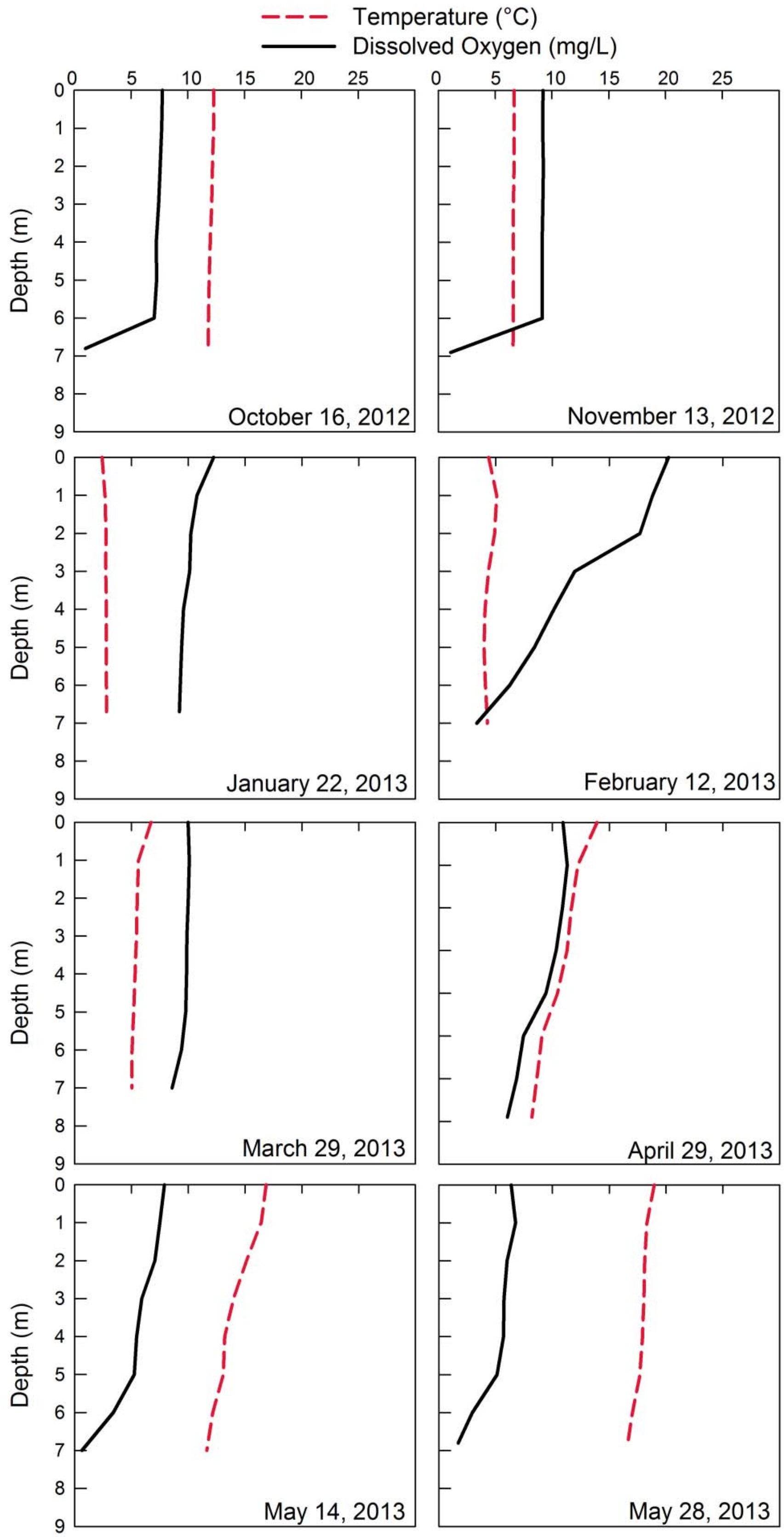
Sample Date	Depth (m)	Temperature (˚C)	Conductivity (µS/cm)	Dissolved Oxygen (mg/L)	pH	ORP (mV)	1% Transmittance (m)	Secchi Disk (m)
10/16/2012	0	12.28	1,148	7.76	8.00	118		
	1	12.26	1,148	7.70	8.04	119		
	2	12.16	1,148	7.57	8.04	120		
	3	12.10	1,148	7.44	8.03	121		
	4	11.97	1,147	7.23	8.02	122		
	5	11.87	1,148	7.25	8.03	123		
	6	11.81	1,148	7.04	8.00	124		
	6.8	11.79	1,147	0.98	7.85	-40		
	--						1.05	0.79
11/13/2012	0	6.67	1,147	9.20	8.03	213		
	1	6.66	1,148	9.18	8.07	214		
	2	6.64	1,149	9.24	8.07	214		
	3	6.60	1,147	9.19	8.09	215		
	4	6.58	1,148	9.13	8.08	215		
	5	6.59	1,147	9.13	8.09	216		
	6	6.59	1,149	9.14	8.08	216		
	6.9	6.55	1,148	1.08	8.07	206		
	--						--	0.87
1/22/2013*	0	2.41	1,226	12.23	8.09	338		
	1	2.66	1,240	10.77	8.03	339		
	2	2.75	1,239	10.22	8.01	340		
	3	2.72	1,241	10.12	8.01	340		
	4	2.78	1,241	9.58	7.96	341		
	5	2.79	1,243	9.41	7.95	341		
	6	2.79	1,242	9.30	7.95	341		
	6.7	2.80	1,242	9.22	7.95	341		
	--						3.00	ICE
2/12/2013*	0	4.37	1,074	20.23	8.11	189		
	1	5.08	1,138	18.82	8.05	190		
	2	4.88	1,153	17.71	8.04	191		
	3	4.35	1,186	11.96	7.82	194		
	4	4.05	1,201	10.13	7.74	197		
	5	3.95	1,205	8.39	7.73	196		
	6	4.09	1,213	6.22	7.51	201		
	7	4.26	1,220	3.33	7.32	205		
	--						2.28	ICE
3/29/2013	0	6.72	1,125	9.99	7.83	197		
	1	5.60	1,127	10.09	7.86	198		
	2	5.50	1,125	10.00	7.86	199		
	3	5.44	1,124	9.88	7.87	200		
	4	5.31	1,125	9.85	7.86	201		
	5	5.18	1,122	9.77	7.86	202		
	6	5.04	1,123	9.40	7.84	203		
	7	5.02	1,123	8.58	7.75	200		
	--						3.49	0.98
4/29/2013	0	13.92	1,266	10.92	8.09	102		
	1	12.25	1,263	11.30	8.06	103		
	2	11.68	1,265	10.88	7.98	106		
	3	11.29	1,263	10.33	7.95	107		
	4	10.45	1,262	9.43	7.87	110		
	5	9.05	1,267	7.43	7.66	115		
	6	8.61	1,262	6.84	7.60	119		
	6.9	8.17	1,262	6.03	7.50	121		
	--						3.35	0.89

Sample Date	Depth (m)	Temperature (˚C)	Conductivity (µS/cm)	Dissolved Oxygen (mg/L)	pH	ORP (mV)	1% Transmittance (m)	Secchi Disk (m)
5/14/2013	0	16.85	1,256	7.90	7.82	273		
	1	16.40	1,252	7.50	7.87	270		
	2	15.12	1,252	7.06	7.82	269		
	3	13.98	1,250	5.90	7.66	271		
	4	13.19	1,252	5.45	7.59	272		
	5	13.07	1,253	5.25	7.56	272		
	6	12.15	1,257	3.40	7.33	275		
	7	11.62	1,260	0.64	7.08	76		
	--						--	0.85
5/28/2013	0	18.96	1,270	6.35	7.97	168		
	1	18.32	1,270	6.74	8.02	168		
	2	18.12	1,270	6.00	7.93	170		
	3	18.06	1,270	5.73	7.89	171		
	4	17.93	1,270	5.68	7.89	172		
	5	17.70	1,271	5.11	7.83	174		
	6	17.04	1,271	2.94	7.62	178		
	6.8	16.65	1,273	1.69	7.52	182		
	--						2.73	0.81
6/12/2013	0	20.74	1,299	8.76	7.90	241		
	1	20.85	1,299	8.81	7.91	239		
	2	20.69	1,299	8.71	7.87	238		
	3	20.29	1,299	8.06	7.82	239		
	4	20.16	1,298	7.49	7.78	240		
	5	18.43	1,297	2.59	7.32	249		
	6	17.98	1,297	0.78	7.18	251		
	6.5	17.95	1,297	0.01	7.12	222		
	--						2.72	0.77
6/26/2013	0	23.02	1,327	8.01	8.41	279		
	1	22.09	1,326	7.69	8.36	274		
	2	21.82	1,324	7.37	8.33	273		
	3	21.55	1,324	7.10	8.30	273		
	4	21.41	1,324	6.76	8.27	272		
	5	21.35	1,325	6.85	8.28	272		
	6	21.07	1,326	5.54	8.16	272		
	6.4	21.01	1,327	4.86	8.12	257		
	--						2.21	0.75
7/10/2013	0	24.41	1,347	8.13	8.16	167		
	1	23.55	1,347	6.89	8.05	171		
	2	23.17	1,347	6.07	7.99	174		
	3	23.08	1,347	5.85	7.95	175		
	4	22.97	1,348	5.05	7.88	177		
	5	22.84	1,349	4.15	7.79	179		
	6	22.67	1,350	2.67	7.67	182		
	6.3	22.66	1,351	2.43	7.63	81		
	--						2.50	0.70
7/22/2013	0	24.91	1,419	8.37	8.25	107		
	1	24.59	1,417	7.74	8.22	109		
	2	23.30	1,418	5.40	8.02	114		
	3	23.00	1,419	4.36	7.93	117		
	4	22.99	1,419	4.16	7.92	118		
	5	22.97	1,420	3.90	7.90	118		
	6	22.95	1,422	3.78	7.89	118		
	6.4	22.93	1,420	3.58	7.88	71		
	--						2.04	0.58

