GEI Consultants

Geotechnical
Environmental
Water Resources
Ecological

Cherry Creek Reservoir 2012 Water Year Aquatic Biological Nutrient Monitoring Study and Cottonwood Creek Pollutant Reduction Facilities Monitoring

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April 2013
Project 062450

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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
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	mean 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 2012 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 with respect to standards and goals identified in the Cherry Creek Reservoir Control Regulation No. 72, selected water quality standards identified for the Reservoir in Regulation No. 38, and 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. The CCBWQA with the approval of the Water Quality Control Division made the decision to switch their reporting to be consistent with a water year designation, (e.g., October to September), rather than the calendar year. Therefore, 2012 represents the second complete water year cycle with data presentations being based on the 12-month period from October 2011 to September 2012 (2012 WY). Historical data have been recalculated based on their respective water year for comparative purposes.

ES 1.1. Flow-weighted Phosphorus Concentrations and Loads

The total normalized inflow for Cherry Creek, Cottonwood Creek, and the ungaged surface water flow combined for the 2012 WY was 10,753 acre-feet per year (ac-ft/yr) and contributing a total of 6,137 pounds (lbs) of phosphorus. The combined stream flow-weighted total phosphorus concentration was 210 micrograms per liter (µg/L). The annual precipitation falling directly on the Reservoir accounted for 997 ac-ft of water and contributed 315 lbs of phosphorus, while the normalized alluvial inflow was 1,974 ac-ft/yr, and contributed 1,023 lbs of phosphorus to the Reservoir. These three primary sources of inflow—streams, precipitation, and alluvium—accounted for a total inflow of 13,724 ac-ft/yr to the Reservoir, contributing a total of 7,475 lbs of phosphorus to the Reservoir. The 2012 WY flow-weighted total phosphorus concentration for all sources of inflow was 200 µg/L which is equal to the flow-weighted total phosphorus goal of 200 µg/L for the Reservoir. The long-term (1992 to 2012) WY median flow-weighted total phosphorus concentration for the Reservoir is 201 µg/L. The total Reservoir outflow was 10,862 ac-ft/yr, exporting 3,477 lbs of phosphorus from the Reservoir with 2012 WY flow-weighted total phosphorus concentration of 118 µg/L. The long-term (1992 to 2012) WY median export flow-weighted total phosphorus concentration from the Reservoir is 102 µg/L. The net external total phosphorus load to the Reservoir was 3,998 lbs.

ES 1.2. Total Phosphorus

Total phosphorus concentrations in the upper 3 meter (m) layer of the Reservoir ranged from 132 to 149 µg/L during the July to September sampling events, with a seasonal mean of 141 µg/L. The long-term (1992 to 2012) seasonal median total phosphorus concentration for the Reservoir is 85 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 during the months of November, March and May, but considerably greater during late summer and fall 2011. From October 2011 through September 2012, chlorophyll *a* concentrations ranged from 11.8 µg/L to 34.4 µg/L. The July through September seasonal mean chlorophyll *a* level was 27.1 µg/L, with a peak seasonal reservoir mean concentration of 34.4 µg/L. The 2012 WY mean chlorophyll *a* concentration was 24.0 µg/L. This is the third 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.

Algal production is typically the lowest during the spring time of year, when the reservoir experiences flushing flows from seasonal storms and the algal community is changing from the winter based assemblage to a summer-based assemblage. During the January 2012 winter ice-covered conditions, cryptomonads were the most abundant algal group that were able to respond to an internal nutrient release event, when chlorophyll *a* concentration was 33.4 µg/L. These algae are well-adapted to growing during low light and low temperature conditions during ice-covered periods. The peak chlorophyll *a* concentration of 34.4 µg/L in early September was associated with diatoms, green algae, and cryptomonads.

Based on the water year, the assemblage was dominated in terms of density by green algae (40%), with diatoms and cryptomonads being the next most abundant taxonomic groups at 31% and 17%, respectively, However, when the size (i.e., biovolume) of each algae was considered, the diatoms were the most dominant algal group (27%) observed over the course of the year, followed by green algae (22%), then cyanobacteria (16%) and cryptomonads (14%). While cyanobacteria were again rare in terms of annual density (5%), a filamentous cyanobacteria bloom occurred in early August and comprised approximately 37% of the total density, and 71% of the total biovolume of the algal assemblage. The filamentous cyanobacteria also comprised a greater portion of the algal assemblage during the months of June, July, and August than in recent years, despite remaining a relatively smaller component of the annual assemblage.

ES 1.4. Temperature and Dissolved Oxygen

The winter period for many front-range reservoirs is often a time of concern, because elevated algal growth combined with aquatic plant growth during the summer season, followed by

mortality and microbial decomposition in the fall can create optimal conditions for reservoir anoxia during ice-covered periods. The flux of decaying organic matter into the bottom sediments can increase the oxygen demand during the fall and winter period. If the winter conditions are unusually cold and the lake becomes completely ice-covered for an extended period of time, the exchange of atmospheric oxygen is blocked and oxygen demand begins consumes the oxygen. These conditions combined with the continued oxygen consumption via decomposition and respiration may lead to anoxia and potentially a fish kill during the ice-covered period or even during spring turnover (aka, "winter kill").

Dissolved oxygen profiles collected in mid-January, during ice-covered conditions, indicated the Reservoir was well oxygenated (7.8 to 16.14 milligrams per liter (mg/L)) and there were no indications of fish mortality during the ice-off period in mid-March. Following spring turnover and the startup of the aeration system, the Reservoir remained well mixed and oxygenated from March to June 2012. There was evidence of early spring stratification due to unseasonably warm April weather warming the upper water layers. In early June, the Reservoir showed signs of a storm-induced thermal stratification. During this time, the large pulse of inflow from the June 8th storm event flowed along the bottom of the Reservoir creating a temperature gradient (i.e., dt/dz greater than 1°C at the 6 depth). During June, the dissolved oxygen concentrations generally remained greater than 5 mg/L throughout the water column, except for the deeper 6-7 m layers and water/sediment interface where dissolved oxygen concentrations averaged 3.4 mg/L.

By the first sampling event in July, dissolved oxygen concentrations began decreasing at depths greater than 5 m with values less than a threshold (2 mg/L) conducive for internal loading at the 7 m layer. 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 and the upper water layer temperatures less than thresholds. However, deep water anoxia (< 2 mg/L) created favorable conditions for internal nutrient loading for approximately 12 weeks during the summer period. In July, the deep layer anoxic conditions were affected by the periodic storm events culminating with the substantial inflow event on July 9th. On July 11th, low dissolved oxygen conditions (~2 mg/L) were observed at the 5 m layer and below. This decrease in dissolved oxygen in the deeper water layers resulted from the combination of cooler high oxygen demand storm water flowing into the Reservoir during peak summer sediment oxygen demand conditions. The cooler water allowed the Reservoir to become thermally stratified as well as increased the oxygen demand in the bottom layers and thereby decreasing the dissolved oxygen concentrations in the Reservoir.

Reservoir profiles were also evaluated to determine the attainment of the dissolved oxygen standard. Over the course of the monitoring year, 84 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 83 of 84 profiles. The exceedance occurred on August 22, 2012 with a minimum average dissolved oxygen value of 4.79 mg/L which occurred at Site CCR-1. During the July to September growing season, the average dissolved oxygen concentration of the upper layer was 6.3 mg/L for all vertical profiles.

ES 1.5. Fish Kill

Between August 14th and August 23rd, a chronic fish kill occurred over a period of five to seven days at Cherry Creek Reservoir. Two species were affected during the event, with gizzard shad comprising 97% of the 548 fish collected by Colorado Parks and Wildlife, and walleye comprising the remaining 3% of the fish collected. No other species such as the black crappie, channel catfish, white sucker or largemouth bass were affected by the event that caused the fish kill. The 2012 fish kill appears to be related to a wind-induced mixing event on August 13th and the corresponding collapse of a filamentous cyanobacteria bloom that comprised 71% of the algal biovolume on August 7th, as discussed above. Following the mixing event, as evident in the wind velocity data for the KAPA weather station and the continuous temperature profile records for the Reservoir, the water column revealed uniform water temperatures from the surface to the bottom of the Reservoir. This event likely resulted in the mixing low/anoxic dissolved oxygen water from the sediment/water interface. While the destratification system has been shown to be effective at mixing the upper water column, the bottom 1 m layer still becomes anoxic during the summer. However, a wind-induced mixing event can turn-over the entire reservoir, including the 1 m anoxic zone and areas that are less likely to mix in the Reservoir. A sudden change in reservoir conditions that mixed anoxic water into the water column combined with the collapse and subsequent decomposition of the filamentosus cyanobacteria bloom likely resulted in the release of cyanotoxins as well as stressful lower dissolved oxygen conditions in the Reservoir that led to the fish kill.

ES 1.6. Destratification System Effectiveness

The 2012 summer season represented the fifth 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 six 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 2012 WY, the Reservoir was thermally stratified for approximately 23 days. These results continue to support the observation that the destratification system has reduced the number of thermally stratified days by approximately 60% 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 193 µg/L upstream to 127 µg/L downstream of the wetland system for a removal efficiency of approximately 16%. Over the past few years the Cottonwood Creek Perimeter Wetland PRF has shown variable removal efficiencies, largely due to the accumulation of sediment and the variable flow conditions for each year; therefore, the PRF was under maintenance from October 2011 through June 2012. The sediment removal project resulted in a bypass of flow around the water quality monitoring station; therefore, the efficiency of this PRF was not evaluated during the 2012 WY.

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 very effective in reducing the flow-weighted total phosphorus concentration. At the upstream end of the reclamation reach in 2012, the annual flow-weighted total phosphorus concentration was 127 µg/L, and at the downstream end it was 91 µg/L. 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 79 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 (364 µg/L) to the downstream (244 µg/L) monitoring location even though remaining above a level considered as background (200 µg/L) for the area. The McMurdo Gulch monitoring sites will continue to be a part of the CCBWQA's monitoring program in 2013, in addition to a new monitoring location on Cherry Creek at Eco Park that will assess water quality as flows pass through the newly reclaimed stream channel on the mainstem.

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 an annual load 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 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 allowable total phosphorus load (total maximum annual load [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 2012). 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 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 1950 by the U.S. Army Corps of Engineers (USACE) to protect the City of Denver from flash floods that may originate 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 hiking.

2.1 Sampling Sites

Sampling during the 2012 WY was routinely conducted at 12 sites, including three sites in Cherry Creek Reservoir, eight 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.

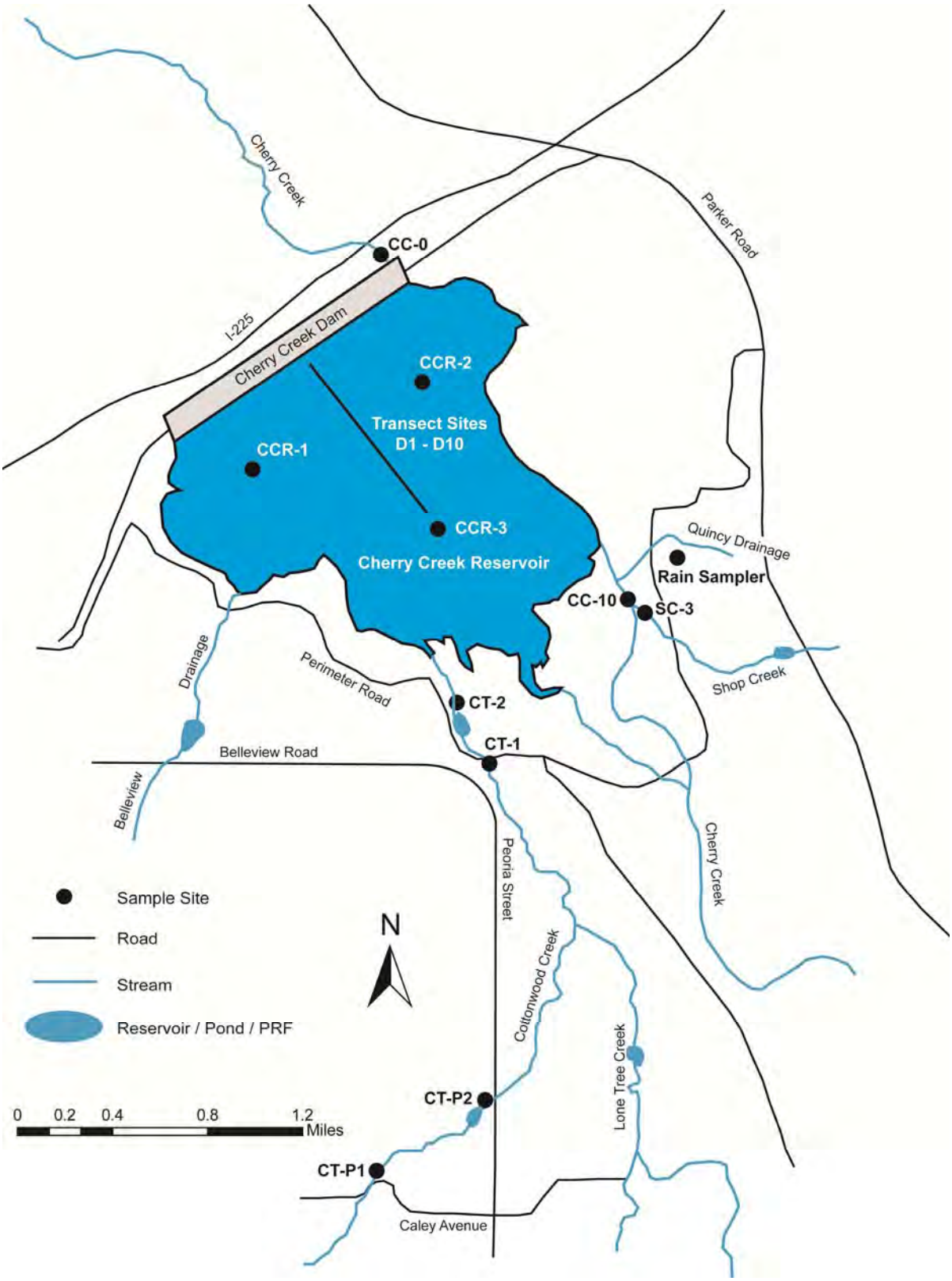

Figure 1: Sampling sites on Cherry Creek Reservoir and selected streams, 2012.

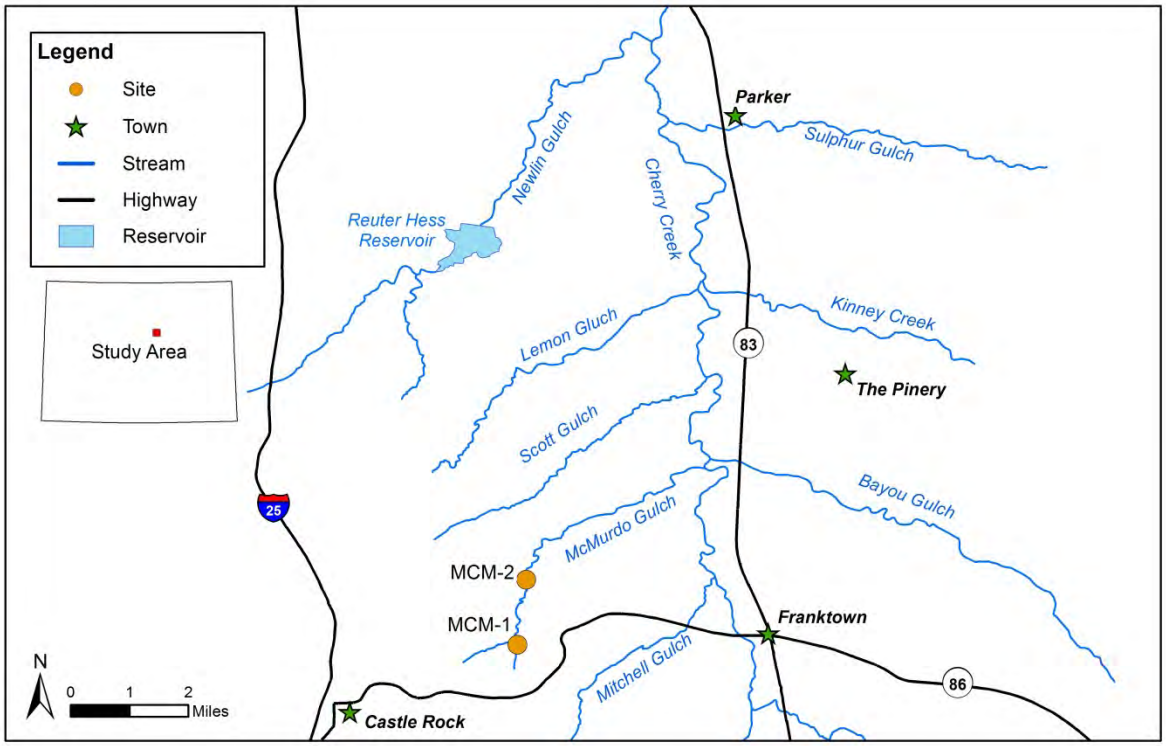

Figure 2: Sampling sites on McMurdo Gulch, 2012.

2.1.3 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 kilometers (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 USGS gage. 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. 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-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 15 reservoir sampling events were conducted during the 2012 WY. The December 2011 and February 2012 sampling events were 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, 2012 WY.

Sampling Period	Frequency	Planned Trips/Period	Actual Trips/Period
Oct - Apr	Monthly	7	5
May - Sept	Bi-Monthly	10	10
Total		**17**	**15**

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). As part of their sampling schedule to reduce mortality to a walleye brood-stock population in Cherry Creek Reservoir, CPW has sampled fish populations every two to three years in the past. The most recent fish population survey was conducted in August through September 2012 by the CPW (personal communication with Paul Winkle, CPW). Therefore, both the 2012 fish stocking and fish population sampling data are presented herein. In an effort to better understand how the fish populations are responding to the changing Reservoir conditions and destratification management strategy, the CPW have increased their fish population sampling to every year.

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 conjunction 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, 2012 WY. See Appendix C for sample dates.

	Sites					
	CC-10	**SC-3**	**CT-P1**	**CT-P2**	**CT-1**	**CT-2**
Number of Storm Samples	7	7	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 six 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.

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.

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-U	2 µg/L
Total Dissolved Phosphorus	QC 10-115-01-4-U	2 µg/L
Soluble Reactive Phosphorus	QC 10-115-01-1-T	2 µg/L
Total Nitrogen	APHA 4500-N B (modified)	2 µg/L
Total Dissolved Nitrogen	APHA 4500-N B (modified)	2 µg/L
Ammonia	QC 10-107-06-3-D	3 µg/L
Nitrate and Nitrite	QC 10-107-04-1-B	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-lake mean values from 1987 to 2012 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 2012 WY Transparency

The whole-reservoir mean Secchi depth varied from 0.49 m in late September to 0.96 m in mid-May (Figure 3). The seasonal (July through September) whole-reservoir mean Secchi depth was 0.61 m (Figure 4). The depth at which 1% of photosynthetically active radiation (PAR) penetrated the water column (i.e., photic zone depth) ranged from 1.52 m in mid-September to a maximum depth 3.15 m in mid-April (Figure 3). The greatest level of whole-reservoir chlorophyll *a* of 34.4 µg/L was observed in mid-September which also coincided with some of the poorest water clarity values (Figure 3).

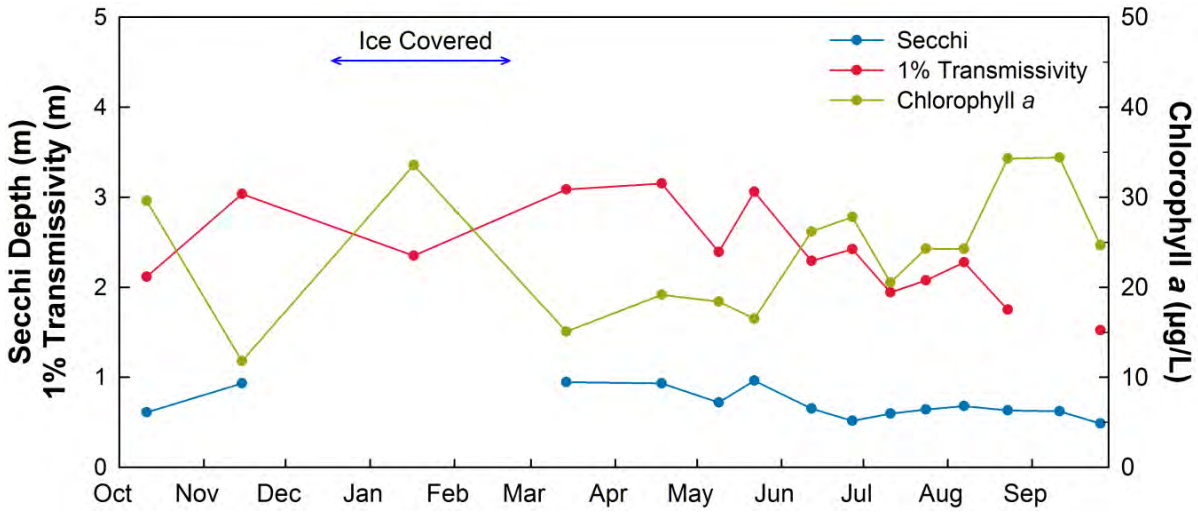

Figure 3: Patterns for mean whole-lake Secchi depth, 1% transmissivity, and chlorophyll *a* in Cherry Creek Reservoir, 2012 WY.

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 2012 seasonal whole-reservoir mean Secchi depth was 0.62 m, which is less than the present long-term (1987 to present) mean value of 0.95 m.

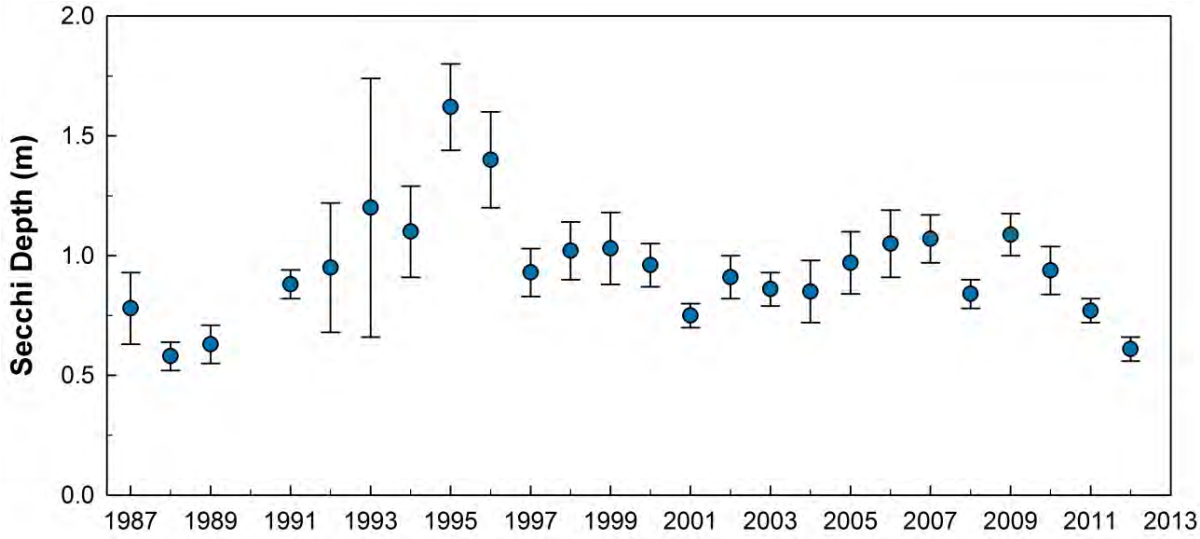

Figure 4: Whole-lake seasonal mean (July through September) Secchi depth (m) measured in Cherry Creek Reservoir. Error bars represent a 95% confidence interval for each mean.