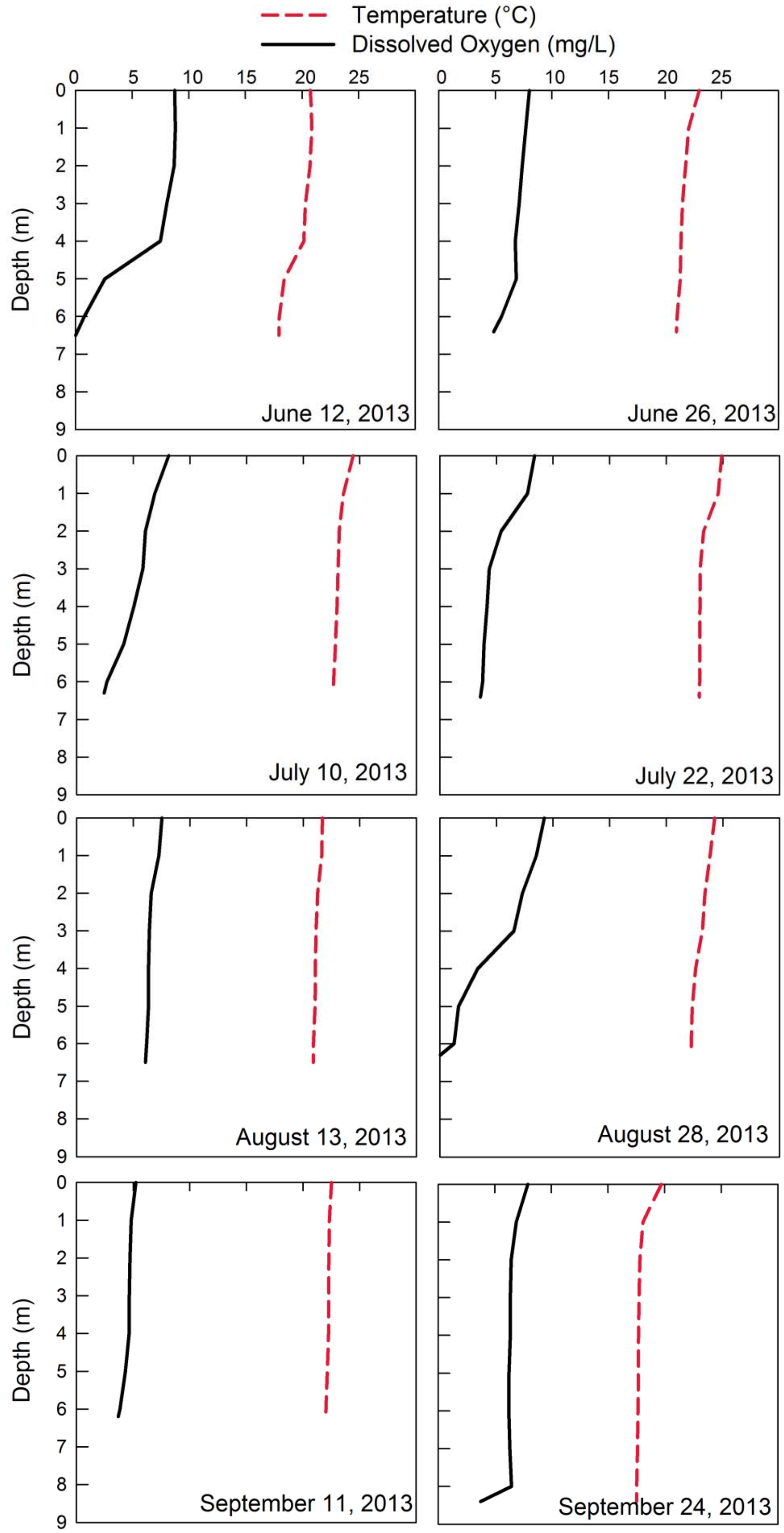
Sample Date	Depth (m)	Temperature (˚C)	Conductivity (µS/cm)	Dissolved Oxygen (mg/L)	pH	ORP (mV)	1% Transmittance (m)	Secchi Disk (m)
8/13/2013	0	21.70	1,282	7.53	8.53	166		
	1	21.62	1,277	7.25	8.52	167		
	2	21.26	1,277	6.58	8.46	169		
	3	21.12	1,277	6.41	8.45	169		
	4	21.07	1,277	6.34	8.43	170		
	5	21.04	1,277	6.34	8.44	170		
	6	20.89	1,276	6.18	8.44	170		
	6.5	20.88	1,277	6.07	8.42	155		
	--						2.00	0.72
8/28/2013	0	24.28	1,324	9.23	8.25	138		
	1	23.87	1,324	8.51	8.22	140		
	2	23.42	1,324	7.29	8.12	142		
	3	23.19	1,324	6.53	8.06	144		
	4	22.60	1,325	3.34	7.78	150		
	5	22.31	1,326	1.65	7.63	154		
	6	22.21	1,326	1.25	7.58	154		
	6.3	22.20	1,325	0.04	7.12	-25		
	--						2.70	0.74
9/11/2013	0	22.51	1,350	5.25	8.19	196		
	1	22.31	1,349	4.82	8.16	196		
	2	22.26	1,349	4.72	8.14	197		
	3	22.25	1,349	4.66	8.14	197		
	4	22.24	1,349	4.65	8.13	197		
	5	22.13	1,347	4.32	8.12	197		
	6	22.02	1,344	3.83	8.07	198		
	6.2	22.02	1,345	3.69	8.03	178		
	--						2.24	0.69
9/24/2013	0	19.71	989	7.91	8.07	174		
	1	18.09	993	6.90	7.98	178		
	2	17.82	993	6.44	7.94	179		
	3	17.75	994	6.36	7.93	180		
	4	17.71	993	6.36	7.93	180		
	5	17.69	993	6.25	7.92	180		
	6	17.66	991	6.23	7.91	181		
	7	17.61	989	6.32	7.91	181		
	8	17.54	991	6.47	7.95	180		
	8.4	17.53	991	3.74	7.92	170		
	--						1.37	0.43

* Denotes data collected when Reservoir was ice-covered (approximately 0.26 m thick).

CCR-2


Temperature (°C)
Dissolved Oxygen (mg/L)
0 5 10 15 20 25
Depth (m)
October 16, 2012
November 13, 2012
January 22, 2013
February 12, 2013
March 29, 2013
April 29, 2013
May 14, 2013
May 28, 2013

CCR-2


Temperature (°C)
Dissolved Oxygen (mg/L)
0 5 10 15 20 25
Depth (m)
0 1 2 3 4 5 6 7 8 9
June 12, 2013
June 26, 2013
July 10, 2013
July 22, 2013
August 13, 2013
August 28, 2013
September 11, 2013
September 24, 2013

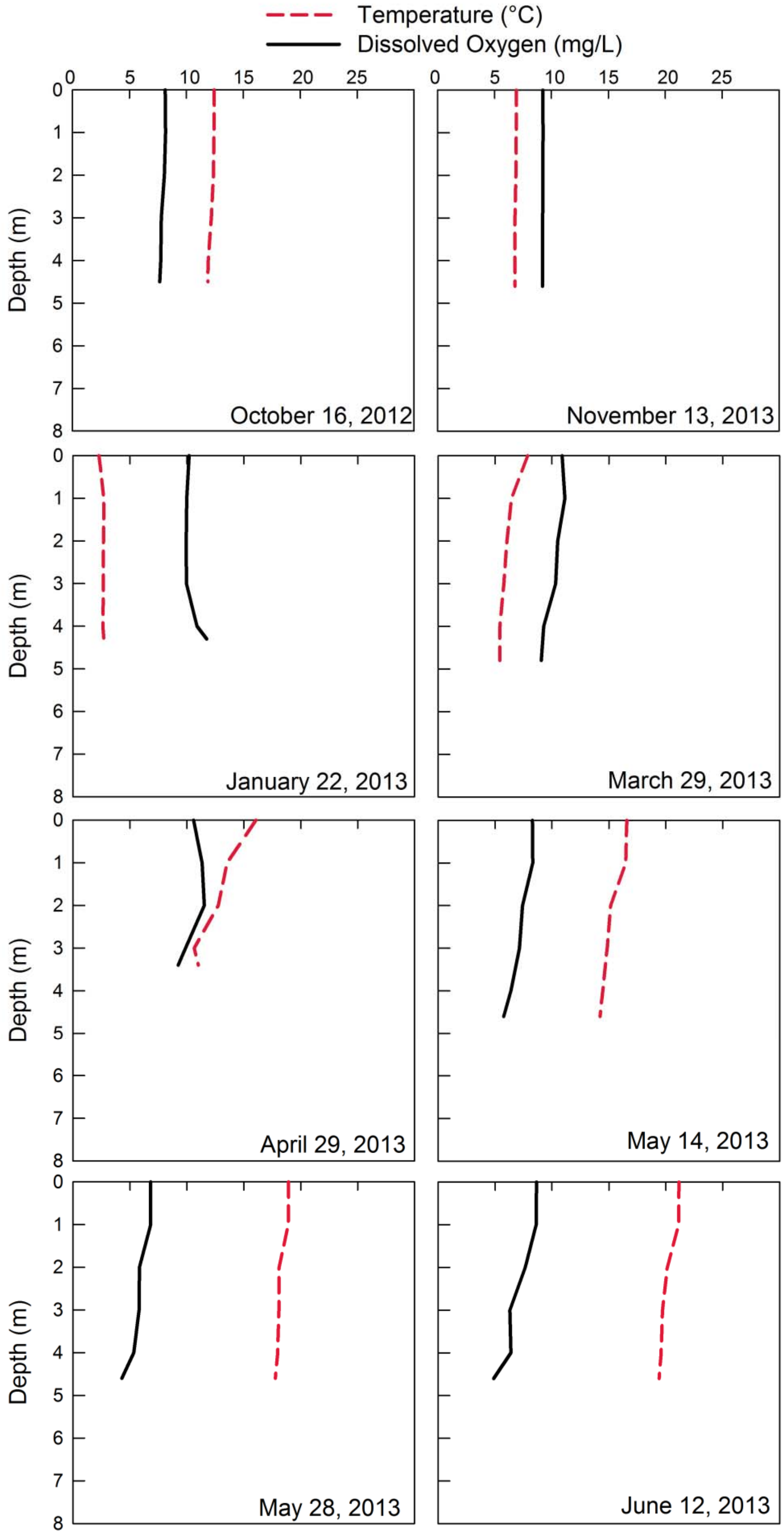
CCR-3 Small Tables

Sample Date	Depth (m)	Temperature (˚C)	Conductivity (µS/cm)	Dissolved Oxygen (mg/L)	pH	ORP (mV)	1% Transmittance (m)	Secchi Disk (m)
10/16/2012	0	12.44	1,149	8.14	8.11	115		
	1	12.42	1,150	8.17	8.14	116		
	2	12.37	1,150	8.06	8.15	117		
	3	12.17	1,149	7.80	8.10	118		
	4	11.90	1,151	7.75	8.12	119		
	4.5	11.87	1,152	7.66	8.11	119		
	--						2.23	0.78
11/13/2012	0	6.91	1,148	9.24	8.00	191		
	1	6.89	1,148	9.25	8.04	193		
	2	6.86	1,147	9.24	8.05	195		
	3	6.78	1,147	9.21	8.06	196		
	4	6.77	1,147	9.20	8.08	197		
	4.6	6.79	1,147	9.20	8.08	198		
	--						--	0.93
1/22/2013*	0	2.27	1,227	10.20	7.94	287		
	1	2.69	1,238	9.98	7.98	287		
	2	2.67	1,240	9.94	8.01	287		
	3	2.67	1,239	9.95	8.01	287		
	4	2.61	1,250	10.88	8.07	287		
	4.3	2.70	1,269	11.74	8.09	287		
	--						2.88	ICE
3/29/2013	0	7.86	1,164	10.90	7.91	202		
	1	6.43	1,145	11.13	7.92	203		
	2	6.03	1,145	10.51	7.88	205		
	3	5.75	1,145	10.33	7.85	206		
	4	5.41	1,152	9.26	7.79	208		
	4.8	5.40	1,151	9.06	7.78	209		
	--						3.45	0.97
4/29/2013	0	16.06	1,278	10.59	8.01	173		
	1	13.52	1,270	11.34	8.05	170		
	2	12.75	1,264	11.53	8.05	170		
	3	10.63	1,275	9.88	7.90	171		
	3.4	11.00	1,274	9.24	7.88	172		
	--						3.40	0.84
5/14/2013	0	16.58	1,251	8.27	7.87	181		
	1	16.49	1,248	8.31	7.94	181		
	2	15.16	1,250	7.40	7.87	184		
	3	14.85	1,252	7.13	7.84	185		
	4	14.47	1,260	6.38	7.74	187		
	4.6	14.23	1,257	5.75	7.66	189		
	--						2.70	0.74
5/28/2013	0	18.93	1,270	6.82	8.00	178		
	1	18.89	1,271	6.82	8.01	178		
	2	18.09	1,270	5.83	7.92	180		
	3	18.07	1,270	5.80	7.92	181		
	4	17.96	1,271	5.34	7.85	182		
	4.6	17.75	1,273	4.28	7.73	185		
	--						2.70	0.82
6/12/2013	0	21.15	1,301	8.63	7.93	275		
	1	21.14	1,300	8.60	7.91	275		
	2	20.14	1,299	7.64	7.79	276		

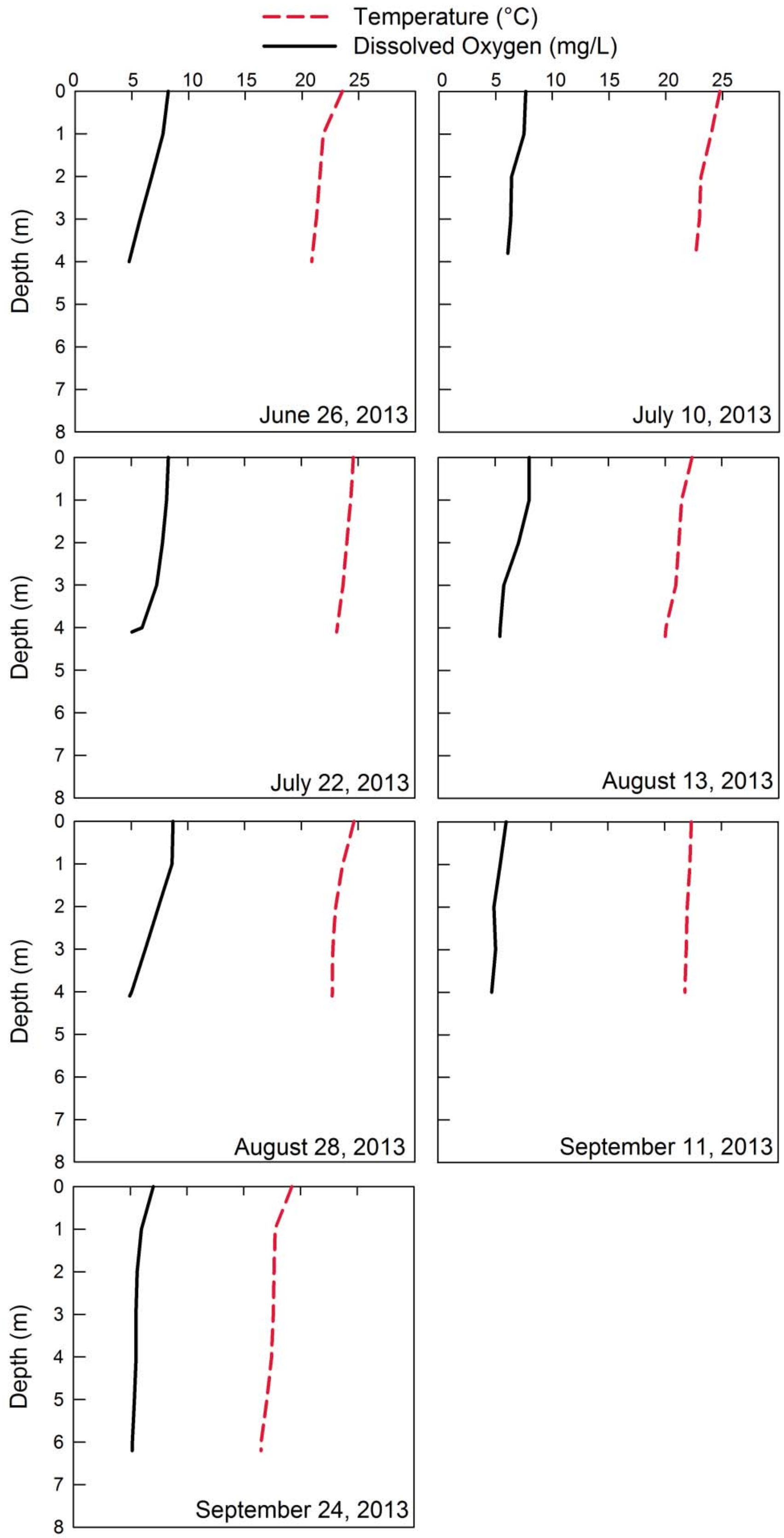
Sample Date	Depth (m)	Temperature (˚C)	Conductivity (µS/cm)	Dissolved Oxygen (mg/L)	pH	ORP (mV)	1% Transmittance (m)	Secchi Disk (m)
	3	19.72	1,300	6.30	7.67	278		
	4	19.59	1,299	6.39	7.63	279		
	4.6	19.42	1,299	4.87	7.51	280		
	--						2.25	0.75
6/26/2013	0	23.56	1,331	8.22	8.48	270		
	1	21.87	1,325	7.75	8.41	269		
	2	21.56	1,328	6.76	8.30	269		
	3	21.25	1,328	5.72	8.19	270		
	4	20.84	1,328	4.77	8.09	270		
	--						2.21	0.75
7/10/2013	0	24.77	1,349	7.65	8.15	188		
	1	24.00	1,345	7.50	8.06	192		
	2	23.11	1,350	6.40	7.95	195		
	3	22.97	1,350	6.32	7.94	195		
	3.8	22.66	1,351	6.07	7.94	195		
	--						2.15	0.73
7/22/2013	0	24.57	1,417	8.28	8.29	95		
	1	24.34	1,417	8.12	8.29	96		
	2	23.99	1,417	7.76	8.25	98		
	3	23.66	1,417	7.26	8.20	100		
	4	23.15	1,418	5.97	8.11	103		
	4.1	23.10	1,419	5.06	8.05	97		
	--						2.20	0.60
8/13/2013	0	22.37	1,275	8.01	8.55	169		
	1	21.47	1,275	8.01	8.56	169		
	2	21.21	1,274	7.07	8.48	171		
	3	20.95	1,272	5.77	8.34	174		
	4	20.07	1,233	5.45	8.34	175		
	4.2	20.01	1,230	5.42	8.34	174		
	--						2.00	0.81
8/28/2013	0	24.64	1,325	8.69	8.24	114		
	1	23.65	1,323	8.60	8.23	115		
	2	23.02	1,323	7.42	8.15	117		
	3	22.76	1,325	6.25	8.06	120		
	4	22.72	1,325	5.05	7.94	123		
	4.1	22.70	1,325	4.87	7.87	109		
	--						2.50	0.73
9/11/2013	0	22.35	1,343	6.02	8.26	194		
	1	22.23	1,343	5.50	8.22	194		
	2	21.99	1,341	4.95	8.16	195		
	3	21.91	1,338	5.10	8.17	194		
	4	21.80	1,340	4.75	8.14	195		
	--						2.21	0.68
9/24/2013	0	19.24	990	7.03	8.01	195		
	1	17.75	983	5.98	7.88	198		
	2	17.66	986	5.60	7.83	199		
	3	17.59	987	5.50	7.81	199		
	4	17.44	983	5.51	7.80	199		
	5	17.03	965	5.36	7.74	200		
	6	16.52	954	5.19	7.68	201		
	6.2	16.52	953	5.17	7.67	196		
	--						1.56	0.49

* Denotes data collected when Reservoir was ice-covered (approximately 0.26 m thick).

CCR-3


Temperature (°C)
Dissolved Oxygen (mg/L)
0 5 10 15 20 25
Depth (m)
0 1 2 3 4 5 6 7 8
October 16, 2012
November 13, 2013
January 22, 2013
March 29, 2013
April 29, 2013
May 14, 2013
May 28, 2013
June 12, 2013

CCR-3


Temperature (°C)
Dissolved Oxygen (mg/L)
0 5 10 15 20 25
Depth (m)
0 1 2 3 4 5 6 7 8
June 26, 2013
July 10, 2013
July 22, 2013
August 13, 2013
August 28, 2013
September 11, 2013
September 24, 2013

Cherry Creek Transect ORP Data

Sample Date	Depth	Transect ORP (mV)											
		D1	D2	D3	D3.5	D4	D5	D6	D7	D8	D9	D10	D11
6/26/2013	0	240	225	112	111	124	129	100	102	84	79	270	101
	1	243	227	119	114	129	131	106	106	89	82	269	103
	2	244	229	122	122	133	135	111	110	94	87	269	108
	3	244	230	124	124	137	138	114	114	97	96	270	113
	4	246	232	126	129	144	141	117	117	102	102	270	--
	5	248	233	132	134	148	146	124	126	107	103	--	--
	6	248	236	134	138	149	110	124	128	17	103	--	--
	Bottom	225	44	59	122	127	15	54	11	13	--	--	--

Sample Date	Depth	Transect ORP (mV)											
		D1	D2	D3	D3.5	D4	D5	D6	D7	D8	D9	D10	D11
7/22/2013	0	231	172	178	167	103	105	52	78	82	82	95	95
	1	232	175	180	168	108	108	57	82	84	85	96	96
	2	234	179	182	171	112	113	62	85	87	89	98	98
	3	234	181	184	172	118	115	65	86	89	91	100	99
	4	234	184	186	173	124	121	56	88	90	91	103	99
	5	236	187	187	176	129	124	70	88	91	92	97	--
	6	237	191	189	178	131	126	72	88	44	65	--	--
	Bottom	108	171	119	62	84	-10	28	52	--	--	--	--

Sample Date	Depth	Transect ORP (mV)											
		D1	D2	D3	D3.5	D4	D5	D6	D7	D8	D9	D10	D11
8/28/2013	0	265	233	199	163	162	118	94	82	80	94	114	23
	1	263	234	201	167	165	121	97	86	84	97	115	124
	2	261	233	203	171	167	125	103	90	89	101	117	128
	3	261	234	204	173	170	129	107	93	92	105	120	130
	4	262	235	205	175	173	135	117	103	100	110	123	--
	5	265	242	212	185	182	145	123	109	104	114	109	--
	6	266	242	212	187	185	81	14	3	87	99	--	--
	Bottom	232	180	135	155	75	-11	5	--	--	--	--	--

Cherry Creek Transect DO Data

Sample Date	Depth	Dissolved Oxygen (mg/L)											
		D1	D2	D3	D3.5	D4	D5	D6	D7	D8	D9	D10	D11
6/26/2013	0	8.09	7.89	8.26	8.51	8.84	8.33	8.41	8.46	8.86	9.04	8.22	9.26
	1	7.03	6.86	6.67	8.62	8.81	8.45	8.01	8.57	8.78	9.10	7.75	9.33
	2	6.23	6.35	6.30	7.00	7.21	7.54	6.89	8.02	8.01	9.15	6.76	8.20
	3	6.04	5.87	6.08	6.46	6.30	6.35	6.12	6.47	7.66	6.53	5.72	6.45
	4	5.02	5.30	5.68	5.12	4.95	5.57	5.40	5.62	5.94	4.16	4.77	--
	5	4.55	4.69	4.03	3.27	2.06	3.81	3.08	2.29	3.82	4.15	--	--
	6	3.82	2.95	2.82	2.27	1.58	1.61	1.63	2.14	2.42	2.23	--	--
	Bottom	3.17	0.12	2.37	1.82	1.45	1.46	0.01	0.01	2.29	--	--	--

Sample Date	Depth	Dissolved Oxygen (mg/L)											
		D1	D2	D3	D3.5	D4	D5	D6	D7	D8	D9	D10	D11
7/22/2013	0	8.09	8.25	8.34	8.54	8.45	8.30	7.79	8.32	7.71	8.03	8.28	8.57
	1	7.60	7.97	8.00	8.08	7.42	7.76	7.46	7.81	7.53	7.99	8.12	8.56
	2	6.78	7.03	7.24	6.79	7.11	6.71	6.93	6.73	6.55	6.79	7.76	8.28
	3	6.56	6.57	6.41	6.15	6.26	6.27	5.98	6.23	6.15	6.20	7.26	6.89
	4	6.15	6.00	5.67	6.06	4.58	4.29	6.23	6.19	6.01	6.14	5.97	6.82
	5	4.74	5.01	4.92	4.47	3.19	3.33	5.18	6.06	6.10	6.02	5.06	--
	6	4.03	3.56	3.71	3.50	2.65	3.19	4.61	4.63	4.99	3.91	--	--
	Bottom	3.58	2.51	3.47	3.06	2.53	2.23	4.18	4.39	--	--	--	--