4.1.3 2012 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. 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 Cherry Creek Reservoir were evaluated for periods of potential stratification and low dissolved oxygen levels.

Seasonal water temperatures during routine profile measurements in Cherry Creek Reservoir ranged from 2.27°C at the surface in mid-January to 27.01°C at the surface in late July 2012 (Figure 5, Figure 7, and Figure 9). Temperature loggers were installed on April 10th and showed an early spring stratification period due to the seasonably warm ambient air temperatures that warmed the upper mixed layer. In early June, the Reservoir began showing signs of storm-induced thermal stratification. During this time, the large pulse of inflow

from the June 8th 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 June, the dissolved oxygen concentrations generally remained greater than 5 milligrams per liter (mg/L) throughout the water column, except for the deeper 6-7 m layers and water/sediment interface where dissolved oxygen concentrations averaged 3.4 mg/L.

By the first sampling event in July 2012, 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 7 m layer. 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) created favorable conditions for internal nutrient loading for several weeks during the summer period. In July, the deep layer anoxic conditions were affected by the periodic storm events culminating with the substantial inflow event on July 9th. On July 11th, low dissolved oxygen conditions (~2 mg/L) were observed at the 5 m layer and below (Figure 6). This decrease in dissolved oxygen in the deeper water layers resulted from the combination of cooler high oxygen demand storm water flowing into the Reservoir during peak summer sediment oxygen demand conditions. The cooler water allowed the Reservoir to become thermally stratified as well as increased the oxygen demand in the bottom layers and thereby decreasing the dissolved oxygen concentrations in the Reservoir.

On August 23rd, dissolved oxygen profiles indicated that the water column had become mixed which had reduced the dissolved oxygen content in the upper photic zone (Figure 6, Figure 8, and Figure 10) and resulted in a more uniform water column with respect to dissolved oxygen content.

Reservoir profiles were also evaluated to determine the attainment of the dissolved oxygen standard. Over the course of the monitoring year, 84 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 83 of 84 profiles. The single exceedance occurred on August 22, 2012 with a minimum average dissolved oxygen value of 4.79 mg/L which occurred at Site CCR-1. During the July to September growing season, the average dissolved oxygen concentration of the upper layer was 6.3 mg/L for all vertical profiles.

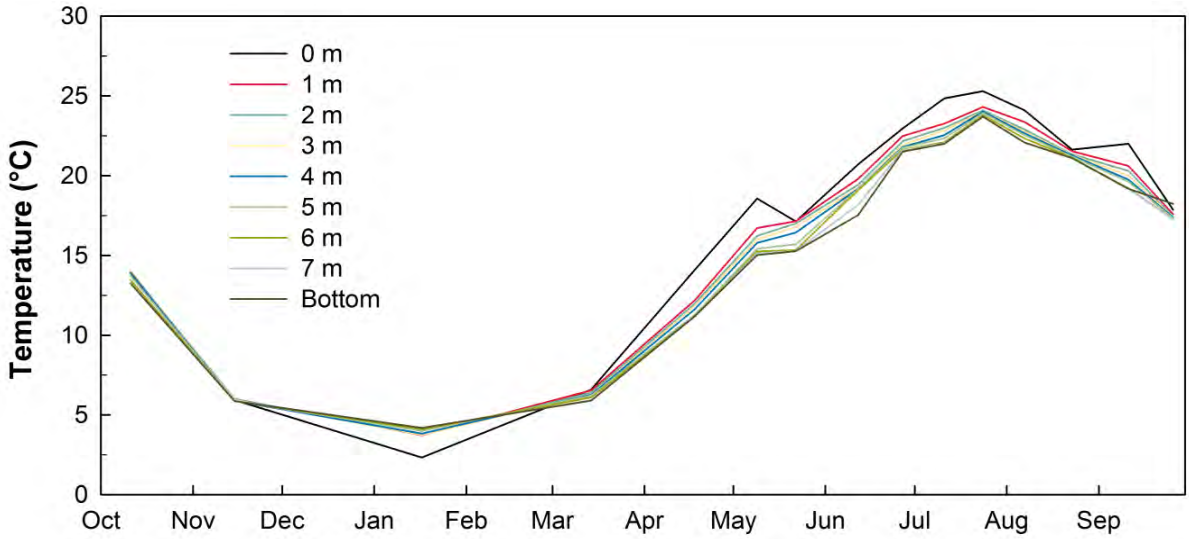

Figure 5: Temperature (°C) recorded at depth during routine monitoring at CCR-1 during the 2012 WY.

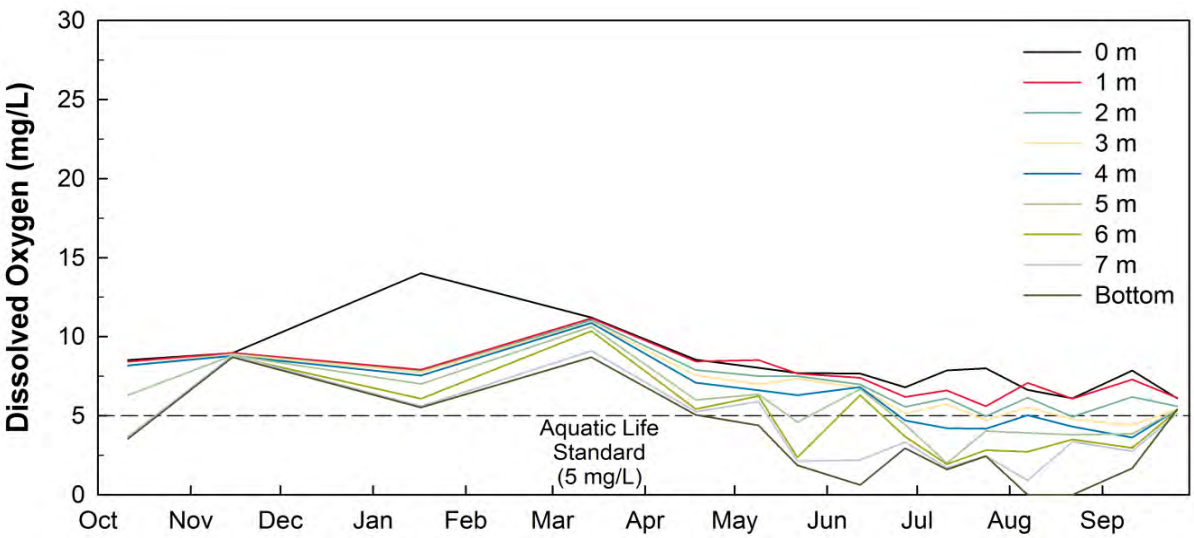

Figure 6: Dissolved oxygen (mg/L) recorded at depth during routine monitoring at CCR-1 during the 2012 WY. The dissolved oxygen basic standards table value for Class 1 warm water lakes and reservoirs is provided for comparison (5 mg/L).

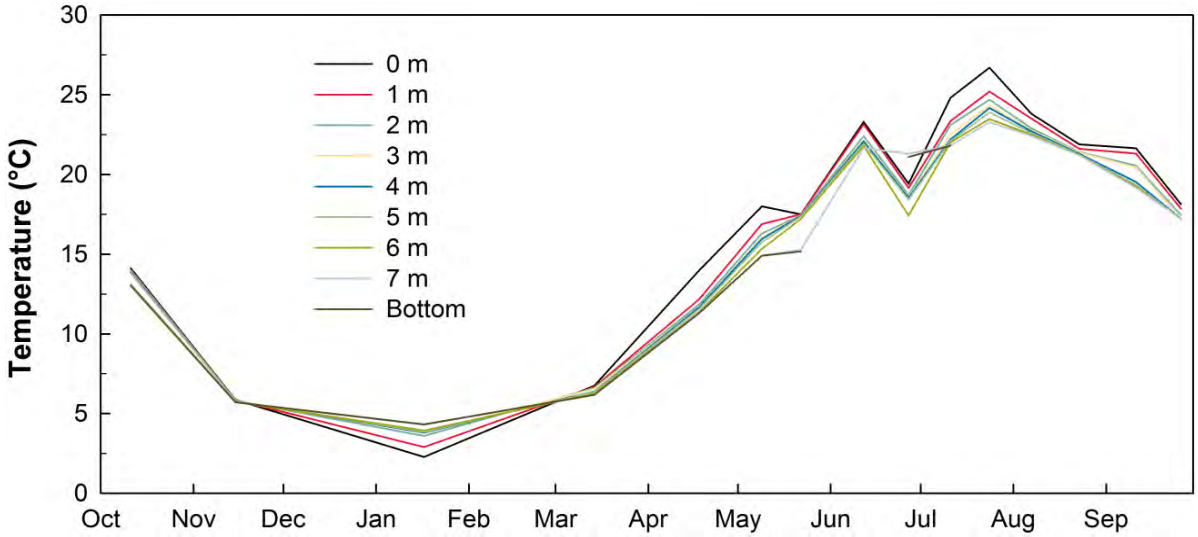

Figure 7: Temperature (°C) recorded at depth during routine monitoring at CCR-2 during the 2012 WY.

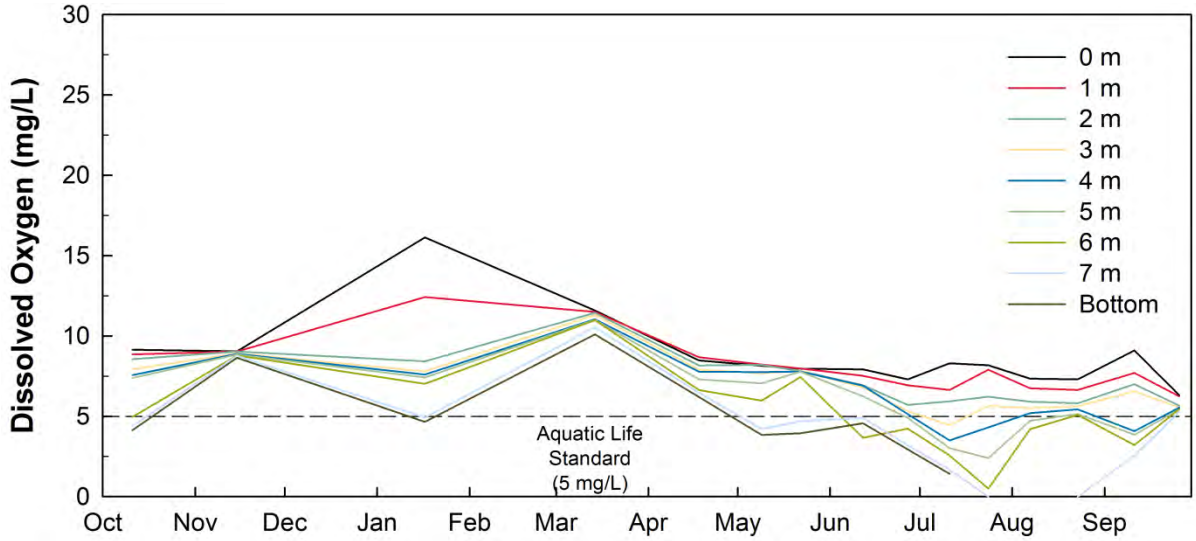

Figure 8: Dissolved oxygen (mg/L) recorded at depth during routine monitoring at CCR-2 during the 2012 WY. The dissolved oxygen basic standards table value for Class 1 warm water lakes and reservoirs is provided for comparison (5 mg/L).

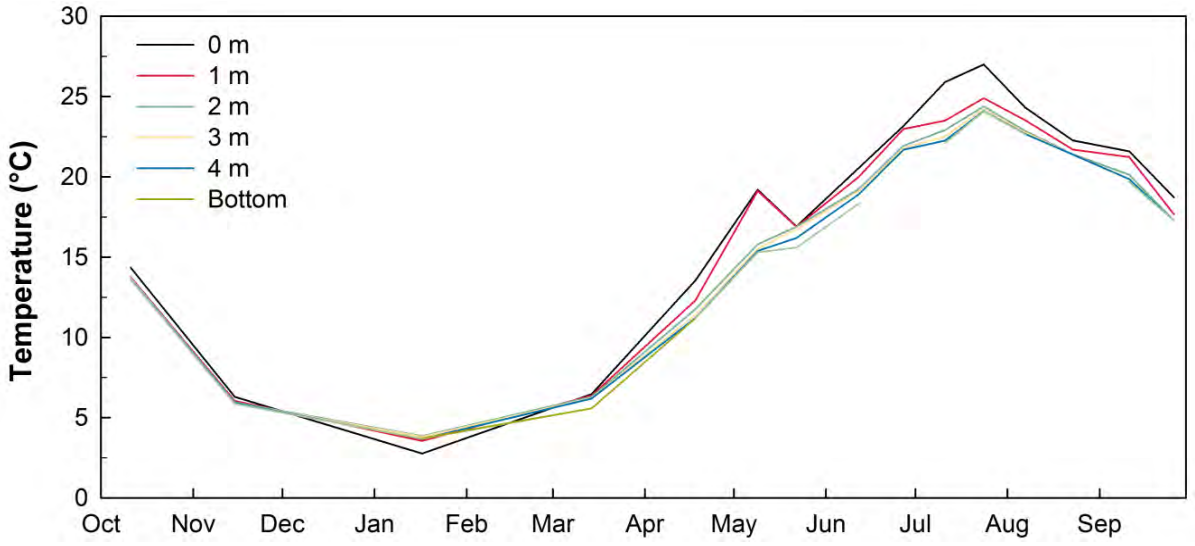

Figure 9: Temperature (°C) recorded at depth during routine monitoring at CCR-3 during the 2012 WY.

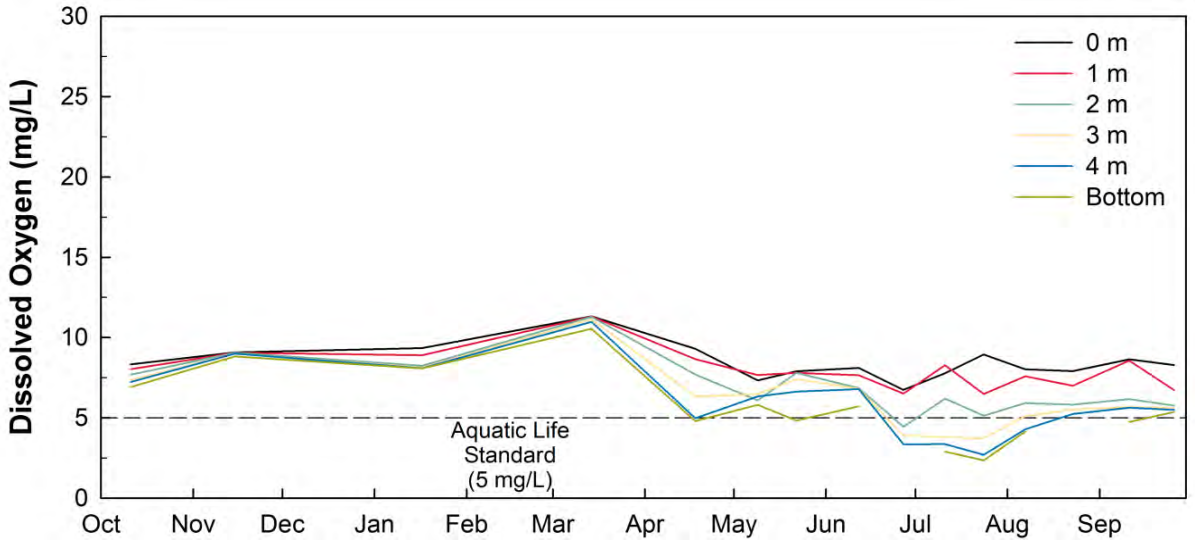

Figure 10: Dissolved oxygen (mg/L) recorded at depth during routine monitoring at CCR-3 during the 2012 WY. The dissolved oxygen basic standards table value for Class 1 warm water lakes and reservoirs is provided for comparison (5 mg/L).

4.1.3.1 Continuous Temperature Monitoring

In April 2012, 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 11th to November 12th (Figure 11, Figure 12, and Figure 13). In late April, the Reservoir became thermally stratified as a result of the seasonably warm spring, and showed two brief periods of storm-induced stratification throughout the rest of the summer. By mid-July the continuous temperature profiles indicated the Reservoir was more thermally consistent with little temperature variation from the surface to the bottom.

On April 22, 2012, the Reservoir began showing signs of brief thermal stratification lasting between three to seven days for each event: April 22nd-28th, June 7th-14th, June 24th-25th, July 11th-14th, and July 21st-22nd. During these brief stratification periods, the deeper water layers of the Reservoir revealed low dissolved oxygen concentrations resulting from the higher sediment oxygen demand during the warmer summer conditions. These low dissolved oxygen levels persisted in the deeper waters throughout much of the summer period, despite the effectiveness of the destratification system at minimizing thermal stratification throughout the remainder of the summer. Within the Reservoir, thermally stratified conditions appear to be more closely linked to ambient weather conditions that either facilitate the onset of stratification or result in complete water column mixing, despite the evidence of the destratification system's effectiveness at circulating the upper water layers (0 to 6 m).

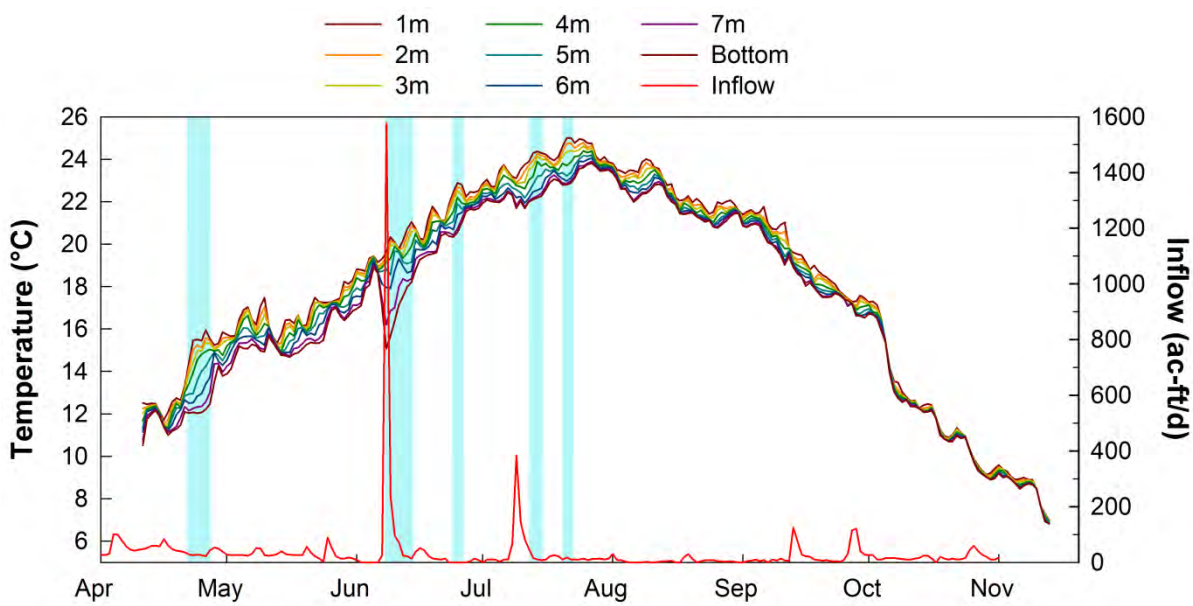

Figure 11: Daily mean temperature (°C) recorded at depth for CCR-1 based on 15-minute interval data collected by temperature loggers, with USACE inflow in 2012. Shaded areas denote periods of thermal stratification.

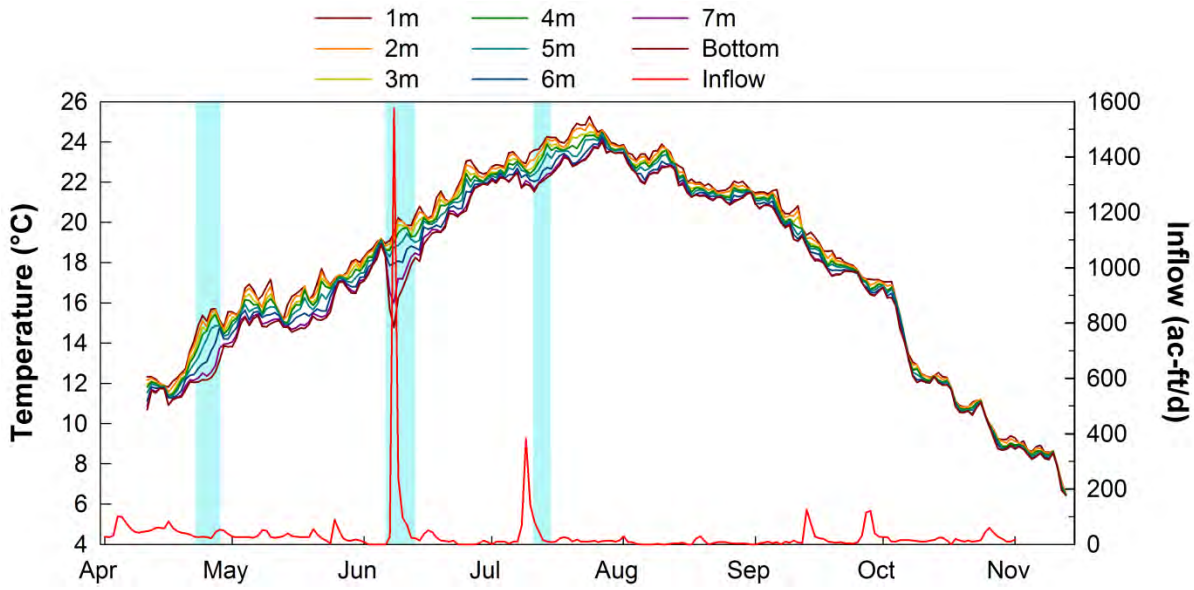

Figure 12: Daily mean temperature (°C) recorded at depth for CCR-2 based on 15-minute interval data collected by temperature loggers, with USACE inflow in 2012. Shaded areas denote periods of thermal stratification.