Sample Date	Depth	Dissolved Oxygen (mg/L)											
		D1	D2	D3	D3.5	D4	D5	D6	D7	D8	D9	D10	D11
8/28/2013	0	8.06	8.29	7.41	7.89	8.15	8.24	8.57	8.54	8.66	8.67	8.69	8.99
	1	8.02	8.22	7.45	7.71	7.87	8.37	8.03	8.50	8.58	8.32	8.60	8.81
	2	7.89	8.32	7.32	7.07	7.49	7.61	7.27	7.90	7.40	6.82	7.42	7.35
	3	7.22	7.43	7.01	6.87	7.04	6.97	6.94	7.60	6.74	5.72	6.25	6.54
	4	5.34	7.08	6.78	6.85	6.26	5.49	3.16	3.30	3.01	3.63	5.05	--
	5	2.36	1.75	3.13	1.93	1.77	1.24	1.32	1.34	1.67	2.38	4.87	--
	6	0.96	0.86	1.22	1.12	0.43	0.03	0.04	0.40	0.63	1.09	--	--
	Bottom	0.74	0.81	0.92	0.13	0.13	0.02	0.02	--	--	--	--	--

Appendix C

2013 WY Stream Water Quality and Precipitation Data

GEI Water Chemistry Data									
Analytical Detection Limits	**2**	**2**	**2**	**2**	**2**	**2**	**3**	**4**	**4**
Site/Sample Date	**Total Phosphorus (µg/L)**	**Total Dissolved Phosphorus (µg/L)**	**Ortho-phosphate (µg/L)**	**Total Nitrogen (µg/L)**	**Total Dissolved Nitrogen (µg/L)**	**Nitrate+ Nitrite (µg/L)**	**Ammonia (µg/L)**	**Total Suspended Solids (mg/L)**	**Total Volatile Suspended Solids (mg/L)**
CC-10									
10/16/2012	205	164	166	560	516	331	22	5.4	--
11/13/2012	182	134	137	779	731	464	26	13.6	--
1/23/2013	167	121	124	1,586	1,559	1,101	64	16.6	--
12/11/2012	177	118	127	1,267	1,225	938	51	18.4	--
2/13/2013	173	94	116	1,474	1,381	1,217	40	36.2	8.8
3/27/2013	120	82	86	1,022	1,008	699	59	16.6	--
4/22/2013	130	105	103	1,131	1,100	751	27	7.2	--
5/21/2013	180	132	145	1,430	1,056	611	68	24.4	--
6/11/2013	228	192	182	816	752	453	51	8.6	--
7/9/2013	186	155	169	885	817	325	36	6.2	--
8/12/2013	289	243	238	1,095	1,073	313	64	10.2	--
9/9/2013	303	184	196	989	767	216	40	31.2	5.4
CC-10 Storm									
5/2/2013	215	122	124	1,095	921	514	138	63.2	7.2
5/9/2013	414	149	153	1,700	1,103	528	158	63.2	7.2
8/5/2013	500	205	197	1,891	1,744	781	104	178	22
8/9/2013	335	229	236	746	725	384	31	24.5	4
9/11/2013	551	296	274	1,330	1,113	406	82	137	22
CC-Out @ I225									
10/16/2012	90	27	18	841	481	6	19	21.2	7.4
11/13/2012	94	22	12	844	516	4	15	15.4	5.2
1/23/2013	66	30	25	966	669	76	76	12.0	5.6
12/11/2012	107	15	9	786	497	6	14	12.2	4.8
2/13/2013	80	51	42	1,068	759	46	153	18.5	8.5
3/27/2013	146	19	7	886	527	9	36	17.8	5.4
4/22/2013	112	29	9	1,086	535	13	25	45.9	13.6
5/21/2013	168	28	25	1,014	680	6	91	36.0	8.8
6/11/2013	123	71	62	860	472	2	50	39.2	8.6
7/9/2013	172	73	75	874	760	13	90	27.4	6.4
8/13/2013	122	27	26	1,246	701	4	55	45.6	11
9/9/2013		44	45	1,124	867	5	63	26.4	7.2

GEI Water Chemistry Data									
Analytical Detection Limits	**2**	**2**	**2**	**2**	**2**	**2**	**3**	**4**	**4**
Site/Sample Date	**Total Phosphorus (µg/L)**	**Total Dissolved Phosphorus (µg/L)**	**Ortho-phosphate (µg/L)**	**Total Nitrogen (µg/L)**	**Total Dissolved Nitrogen (µg/L)**	**Nitrate+ Nitrite (µg/L)**	**Ammonia (µg/L)**	**Total Suspended Solids (mg/L)**	**Total Volatile Suspended Solids (mg/L)**
CT-1									
10/16/2012	54	19	9	1,185	968	574	37	45.8	7.4
11/13/2012	73	15	8	2,130	1,937	1,404	56	38.4	5.4
1/23/2013	107	19	17	3,298	3,104	2,319	100	62.0	10.5
12/11/2012	72	16	13	2,739	2,576	1,964	99	32.0	5.2
2/13/2013	150	20	15	2,828	2,395	2,069	55	112.5	12.5
3/27/2013	53	15	11	1,651	1,510	1,131	46	14.4	--
4/22/2013	75	34	8	2,033	1,776	1,176	77	55.5	10
5/21/2013	57	43	9	1,275	1,107	375	101	25.2	5.4
6/11/2013	82	33	22	819	858	78	140	32.4	7.8
7/9/2013	60	36	19	1,136	1,001	303	68	29.8	5
8/12/2013	93	24	23	948	779	209	57	27.4	5
9/9/2013	73	19	6	1,718	1,558	643	143	48.4	6.6
CT-1 Storm									
5/2/2013	56	23	7	2,700	2,400	1,799	172	46.5	6.3
5/9/2013	188	14	12	2,339	2,391	1,280	236	46.5	6.3
6/24/2013	74	20	20	1,619	1,371	674	123	33	7.4
7/16/2013	61	20	4	1,126	909	352	27	17.6	
8/5/2013	209	31	21	1,798	1,738	727	115	121	20
8/9/2013	172	22	18	2,112	1,586	958	35	59.7	11
9/11/2013	221	49	42	1,923	1,871	820	233	237	29.5
CT-2									
10/16/2012	39	12	7	1,858	1,723	1,271	58	18.4	4.8
11/13/2012	53	13	10	3,817	3,550	2,798	76	23.8	--
1/23/2013	79	13	8	3,341	3,061	2,468	112	29.0	6.0
12/11/2012	44	17	6	2,443	2,290	1,876	37	18.4	--
2/13/2013	53	12	6	1,996	1,865	1,276	62	22.7	6.2
3/27/2013	60	15	2	2,160	1,945	1,264	82	19.8	--
4/22/2013	75	25	3	939	808	161	102	30	6.7

GEI Water Chemistry Data									
Analytical Detection Limits	**2**	**2**	**2**	**2**	**2**	**2**	**3**	**4**	**4**
Site/Sample Date	**Total Phosphorus (µg/L)**	**Total Dissolved Phosphorus (µg/L)**	**Ortho-phosphate (µg/L)**	**Total Nitrogen (µg/L)**	**Total Dissolved Nitrogen (µg/L)**	**Nitrate+ Nitrite (µg/L)**	**Ammonia (µg/L)**	**Total Suspended Solids (mg/L)**	**Total Volatile Suspended Solids (mg/L)**
5/21/2013	30	18	8	906	809	10	170	13.2	--
6/11/2013	50	8	8	804	672	11	60	13.2	--
7/9/2013	26	24	21	919	917	157	43	5.3	--
8/12/2013	81	7	3	1,628	1,392	401	109	16.6	4.6
9/9/2013	67							25.8	7.8
CT-2 Storm									
5/2/2013	53	14	2	2,622	2,423	1,680	217	24.7	4
5/9/2013	109	20	20	1,697	1,464	823	204	24.7	4
6/24/2013	41	17	17	962	857	202	89	14.2	4
7/16/2013	33	17	--	756	707	101	41	5.6	--
8/5/2013	86	20	12	1,760	1,450	693	76	25	7.5
8/9/2013	60	16	14	1,678	1,637	858	76	16.5	--
9/11/2013	103	33	27	1,847	1,655	722	174	60	19
CT-P1									
10/16/2012	39	12	9	826	742	407	69	11.6	--
11/13/2012	46	7	5	999	877	465	74	20.4	4.4
1/23/2013	22	9	10	1,206	1,050	689	58	--	--
12/11/2012	26	21	8	1,215	1,098	674	127	8.6	--
2/13/2013	22	13	6	1,038	1,012	726	73	7.2	--
3/27/2013	49	10	5	833	728	327	54	9.4	--
4/22/2013	35	10	7	843	706	248	55	9.7	4.3
5/21/2013	43	10	5	1,321	1,038	311	140	10.6	--
6/11/2013	83	23	17	1,309	1,166	539	72	46.8	8.8
7/9/2013	91	25	14	1,168	758	188	57	31.8	6.6
8/12/2013	94	39	38	994	938	270	67	20.6	5.4
9/9/2013	39	21	16	1,109	978	311	93	26.2	5.8
CT-P1 Storm									
5/2/2013	119	18	16	1,080	1,019	443	259	105	16.5
5/9/2013	215	8	5	2,056	1,257	522	150	105	16.5
6/24/2013	370	12	8	3,343	2,483	1222	504	211	37

GEI Water Chemistry Data									
Analytical Detection Limits	2	2	2	2	2	2	3	4	4
Site/Sample Date	Total Phosphorus (µg/L)	Total Dissolved Phosphorus (µg/L)	Ortho-phosphate (µg/L)	Total Nitrogen (µg/L)	Total Dissolved Nitrogen (µg/L)	Nitrate+ Nitrite (µg/L)	Ammonia (µg/L)	Total Suspended Solids (mg/L)	Total Volatile Suspended Solids (mg/L)
7/16/2013	226	19	6	1,282	944	353	32	102.8	13.2
8/5/2013	513	37	26	1,963	1,405	582	139	327	37
8/9/2013	364	32	25	1,549	1,251	541	94	215.5	22.5
9/11/2013	485	33	34	1,954	1,520	643	276	468	58
CT-P2									
10/16/2012	40	18	7	986	899	577	57	18.4	--
11/13/2012	37	8	6	1,056	936	615	39	13.4	4.2
1/23/2013	45	15	10	1,581	1,341	964	30	24.0	5.7
12/11/2012	22	5	7	1,407	1,328	939	86	12.6	--
2/13/2013	42	12	7	1,250	1,145	932	55	23.7	6.7
3/27/2013	49	12	7	770	657	318	63	8.8	--
4/22/2013	32	13	4	964	810	349	37	12.7	4
5/21/2013	41	4	5	1,384	1,125	490	119	11.8	--
6/11/2013	61	23	7	1,133	1,146	347	28	23.6	5.2
7/9/2013	80	12	14	1,223	964	252	105	18.6	5.8
8/12/2013	116	49	43	1,219	1,013	385	92	25	6.4
9/9/2013	50	12	15	1,435	1,197	425	141	25.4	5.4
CT-P2 Storm									
5/2/2013	85	29	23	1,347	1,205	427	237	42	9
5/9/2013	68	--	4	1,701	1,684	459	185	42	9
6/24/2013	283	14	13	3,268	2,527	1,054	381	73	21
7/16/2013	156	22	10	1,076	973	322	32	17.4	5
8/5/2013	130	54	46	1,473	1,321	360	124	22.7	5.7
8/9/2013	145	46	40	1,711	1,298	602	93	42.5	9.5
9/11/2013	370	66	49	2,095	1,794	811	277	202	38

GEI Water Chemistry Data									
Analytical Detection Limits	**2**	**2**	**2**	**2**	**2**	**2**	**3**	**4**	**4**
Site/Sample Date	**Total Phosphorus (µg/L)**	**Total Dissolved Phosphorus (µg/L)**	**Ortho-phosphate (µg/L)**	**Total Nitrogen (µg/L)**	**Total Dissolved Nitrogen (µg/L)**	**Nitrate+ Nitrite (µg/L)**	**Ammonia (µg/L)**	**Total Suspended Solids (mg/L)**	**Total Volatile Suspended Solids (mg/L)**
SC-3									
1/23/2013	101	53	47	3502	3245	2727	67	17.0	6.0
3/27/2013	56	28	20	902	857	553	39	25.8	--
4/22/2013	46	20	9	610	372	11	10	34.1	7.7
5/21/2013	86	56	57	774	539	128	40	9.8	--
SC-3 Storm									
5/2/2013	50	41	29	777	709	516	38	6.6	--
5/9/2013	83	46	51	698	646	235	75	6.6	--
6/24/2013	184	150	129	1028	1026	257	52	7.1	--
7/16/2013	158	142	113	737	733	28	17	18.2	--
8/5/2013	74	98	93	569	483	49	38	4.6	--
8/9/2013	134	121	107	729	641	164	--	8.2	--

-- Denotes result less than MDL.

Appendix D

2013 WY Streamflow, Rainfall, Phosphorus Loading Calculations and Final Inflow and Load Data Normalized to the U.S. Army Corps of Engineers Inflow Data

D.1 Streamflow Determination

Water levels (stage) were monitored on 15-minute intervals using ISCO Model 6700 and 6712 flowmeters, with each unit being calibrated on a monthly basis using in situ staff gage measurements. Stage-discharge data were collected for sites CC-10, SC-3, CT-P1, and CT-1 by measuring stream discharge (ft^3/sec) with a Marsh McBirney Model 2000 flowmeter, and recording the water level at the staff gage and ISCO flowmeter (Table D-1).

Stage-discharge data collected in the 2013 WY were combined with data collected during previous years to develop rating curves for each site, as long as historical data reflected no major changes to the streambed morphology, transducer, or staff gage. For example, if the transducer or staff gage was relocated or reset, then only the data collected post-change would be used to develop the rating curve.

Rating curves were developed for sites CC-10, SC-3, CT-P1, and CT-1 by fitting a nonlinear regression model to the data (Table D-2). For all sites a two-stage rating curve was developed to more accurately estimate low or high flows at these sites. A multi-level weir equation is used to estimate flows at Site CT-P2 located in the outlet structure of the pond. The weir equations for sites CT-P2 and CT-2 (Table D-2) were provided by Muller Engineering (unpublished data, 2004). In 2012, the outlet weir structure at Site CT-2 was slightly modified which resulted in extremely high discharge values compared to previous years or to Site CT-1. Therefore, the weir equation for Site CT-2 was not used to estimate discharge for the Cottonwood Perimeter PRF. Instead Site CT-1 discharge was substituted to estimate flow-weighted concentrations.

While water levels for Cherry Creek, Shop Creek, and Cottonwood Creek are monitored on a fairly continuous basis, there were periods of time when daily mean flows were estimated due to a dead battery, pressure transducer malfunction, ice, or flooding (Table D-3). To estimate mean daily water levels for periods of missing data, stage relationships were evaluated among nearby sites, with the best-fit linear regression model being used to estimate the missing level data.

Table D-1: Stage-discharge data used to develop rating curves for sites CC-10, SC-3, CT-P1, CT-P2, and CT-1 in 2013.

Site	Year	Date	Staff Gage Level (ft)	Transducer Level (ft)	Discharge (cfs)
CC-10	2004	27-May-04	1.09	1.463	3.10
CC-10	2004	22-Jun-04	2.50	2.493	24.45
CC-10	2004	23-Jun-04	1.54	1.530	8.65
CC-10	2004	24-Aug-04	2.47	2.472	23.93
CC-10	2005	01-Apr-05	2.39	2.531	20.11
CC-10	2005	14-Apr-05	4.84	4.890	142.89
CC-10	2005	25-Apr-05	4.05	4.093	91.76
CC-10	2005	02-May-05	2.63	2.630	40.14
CC-10	2005	19-May-05	1.68	1.612	14.27
CC-10	2005	26-May-05	1.40	1.422	8.79
CC-10	2005	01-Jun-05	1.47	1.469	17.86
CC-10	2005	16-Aug-05	0.81	0.808	3.60
CC-10	2005	13-Oct-05	2.41	2.418	29.81
CC-10	2006	20-Apr-06	1.40	1.391	10.92
CC-10	2006	13-Jun-06	0.56	0.567	2.05
CC-10	2006	12-Jul-06	1.56	1.482	23.62
CC-10	2006	08-Aug-06	0.55	0.550	5.18
CC-10	2006	27-Dec-06	1.27	1.230	20.51
CC-10	2007	13-Mar-07	4.27	4.317	93.87
CC-10	2007	10-May-07	3.10	3.100	62.15
CC-10	2007	26-Jul-07	0.61	0.621	1.63
CC-10	2007	9-Aug-07	1.32	1.306	11.11
CC-10	2007	13-Nov-07	1.70	1.692	6.27
CC-10	2008	19-Feb-08	2.50	2.470	31.14
CC-10	2008	27-Mar-08	1.98	1.980	25.65
CC-10	2008	26-Jun-08	0.64	0.617	2.79
CC-10	2008	15-Aug-08	0.87	0.864	5.92
CC-10	2008	11-Dec-08	1.36	1.387	21.28
CC-10	2009	22-Jan-09	1.27	--	21.53
CC-10	2009	24-Mar-09	1.18	1.126	17.98
CC-10	2009	23-Jun-09	1.80	1.767	19.25
CC-10	2009	08-Dec-09	1.79	1.802	11.11
CC-10	2009	18-Aug-09	2.48	2.470	38.79
CC-10	2009	20-Nov-09	2.12	2.081	27.89
CC-10	2010	26-Jan-10	1.76	1.733	21.03
CC-10	2010	15-Apr-10	2.15	2.136	28.03
CC-10	2010	29-Jun-10	0.91	0.889	6.10
CC-10	2010	10-Aug-10	1.58	1.566	21.51
CC-10	2010	8-Sep-10	0.42	0.468	1.77

Site	Year	Date	Staff Gage Level (ft)	Transducer Level (ft)	Discharge (cfs)
CC-10	2011	1-Mar-11	1.76	1.767	21.17
CC-10	2011	31-Mar-11	1.52	1.656	22.81
CC-10	2011	27-Apr-11	1.48	1.414	18.63
CC-10	2011	11-May-11	2.35	2.485	29.56
CC-10	2011	4-Aug-11	1.15	1.153	5.36
CC-10	2011	27-Sep-11	0.78	0.662	1.88
CC-10	2012	6-Jan-12	1.35	1.344	12.05
CC-10	2012	24-Jan-12	1.60	1.542	18.59
CC-10	2012	8-Mar-12	1.58	1.584	12.82
CC-10	2012	18-Apr-12	2.02	2.016	20.40
CC-10	2012	24-May-12	2.31	2.320	24.74
CC-10	2012	16-Jun-12	1.74	1.650	8.29
CC-10	2012	1-Jul-12	0.98	0.973	2.24
CC-10	2012	17-Aug-12	0.40	0.424	1.20
CC-10	2013	2-Mar-13	1.17	1.168	11.81
CC-10	2013	26-Mar-13	2.04	2.069	29.63
CC-10	2013	28-Apr-13	1.60	1.613	17.61
CC-10	2013	25-May-13	1.44	1.440	11.29
CC-10	2013	11-Aug-13	1.15	1.130	4.61
CC-10	2013	13-Sep-13	1.90	1.900	25.87
SC-3	2009	24-Mar-09	0.18	0.021	0.13
SC-3	2009	26-May-09	1.04	1.014	6.29
SC-3	2009	18-Aug-09	0.75	0.684	1.29
SC-3	2009	20-Nov-09	0.30	0.376	0.11
SC-3	2010	29-Jun-10	0.26	0.237	0.08
SC-3	2010	10-Aug-10	0.35	0.349	0.75
SC-3	2011	04/27/2011	0.29	0.316	0.14
SC-3	2011	05/11/2011	1.10	1.000	5.28
SC-3	2012	16-Apr-12	0.40	0.202	0.16
SC-3	2012	24-May-12	0.59	0.690	2.61
SC-3	2012	14-Jun-12	0.10	0.153	0.01
CT-P1	2009	26-May-09	2.29	2.286	21.80
CT-P1	2009	23-Jun-09	1.42	1.401	1.27
CT-P1	2009	12-Aug-09	1.38	1.375	0.82
CT-P1	2009	18-Aug-09	2.00	1.916	12.43
CT-P1	2009	20-Nov-09	1.64	1.634	1.79
CT-P1	2010	26-Jan-10	1.50	1.497	0.78
CT-P1	2010	20-Apr-10	1.51	1.511	1.15
CT-P1	2010	29-Jun-10	1.57	1.582	1.79
CT-P1	2010	10-Aug-10	1.72	1.704	3.29
CT-P1	2010	8-Sep-10	1.48	1.446	0.57

Site	Year	Date	Staff Gage Level (ft)	Transducer Level (ft)	Discharge (cfs)
CT-P1	2011	1-Mar-11	1.46	1.463	0.57
CT-P1	2011	31-Mar-11	1.50	1.483	0.84
CT-P1	2011	27-Apr-11	1.65	1.639	2.97
CT-P1	2011	11-May-11	2.45	2.423	31.15
CT-P1	2011	26-May-11	1.64	1.632	2.23
CT-P1	2011	20-Jun-11	3.00	3.360	64.62
CT-P1	2011	4-Aug-11	1.50	1.502	0.62
CT-P1	2011	27-Sep-11	1.50	1.542	0.61
CT-P1	2012	6-Jan-12	1.59	1.590	0.95
CT-P1	2012	24-Jan-12	1.50	1.540	0.71
CT-P1	2012	6-Mar-12	1.60	1.607	0.56
CT-P1	2012	16-Apr-12	1.68	1.722	2.77
CT-P1	2012	24-May-12	2.06	2.042	12.55
CT-P1	2012	14-Jun-12	1.37	1.374	0.94
CT-P1	2012	29-Jun-12	1.36	1.364	0.94
CT-P1	2012	15-Aug-12	1.32	1.275	0.55
CT-P1	2013	24-Jan-13	1.40	1.366	0.51
CT-P1	2013	28-Feb-13	1.47	1.525	1.28
CT-P1	2013	27-Mar-13	1.62	1.615	4.85
CT-P1	2013	26-Apr-13	1.45	1.492	1.06
CT-P1	2013	23-May-13	1.45	1.473	1.34
CT-P1	2013	24-Jun-13	1.54	1.550	2.26
CT-P1	2013	9-Aug-13	2.00	1.959	12.72
CT-P1	2013	11-Sept-13	2.40	2.382	27.81
CT-1	2011	20-Jun-11	1.80	2.237	119.77
CT-1	2012	14-Jun-12	1.06	--	1.85
CT-1	2012	29-Jun-12	0.88	0.793	1.14
CT-1	2012	15-Aug-12	0.91	0.897	1.66
CT-1	2013	24-Jan-13	0.89	0.973	4.36
CT-1	2013	28-Feb-13	0.95	0.953	4.87
CT-1	2013	27-Mar-13	1.04	1.070	9.80
CT-1	2013	26-Apr-13	0.95	0.968	5.62
CT-1	2013	23-May-13	0.88	0.825	2.11
CT-1	2013	24-Jun-13	0.96	0.955	5.64
CT-1	2013	9-Aug-13	1.30	1.257	11.79
CT-1	2013	11-Sept-13	1.68	1.645	49.03

Table D-2: Discharge (Q, cfs) and stage height (H, ft) relationships for all sites. Rating curves are developed for sites CC-10, SC-3, CT-P1, and CT-1, while multi-level orifice and weir equations are used for sites CT-P2, and CT-2.