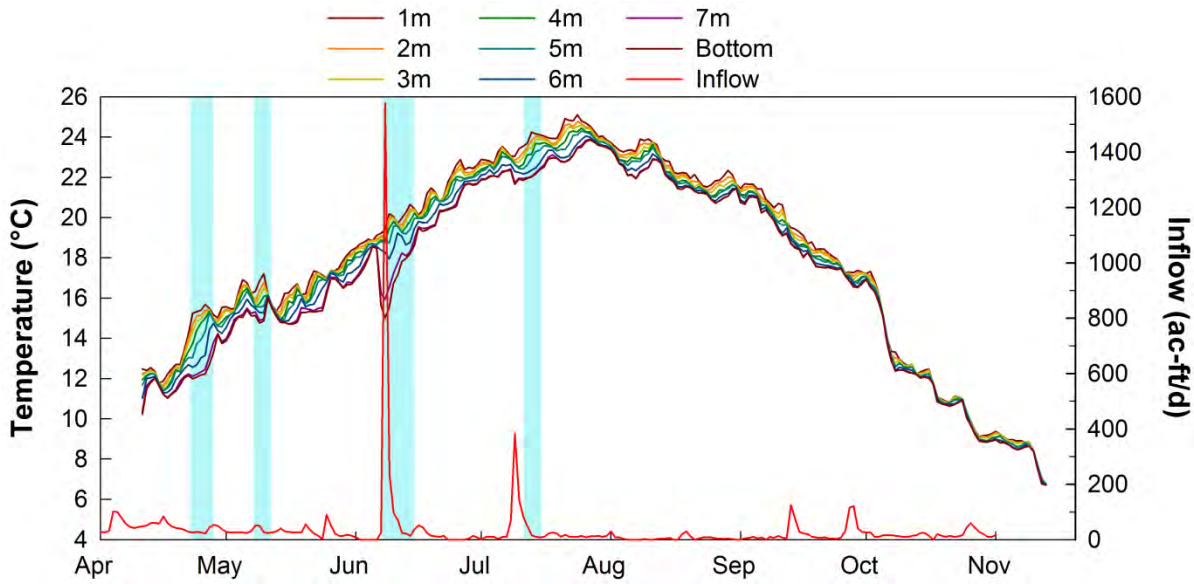

Figure 13: Daily mean temperature (°C) recorded at depth for CCR-3 based on 15-minute interval data collected by temperature loggers, with USACE inflow in 2012. Shaded areas denote periods of thermal stratification.

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 eleven locations along the transect and the nearby Site CCR-3 location, on three sample dates (Figure 14).

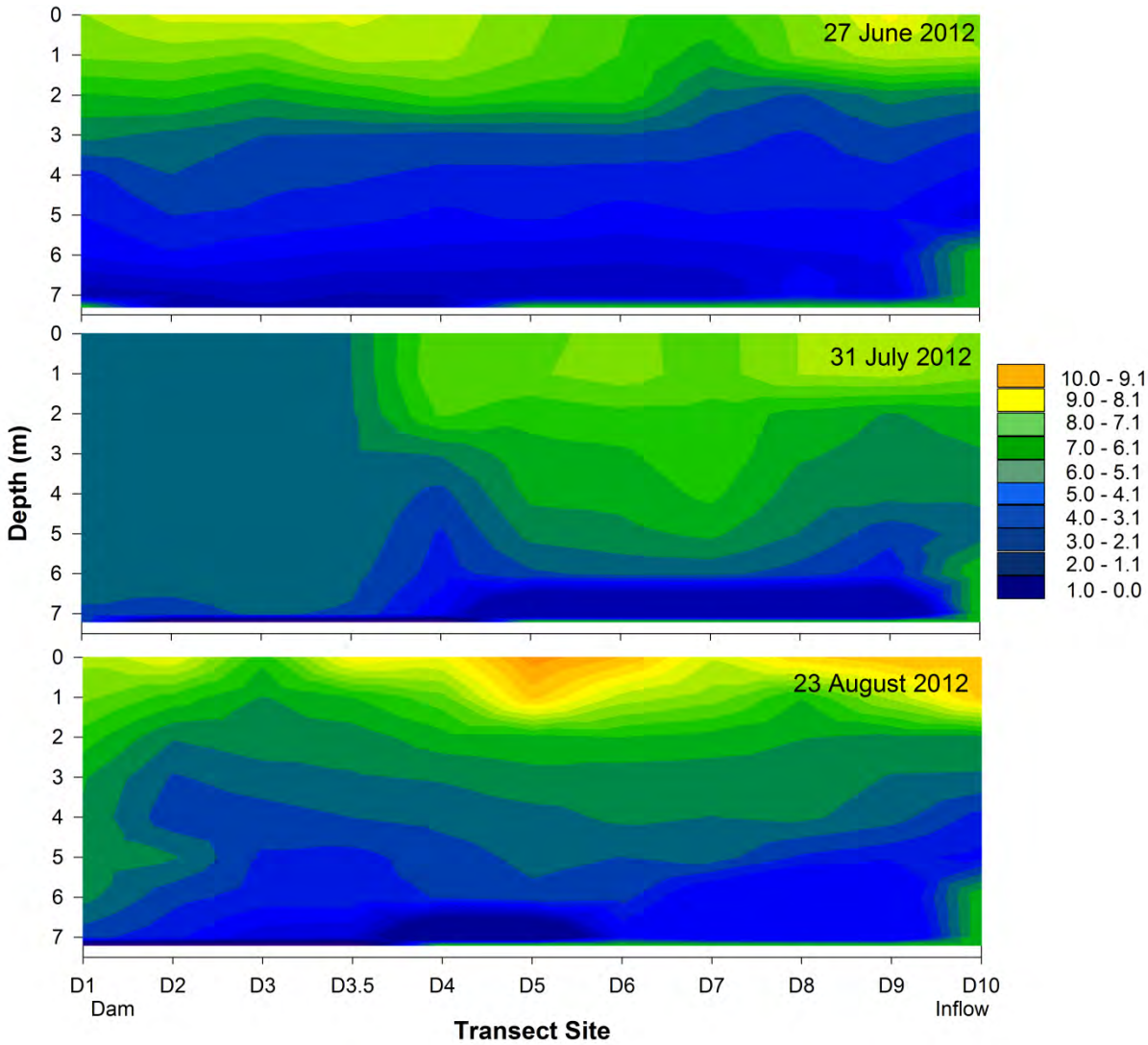

Figure 14: Dissolved oxygen conditions in Cherry Creek Reservoir for three dates based on transect profile data during the 2012 WY.

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 lakes 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 at the water-sediment interface, the redox potential will greatly decrease, often ranging from -200 to 0 mV, indicating conditions are favorable for internal nutrient loading as well as other elemental releases. When reviewing ORP profile measurements (Figure 15), 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 27th, the Reservoir was well oxygenated (dissolved oxygen values of 5 to 7 mg/L) from the surface down to a depth of approximately 3 m (Figure 14). 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 6.2 mg/L indicating the Reservoir was in attainment of the dissolved oxygen standard. At the water-sediment interface the mean dissolved oxygen concentration was 2.9 mg/L (Figure 14; Appendix B).

The July 31st transect profiles documented the extent of the anoxic zone as discussed above (Figure 14). The average dissolved oxygen concentration of the 1 m and 2 m layer values along the transect was 6.0 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 5.3 mg/L and 5.1 mg/L, respectively. The dissolved oxygen concentration at the 7 m layer and at the water-sediment interface was 4.5 mg/L and 0.5 mg/L, respectively. Similarly, the oxidation-reduction potentials at the water/sediment interface revealed favorable conditions for a reducing environment (Figure 15).

The last transect profile was collected on August 23rd and showed similar conditions in the dissolved oxygen concentrations in the Reservoir in the upper layer (1 m and 2 m) and the water-sediment interface. The average concentration in the upper layer was 6.3 mg/L and in attainment of the standard, while the dissolved oxygen concentration in the 4 m and 5 m layers was 4.9 mg/L and 4.7 mg/L, respectively. The dissolved oxygen concentration at the 7 m layer and at the water-sediment interface was 2.5 mg/L and 0.9 mg/L, respectively.

The oxidation-reduction potential profiles on June 27th, July 31st, and August 23rd also indicate that conditions were favorable for a reducing environment at the water-sediment interface (Figure 15). 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).

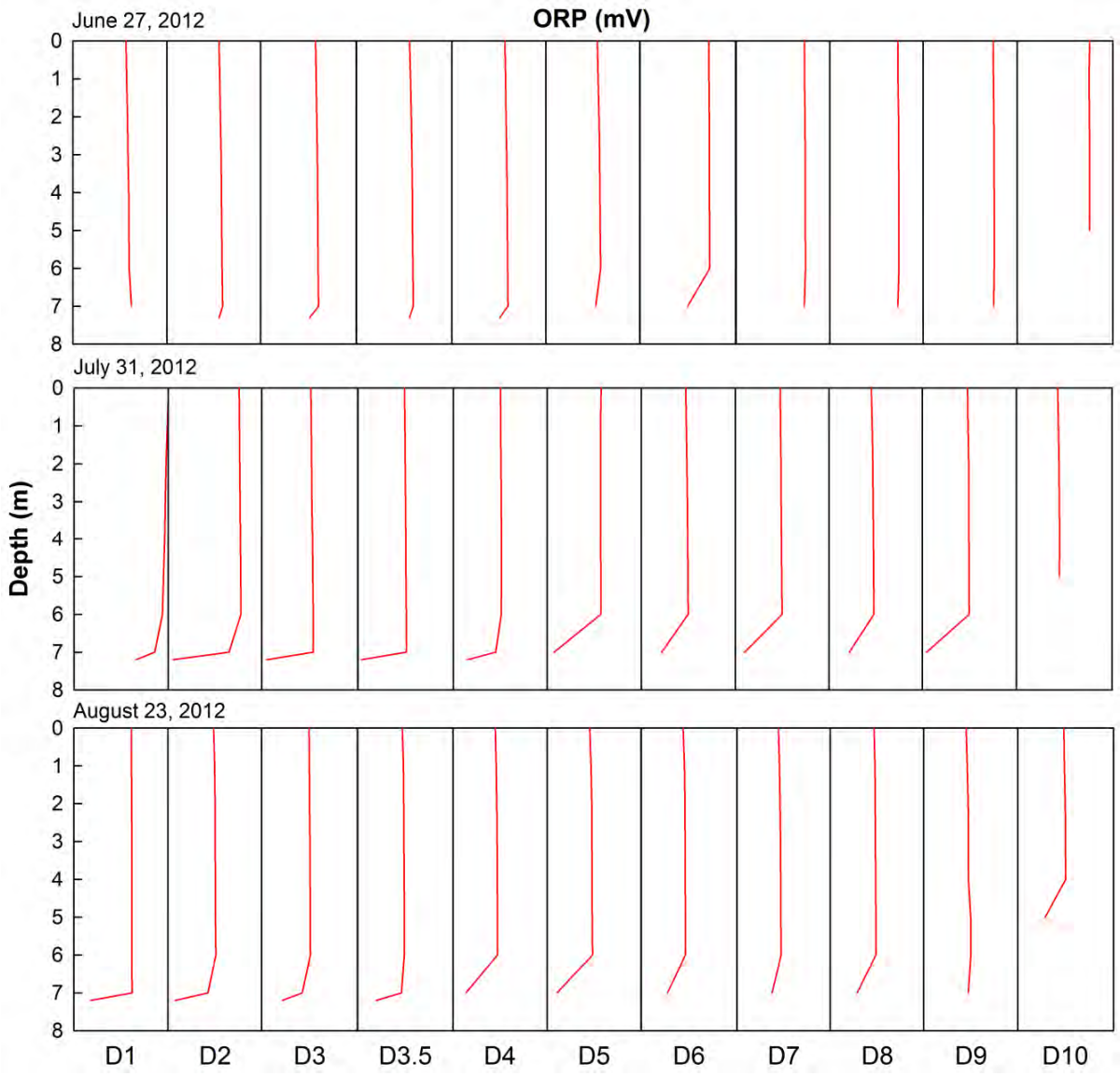

Figure 15: Oxidation reduction potentials (ORP) in Cherry Creek Reservoir for three dates based on transect profile data during the 2012 WY. The ORP scales for each transect are all relative to each other within and among sampling events.

4.1.4 2012 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 2012 WY, the photic zone mean concentration of total phosphorus ranged from 66 to 149 µg/L with an overall water year mean of 114 µg/L. The seasonal (July through September) photic zone concentrations ranged from 132 to 149 µg/L (Figure 16), with a seasonal mean of 141 µg/L. Reservoir internal loading contributed substantially to the higher seasonal mean total phosphorous concentrations because an internal loading period began in May 2012.

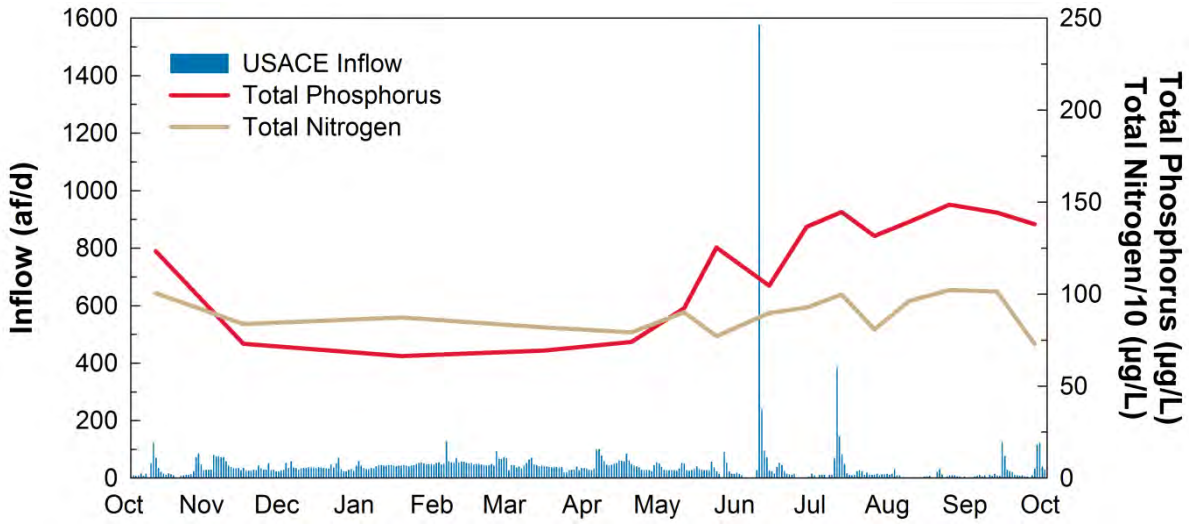

Figure 16: Annual pattern of photic zone total phosphorus, total nitrogen and USACE inflow in Cherry Creek Reservoir, 2012 WY.

Patterns in soluble reactive phosphorus concentrations collected during profile sampling at Site CCR-2 showed a well-mixed Reservoir throughout the year (Figure 17). In mid-January there was an internal release of soluble reactive phosphorous. 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 lead to brief anoxic conditions that 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 17). The period of internal phosphorous loading shows a substantial increase in phosphorus at the 6 m and 7 m depths, and a pattern of more consistent concentrations among the upper layers, though also elevated. This consistency within the upper layers is due to the upward diffusion of phosphorus from the sediment layer at approximately 7.2 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 July and August period, the soluble reactive phosphorus fraction in the 7 m water layer accounted for approximately 44 to 56% 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 729 to 1,023 µg/L, with a 2012 WY average of 891 µg/L. During the July through September period, the photic zone total nitrogen concentration also ranged from 729 to 1,023 µg/L, with a mean concentration of 923 µg/L.

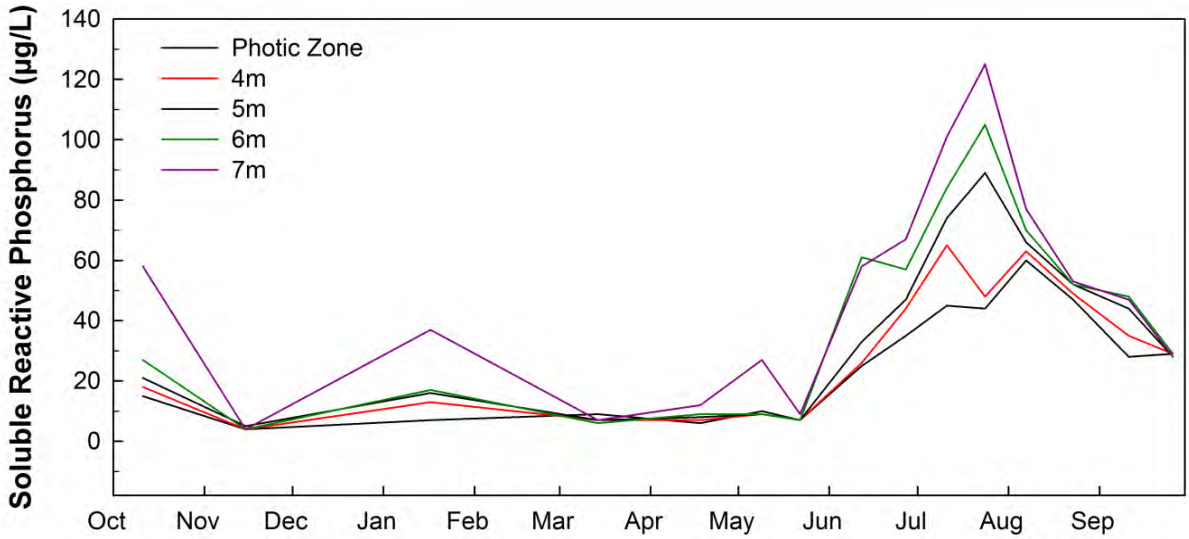

Figure 17: Soluble phosphorus concentrations recorded for the photic zone and at depth during routine monitoring during the 2012 WY.

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 2012 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. Therefore, GEI also evaluated more recent trends in the data from 1999 through 2012.

Routine monitoring data collected since 1987 indicates a general increasing pattern in summer mean concentrations of total phosphorus (Figure 18). In 2012, the July through September mean concentration of total phosphorus was 141 µg/L. This value is less than last year's 154 µg/L concentration, and it is greater than the long-term median value of 85 µg/L (Table 4). Regression analyses performed on 1987 to 2012 seasonal mean total phosphorous data indicates a significant ($p < 0.001$) increasing trend.

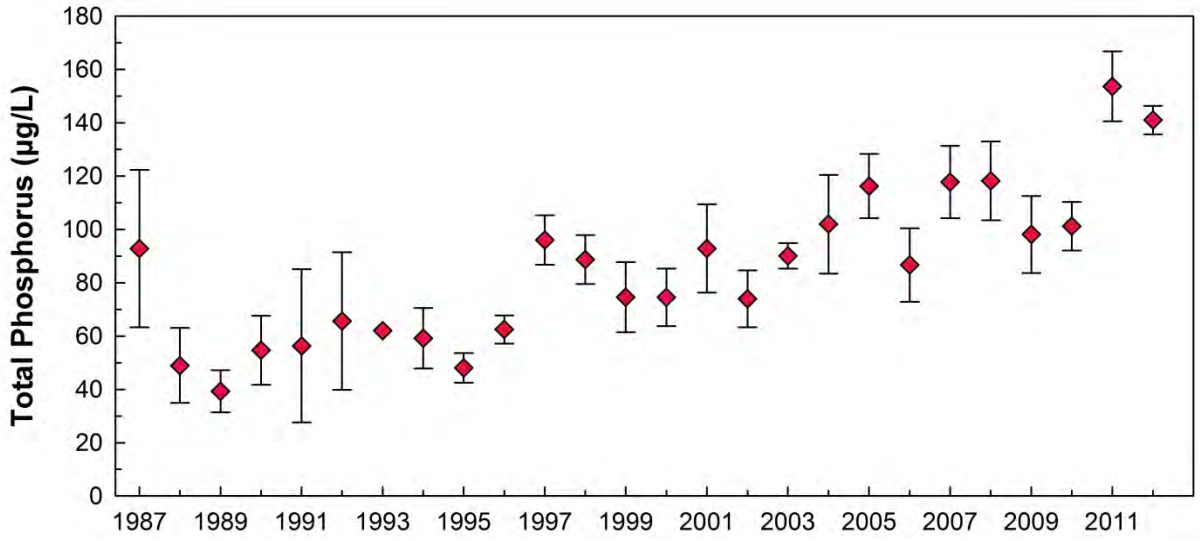

Figure 18: Seasonal mean (July through September) total phosphorus concentrations (µg/L) measured in Cherry Creek Reservoir, 1987 to 2012. Error bars represent a 95% confidence interval for each mean.

Table 4: Comparison of water year mean and July through September mean phosphorus, nitrogen, and chlorophyll *a* levels in Cherry Creek Reservoir, 1988 to 2012.

	Total Nitrogen (µg/L)		Total Phosphorus (µg/L)		Mean Chlorophyll *a* (µg/L)	
Year	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

Table 4 Cont.

Year	Total Nitrogen (µg/L)		Total Phosphorus (µg/L)		Mean Chlorophyll *a* (µg/L)	
	WY	Jul-Sep	WY	Jul-Sep	WY	Jul-Sep
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
Mean	**883**	**946**	**77**	**85**	**17.2**	**19.5**
Median	**891**	**934**	**81**	**87**	**16.5**	**18.2**

4.1.6 2012 WY Chlorophyll a Levels

The annual pattern of chlorophyll *a* concentrations was quite variable with chlorophyll *a* less than 18 µg/L during the months of November, March and May, but considerably greater during fall 2011, winter, and late summer (Figure 19). From October 2011 through September 2012, chlorophyll *a* concentrations ranged from 11.8 µg/L to 34.4 µg/L. Algal production is typically the lowest during the spring time of year, when the reservoir experiences flushing flows from spring runoff and seasonal storms. During the fall and winter, diatoms typically dominate the algal community and contribute to the increased chlorophyll *a* levels due to their larger chloroplast size and enhanced light capturing abilities of these algae. During the 2012 winter ice-covered conditions, cryptophytes were the most abundant algal group that 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). The July through September seasonal mean chlorophyll *a* level was 27.1 µg/L, with a peak seasonal reservoir mean concentration of 34.4 µg/L. The 2012 WY mean chlorophyll *a* concentration was 24.0 µg/L.

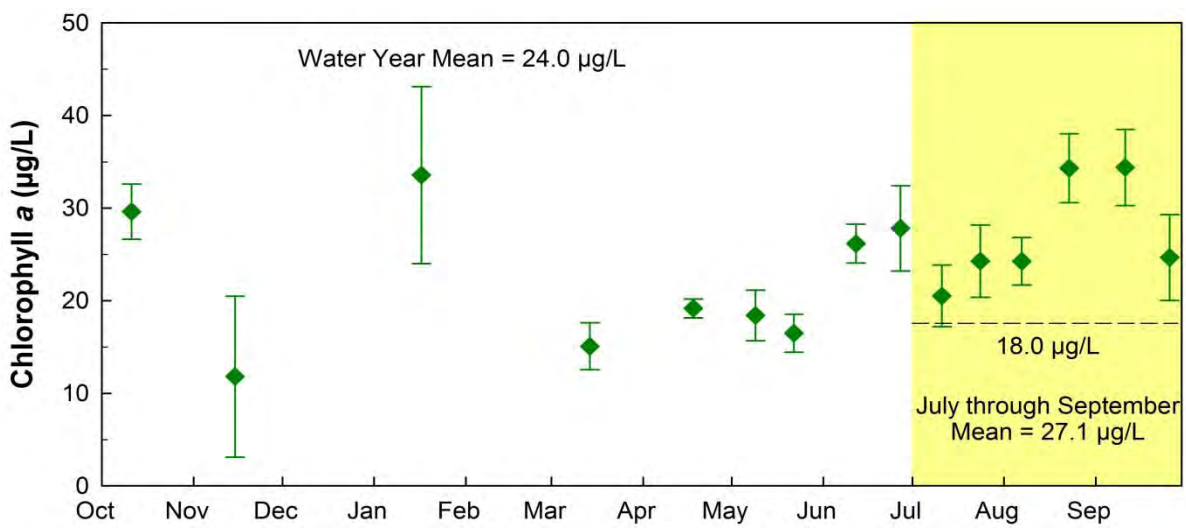

Figure 19: Concentration of chlorophyll *a* (µg/L) in Cherry Creek Reservoir, 2012 WY. Error bars represent a 95% confidence interval around each mean. Highlighted area denotes the seasonal period for the chlorophyll *a* standard.

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 20). 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 and 2012 seasonal mean chlorophyll *a* level was not as high as 2010, but were considerably greater than the 18 µg/L chlorophyll *a* standard. The 2012 chlorophyll *a* conditions represent the third consecutive year the Reservoir has exceeded the seasonal chlorophyll standard, as well as the allowable exceedance frequency of one in five years (Figure 20).

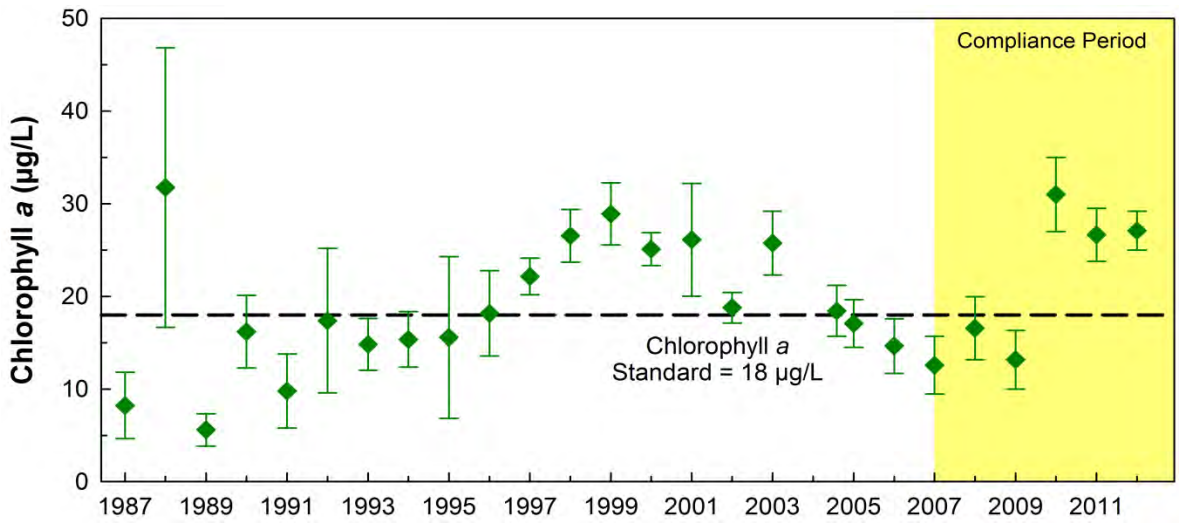

Figure 20: Seasonal mean (July through September) concentrations of chlorophyll *a* (µg/L) measured in Cherry Creek Reservoir, 1987 to 2012. Error bars represent a 95% confidence interval around each mean.

4.2 Reservoir Biology

4.2.1 2012 WY Phytoplankton

Phytoplankton density in the photic zone ranged from 286 #/mL on April 18th to 7,770 #/mL on March 14th (Table 5). The number of algal taxa present in the Reservoir ranged from 10 on March 14th, to 28 on August 23rd. Based on the water year, the assemblage was dominated in terms of density by green algae (40%), with diatoms and cryptomonads being the next most abundant taxonomic groups at 31% and 17%, respectively (Figure 21). Similar to 2011, the relative density of large filamentous cyanobacteria (5%) was extremely low in 2012. Diatoms were relatively abundant throughout most of the year with exception to the month of January, when cryptomonads dominated the algal assemblage in terms of density. In March 2012, the majority of the algal assemblage was comprised of diatoms (96%) which changed to an algal assemblage dominated by green algae in April 2012 (Figure 21).

Table 5: Density (#/mL) of phytoplankton and total number of taxa collected from all three sites on Cherry Creek Reservoir, 2012 WY.

Sample Date	Taxonomic Group									
	Diatoms	Green Algae	Cyano-bacteria	Golden Algae	Euglenoid	Dino-flagellate	Crypto-monads	Unknown flagellate	Total Density	Total Taxa
10/11/2011	1,592	3,979	66	--	66	862	531	--	7,097	26
11/15/2011	1,611	2,416	--	215	107	644	1,128	--	6,121	22
1/17/2012	--	1,106	--	638	43	43	2,766	43	4,638	11
3/14/2012	7,444	163	--	163	--	--	--	--	7,770	10
4/18/2012	28	216	--	28	14	--	--	--	286	13
5/9/2012	528	1,480	--	106	247	35	1,762	--	4,158	25
5/22/2012	362	2,094	--	--	81	--	2,174	--	4,711	18
6/12/2012	972	1,866	156	39	194	--	622	--	3,849	26
6/27/2012	1,409	1,070	209	--	26	--	26	--	2,740	21
7/11/2012	855	1,267	380	32	127	--	253	--	2,914	25
7/24/2012	1,634	2,288	368	--	82	41	449	--	4,861	23
8/7/2012	606	1,002	1,002	--	42	--	84	--	2,735	21
8/23/2012	3,440	1,481	430	--	--	48	48	--	5,446	28
9/11/2012	2,436	1,970	104	--	52	52	1,451	52	6,117	24
9/26/2012	1,111	1,616	--	--	202	202	438	--	3,568	26

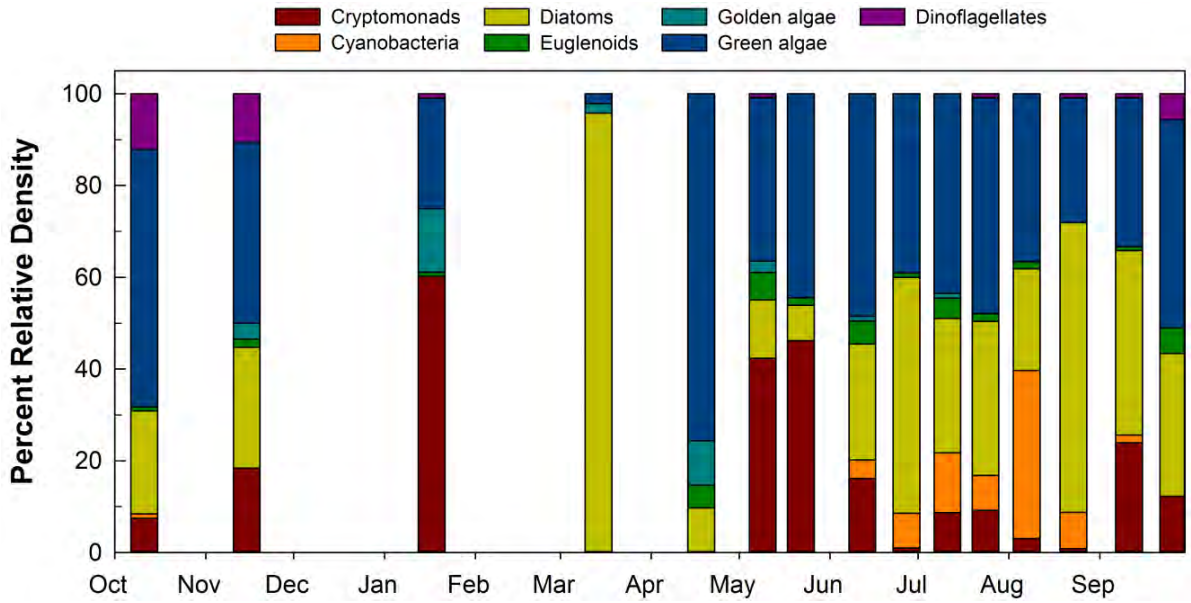

Figure 21: Percent relative density of algal groups by sample date in Cherry Creek Reservoir, 2012 WY.

When the size (i.e., biovolume) of each algae is considered, the diatoms were the most dominant algal group (27%) observed over the course of the year, followed by green algae (22%), then cyanobacteria (16%) and cryptomonads (14%) (Figure 22). The dinoflagellates only accounted for approximately 7% of the total 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 2012, diatoms were abundant, but dinoflagellates were also common in late September. 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 the late winter, the flagellated cryptomonad algae (*Cryptomonas erosa*), a green algae (*Chlamydomonas* sp.) were abundant in terms of biovolume; although another cryptomonad (*Rhodomonas minuta*), the nonmotile green algae (*Ankistrodesmus falcatus*) and a golden algae (*Chrysococcus rufescens*) were the most dominant algae in terms of density. The diatoms and cryptomonads were the dominant algal groups in terms of density in the spring. Diatom dominance in the spring is common given the changing water temperature conditions and light typically occurring after ice off conditions. The cryptomonads (motile algae) also likely gain a competitive advantage in the spring given the constant mixing conditions of the destratification system.

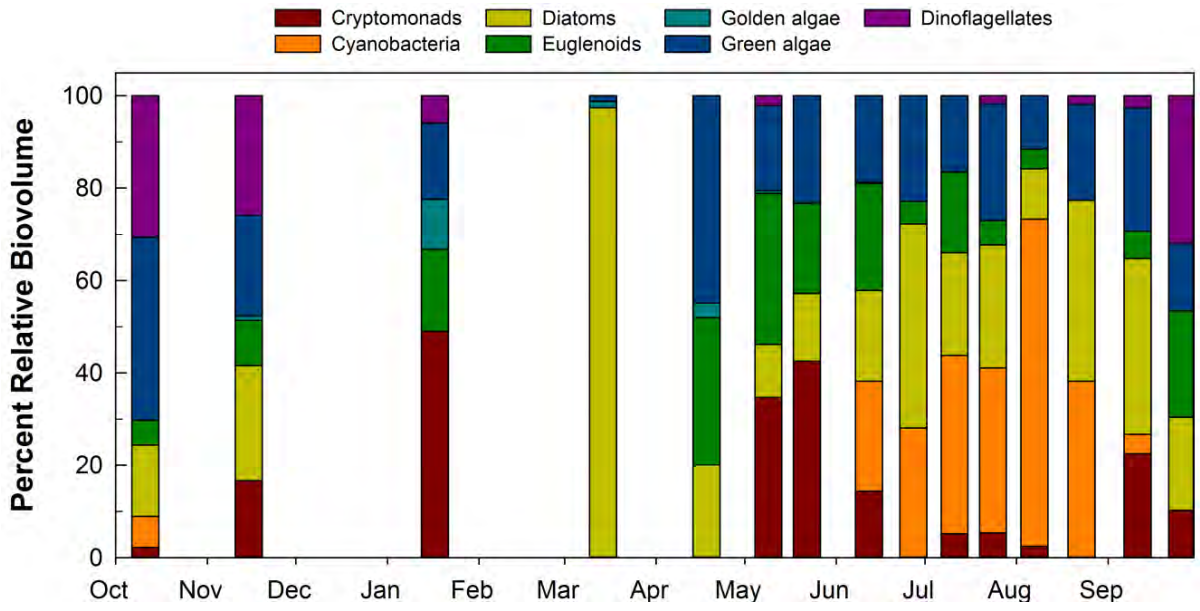

Figure 22: Percent relative biovolume of algal groups by sample date in Cherry Creek Reservoir, 2012 WY.

In the Rocky Mountain region, cryptomonads appear to prefer colder water (Kugrens and Clay 2003) which explains their dominance 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). During the fall, the diatoms became the more dominant algal group. Cyanobacteria were again rare in terms of annual density (5%), although this group did have an early August bloom when they comprised approximately 37% of the total density, and 71% of the total biovolume of the algal assemblage. This early August cyanobacteria bloom was primarily comprised of *Aphanizomenon flos-aquae*, a filamentous nitrogen fixing cyanobacterium whose trichome is composed of many individual cells to form one physiological entity (Komárek et al. 2003) which explains their larger biovolume relative to their density. The larger filamentous cyanobacteria were present in early June 2012, and comprised approximately 34% of the algal biovolume during June through August. 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) and were more dominant in terms of density and biovolume in the Reservoir during the 2012 summer than in previous years.

A key aspect in the algal successional patterns is that cyanobacteria were only dominant during a few weeks in early to mid-August. Thirty-five days after this cyanobacteria bloom was observed on August 7th, this group comprised less than 2% of the assemblage in terms of density and approximately 4% 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 early June storm event, the Reservoir was likely "flushed" of the cryptomonads, either by direct outflow or the sudden changes in reservoir conditions (i.e., lower temperature and lower light due to sediment influx) that were less conducive to their growth. This resetting of the assemblage in late June provided a competitive edge to the diatom (*Stephanodiscus astraea minutula*) that dominated the assemblage in terms of density and biovolume.

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. However, the sudden decline of cyanobacteria in late August is likely a result of reduced internal phosphorus loading at this time combined with the collapse of the population due to a wind-driven mixing event, as discussed herein.

In the event of reduced top-down pressure such as low zooplankton grazing, the algal assemblage can maximize their relative density given constraints 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 2012 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).

During the 2012 WY, the Reservoir exhibited extremely high chlorophyll *a* level at various periods throughout the year. In late August, the high chlorophyll *a* level of 34.3 µg/L was associated with an abundance of *Aphanizomenon flos-aquae* (cyanobacteria), *Chlamydomonas* sp. (green algae), and *Stephanodiscus astraea minutula* (diatom). The high chlorophyll *a* level of 34.4 µg/L in early September was associated with an abundance similar species compared to August, with the exception of *Aphanizomenon flos-aquae* (cyanobacteria) which was replaced by *Cryptomonas erosa* (cryptomonad). The high chlorophyll *a* levels measured in June ranged from 26.2 µg/L to 27.8 µg/L were associated with a variety of algae; however several diatoms comprised a large proportion of the algal biovolume (44%).

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 23). 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 23). Cryptomonads, diatoms, and green algae have become the dominant algal types, all of which are a better food source for zooplankton and fish.

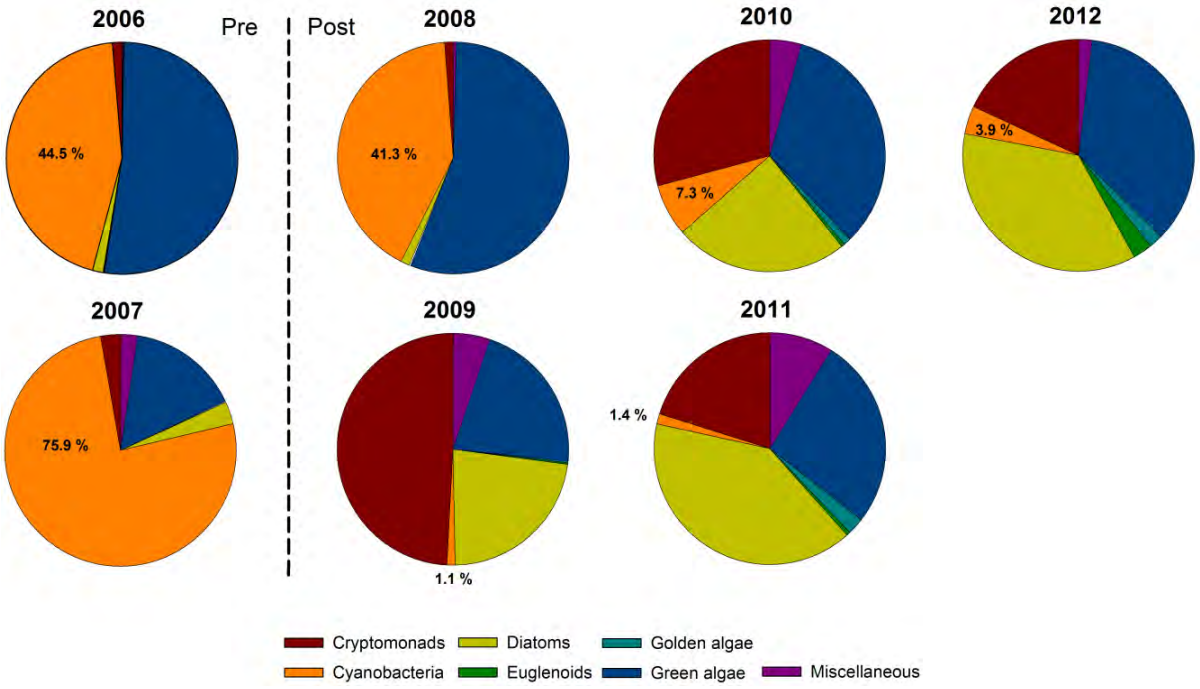

Figure 23: Percent algal density of major taxonomic groups in Cherry Creek Reservoir, pre- and post-operation of the destratification system. For comparative purposes, diagrams are based on the calendar year composition rather than water year.

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 2012 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.

4.2.3 2012 Zooplankton

Zooplankton density ranged from 45 organisms/L in mid-July to 427 organisms/L which occurred in mid-April 2012 (Figure 24). A total of eight zooplankton crustacean species—five cladocerans and three copepods with immature copepodids and nauplius—and nine species of rotifers were collected during the 12 sampling events (Appendix C). There were three species that were collected during all 12 sampling events: one relatively smaller cladoceran (*Bosmina longirostris*), a copepod *(Diacyclops thomasi*), and a rotifer (*Keratella cochlearis*). One cladoceran (*Skistodiaptomus pallidus*) was collected during 11 of the 12 sampling events and another cladoceran (*Daphnia galeata mendotae*) was found during 10 sampling events. The other two cladoceran taxa, mainly larger daphnia, were observed to occur over shorter time periods (i.e., 1 to 8 weeks) and were more common in late July and early August 2012. The immature copepods (copepodids and nauplius) were also observed during all 12 sampling events. *Bosmina longirostris* have been found to be the dominant cladoceran in other eutrophic lakes (Harman et al. 1995).

During the March 2012 sampling event, rotifers comprised only 3% of the total zooplankton density, while during the April and May 2012 this group comprised approximately 49 to 75% of the zooplankton density. Cladocera were relatively abundant in mid-March, and then again during early August through mid-Septembers cladocerans comprised the majority of the zooplankton assemblage (Figure 24). The total density of zooplankton generally follows the pattern of chlorophyll *a* concentration (Figure 24); 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.

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.

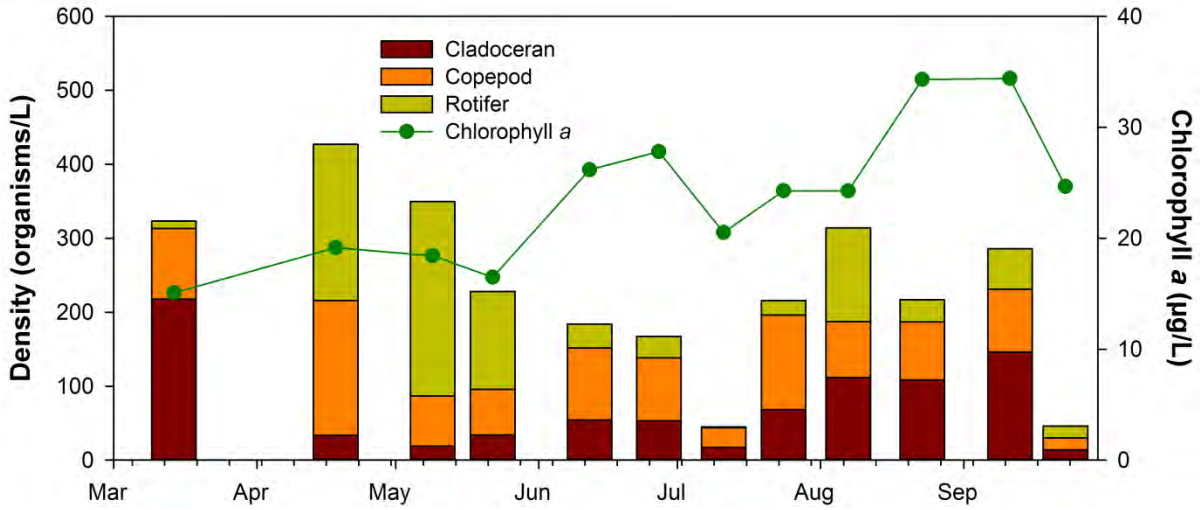

Figure 24: Total density of zooplankton groups and chlorophyll *a* concentration by sample date in Cherry Creek Reservoir, 2012 WY.

4.2.4 2012 Fish Stocking and Populations

Historically, the fish assemblage has been composed of many species that represent a variety of trophic levels, which include omnivores, insectivores, zooplanktivores, and piscivores. Fish can exert a strong influence on the structure and productivity of phytoplankton and zooplankton assemblage through food web pathways between different levels (phytoplankton, zooplankton, and fish) of the aquatic ecosystem (Carpenter et al. 1985). In addition, these trophic dynamics can affect the variability, distribution, and ratios of limiting nutrients, such as phosphorus and nitrogen (Vanni et al. 1996). Mechanisms that may possibly result because of fish predation include decreased herbivory by zooplankton when fish are abundant, modification of nutrient recycling rates by herbivorous zooplankton as fish abundance varies, and nutrient recycling by fish (Vanni and Layne 1996).

Stocking data from the Colorado Parks and Wildlife (CPW) shows that 11 species and 3 hybrids have been stocked in Cherry Creek Reservoir from 1985 to 2012 (Appendix E). The three stocked hybrids have been the wiper (striped bass × white bass), the tiger musky (northern pike × muskellunge), and a trout hybrid (rainbow × cutthroat trout). Of these 14 stocked fish taxa, rainbow trout and walleye have been stocked every year. In 2012, the CPW stocked 29,872 rainbow trout (*Oncorhynchus mykiss*). CPW also stocked warm water species that included 11,750 channel catfish (*Ictalurus punctatus*), 41,541 black crappie (*Pomoxis nigromaculatus*), and 4 million walleye (*Sander vitreus*). All of the warm water fish were subcatchable size fish.

CPW performed a fish population survey on August 29, 2012, and observed that 41% of the fish collected were gizzard shad (*Dorosoma cepedianum*), while walleye and white sucker (*Catostomus commersonii*) comprised the majority of the remaining individuals collected, 18% and 30% respectively. In 2008, CPW observed that gizzard shad only comprised 20% of the fish collected, thus over the 3 years the gizzard shad population has increased at least

2.5 fold. In contrast, the walleye have decreased 2.5 fold from 41% (2008) to 18% of the fish collected. This is one of the relationships in food web dynamics between the beneficial algae, zooplankton, forage fish and predatory fish that should be evaluated in the future to fully understand the effects of the destratification system on reservoir ecology.