Site	Stage Interval	Discharge Equations	R^2
CC-10	< 0.93	Q = EXP((H+0.1730)/0.723)	0.75
	> 0.93	Q = EXP((H+9.8328)/2.8329)-40.2584	0.89
CT-P1	<1.49	Q = EXP(H-1.4896)/0.2551	0.87
	>1.49	Q = EXP(H)-4.1860/0.2537	0.96
CT-P2	< 0.60	Q = (3.3)*(1)*(H)^(1.5)	
	0.61 - 1.09	Q = (0.60)*(0.50)*((2*32.2*(H_{adj}))^(0.5)	
	1.10 - 1.99	Q = (0.60)*(0.50)*((2*32.2*(H_{adj}))^(0.5))+((3.33)*(1)*(H-1.0)^(1.5)	
	2.00 - 2.59	Q = (0.60)*(0.50)(2*32.2*(H_{adj}))^(0.5)+((0.60)*(0.50)*((2*32.2*(H_{adj}-1.0))^(0.5))+((3.33) *(1)*(H-2.0)^(1.5)	
	2.60 - 2.99	Q = (0.60)*(0.50)(2*32.2*(H_{adj}))^(0.5)+((0.60)*(0.50)*((2*32.2*(H_{adj}-1.0))^(0.5))+((0.60) *(0.50)*(H_{adj}-2.0)^(0.5)	
	3.00 - 3.59	Q = (0.60)*(0.50)(2*32.2*(H_{adj}))^(0.5)+((0.60)*(0.50)*((2*32.2*(H_{adj}-1.0))^(0.5))+((0.60) *(0.50)*(H_{adj}-2.0)^(0.5))+((3.3)*(1)*(H-3.0)^(1.5)	
	3.60 - 3.99	Q = (0.60)*(0.50)(2*32.2*(H_{adj}))^(0.5)+((0.60)*(0.50)*((2*32.2*(H_{adj}-1.0))^(0.5))+((0.60) *(0.50)*(H_{adj}-2.0)^(0.5))+((0.60)*(0.50)*(2*32.2*(H_{adj}-3.0)^(0.5)	
	4.00 - 4.49	Q = (0.60)*(0.50)(2*32.2*(H_{adj}))^(0.5)+((0.60)*(0.50)*((2*32.2*(H_{adj}-1.0))^(0.5))+((0.60) *(0.50)*(H_{adj}-2.0)^(0.5))+((0.60)*(0.50)*(2*32.2*(H_{adj}-3.0)^(0.5))+((3.3)(1)(H-4.0))^ (1.5)	
	4.50 - 5.19	Q = (0.60)*(0.50)(2*32.2*(H_{adj}))^(0.5)+((0.60)*(0.50)*((2*32.2*(H_{adj}-1.0))^(0.5))+((0.60) *(0.50)*(H_{adj}-2.0)^(0.5))+((0.60)*(0.50)*(2*32.2*(H_{adj}-3.0)^(0.5))+((0.60)(0.50)(2* 32.2*H_{adj}-4.0))^(0.5)	
	5.20 - 6.80	Q = (0.60)*(0.50)(2*32.2*(H_{adj}))^(0.5)+((0.60)*(0.50)*((2*32.2*(H_{adj}-1.0))^(0.5))+((0.60) *(0.50)*(H_{adj}-2.0)^(0.5))+((0.60)*(0.50)*(2*32.2*(H_{adj}-3.0)^(0.5))+((0.60)(0.50)(2* 32.2*H_{adj}-4.0))^(0.5))+((3.3)(1)(H-5.2)^(1.5)	
CT-1	<0.94	Q = EXP((H-0.6210)/0.2938)	0.80
CT-1	>0.94	Q = EXP((H+4.2345)/1.2866)-52.7615	0.97

H_{adj} = Mean daily level - 0.25 ft

Table D-3: Equations used to estimate missing daily mean data and percent of annual data estimated.

Site	Equations	R^2	Percent of Annual Data Estimated
CC-10	CC-10 Level = 1.9218*(EcoPark Level) – 0.2443	0.77	5%
CT-P1, Oct to Nov	CT-P1 Level = (CT-P2 Level + 5.7403)/4.4441	0.82	3%
CT-P1, Aug to Sep	CT-P1 Level = 1.1819*(CT-1 Level) + 0.4803	0.81	10%
CT-P2, Jan	CT-P2 Level = 3.4112*(CT-P1 Level) – 4.2813	0.89	2%
CT-P2, Aug to Sep	CT-P2 Level = 5.9731*(CT-P1 Level) – 3.8781	0.82	6%
CT-1, Oct to Jan	CT-1 Level = 0.1409*(CT-P2 Level) + 0.915	0.56	5%
CT-1, May to June	CT-1 Level = 0.1553*(CT-P2 Level) + 0.8166	0.86	2%

D.2 Phosphorus Loading

The USACE reports daily inflow to Cherry Creek Reservoir as a function of storage, based on changes in reservoir level. This daily inflow value incorporates information regarding measured outflow, precipitation, and evaporation. GEI monitors stream inflows to the reservoir using gaging stations on Cherry Creek, Cottonwood Creek, and Shop Creek (the three main surface inflows) to provide a daily surface inflow record. Given the differences in the two methods for determining inflow, combined with the potential of unmonitored surface flows that may result in greater seepage through the adjacent wetlands during storm events, an exact match between USACE and GEI calculated inflows is not expected.

In an effort to maintain a seasonality component in phosphorus loads and exports for the reservoir, the normalization process was performed on monthly data. Loads attributed to stream inflow, reservoir outflow, precipitation and the alluvium were still calculated on a daily basis, using the daily inflow records and respective concentration data, but summed to create a monthly inflow value. In the case of the alluvial inflow constant, the annual value was divided by the number of days in the year to create a daily value, and then summed to create a monthly value, with no seasonal dynamics. The monthly precipitation and alluvial inflow values are subtracted from the monthly USACE inflow value to create an Adjusted USACE Inflow. The monthly GEI stream flow (sites CC-10 and CT-1 flow) is subtracted from the Adjusted USACE Inflow to determine the quantity of flow that needs to be redistributed proportionally among the two primary surface inflow streams (Cherry Creek and Cottonwood Creek). If the monthly Redistributed Inflow is greater than 1,000 ac-ft, then the first 1,000 ac-ft is redistributed proportionally to the stream sites, with the remainder being placed in an Ungaged Flow category. This category represents unmonitored flow that may be attributed to wetland seepage, stream bank storage, or ungaged surface flows during the respective month. Once the redistributed inflows are apportioned to the stream sites, monthly loads are computed using their respective flow-weighted phosphorus concentrations and identified as “Normalized” to the USACE inflow. The alluvial load is based on the long-term median phosphorus concentration for Site MW-9 (1995 to 2013, 190 µg/L). Notably, flow and loads for sites upstream of Site CT-2 or on Shop Creek are not normalized. Only the unadjusted flow and load data was used to evaluate the effectiveness of the PRFs on Cottonwood Creek.

D.3 Tributary Streams

Once the water year flow record for each stream site was finalized, the mean daily flows were categorized as either base flow or storm flow events. If the mean daily flow was greater than the 90th percentile of the annual value (Table D-4), then the flow was categorized as storm flow. Flows less than the 90th percentile were categorized as base flows. Flows at Site CT-2 were not categorized due to the pond maintenance construction.

Table D-4: Threshold flow value used to categorize base flows and storm flows in 2013.

Site	90th Percentile (cfs)
CC-10 Oct-Feb	6.450
CC-10 Jun-Sep	24.265
CT-P1	3.361
CT-P2	4.072
CT-1	8.34

For all streams, total phosphorus concentrations were determined for base flow samples collected on a monthly basis, and for storm flow samples collected at irregular intervals throughout the year (Appendix C). For each monitoring site, the monthly base flow TP concentration (Table D-5) was applied to the daily base flows during that month, while the annual median storm flow TP concentration was applied to storm flows (Equation 1). Daily loadings were then summed to obtain estimates of monthly and water year phosphorus loading for each stream site (Table D-6).

EQUATION 1:

$$L_{day} = \mu g/L \times Q_{in} \times \frac{86400 sec}{day} \times \frac{28.3169 L}{ft^3} \times \frac{2.205 \times 10^{-9} lbs}{\mu g}$$

where:

L_{day} = pounds per day phosphorus loading,

$\mu g/L$ = total phosphorus concentration of base flow or storm flow

Q_{in} = mean daily flow in ft^3/sec.

Table D-5: Monthly base flow TP concentrations (µg/L) and median annual storm flow TP concentration (µg/L) applied to respective flows in 2013.

Month	CC-O	EcoPark	CC-10	SC-3	CT-P1	CT-P2	CT-1	CT-2
October 2012	113	--	205	47	39	40	54	39
November 2012	90	--	182	49	46	37	73	53
December 2012	66	--	177	76	26	22	72	44
January 2013	188	--	167	101	22	45	107	79
February 2013	107	--	173	72	22	42	150	53
March 2013	80	--	120	56	49	49	53	60
April 2013	146	78	130	46	35	32	75	75
May 2013	112	132	180	86	43	41	57	30
June 2013	168	93	228	155	83	61	82	50
July 2013	123	54	186	143	91	80	60	26
August 2013	172	158	289	152	94	116	93	81
September 2013	122	142	303	84	39	50	73	67
Water Year Storm Flow Median	--	431	414	109	364	145	172	60

D.4 Reservoir Outflow

The USACE monitors flows through the outlets gates on a regular interval and provides GEI with estimates of daily outflow for the reservoir. GEI monitors water quality of the outflow at a site located approximately 75 m downstream of the concrete outflow structure at the base of the dam (CC-O @ I-225). The monthly total phosphorus concentration collected from this site was applied to the USACE outflow to estimate the 2013 WY export load (Equation 1).

D.5 Precipitation

Precipitation data collected at Denver/Centennial Airport (KAPA) was used to estimate phosphorus loading due to precipitation in 2013 (Appendix D), with the basic premise that precipitation generally falls evenly across the reservoir, although rain showers in the Cherry Creek Reservoir area can be localized. Calculation of the phosphorus load into Cherry Creek Reservoir from precipitation was based on the long-term median phosphorus concentration (1987 to 2005) and Equation 2.

EQUATION 2:

$$L_{precip} = \frac{PR}{12in} \times A_{res} \times \frac{43650ft^2}{acre} \times \frac{\mu g}{L} \times \frac{28.3169L}{ft^3} \times \frac{2.205 \times 10^{-9} lbs}{\mu g}$$

where:

L_{precip} = pounds of phosphorus from precipitation,

PR = rainfall precipitation in inches,

A_{res} = surface area of the reservoir (852 ac), and

µg/L = 116 µg/L, long-term median TP concentration.

D.6 Alluvium

The alluvial water component remains one of the unmonitored sources of inflow to the reservoir. The annual flow is relatively constant given the boundaries of the alluvium in relation to the reservoir, with the majority of the alluvial water monitored at Site MW-9 flowing beneath the reservoir and under the dam, because the dam is not grounded on bedrock.