4.2.5 2012 Fish Kill

Between August 14th and August 23rd, a chronic fish kill occurred over a period of five to seven days at the Reservoir. Two species were affected by the event, with gizzard shad (*Dorosoma cepedianum*) comprising 97% of the 548 fish collected by CPW, and walleye (*Sander vitreus*) comprising the remaining 3% of the fish collected. This resulted in GEI conducting additional water column surveys on August 22 and 23, 2012 at the three monitoring locations to better assess diurnal fluctuation (August 22nd at 3:00 pm and 8:30 pm, August 23rd at 6:30 am) and potential factors that contributed to the fish kill. In addition, GEI performed the routine bi-monthly sampling events on August 7th and August 23rd that included nutrient, algal biomass, phytoplankton, zooplankton analyses, and thermistor data.

4.2.5.1 Continuous Temperature Data

The three thermistor arrays were downloaded on August 23rd and daily average water temperatures at depth were calculated for the period between June 1, 2012 and August 23, 2012. Daily average water temperature ranged from ~19°C to ~25°C near the water surface (Figure 25). Despite the seasonally high ambient air temperatures for the 2012 summer, the daily average 1 m water temperatures recorded from June 1, 2012 through August 23, 2012 were similar to the 2011 water temperatures. In June 2012, the 1 m water temperatures were about 1.1°C warmer than June 2011; however, in August 2012, the 1 m water temperature was approximately 1.3°C cooler than during August 2011.

During the initial reporting of the fish kill on August 14, 2012 the daily average temperature at 1 m depth was 22.8°C which was less than the maximum daily water temperature of 25.0°C that was recorded in late July (Figure 25). These temperatures are within the tolerance ranges for both species and are below the Upper Incipient Lethal Temperature for gizzard shad (34.75°C) and walleye (34.1°C). The chronic (MWAT) and acute (DM) temperature thresholds for the gizzard shad are 29.73°C and 33.67°C, respectively, while the chronic and acute values for the walleye are 28.67°C and 32.48°C, respectively (CDPHE 2010).

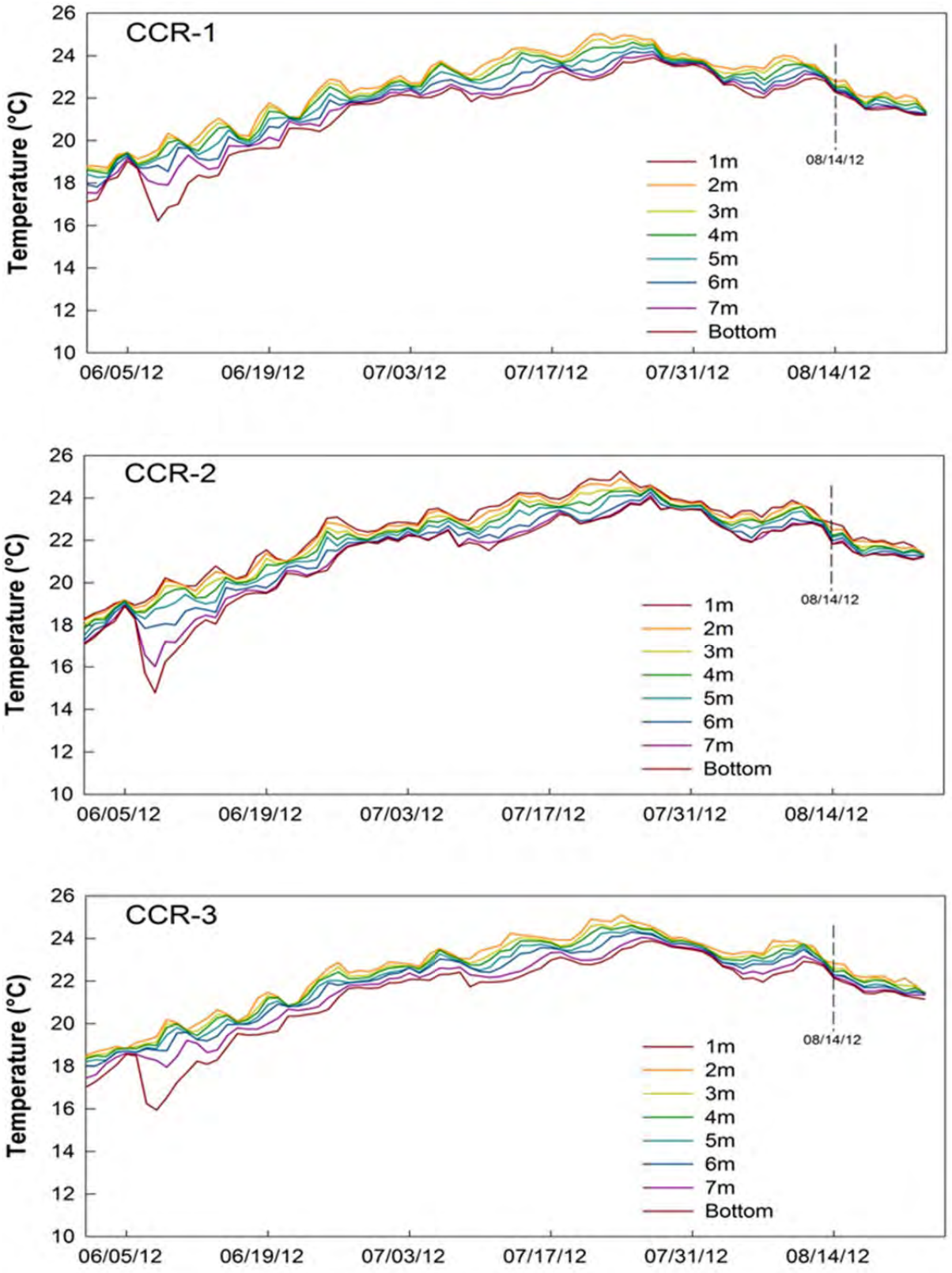

Figure 25: Temperature data collected from June 1, 2012 through August 23, 2012 at three monitoring sites on Cherry Creek Reservoir. The dashed line represents August 14, 2012 and marks the initial fish kill reports at Cherry Creek Reservoir.

On August 13, 2012 a weather driven mixing event occurred which is indicated by the minimal temperature difference between the surface and bottom (~7.2 m) sensors at the three monitoring locations (Figure 25). Measured wind speed at the KAPA station, Centennial Airport, averaged 10 miles per hour (mph) with gusts to 31 mph in the afternoon of the August 13th. The water temperature difference between the 1 m and 6 m water depth was 0.2°C. Prior to this date, the water temperature difference between the 1 m and 6 m depths ranged from 0.5 to 1.5°C.

4.2.5.2 Dissolved Oxygen, Oxygen Reduction Potential and pH

Dissolved oxygen levels recorded during the diurnal survey period (August 22nd and 23rd) were within normal ranges for the reservoir during the summer and were not low enough to produce anoxic conditions throughout the water column (Figure 26). The warm water dissolved oxygen standard is 5 mg/L, although most fish can tolerate dissolved oxygen conditions down to ~ 3 mg/L (Chapman 1986) or seek more suitable habitat provided water temperature is not constraining movement either. No substantial changes in dissolved oxygen were recorded during the sampling event prior to the fish kill (August 7, 2012) and levels were very similar to the data presented on Figure 26. Based on personal communication with Paul Winkle (August 20th, Colorado Parks and Wildlife, Aquatic Biologist), the 531 dead gizzard shad and 17 dead walleye that were collected on August 21st, after the initial fish kill, showed no signs of prolonged dissolved oxygen stress such as flared gills. The dissolved oxygen data Paul collected was also not indicative of low oxygen stress conditions. Dissolved oxygen data collected by GEI corroborated the CPW data.

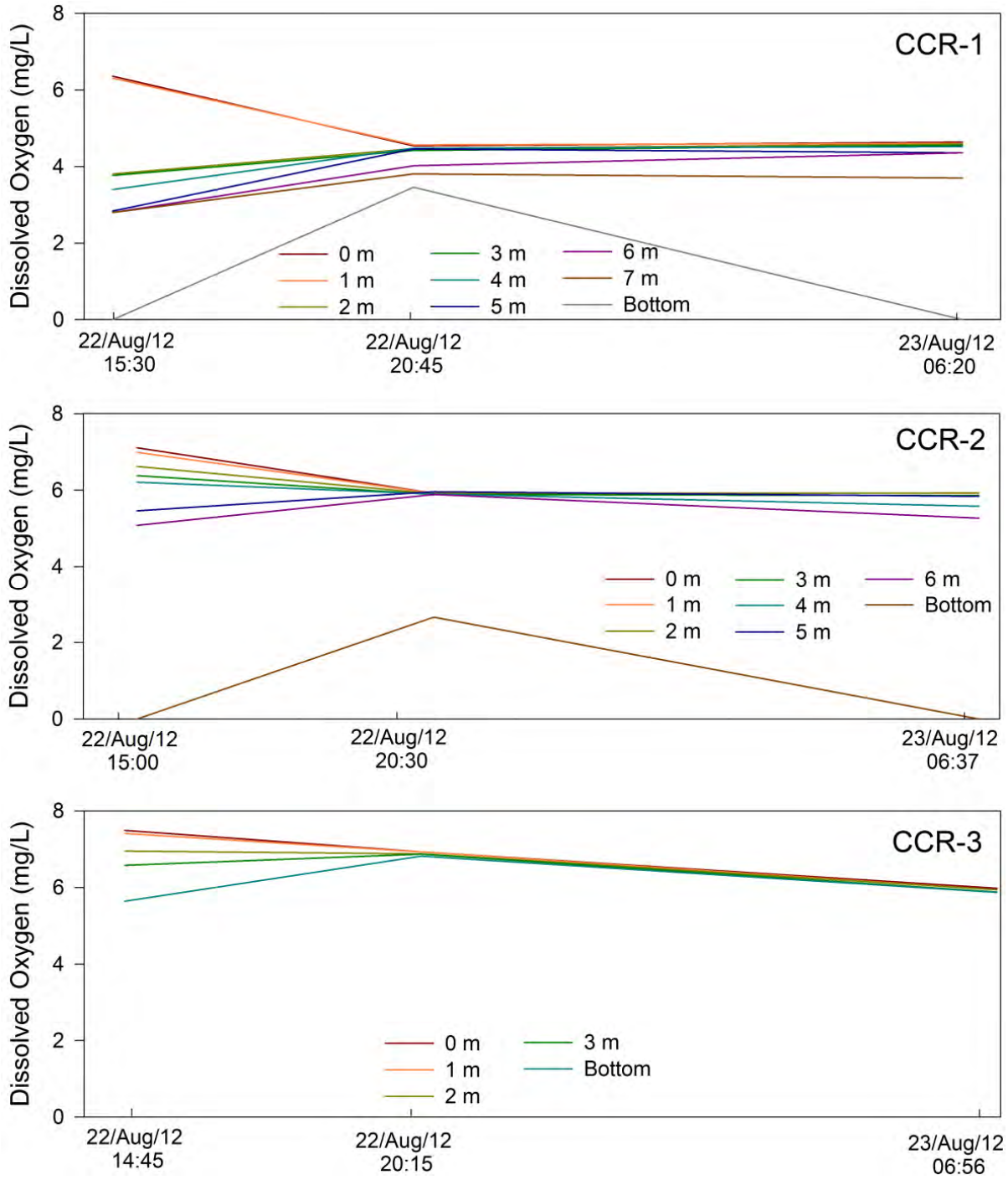

Figure 26: Dissolved oxygen data collected from diurnal surveys at three monitoring sites on Cherry Creek Reservoir during the 2012 WY.

On August 23, 2012, early afternoon, the dissolved oxygen transect profiles (D1 to D10) revealed dissolved oxygen conditions were generally greater than 4.5 mg/L at the 6 m depth, and showed the typical decrease in oxygen concentration at depths closer to the sediment interface. At the sediment interface, anoxic conditions (<1 mg/L) were present at sites D1 through D5 (Figure 27).

Over the two day period, GEI collected 23 dissolved oxygen profiles and calculated the 303(d) assessment value for each profile. Two profiles at Site CCR-1 were slightly less than the 5.0 mg/L standard. The profile collected at 8:45 pm on August 22nd and the 6:20 am profile on August 23rd were 4.52 mg/L and 4.60 mg/L, respectively. However, according to the assessment standard dissolved oxygen values collected at the same site on the same day should be averaged prior to comparing the value to the standard. When the above values are averaged appropriately there is only a single exceedance on August 22nd with an average dissolved oxygen concentration of 4.79 mg/L. All other profiles collected throughout the reservoir ranged from 5.06 mg/L to 7.39 mg/L during these two days. While there was an exceedance of the dissolved oxygen standard at Site CCR-1, the value is not low enough to cause immediate fish mortality.

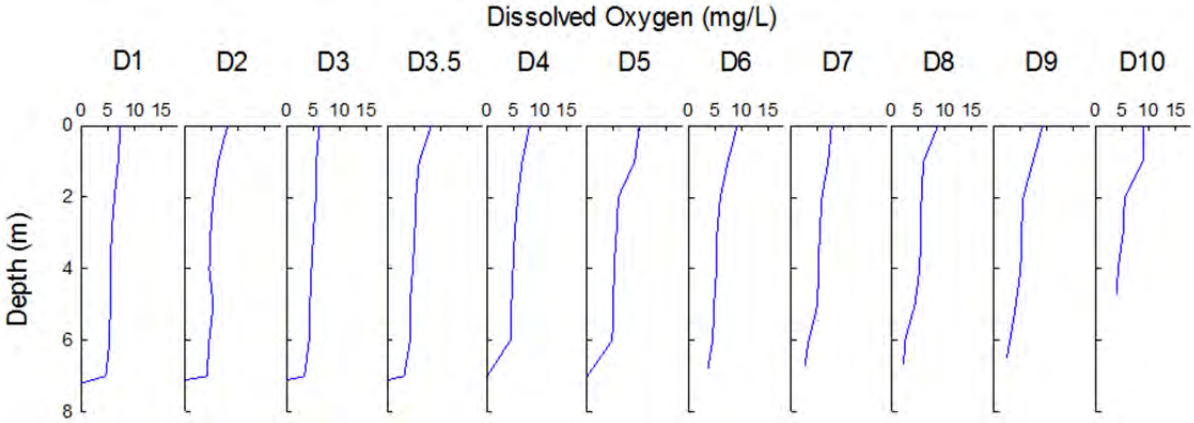

Figure 27: Dissolved oxygen profiles along the transect perpendicular to the middle of the dam face in Cherry Creek Reservoir, August 23, 2012.

Additionally, pH levels were within typical ranges for the reservoir at all three sampling sites during the diurnal surveys (Figure 28). No substantial changes in pH were recorded during the sampling event following to the fish kill event and values ranged from 7.43 to 8.28 std units among sites and depths. On August 7th, prior to the fish kill event, the pH ranged from 7.1 to 8.26 among sites and depths.

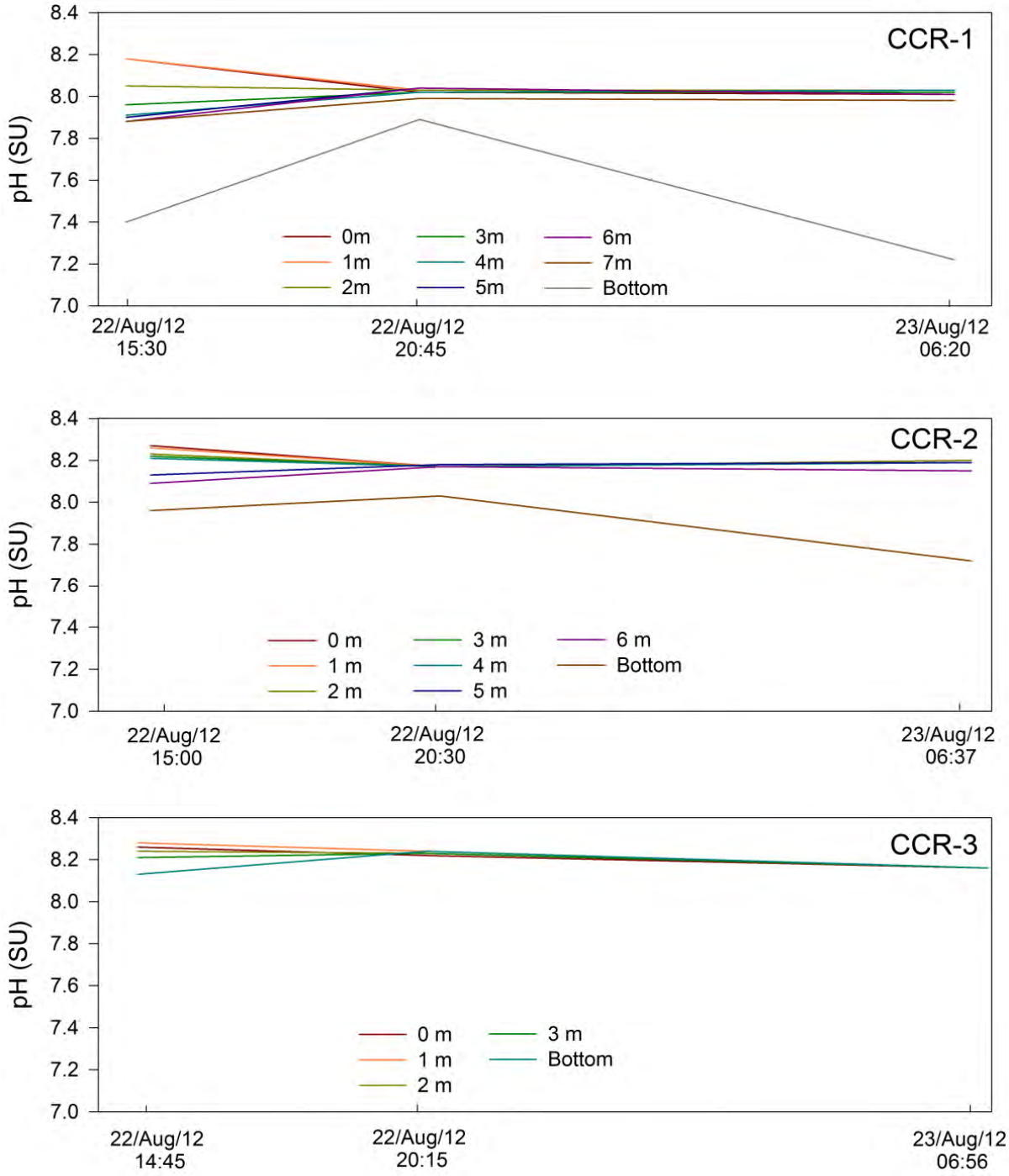

Figure 28: pH data collected from diurnal surveys at three monitoring sites on Cherry Creek Reservoir during the 2012 WY.

4.2.5.3 Algae

Algal biomass (chlorophyll *a*) was measured on August 23rd at sites CCR-1, CCR-2, and CCR-3 with levels being 30.4 µg/L, 34.5 µg/L, and 38.1 µg/L, respectively. Secchi disk readings for the same sites were 0.75 m, 0.67 m, and 0.58 m. The chlorophyll *a* measurements were greater than what was observed on August 7th. Chlorophyll *a* levels during the August 7th sampling date were 27.3 µg/L, 23.9 µg/L, and 21.7 µg/L for sites CCR-1, CCR-2 and CCR-3, respectively. As discussed above, there was a filamentous cyanobacteria bloom that coincided with the fish kill, comprising 36%, 71% and 38% of the algal biovolume on the sample events (July 24th, August 7th, and August 23rd) that pre and post-dated the fish kill. On August 7th, a week before the first noted occurrence of the fish kill, *Aphanizomenon flos-aquae* comprised 66% and *Anabaena flos-aquae* comprised 5% of the total algal biovolume. Both species produce cyanotoxins although the level of toxin production may be dependent upon the ratio of particulate to dissolved nutrients (Oh et al. 2001), concentrations of soluble reactive phosphorus (Jacoby et al. 2000), total nitrogen and irradiance (Rolland et al. 2005) or total phosphorus (Rapala et al. 1997). Cyanotoxins were not measured during the event.

The peak internal loading event occurred near the July 24th sampling event, when the soluble reactive phosphorus was 125 µg/L at the 7 m depth. The filamentous cyanobacteria bloom developed during the following weeks until reservoir conditions apparently became unfavorable and the bloom collapse between August 7th and August 23rd. Conditions that may lead to a collapse of a bloom include a variety of weather conditions such as multiple cloudy days, intense rainfall, increased flushing, and wind-induced mixing events (Havens 2008; Reichwaldt and Ghadouani 2012; Barica 1978). On August 13th, the reservoir experienced a strong wind-induced mixing event, evident in the thermistor data, which may have resulted in the collapse of the cyanobacteria bloom (see Figure 22). The collapse and subsequent decomposition of the cyanobacteria may have resulted in reduced dissolved oxygen concentrations and increased cyanotoxin release. Barica (1978) isolated a weather-induced low dissolved oxygen condition that resulted in the collapse of an *Aphanizomenon flos-aquae* bloom which lead to a similar fish kill. The reservoir conditions prior to and following the cyanobacteria bloom collapse likely provided increased stress on the gizzard shad and walleye populations that were already stressed given mid-summer conditions.

4.2.5.4 Fish

While the CPW collected numerous dead gizzard shad in the open water and some walleye along the dam face on August 21st (presumably wind driven to the dam face), they did not submit any of the specimens to their laboratory for necropsy to help identify a reason for the fish kill. This fish kill appears to be a chronic-isolated event rather than a whole-reservoir acute event because other species such as the black crappie, channel catfish, white sucker or largemouth bass did not show up in the fish kill. CPW set gill nets the week of August 27th for their annual reservoir fish survey (not prompted by the fish kill) and electrofished during

the week of September 3rd to sample littoral zone fish habitat. Multiple species were collected but none of the specimens were submitted for necropsy to evaluate the overall health of the fish (e.g. ectoparasites, presence of cyanotoxins).

4.3 Stream Water Quality

4.3.1 2012 WY Phosphorus Concentrations in Streams

The median annual total phosphorus concentration for base flow conditions ranged from 47 µg/L at Site CT-P2 to 181 µg/L at Site CC-10 (Table 6). The median seasonal (July through September) base flow concentration was greater the annual median concentration at both Cherry Creek sites (sites CC-10 and CC-Out @ I225) and two of the four Cottonwood Creek sites (sites CT-P1 and CT-P2; Table 6). The seasonal median concentration of total phosphorus ranged from 41 µg/L at Site CT-2 to 236 µg/L at Site CC-10. At most stream sites, the storm flow total phosphorous concentration was greater than concentrations during base flow conditions. The annual median storm flow concentration ranged from 110 µg/L at Site CT-2 to 471 µg/L at Site CC-10.

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, 2012 WY.

	Base Flow				Storm Flow	
	July - September		Annual		Annual	
Stream/Site	TP (µg/L)	TSS (mg/L)	TP (µg/L)	TSS (mg/L)	TP (µg/L)	TSS (mg/L)
Cherry Creek						
CC-10	236	13	181	17	471	110
CC-Out @ I225	167	47	128	26	--	--
Cottonwood Creek						
CT-P1	79	25	51	16	312	154
CT-P2	94	27	47	20	239	73
CT-1	54	16	61	23	115	48
CT-2	41	14	56	25	110	50
Shop Creek						
SC-3	--	--	61	10	231	84

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

Long-term patterns (1995 to 2012) 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 214 µg/L and 88 µg/L, respectively (Table 7), with storm flow concentrations being approximately 68 to 86% 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. Soluble reactive phosphorus fractions for base flows in Cherry Creek and Shop Creek were approximately 77% and 73%, 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, many of the stream nutrient conditions have decreased due to the Authority's efforts in stream reclamation to reduce erosion and improve water quality. Therefore, median values for the most recent 5-year period have been provided for comparison to long-term statistics.

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 2012.

	CC-10		SC-3		CT-2	
Water Year	**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
Median (1995-2012)	**214**	**164**	**88**	**64**	**69**	**11**
Median (2008-2012)	**200**	**147**	**58**	**27**	**56**	**6**

[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 2012.

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
Median (1995-2012)	**360**	**202**	**171**	**101**	**204**	**33**
Median (2008-2012)	**378**	**197**	**142**	**101**	**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 29 through 32). However, at Site CT-2, both the total phosphorus and soluble reactive phosphorus concentrations reveal a significant ($p < 0.001$) decreasing trend (Figures 33 and 34) during base flow conditions. The observed decreasing trend and greatly reduced variability in soluble reactive phosphorus concentrations at Site CT-2 from 1995 to 2012 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.

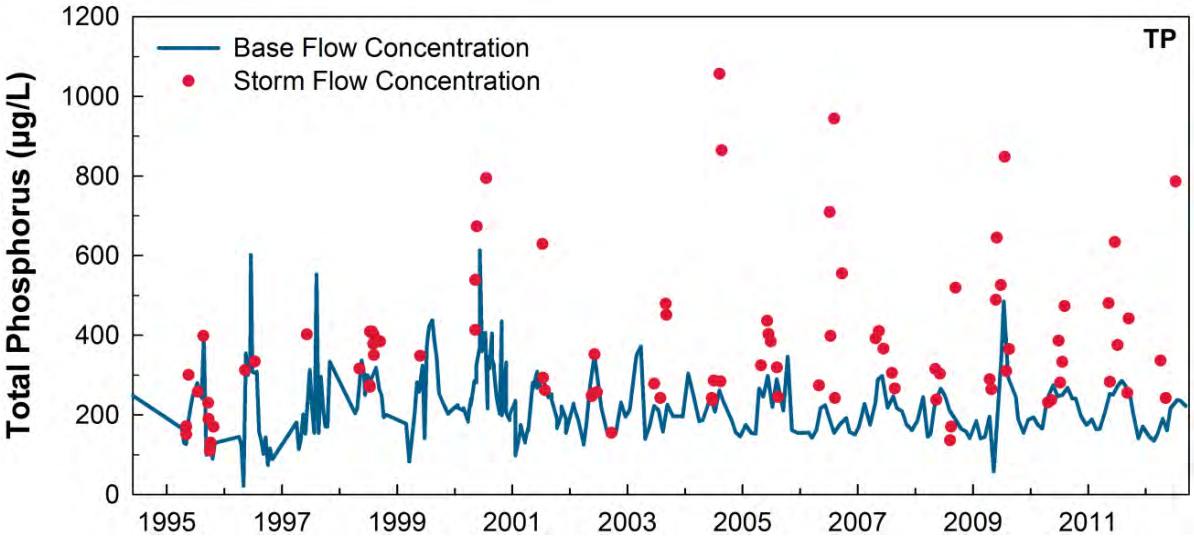

Figure 29: Base flow and storm flow total phosphorus concentrations measured at CC-10, 1994 to 2012.

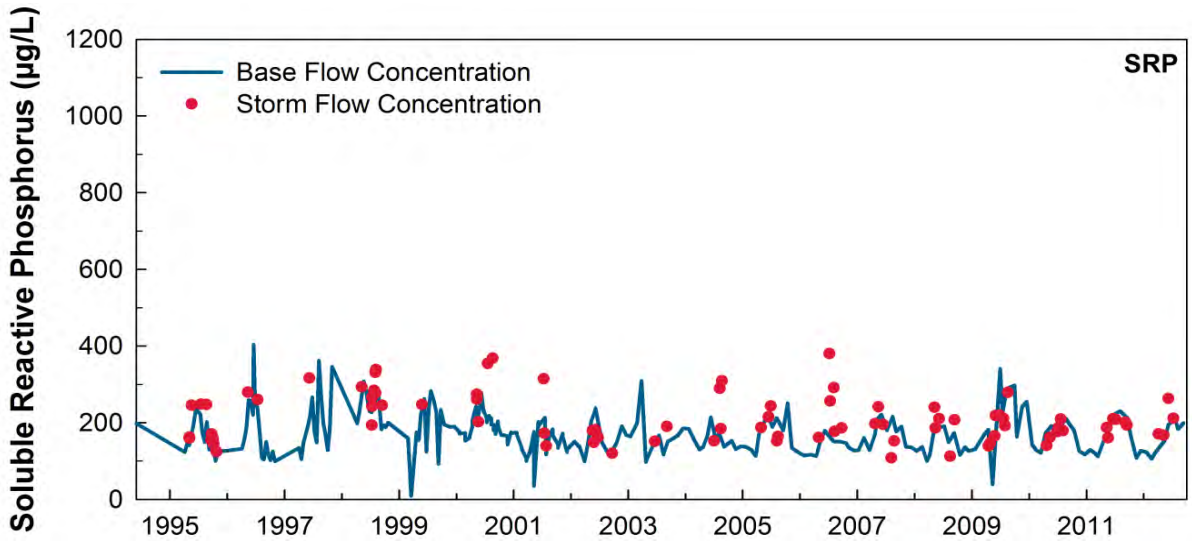

Figure 30: Base flow and storm flow soluble reactive phosphorus concentrations measured at CC-10, 1994 to 2012.

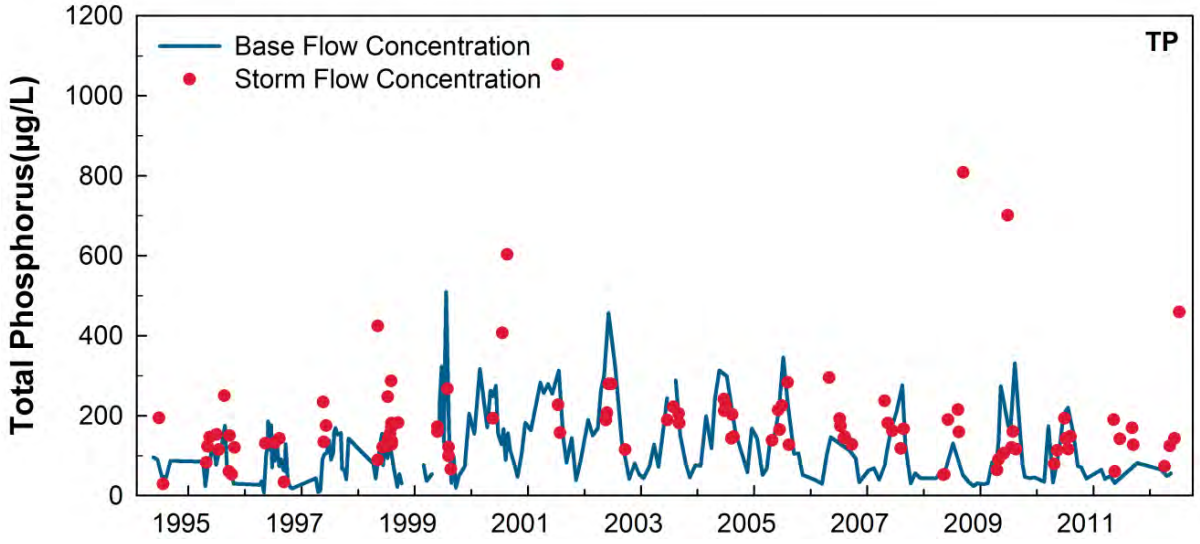

Figure 31: Base flow and storm flow total phosphorus concentrations measured at SC-3, 1994 to 2012.

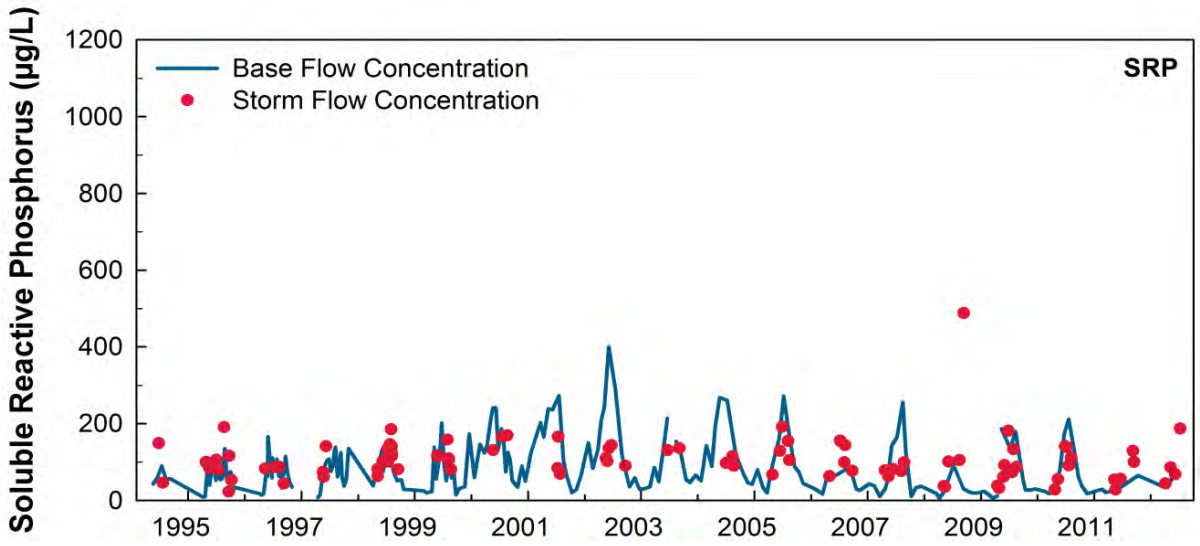

Figure 32: Base flow and storm flow soluble reactive phosphorus concentrations measured at SC-3, 1994 to 2012.

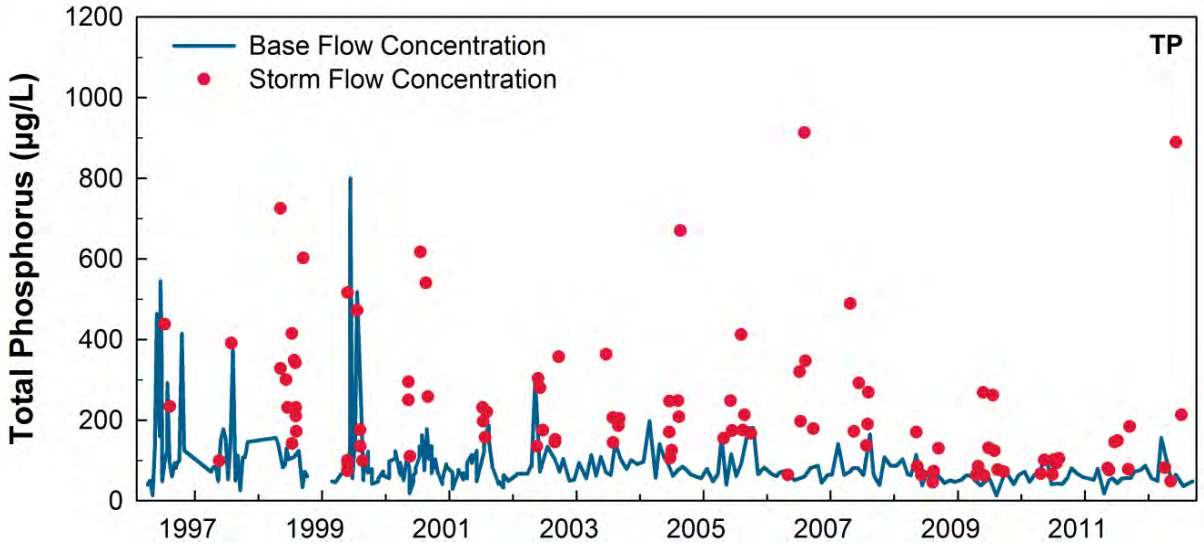

Figure 33: Base flow and storm flow total phosphorus concentrations measured at CT-2, 1996 to 2012.

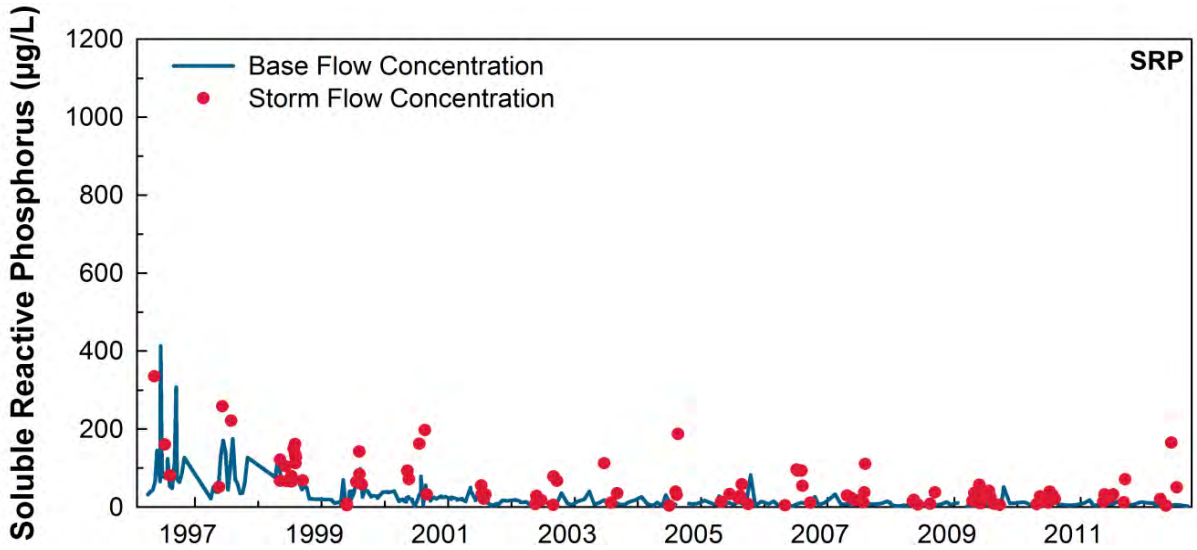

Figure 34: Base flow and storm flow soluble reactive phosphorus concentrations measured at CT-2, 1996 to 2012.

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). 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 2012) at Site MW-9 (Figure 35).

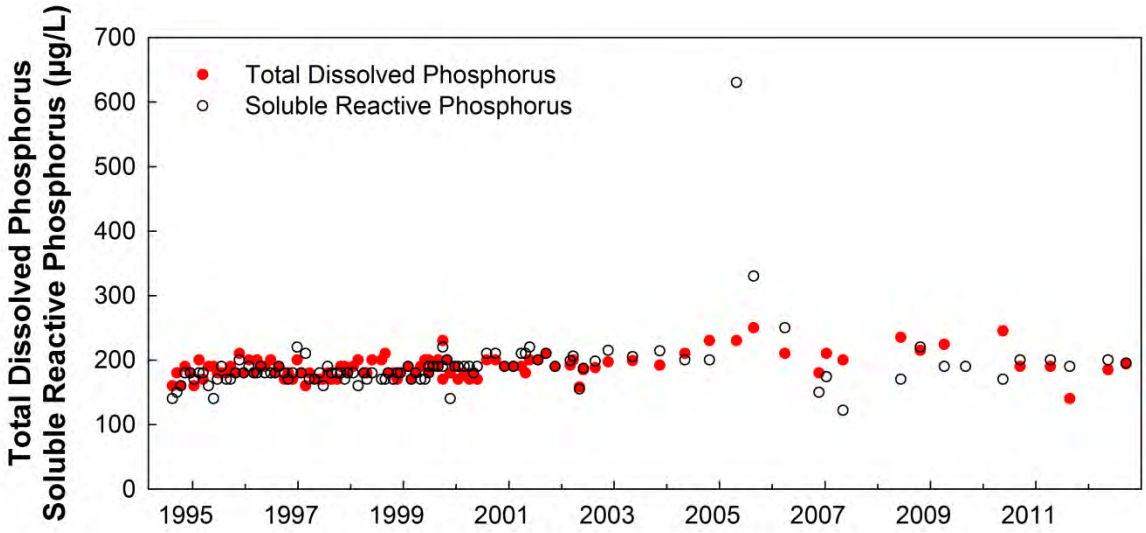

Figure 35: Total dissolved phosphorus and soluble reactive phosphorus concentrations measured at MW-9, 1994 to 2012.

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 simply 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 (74%) of the normalized total phosphorus load to the Reservoir was from Cherry Creek mainstem flows (5,405 lbs). Because Cherry Creek is monitored downstream of Shop Creek, the 140 lbs (<1%) contributed by Shop Creek has been subtracted from the normalized total load calculated for Site CC-10. Cottonwood Creek accounted for 8% of the phosphorus load, or 592 lbs. During the 2012 WY, the total phosphorus load to Cherry Creek Reservoir from tributary streams was 6,137 lbs and includes no 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 10,862 acre-feet (ac-ft) in 2012 (Appendix D). Monthly total phosphorus data collected from Site CC-Out @ I225 near the dam outlet was used to estimate the phosphorus export at 3,477 lbs/yr for the Reservoir in 2012 (Table 9).

Table 9: Normalized phosphorus loads and export (lbs/year) for Cherry Creek Reservoir, 1992 to 2012 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	5,179
2012	5,545	592	6,137	1,023	315	7,475	3,477	3,998
Median (1992-2012)	**6,215**	**1,039**	**7,894**	**1,026**	**369**	**9,309**	**3,964**	**4,598**
Median (2008-2012)	**7,354**	**833**	**8,096**	**1,023**	**315**	**9,388**	**4,785**	**5,195**

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

4.4.3 Phosphorus Load from Precipitation

During the 2012 WY, a total of 14.1 inches of precipitation was recorded at the KAPA meteorological station located at Centennial Airport (as of 30 September 2012). When scaled to the areal extent of the Reservoir (852 acres), precipitation accounted for a total of 998 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 2012 WY total phosphorus load of 315 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 2012 is 369 lbs (Table 9).

4.4.4 Phosphorus Load from Alluvium

During the 2012 WY, the alluvial inflow constant of 2,000 ac-ft/yr was reduced during the normalization process by 28 ac-ft to account for an imbalance of flows in August. Extremely

low flows reported by the USACE for August 2012 substantially reduced the measured stream flows to ZERO for sites CC-10 and CT-1, and reduced the annual alluvial flows during the normalization process to 1,972 ac-ft/yr (see Appendix D). The long-term (1994 to 2012) 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 1,023 lbs in 2012 (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 2012 WY, the USACE calculated inflow was 13,724 ac-ft/yr, while GEI calculated stream inflow was 11,369 ac-ft/yr (Appendix D). To compare these two inflow values, the USACE inflow was adjusted for precipitation (997 ac-ft/yr) and alluvial inflows (1,972 ac-ft/yr), which resulted in an adjusted USACE inflow of 10,725 ac-ft/yr. The difference between the adjusted USACE inflow and the GEI stream inflow was -647 ac-ft of water. This water volume difference was reapportioned between Cherry Creek (74%), Cottonwood Creek (26%), and Ungaged Inflow (0%) on a monthly basis. Flow-weighted total phosphorus concentrations for Cherry Creek and Cottonwood Creek were used to calculate the combined reapportioned load of -494 lbs.

Following the water balance normalization process, flow from the two tributary streams accounted for a total phosphorus load of 6,137 lbs to the Reservoir during the 2012 WY (Figure 32). The alluvial inflow contributed 1,023 lbs of phosphorus, with precipitation events contributing 315 lbs to the Reservoir. The total external load of phosphorus to the Reservoir in 2012 was 7,475 lbs (Figure 36).

The Reservoir outflow phosphorus load was estimated to be 3,477 lbs. The flow-weighted total phosphorus concentration for all external sources of inflow to the Reservoir is 200 µg/L and the flow-weighted export concentration for the Reservoir is 118 µg/L (Table 10). The difference of 82 µg/L was retained by the Reservoir. The net external phosphorus load to the Reservoir was 3,998 lbs during the 2012 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 193 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 91 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 2012 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
Median (1992-2012)	**254**	**136**	**205**	**99**
Median (2008-2012)	**244**	**81**	**200**	**115**

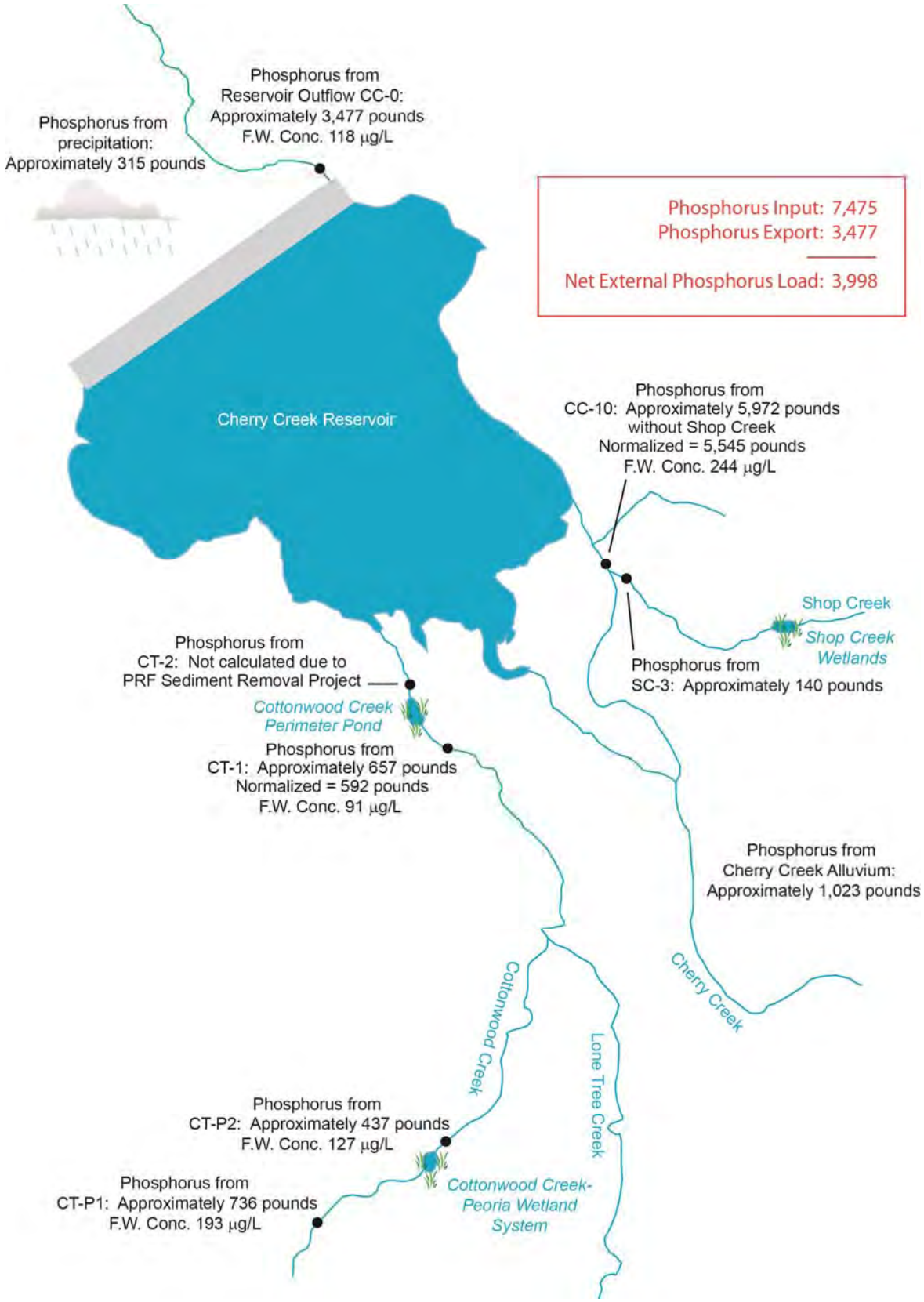

Figure 36: Mass balance diagram of phosphorus loading in Cherry Creek Reservoir, 2012 WY.