In 2005, Lewis et al. evaluated the ground water contribution and its relationship to the phosphorus budget to the reservoir. They observed a zone of high alluvial seepage located in the southeastern margin of the reservoir that covered approximately 1.5 acres and extended further into the reservoir to an approximate depth of 2 feet. At depths greater than 2 feet the composition of the sediment changed from one of coarse sand to one of high organic matter and carbonate content which greatly limited alluvial seepage. Lewis et al. used three different methods to derive the alluvial water component of 2,200 ac-ft/yr; direct measurements of alluvial inflow which included seepage estimates from the adjacent wetlands (submerged seepage meters and piezometers), ionic mass balance, and water budget balances.

Based on this study, and analysis of long-term residual inflow estimates, the 2013 alluvial component was defined as a constant source of water to the reservoir that accounted for 1,998 ac-ft/yr with no seasonal fluctuations. The long-term (1994-2012) median total dissolved phosphorus concentration for Site MW-9 (190 µg/L) was used to estimate the alluvial load component (Equation 3).

EQUATION 3:

$$L_{alluvium} = \mu g/L \; (\; Q_{alluvium} \; (\; \frac{2.205 \text{ H } 10^{-9} \text{ lbs}}{\mu g} \; (\; \frac{1{,}233{,}482 \text{ L}}{\text{Ac-ft}}$$

where:

$L_{alluvium}$ = alluvial phosphorus loading in pounds per year

µg/L = 190 µg/L, long-term median TDP concentration

$Q_{alluvium}$ = alluvial inflow in ac-ft

D.7 Redistributed Inflows

During the 2012 WY, the repartitioning of the alluvial inflow component created a "Redistributed Inflow" category that is comprised of flows that are currently unaccounted for given the current monitoring regime. The majority of these flows are likely the result of bank full flooding that occurs along Cherry Creek, upstream of Site CC-10, which eventually enters the reservoir as seepage from the wetland area. Other flows in this category include unmonitored inflows from the Belleview and Quincy drainages, and surface inflows around the margin of the reservoir. The monthly "Redistributed Inflow" is calculated as presented below (Equation 4, Table D-6), and is either a positive or negative value depending on the monthly balance.

EQUATION 4:

Redistributed Inflow = (USACE Inflow - Precipitation - Alluvial Inflow) - GEI Stream Inflow

If the value is positive, then the inflow or load is added proportionally to Cherry Creek and Cottonwood Creek inflows. If the value is negative, the inflow or load value is subtracted proportionally from Cherry Creek and Cottonwood Creek inflows.

In the case when the redistributed inflow or load results in a negative monthly balance for a stream, the inflow or load for that stream is set to ZERO, with the remaining balance being subtracted from the other stream site. In the rare case when the redistributed inflow or load results in negative monthly balances for both streams, then the inflow or load for each stream is set to ZERO, with the remaining balance being subtracted from the monthly alluvial value.

Additionally, when the redistributed inflow is greater than 1,000 ac-ft/month (mo), the first 1,000 ac-ft will be redistributed among the two streams, and the remainder will be placed into an "Ungaged Inflow" category. The reasoning behind this category is if the redistributed inflow is truly this great, then the current inflow monitoring regime should be reevaluated to address such occurrences.

In 2013, the September storm events resulted in an Ungaged Residual Flow of 1,678 ac-ft which accounted for 1,260 lbs of phosphorous input into the Reservoir.

Table D-6: Unadjusted monthly flow and load data and the final normalized flow and load.

Month	Unadjusted Flow (ac-ft/mo)									Normalized Flow (ac-ft/mo)		
	USACE Inflow	USACE Outflow	CC-10	SC-3	CT-P1	CT-P2	CT-1	CT-2	Precip	Alluvium	CC-10	CT-1/CT-2
October 2012	563	679	211	0	69	91	350	--	44	169	132	218
November 2012	619	615	280	0	43	58	309	--	16	164	208	230
December 20112	774	600	348	0	38	48	284	--	7	169	329	269
January 2013	801	711	320	0	37	44	232	--	9	170	361	262
February 2013	855	757	348	3	59	74	165	--	40	153	448	213
March 2013	1,444	1,354	1,100	169	133	168	323	--	50	170	947	278
April 2013	1,283	1,328	1,045	16	111	139	279	--	57	164	838	224
May 2013	1,730	1,759	1,159	13	226	232	382	--	128	170	1,077	355
June 2013	399	407	288	0	73	93	120	--	86	164	105	44
July 2013	329	155	204	1	55	137	111	--	43	170	76	41
August 2013	708	519	342	0	169	325	267	--	230	170	173	135
September 2013	7,101	1,475	2,574	830	842	942	1,188	--	497	164	3,258	1,504
Water Year Total	**16,606**	**10,359**	**8,219**	**1,032**	**1,855**	**2,351**	**4,010**	**--**	**1,206**	**1,998**	**7,951**	**3,773**
Month	**Unadjusted Total Phosphorus Load (lbs/mo)**									**Normalized Load (lbs/mo)**		
	USACE Inflow	**USACE Outflow (CC-O)**	**CC-10**	**SC-3**	**CT-P1**	**CT-P2**	**CT-1**	**CT-2**	**Precip**	**Alluvium**	**CC-10**	**CT-1/CT-2**
October 2012	--	209	145	0	21	14	79	--	14	88	91	49
November 2012	--	150	155	0	5	6	73	--	5	85	116	55
December 2012	--	108	184	0	3	3	56	--	2	88	174	53
January 2013	--	364	145	0	2	5	68	--	3	88	164	76
February 2013	--	220	264	1	15	12	69	--	13	79	340	88
March 2013	--	295	522	50	64	38	85	--	16	88	449	73
April 2013	--	527	445	5	66	28	80	--	18	85	357	64
May 2013	--	536	801	4	169	72	118	--	40	88	745	110
June 2013	--	186	207	0	36	21	31	--	27	85	75	11
July 2013	--	52	113	0	25	40	18	--	13	88	42	7
August 2013	--	246	314	0	137	121	101	--	73	88	159	51
September 2013	--	489	2,881	245	806	365	524	--	157	85	3,646	663
Water Year Total	**--**	**3,378**	**6,176**	**305**	**1,349**	**725**	**1,302**	**--**	**381**	**1,033**	**6,357**	**1,300**

Table D-7: Calculation of the monthly redistributed inflow and load values and the apportioning of these data to sites CC-10 and CT-1.

Month	Adjusted USACE Inflow (USACE Precip Alluvium)	GEI Inflow CC-10 +CT-1 (ac-ft/mo)	Redistributed Inflow (ac-ft/mo)	CC-10 Percent of GEI Inflow	CT-1 Percent of GEI Inflow	CC-10 Redistributed Flow (ac-ft/mo)	CT-1 Redistributed Flow (ac-ft/mo)	Ungaged Residual Flow (ac-ft/mo)	Redistributed Load (lbs/mo)	CC-10 Redistributed Load (lbs/mo)	CT-1 Redistributed Load (lbs/mo)	Ungaged Residual Load (lbs/mo)
October 2012	350	561	-211	38%	62%	-80	-131	0	-84	-55	-30	0
November 2012	439	589	-150	47%	53%	-71	-79	0	-58	-40	-19	0
December 2012	597	632	-35	55%	45%	-19	-16	0	-13	-10	-3	0
January 2013	622	552	70	58%	42%	41	29	0	27	18	9	0
February 2013	662	513	149	68%	32%	101	48	0	96	76	20	0
March 2013	1,224	1,423	-198	77%	23%	-153	-45	0	-85	-73	-12	0
April 2013	1,062	1,325	-263	79%	21%	-208	-55	0	-104	-88	-16	0
May 2013	1432	1,541	-109	75%	25%	-82	-27	0	-65	-56	-8	0
June 2013	148	408	-259	71%	29%	-183	-76	0	-152	-132	-20	0
July 2013	117	316	-199	65%	35%	-129	-70	0	-83	-71	-11	0
August 2013	308	610	-301	56%	44%	-169	-132	0	-205	-155	-50	0
September 2013	6,440	3,762	2,678	68%	32%	1,832	846	1,678	905	766	139	1,260
Water Year Total	**13,401**	**12,230**	**1,171**	**63%**	**37%**	**880**	**291**	**1,678**	**179**	**181**	**-1**	**1,260**

Appendix E

2013 Biological Data

Table E-1: 2013 Cherry Creek Reservoir phytoplankton data represented in cells per mililter (cells/mL).																
	2013															
	22-Jan	12-Feb	29-Mar	29-Apr	14-May	28-May	12-Jun	26-Jun	10-Jul	22-Jul	13-Aug	28-Aug	11-Sep	24-Sep	15-Oct	18-Nov
Bacillariophyta																
Centrales																
Amphora ovalis	--	--	--	21	--	--	--	--	--	--	--	--	--	--	--	--
Cyclotella meneghiniana	--	--	--	--	--	19	--	--	--	39	146	--	73	--	67	--
Cyclotella stelligera	--	--	--	--	--	--	--	--	--	--	--	--	147	236	--	--
Stephanodiscus astraea minutula	--	--	--	21	26	57	82	40	163	543	2,538	949	660	572	841	86
Stephanodiscus hantzschii	--	--	--	--	26	19	--	40	33	78	1,171	1,780	733	438	1,144	1,319
Synedra ulna	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	65
Pennate																
Achnanthes clevei	--	--	--	--	--	--	--	--	--	--	--	--	37	--	--	--
Achnanthes lanceolata	--	--	--	--	--	--	--	--	--	--	--	40	37	--	--	--
Asterionella formosa	--	--	--	--	522	816	--	--	--	--	--	--	--	--	--	--
Cymbella affins	17	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Cymbella sinuata	--	--	--	--	--	--	--	--	--	--	--	--	--	--	34	--
Fragilaria construens	--	--	--	--	--	--	21	--	33	39	--	--	37	--	34	22
Fragilaria construens venter	--	--	--	--	--	--	--	--	--	--	--	--	37	--	--	--
Fragilaria pinnata	--	--	--	--	--	19	--	--	--	39	--	--	--	34	--	--
Fragilaria vaucheria	--	--	--	--	--	--	--	--	--	--	--	--	--	34	--	--
Gomphonema angustatum	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Melosira ambigua	--	--	--	--	--	19	--	--	--	--	--	--	--	--	--	--
Melosira granulata	--	--	--	--	--	--	--	--	33	39	--	--	--	--	--	43
Navicula capitata	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	22
Navicula graciloides	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	22
Navicula decussis	--	--	--	--	--	--	--	--	--	39	--	--	--	--	--	--
Navicula viridula	--	--	--	--	--	--	--	--	--	--	--	--	--	--	34	--
Nitzschia acicularis	--	--	--	--	--	--	--	--	--	--	--	--	--	--	67	43
Chlorophyta																
Ankistrodesmus falcatus	612	201	278	123	104	152	103	79	163	388	244	79	220	168	135	130
Chlamydomonas sp.	105	161	131	--	--	--	62	159	813	621	98	119	73	370	168	108
Chodatella wratislawiensis	--	40	49	41	26	--	--	--	--	--	--	--	--	34	34	--
Closteriopsis longissima	--	--	--	--	--	--	--	40	--	--	--	40	--	--	--	--
Crucigenia crucifera	--	--	--	--	--	--	--	--	33	116	49	--	37	--	--	--
Crucigenia quadrata	70	--	--	21	78	95	62	119	325	116	49	--	37	34	--	--
Crucigenia tetrapedia	--	--	--	--	104	19	--	--	195	39	--	--	37	67	--	22
Gloeocystis ampla	35	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Micractinium pusillum	--	--	--	--	--	--	--	--	--	--	--	--	37	67	--	--
Oocystis pusilla	52	--	16	123	52	152	472	1,906	325	349	98	40	73	34	202	43
Pediastrum boryanum	--	--	--	41	--	--	62	--	--	--	--	--	--	--	--	--
Pediastrum duplex	--	--	16	--	--	--	--	--	--	--	49	--	--	--	--	22
Pediastrum tetras	--	--	--	21	--	--	--	--	--	--	--	--	--	--	--	--
Scenedesmus abundans	--	--	--	--	26	--	--	40	--	39	--	--	--	--	34	--
Scenedesmus acuminatus	--	--	--	--	26	--	41	--	33	--	49	--	--	--	101	--
Scenedesmus quadricauda	17	40	16	226	548	304	534	754	618	931	244	237	183	269	370	130
Schroderia sp.	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Selenastrum minutum	262	161	392	165	26	--	21	40	--	39	49	--	73	34	--	130
Sphaerocystis schroeteri	--	--	--	--	--	--	21	119	98	39	49	40	--	--	--	--
Tetraedron minimum	--	--	16	--	52	152	123	40	65	39	--	40	147	135	--	--
Tetraedron regulare	--	--	16	--	--	--	21	--	--	39	--	40	--	--	--	--
Tetrastrum staurogeniaforme	--	--	--	21	26	19	--	79	33	78	--	--	--	--	--	43
Chrysophyta																
Chrysococcus rufescens	52	3,825	409	144	26	--	--	--	--	--	--	--	--	--	--	--
Dinobyron sertularia	17	40	--	--	--	--	--	--	--	--	--	--	--	--	34	--
Kephyrion littorale	17	40	245	494	26	--	62	--	--	--	--	--	--	--	--	--
Kephyrion sp.	--	121	49	--	26	38	--	--	--	--	--	--	--	--	--	--
Cyanobacteria																
Anabaena flos-aquae	--	--	--	--	--	--	--	40	--	--	342	40	37	34	34	--
Aphanizomenon flos-aquae	--	--	--	21	--	--	--	--	--	--	146	40	--	--	--	--
Euglenophycota																
Euglena sp.	--	--	--	--	--	--	--	--	33	--	--	--	--	34	--	--
Trachelomonas charkowensis	--	40	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Trachelomonas crebea	--	--	--	309	--	--	--	--	--	--	--	--	37	34	34	--
Trachelomonas hispida	--	--	--	--	52	--	--	--	33	--	--	--	--	--	--	--
Trachelomonas pulchella	--	--	--	--	--	--	--	--	--	--	--	--	--	34	--	--
Trachelomonas scabra	52	121	--	41	--	--	--	--	--	--	--	158	73	--	101	86
Trachelomonas volvocina	--	--	16	21	--	--	--	--	--	--	--	--	--	--	--	--