4.5 Effectiveness of Pollutant Reduction Facilities

4.5.1 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 55% in 2012, with the long-term average showing a 21% reduction. The flow-weighted total phosphorus concentration upstream and downstream of the PRF was 193 µg/L and 127 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 a 16% 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 the June 7, 2012 storm event as the inflow total suspended solids concentrations at Site CT-P1 were approximately 1,050 mg/L while the outflow total suspended solids concentrations at Site CT-P2 were approximately 400 mg/L. Similarly, the total phosphorous concentrations entering the PRF during the storm event were approximately 2,200 µg/L while the outflow concentrations were approximately 860 µg/L. During the event the PRF removed approximately 60% of the total suspended solids and total phosphorous in Cottonwood Creek flows.

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 2012 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
	Mean	**61**	**43**	**-18**	**-21**
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
	Mean	**138**	**115**	**-23**	**-16**

* Eight months of operation.

4.5.2 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). In October 2011, the bypass gate was opened to drain the Cottonwood Creek Perimeter Pond which also resulted in bypassing the flow monitoring station at Site CT-2 until June 2012. During that time the stream flow monitoring system was offline. Approximately 65% of the 2012 WY flow record is missing due to PRF maintenance; therefore, PRF efficiency was not evaluated in 2012. Data from Site CT-1 was used to provide estimates of loading to the Reservoir in 2012.

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 2012 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
	Mean	**116**	**64**	**-52**	**-28**
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
	Mean	**179**	**125**	**-54**	**-21**

* Nine months of operation.

4.5.3 McMurdo Stream Reclamation

Due to long-term erosion control issues 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.

Base flow water quality samples were collected at both sites (MCM-1 and MCM-2) during January through September 2012. Total phosphorous concentrations at Site MCM-1 ranged from 247 to 565 µg/L with a yearly mean concentration of 363 µg/L. Total phosphorous concentrations at Site MCM-2 were reduced compared to Site MCM-1 and ranged from 170 to 380 µg/L with a yearly mean concentration of 254 µg/L. Total suspended solids were similar throughout the year at both sites and had similar yearly mean values (9.4 mg/L at Site MCM-1 and 9.3 mg/L at Site MCM-2).

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 2013 WY.

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Appendix A

Cherry Creek Reservoir Sampling and Analysis Plan

GEI Consultants

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

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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.

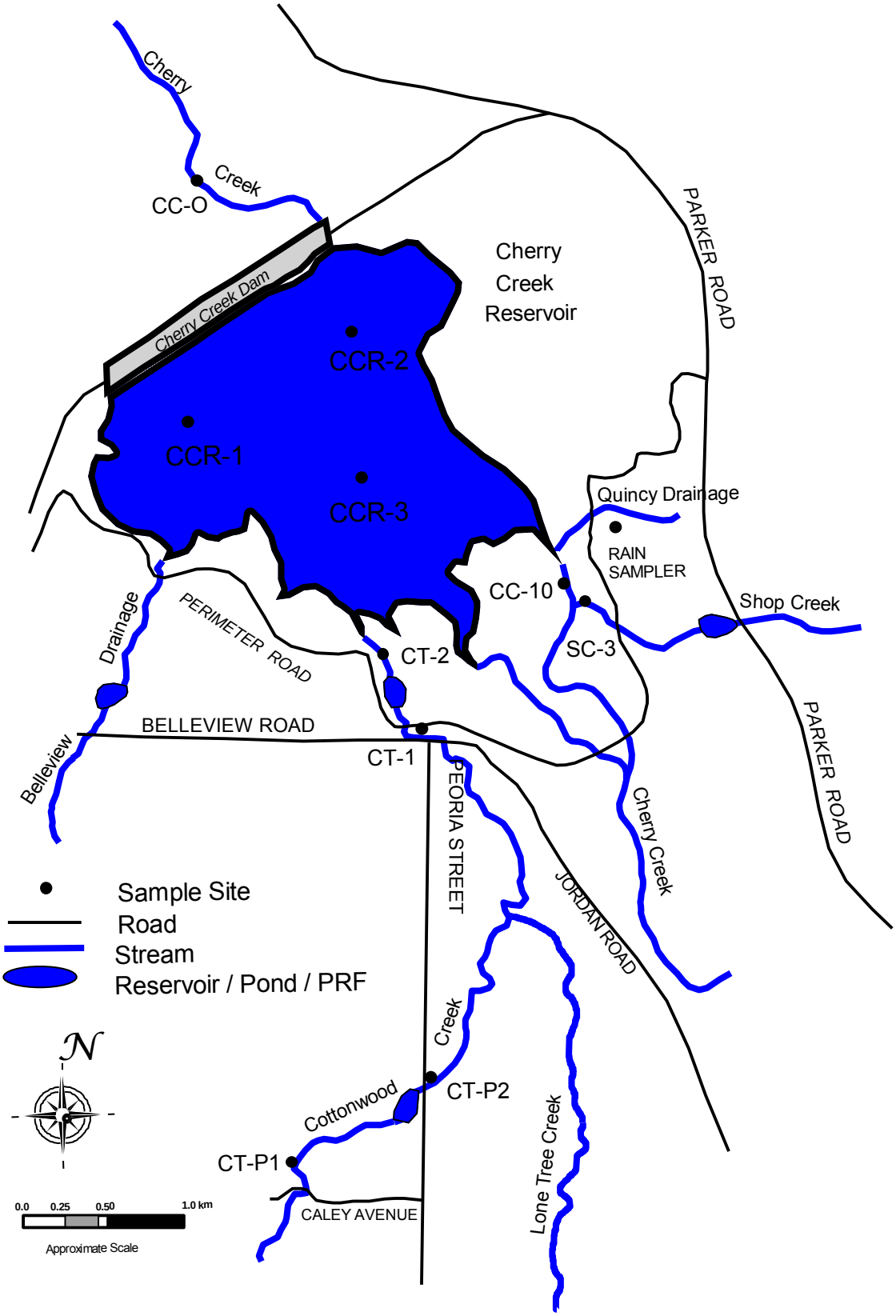

Figure 1: Sampling sites on Cherry Creek Reservoir and selected streams.

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 <u>five</u> storm events shall be collected over the summer for Cherry Creek (Site CC-10) and on Shop Creek (Site S-3). Up to <u>seven</u> 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.

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Appendix B

2012 WY Reservoir Water Quality Data

CCR-1 GEI Water Chemistry Data									
Analytical Detection Limits		**2**	**2**	**2**	**2**	**2**	**2**	**3**	**0.1**
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)**
10/11/2011	CCR-1 Photic	119	22	15	1,057	508	2	16	30.7
11/15/2011	CCR-1 Photic	71	20	6	825	534	2	11	8.3
1/17/2012	CCR-1 Photic	76	17	8	872	510	26	43	36.7
3/14/2012	CCR-1 Photic	61	13	8	789	462	4	7	17.0
4/18/2012	CCR-1 Photic	70	16	4	787	473	3	13	20.3
5/9/2012	CCR-1 Photic	93	24	13	870	505	8	14	17.4
5/22/2012	CCR-1 Photic	91	22	8	738	474	7	22	14.7
6/12/2012	CCR-1 Photic	106	36	30	886	518	10	61	23.6
6/27/2012	CCR-1 Photic	138	50	44	974	452	2	14	31.9
7/11/2012	CCR-1 Photic	144	45	39	919	504	2	17	20.6
7/24/2012	CCR-1 Photic	149	57	44	910	546	6	27	27.0
8/7/2012	CCR-1 Photic	144	68	59	979	572	8	30	27.3
8/23/2012	CCR-1 Photic	136	59	50	973	586	10	24	30.4
9/11/2012	CCR-1 Photic	129	48	29	1,008	474	2	17	29.5
9/26/2012	CCR-1 Photic	133	41	28	767	358	6	27	25.7

CCR-2 GEI Water Chemistry Data									
Analytical Detection Limits		**2**	**2**	**2**	**2**	**2**	**2**	**3**	**0.1**
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)**
10/11/2011	CCR-2 Photic	124	23	15	970	512	--	12	28.2
10/11/2011	CCR-2 4m	105	27	18	886	501	2	16	
10/11/2011	CCR-2 5m	109	25	21	881	499	4	31	
10/11/2011	CCR-2 6m	110	33	27	879	529	9	61	
10/11/2011	CCR-2 7m	140	59	58	908	679	24	183	
11/15/2011	CCR-2 Photic	78	15	4	830	475	--	6	14.2
11/15/2011	CCR-2 4m	61	17	4	763	534	--	5	
11/15/2011	CCR-2 5m	70	17	5	839	475	--	6	
11/15/2011	CCR-2 6m	67	17	4	848	490	--	4	
11/15/2011	CCR-2 7m	63	16	4	798	480	--	6	
1/17/2012	CCR-2 Photic	67	9	7	844	490	23	11	42.2
1/17/2012	CCR-2 4m	50	21	13	765	542	64	80	
1/17/2012	CCR-2 5m	61	24	16	818	573	83	92	
1/17/2012	CCR-2 6m	66	31	17	808	589	87	92	
1/17/2012	CCR-2 7m	75	41	37	962	713	109	195	
3/14/2012	CCR-2 Photic	74	12	9	833	456	4	6	12.3
3/14/2012	CCR-2 4m	66	12	7	802	441	5	5	
3/14/2012	CCR-2 5m	64	14	7	784	427	3	6	
3/14/2012	CCR-2 6m	58	12	6	746	427	4	7	
3/14/2012	CCR-2 7m	59	14	7	759	435	3	6	
4/18/2012	CCR-2 Photic	79	17	6	803	455	5	15	18.2
4/18/2012	CCR-2 4m	54	17	7	827	484	3	8	
4/18/2012	CCR-2 5m	72	19	8	780	466	4	9	
4/18/2012	CCR-2 6m	72	22	9	748	433	2	7	
4/18/2012	CCR-2 7m	77	20	12	763	448	4	9	
5/9/2012	CCR-2 Photic	84	20	10	918	566	7	10	16.1

CCR-2 GEI Water Chemistry Data									
Analytical Detection Limits		**2**	**2**	**2**	**2**	**2**	**2**	**3**	**0.1**
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)**
5/9/2012	CCR-2 4m	90	8	9	823	499	7	7	
5/9/2012	CCR-2 5m	84	10	9	789	494	7	7	
5/9/2012	CCR-2 6m	74	19	9	838	460	6	6	
5/9/2012	CCR-2 7m	141	14	27	920	530	7	6	
5/22/2012	CCR-2 Photic	86	17	7	724	449	9	15	15.8
5/22/2012	CCR-2 4m	85	19	7	769	504	7	13	
5/22/2012	CCR-2 5m	93	22	7	669	483	5	14	
5/22/2012	CCR-2 6m	85	19	7	695	447	8	13	
5/22/2012	CCR-2 7m	101	12	9	772	468	8	11	
6/12/2012	CCR-2 Photic	106	31	25	883	483	8	12	27.4
6/12/2012	CCR-2 4m	103	30	26	983	448	7	13	
6/12/2012	CCR-2 5m	117	35	33	879	435	7	9	
6/12/2012	CCR-2 6m	196	60	61	965	477	17	28	
6/12/2012	CCR-2 7m	208	61	58	972	552	50	55	
6/27/2012	CCR-2 Photic	129	41	35	952	525	4	14	29.5
6/27/2012	CCR-2 4m	130	49	44	850	447	5	13	
6/27/2012	CCR-2 5m	127	52	47	819	416	6	11	
6/27/2012	CCR-2 6m	140	61	57	839	437	7	34	
6/27/2012	CCR-2 7m	196	68	67	988	514	7	90	
7/11/2012	CCR-2 Photic	135	55	45	1,005	660	5	29	16.8
7/11/2012	CCR-2 4m	143	79	65	894	535	10	71	
7/11/2012	CCR-2 5m	154	81	74	919	555	12	85	
7/11/2012	CCR-2 6m	192	93	84	844	576	15	96	
7/11/2012	CCR-2 7m	216	105	101	929	578	10	107	
7/24/2012	CCR-2 Photic	114	57	44	763	532	3	19	22.9
7/24/2012	CCR-2 4m	111	56	48	702	450	2	16	

CCR-2 GEI Water Chemistry Data									
Analytical Detection Limits		**2**	**2**	**2**	**2**	**2**	**2**	**3**	**0.1**
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)**
7/24/2012	CCR-2 5m	151	90	89	681	458	3	21	
7/24/2012	CCR-2 6m	167	114	105	620	473	3	33	
7/24/2012	CCR-2 7m	225	130	125	653	474	3	50	
8/7/2012	CCR-2 Photic	140	69	60	1,009	661	7	25	23.9
8/7/2012	CCR-2 4m	137	70	63	856	513	8	26	
8/7/2012	CCR-2 5m	145	73	66	833	523	8	29	
8/7/2012	CCR-2 6m	149	83	70	857	514	9	47	
8/7/2012	CCR-2 7m	172	83	77	868	526	8	71	
8/23/2012	CCR-2 Photic	156	57	47	1,040	550	9	17	34.5
8/23/2012	CCR-2 4m	136	57	49	972	526	8	19	
8/23/2012	CCR-2 5m	123	59	52	997	530	9	21	
8/23/2012	CCR-2 6m	149	60	52	881	540	9	19	
8/23/2012	CCR-2 7m	121	97	53	890	536	9	28	
9/11/2012	CCR-2 Photic	154	38	28	961	486	3	14	36.0
9/11/2012	CCR-2 4m	129	43	35	806	446	6	14	
9/11/2012	CCR-2 5m	135	51	44	822	575	3	15	
9/11/2012	CCR-2 6m	139	55	48	812	503	2	16	
9/11/2012	CCR-2 7m	129	55	47	846	474	3	18	
9/26/2012	CCR-2 Photic	131	37	29	680	342	7	39	20.1
9/26/2012	CCR-2 4m	124	39	29	614	351	8	44	
9/26/2012	CCR-2 5m	123	36	28	643	344	7	44	
9/26/2012	CCR-2 6m	127	37	29	665	367	8	47	
9/26/2012	CCR-2 7m	130	37	28	637	327	8	49	

CCR-3 GEI Water Chemistry Data									
Analytical Detection Limits		**2**	**2**	**2**	**2**	**2**	**2**	**3**	**0.1**
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)**
10/11/2011	CCR-3 Photic	127	25	19	990	516	7	20	30.1
11/15/2011	CCR-3 Photic	70	15	5	856	472	--	5	13.0
1/17/2012	CCR-3 Photic	56	30	8	903	550	44	48	21.8
3/14/2012	CCR-3 Photic	73	13	7	836	439	4	11	16.1
4/18/2012	CCR-3 Photic	73	12	6	788	430	2	8	19.1
5/9/2012	CCR-3 Photic	100	33	22	916	538	6	9	21.8
5/22/2012	CCR-3 Photic	199	18	7	851	488	8	12	19.1
6/12/2012	CCR-3 Photic	102	33	28	924	522	8	19	27.6
6/27/2012	CCR-3 Photic	143	52	49	855	448	5	16	22.1
7/11/2012	CCR-3 Photic	155	53	42	1,070	576	2	17	24.2
7/24/2012	CCR-3 Photic	132	54	44	753	495	2	20	23.0
8/7/2012	CCR-3 Photic	134	68	56	903	502	8	22	21.7
8/23/2012	CCR-3 Photic	154	56	47	1,055	569	10	21	38.1
9/11/2012	CCR-3 Photic	150	41	30	1,074	462	2	15	37.8
9/26/2012	CCR-3 Photic	150	38	24	741	355	9	15	28.3

-- Denotes result less than MDL.

Site CCR-1 Small Tables

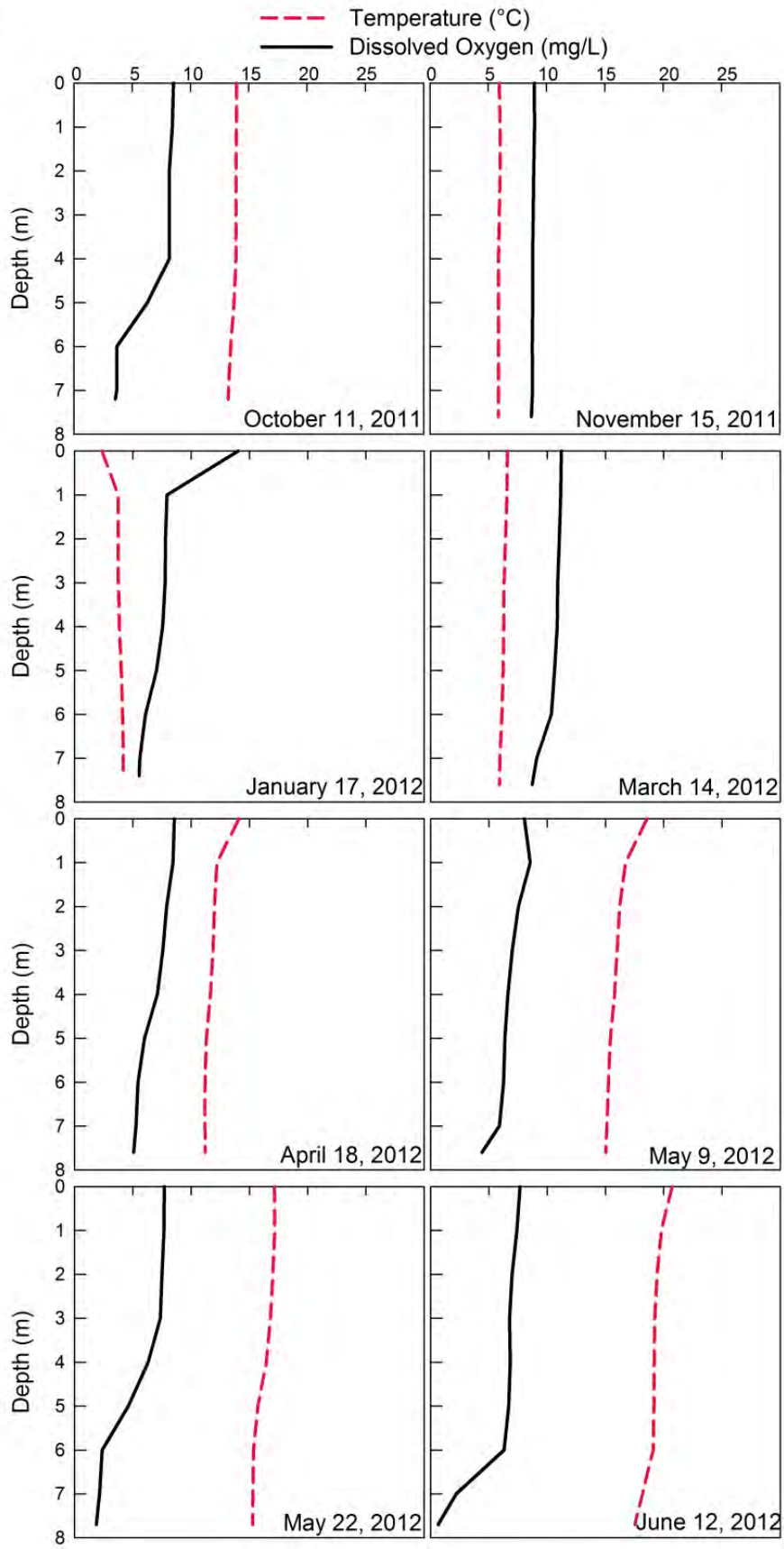
Sample Date	Depth (m)	Temperature (˚C)	Conductivity (µS/cm)	Dissolved Oxygen (mg/L)	pH	ORP (mV)	1% Transmittance (m)	Secchi Disk (m)
10/11/2011	0	13.95	964	8.53	8.08	127		
	1	13.92	963	8.43	8.37	117		
	2	13.90	963	8.18	8.35	116		
	3	13.90	964	8.18	8.31	113		
	4	13.88	964	8.18	8.24	113		
	5	13.72	963	6.30	8.05	116		
	6	13.44	964	3.68	7.88	121		
	7	13.24	965	3.66	7.86	119		
	7.2	13.24	965	3.55	7.77	106		
	--						2.00	0.60
11/15/2011	0	5.93	1,053	8.97	7.96	185		
	1	6.00	1,051	8.98	7.98	183		
	2	6.01	1,051	8.91	7.99	181		
	3	5.93	1,052	8.87	8.00	180		
	4	5.87	1,052	8.79	8.01	180		
	5	5.87	1,052	8.82	8.02	179		
	6	5.86	1,053	8.76	8.02	179		
	7	5.87	1,052	8.80	8.03	178		
	7.6	5.86	1,052	8.70	8.03	178		
	--						3.00	0.90
1/17/2012	0	2.33*	1,101*	14.02*	8.21**			
	1	3.73*	1,104*	7.92*	8.21**			
	2	3.75*	1,104*	7.80*	8.21**			
	3	3.75*	1,109*	7.76*	8.21**			
	4	3.83*	1,114*	7.55*				
	5	3.99*	1,122*	7.02*				
	6	4.11*	1,144*	6.08*				
	7	4.18*	1,158*	5.60*				
	7.4	4.18*	1,158*	5.53*				
	--						ICE	ICE
3/14/2012	0	6.58	1,122	11.22	8.04	180		
	1	6.54	1,120	11.17	8.11	173		
	2	6.40	1,120	11.05	8.13	167		
	3	6.28	1,120	10.90	8.12	166		
	4	6.26	1,119	10.87	8.12	165		
	5	6.21	1,120	10.64	8.10	164		
	6	6.10	1,120	10.36	8.07	164		
	7	5.92	1,121	9.11	8.00	164		
	7.6	5.89	1,121	8.71	7.84	72		
	--						3.13	0.95
4/18/2012	0	14.10	1,551	8.55	8.03	271		
	1	12.20	1,550	8.44	8.10	271		
	2	11.99	1,550	7.89	8.07	272		
	3	11.86	1,550	7.56	8.05	274		
	4	11.64	1,550	7.09	8.01	275		
	5	11.30	1,551	6.00	7.92	278		
	6	11.18	1,550	5.43	7.84	280		
	7	11.18	1,552	5.26	7.83	270		
	7.6	11.20	1,550	5.06	7.82	258		
	--						3.21	0.94