Table E-1: 2013 Cherry Creek Reservoir phytoplankton data represented in cells per mililter (cells/mL). (cont.)

	2013															
	22-Jan	**12-Feb**	**29-Mar**	**29-Apr**	**14-May**	**28-May**	**12-Jun**	**26-Jun**	**10-Jul**	**22-Jul**	**13-Aug**	**28-Aug**	**11-Sep**	**24-Sep**	**15-Oct**	**18-Nov**
Pyrrophycophyta																
Ceratium hirundinella	--	--	--	--	--	--	--	--		--	49	--	--	--	--	--
Glenodinium sp.	52	--	--	--	--	--	--	--	65	--	--	--	73	--	34	--
Peridinium cinctum	--	--	--	--	--	--	21	--	33	--	--	--	--	--	--	--
Cryptophyta																
Cryptomonas erosa	420	--	82	41	705	721	431	556	163	155	98	40	513	438	135	173
Rhodomonas minuta	105	--	16	103	261	95	21	635	456	427	146	475	440	438	67	281
Total Density (cells/mL)	1,888	4,792	1,750	1,996	2,740	2,695	2,156	4,685	3,742	4,231	5,613	4,154	3,850	3,534	3,702	2,789
Total Taxa	15	11	15	19	20	16	17	16	21	22	18	16	24	21	21	19

Table E-2: Total reservoir phytoplankton density (cells/mL) and number of taxa in Cherry Creek Reservoir, 1984 to 2013

	1984	1985	1986	1987	1988	1989	1991	1992	1993	1994	1995	1996
Blue-Green Algae												
Density	71,780	66,496	99,316	168,259	155,180	273,175	307,691	77,516	15,708	10,015	18,194	16,599
Taxa	7	7	6	18	24	24	14	16	7	3	7	9
Green Algae												
Density	5,864	11,760	25,595	11,985	19,177	55,415	18,688	41,899	1,198	314	355	738
Taxa	11	10	13	58	76	66	46	48	16	2	11	11
Diatoms												
Density	1,776	3,863	5,428	10,677	12,880	9,311	4,160	1,243	946	194	2,189	2,354
Taxa	6	4	7	34	30	31	21	11	15	2	15	13
Golden-Brown Algae												
Density	--	7	125	469	56	505	821	93	158	3	63	249
Taxa	--	1	1	6	4	7	5	4	1	1	2	4
Euglenoids												
Density	514	135	208	251	276	108	89	23	231	196	304	409
Taxa	2	1	1	9	9	6	3	5	2	1	2	3
Dinoflagellates												
Density	--	13	19	19	83	28	23	54	--	31	5	21
Taxa	--	1	1	2	4	3	2	2	--	1	2	4
Cryptomonads												
Density	1,513	718	1,113	1,090	2,689	1,689	628	529	332	450	919	1,104
Taxa	2	3	3	6	4	5	2	3	1	1	1	1
Miscellaneous												
Density	--	--	--	--	--	--	--	--	--	--	--	--
Taxa	--	--	--	--	--	--	--	--	--	--	--	--
Total Density (#/mL)	81,447	82,992	131,804	192,750	190,341	340,231	329,773	121,357	18,573	11,203	22,029	21,474
Total Number of Taxa	28	27	32	133	151	142	93	89	42	11	40	45

Table E-2: Total reservoir phytoplankton density (cells/mL) and number of taxa in Cherry Creek Reservoir, 1984 to 2013 (cont.)

	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Blue-Green Algae												
Density	19,716	44,951	15,263	164,290	148,691	941	54,114	165,677	79,154	665,696	1,266,765	1,124,197
Taxa	10	11	8	19	12	3	21	27	19	19	21	19
Green Algae												
Density	2,461	1,809	898	43,881	33,217	1,973	55,190	56,236	189,777	1,358,248	563,344	1,531,579
Taxa	18	18	18	71	56	27	70	75	66	63	63	67
Diatoms												
Density	1,109	628	838	12,019	5,256	978	2,026	1,720	3,610	32,036	60,127	27,681
Taxa	8	18	16	34	22	24	22	26	24	21	21	17
Golden-Brown Algae												
Density	227	56	--	391	1,346	34	44	57	335	542	2,380	6,270
Taxa	2	2	--	14	13	3	5	5	4	5	3	3
Euglenoids												
Density	838	698	1,252	126	91	22	308	24	39	1,549	1,303	259
Taxa	3	3	1	6	4	3	9	11	8	10	10	11
Dinoflagellates												
Density	--	18	45	80	157	193	20	57	60	330	595	722
Taxa	--	2	2	8	6	5	3	5	6	5	5	3
Cryptomonads												
Density	1,487	1,393	559	2,472	2,851	355	3,282	3,158	3,293	40,511	61,037	35,962
Taxa	1	1	1	4	6	4	8	8	9	12	9	11
Miscellaneous												
Density	--	--	--	1,923	5,714	15	1,294	164	2,014	4,855	73,435	53,330
Taxa	--	--	--	1	1	1	3	6	6	6	7	8
Total Density (#/mL)	25,838	49,553	18,855	225,182	197,323	4,511	116,278	227,093	278,282	2,103,767	2,028,986	2,780,000
Total Number of Taxa	39	55	46	157	120	70	141	164	142	141	139	139

Table E-2: Total reservoir phytoplankton density (cells/mL) and number of taxa in Cherry Creek Reservoir, 1984 to 2013 (cont.)

	2009	2010	2011	2012	2013	Long-term
Blue-Green Algae						
Density	332	4,177	1,136	2,648	731	**66,496**
Taxa	3	6	3	2	2	**10**
Green Algae						
Density	10,733	19,202	26,055	23,851	21,270	**19,202**
Taxa	20	22	23	20	21	**23**
Diatoms						
Density	11,609	13,975	39,654	24,186	16,380	**4,160**
Taxa	25	30	21	34	22	**21**
Golden-Brown Algae						
Density	246	587	1,895	1,304	6,371	**249**
Taxa	4	3	4	3	5	**4**
Euglenoids						
Density	83	272	570	1,802	1,308	**259**
Taxa	3	4	4	5	7	**4**
Dinoflagellates						
Density	4,497	2,556	6,253	1,158	326	**59**
Taxa	4	3	1	2	3	**3**
Cryptomonads						
Density	22,277	16,794	14,850	12,130	7,930	**1,689**
Taxa	2	2	2	2	2	**3**
Miscellaneous						
Density	--	--	--	94	--	**1,969**
Taxa	--	--	--	1	--	**5**
Total Density (#/mL)	49,777	57,563	90,413	67,173	54,316	**90,413**
Total Number of Taxa	61	70	58	68	62	**70**

Table E-3: 2013 Cherry Creek Reservoir zooplankton.

	2013													
	22-Jan	**12-Feb**	**29-Mar**	**29-Apr**	**14-May**	**28-May**	**12-Jun**	**26-Jun**	**10-Jul**	**22-Jul**	**13-Aug**	**28-Aug**	**11-Sep**	**24-Sep**
Cladocera														
Bosmina longirostris	24.2	12.9	27.8	41.5	78.0	58.3	18.6	46.5	16.4	34.9	331.0	142.3	184.7	175.5
Daphnia galeata mendotae	1.1	--	--	--	6.8	0.9	--	--	--	--	--	--	--	--
Daphnia lumholtzi	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Daphnia parvula	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Daphnia pulicaria	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Daphnia sp.	0.2	--	--	--	1.8	0.9	1.9	--	31.2	39.9	4.1	10.3	5.3	32.6
Diaphanosoma leuchtenbergianum	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Copepod														
Diacyclops thomasi	24.9	21.6	27.8	11.3	13.6	3.2	2.8	1.3	0.9	1.4	4.1	0.7	0.8	1.4
Immature instar (copepodid)	52.5	21.2	14.1	42.5	20.0	12.4	8.4	7.6	6.8	10.4	10.9	19.2	63.1	23.4
Mesocyclops edax	--	--	--	--	0.9	0.5	0.9	3.4	0.7	2.3	--	--	--	1.4
Nauplius	37.7	--	56.6	63.2	146.9	7.3	14.2	27.0	82.6	118.9	16.1	49.4	95.0	42.5
Skistodiaptomus pallidus	1.5	--	0.5	--	--	--	--	--	8.0	14.0	2.7	6.8	11.4	9.9
Rotifer														
Asplanchna sp.	--	--	--	--	--	--	--	--	--	--	--	66.5	65.5	23.6
Bdelloid rotifers	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Brachionus angularis	--	--	--	--	--	--	--	--	36.1	0.9	--	--	--	--
Brachionus calyciflorus	0.9	1.3	25.6	2.8	0.9		0.9	--	--	--	--	--	--	--
Gastropus sp.	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Keratella cochlearis	258.1	324.3	30.6	125.5	136.9	475.9	212.3	366.9	190.9	71.7	0.9	--	--	0.9
Keratella quadrata	--	--	--	0.9	--	--	--	--	--	--	--	--	--	--
Lecane sp.	--	--	--	--	--	2.8	--	--	--	--	--	--	--	--
Polyarthra sp.	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Trichocerca sp.	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Total Concentration (#/L)	401.1	381.3	183.0	287.7	405.8	562.2	260.0	452.7	373.6	294.4	369.8	295.2	425.8	311.2
Total Number of Taxa	9	5	7	7	9	9	8	6	9	9	7	7	7	9