Sample Date	Depth (m)	Temperature (˚C)	Conductivity (µS/cm)	Dissolved Oxygen (mg/L)	pH	ORP (mV)	1% Transmittance (m)	Secchi Disk (m)
5/9/2012	0	18.57	1,201	8.04	8.18	329		
	1	16.73	1,195	8.53	8.21	320		
	2	16.24	1,195	7.52	8.15	322		
	3	16.00	1,196	6.99	8.12	322		
	4	15.79	1,196	6.62	8.11	322		
	5	15.43	1,195	6.36	8.06	322		
	6	15.26	1,196	6.25	8.06	322		
	7	15.14	1,196	5.89	8.03	323		
	7.6	15.03	1,196	4.39	7.88	322		
	--						2.25	0.65
5/22/2012	0	17.14	1,186	7.70	7.89	329		
	1	17.15	1,185	7.67	8.12	321		
	2	17.00	1,184	7.50	8.13	317		
	3	16.80	1,185	7.35	8.14	312		
	4	16.44	1,184	6.31	8.06	311		
	5	15.71	1,186	4.61	7.89	312		
	6	15.34	1,188	2.37	7.65	312		
	7	15.28	1,190	2.13	7.63	310		
	7.7	15.27	1,190	1.87	7.61	305		
	--						3.00	0.97
6/12/2012	0	20.72	1,124	7.67	8.24	246		
	1	19.81	1,115	7.40	8.24	239		
	2	19.44	1,111	6.98	8.19	235		
	3	19.24	1,113	6.76	8.18	230		
	4	19.19	1,116	6.82	8.20	228		
	5	19.17	1,117	6.69	8.19	226		
	6	19.10	1,115	6.30	8.15	226		
	7	18.18	1,051	2.20	7.67	232		
	7.7	17.54	1,023	0.63	7.46	177		
	--						2.25	0.60
6/27/2012	0	22.97	1,139	6.80	8.18	286		
	1	22.49	1,139	6.19	8.17	276		
	2	22.17	1,139	5.57	8.12	273		
	3	21.94	1,139	5.15	8.08	271		
	4	21.80	1,139	4.70	8.06	269		
	5	21.75	1,139	4.45	8.06	148		
	6	21.63	1,140	3.68	7.97	152		
	7	21.59	1,140	3.34	7.92	154		
	7.4	21.52	1,142	2.95	7.91	58		
	--						2.75	0.54
7/11/2012	0	24.85	1,114	7.87	8.23	169		
	1	23.27	1,112	6.60	8.15	172		
	2	23.00	1,111	6.11	8.11	173		
	3	22.84	1,112	5.74	8.07	173		
	4	22.55	1,110	4.22	7.90	177		
	5	22.35	1,113	2.00	7.68	182		
	6	22.10	1,113	1.94	7.68	182		
	7	22.04	1,108	1.71	7.61	119		
	7.4	22.01	1,108	1.6	7.42	116		
	--						1.92	0.56

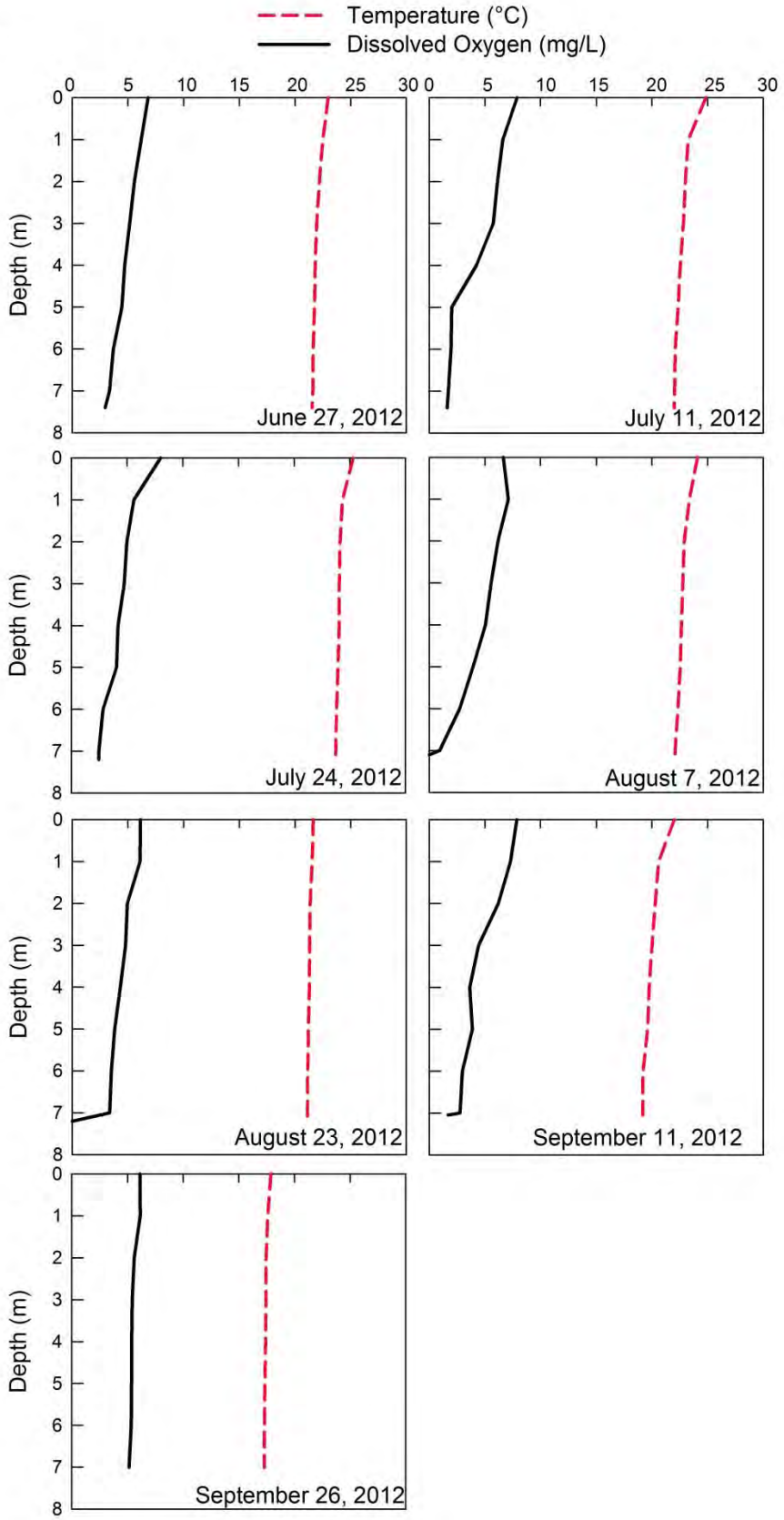
Sample Date	Depth (m)	Temperature (˚C)	Conductivity (µS/cm)	Dissolved Oxygen (mg/L)	pH	ORP (mV)	1% Transmittance (m)	Secchi Disk (m)
7/24/2012	0	25.30	1,074	8.01	8.23	358		
	1	24.32	1,074	5.61	8.09	360		
	2	24.11	1,074	4.97	8.04	362		
	3	24.04	1,074	4.73	8.04	362		
	4	24.03	1,074	4.18	7.98	360		
	5	23.94	1,075	4.04	7.98	316		
	6	23.80	1,077	2.83	7.83	307		
	7	23.72	1,077	2.46	7.78	279		
	7.2	23.71	1,077	2.45	7.78	260		
	--						2.10	0.60
8/7/2012	0	24.10	1,089	6.64	8.15	249		
	1	23.37	1,086	7.08	8.20	246		
	2	22.91	1,086	6.15	8.15	244		
	3	22.77	1,087	5.54	8.08	243		
	4	22.66	1,088	5.04	8.04	242		
	5	22.55	1,089	3.92	7.94	243		
	6	22.34	1,089	2.73	7.84	244		
	7	22.08	1,091	0.92	7.71	246		
	7.1	22.08	1,092	0.00	7.12	-189		
	--						2.25	0.65
8/23/2012	0	21.64	1,150	6.11	8.09	303		
	1	21.54	1,150	6.08	8.14	295		
	2	21.35	1,150	4.94	8.03	294		
	3	21.30	1,151	4.78	8.01	288		
	4	21.28	1,152	4.32	7.99	287		
	5	21.20	1,152	3.80	7.96	285		
	6	21.13	1,152	3.50	7.91	283		
	7	21.11	1,153	3.36	7.90	280		
	7.2	21.11	1,152	0.00	7.27	-188		
	--						1.75	0.65
9/11/2012	0	22.01	1,182	7.86	8.14	251		
	1	20.62	1,177	7.29	8.15	244		
	2	20.31	1,179	6.19	8.10	240		
	3	20.02	1,182	4.42	7.94	240		
	4	19.76	1,184	3.63	7.87	240		
	5	19.63	1,185	3.86	7.90	236		
	6	19.21	1,184	2.97	7.80	236		
	7	19.17	1,186	2.76	7.79	236		
	7.05	19.18	1,185	1.68	7.32	23		
	--							0.65
9/26/2012	0	17.87	1,203	6.11	7.91	210		
	1	17.59	1,202	6.14	7.96	205		
	2	17.44	1,204	5.60	7.95	204		
	3	17.42	1,203	5.43	7.93	204		
	4	17.39	1,203	5.38	7.93	203		
	5	17.34	1,201	5.37	7.93	203		
	6	17.29	1,201	5.34	7.92	201		
	7	17.27	1,201	5.14	7.92	201		
	--						1.48	0.47

* Denotes value obtained from within the ice layer (approximately 18.3 cm thick).
** Denotes probe malfunction, so values were obtained from water samples in the laboratory.

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
October 11, 2011
November 15, 2011
January 17, 2012
March 14, 2012
April 18, 2012
May 9, 2012
May 22, 2012
June 12, 2012

CCR-1


Temperature (°C)
Dissolved Oxygen (mg/L)
Depth (m)
June 27, 2012
July 11, 2012
July 24, 2012
August 7, 2012
August 23, 2012
September 11, 2012
September 26, 2012

CCR-2 Small Tables

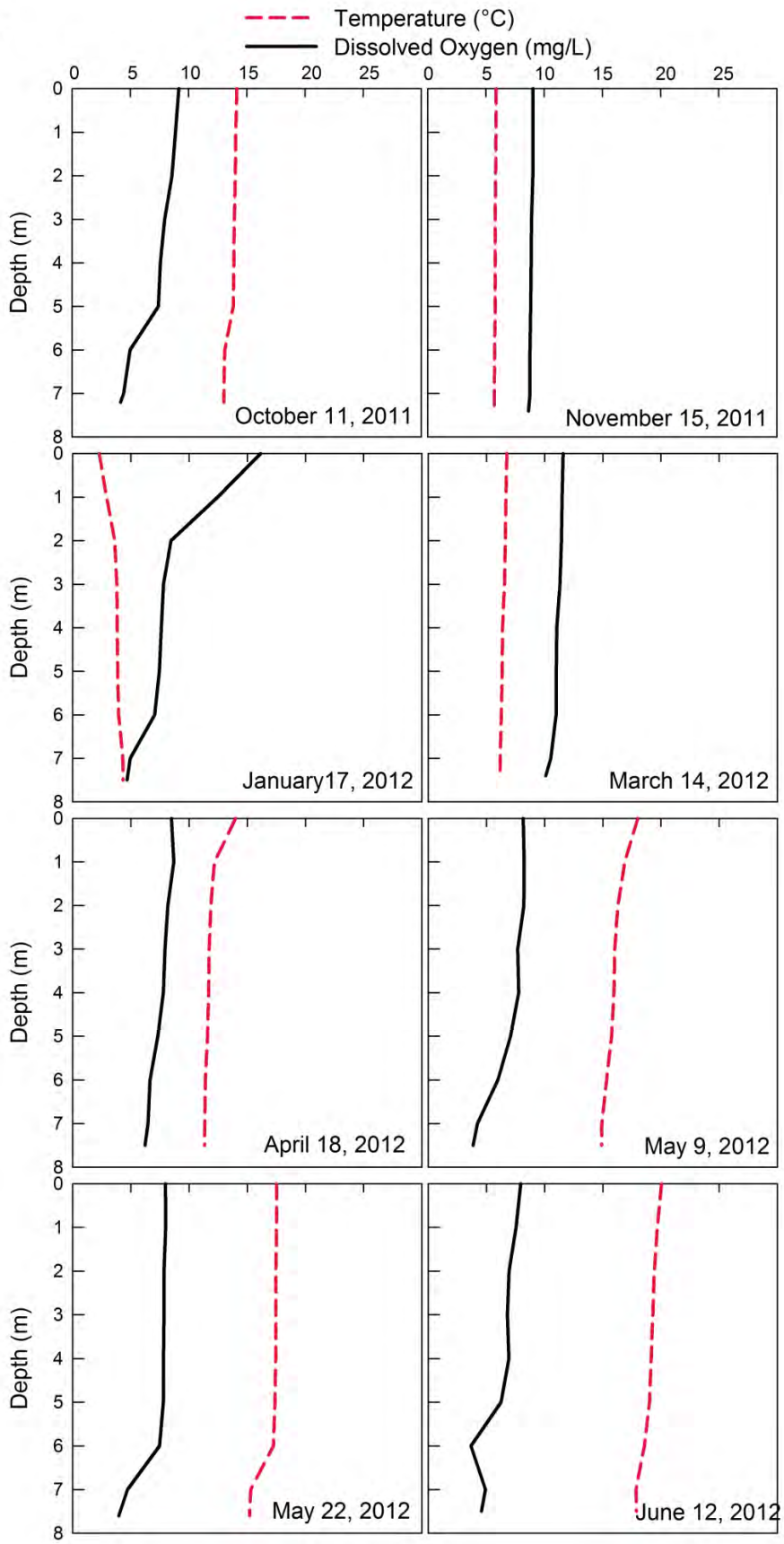
Sample Date	Depth (m)	Temperature (˚C)	Conductivity (µS/cm)	Dissolved Oxygen (mg/L)	pH	ORP (mV)	1% Transmittance (m)	Secchi Disk (m)
10/11/2011	0	14.13	962	9.15	8.25	139		
	1	14.03	962	8.86	8.31	137		
	2	14.00	962	8.56	8.38	135		
	3	13.91	962	7.94	8.29	135		
	4	13.88	963	7.57	8.21	132		
	5	13.82	963	7.39	8.17	131		
	6	13.10	962	4.97	7.99	136		
	7	13.01	964	4.41	7.98	136		
	7.2	13.04	964	4.15	7.70	54		
	--						2.35	0.65
11/15/2011	0	5.86	1,051	9.05	8.07	193		
	1	5.85	1,051	9.04	8.05	192		
	2	5.81	1,052	9.04	8.08	191		
	3	5.78	1,051	8.92	8.07	191		
	4	5.78	1,052	8.89	8.09	190		
	5	5.78	1,052	8.85	8.09	190		
	6	5.73	1,051	8.79	8.09	190		
	7	5.71	1,052	8.78	8.09	189		
	7.4	5.71	1,053	8.65	8.09	186		
	--						3.11	0.92
1/17/2012	0	2.27*	1,075*	16.14*	8.34**			
	1	2.89*	1,091*	12.43*	8.34**			
	2	3.60*	1,109*	8.43*	8.34**			
	3	3.78*	1,114*	7.80*	8.34**			
	4	3.81*	1,118*	7.61*	8.16**			
	5	3.85*	1,123*	7.43*	8.10**			
	6	3.93*	1,133*	7.03*	8.15**			
	7	4.29*	1,174*	4.93*	8.05**			
	7.5	4.32*	1,175*	4.66*				
	--						2.35	ICE
3/14/2012	0	6.75	1,116	11.59	8.04	181		
	1	6.67	1,116	11.51	8.13	180		
	2	6.61	1,117	11.45	8.19	178		
	3	6.54	1,117	11.32	8.17	178		
	4	6.37	1,118	11.05	8.18	177		
	5	6.34	1,119	11.01	8.18	177		
	6	6.26	1,119	10.99	8.18	176		
	7	6.17	1,121	10.54	8.13	175		
	7.4	6.17	1,121	10.10	7.89	41		
	--						3.03	0.92
4/18/2012	0	13.98	1,552	8.48	8.06	253		
	1	12.17	1,545	8.68	8.13	251		
	2	11.85	1,545	8.17	8.10	252		
	3	11.71	1,547	7.92	8.08	253		
	4	11.67	1,545	7.78	8.07	253		
	5	11.56	1,548	7.31	8.02	254		
	6	11.38	1,547	6.64	7.96	256		
	7	11.34	1,550	6.47	7.95	150		
	7.5	11.31	1,550	6.21	7.93	145		
	--						3.25	0.92

Sample Date	Depth (m)	Temperature (˚C)	Conductivity (µS/cm)	Dissolved Oxygen (mg/L)	pH	ORP (mV)	1% Transmittance (m)	Secchi Disk (m)
5/9/2012	0	18.00	1,204	8.15	8.20	284		
	1	16.89	1,198	8.23	8.24	283		
	2	16.31	1,195	8.21	8.26	283		
	3	16.04	1,195	7.68	8.21	284		
	4	15.96	1,195	7.76	8.22	284		
	5	15.76	1,193	7.06	8.18	285		
	6	15.34	1,199	5.98	8.01	289		
	7	14.92	1,199	4.22	7.88	289		
	7.5	14.91	1,199	3.85	7.85	292		
	--						2.48	0.76
5/22/2012	0	17.51	1,185	7.97	8.17	322		
	1	17.50	1,185	7.98	8.20	315		
	2	17.44	1,186	7.83	8.20	311		
	3	17.45	1,185	7.84	8.20	306		
	4	17.42	1,185	7.79	8.20	302		
	5	17.36	1,185	7.78	8.20	296		
	6	17.22	1,186	7.45	8.18	292		
	7	15.28	1,185	4.71	7.88	296		
	7.6	15.18	1,186	3.95	7.81	295		
	--						3.23	0.98
6/12/2012	0	20.05	1,121	7.93	8.25	242		
	1	19.69	1,120	7.53	8.24	237		
	2	19.43	1,121	6.94	8.20	235		
	3	19.30	1,118	6.80	8.20	232		
	4	19.16	1,118	6.92	8.21	230		
	5	19.02	1,116	6.25	8.14	228		
	6	18.58	1,115	3.67	7.82	230		
	7	17.87	1,120	4.91	7.91	229		
	7.5	17.91	1,121	4.57	7.89	222		
	--						2.25	0.71
6/27/2012	0	23.30	1,138	7.30	8.32	107		
	1	23.15	1,138	6.94	8.33	110		
	2	22.42	1,140	5.72	8.20	116		
	3	22.15	1,139	5.32	8.16	119		
	4	22.08	1,140	5.14	8.13	121		
	5	21.94	1,140	4.90	8.10	123		
	6	21.79	1,140	4.24	8.03	126		
	7	21.67	1,141	3.21	7.94	116		
	--						1.82	0.51
7/11/2012	0	24.82	1,112	8.31	8.20	83		
	1	23.35	1,110	6.65	8.11	92		
	2	23.10	1,110	5.94	8.05	95		
	3	22.50	1,105	4.46	7.90	98		
	4	22.20	1,096	3.50	7.77	100		
	5	22.11	1,093	3.03	7.71	101		
	6	22.03	1,093	2.57	7.67	102		
	7	21.83	1,087	1.68	7.57	104		
	7.3	21.81	1,086	1.43	7.55	50		
	--						1.96	0.55

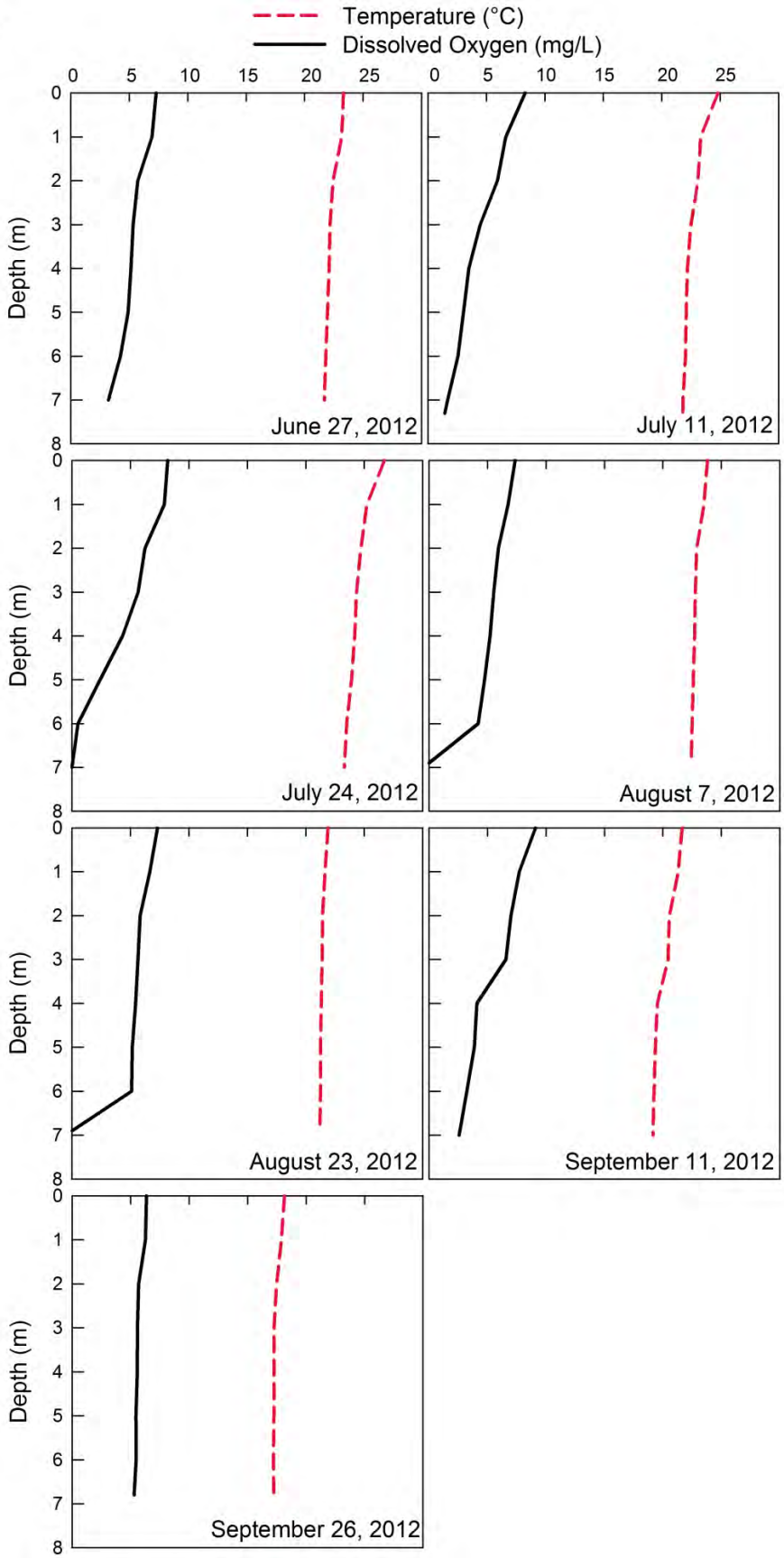
Sample Date	Depth (m)	Temperature (˚C)	Conductivity (µS/cm)	Dissolved Oxygen (mg/L)	pH	ORP (mV)	1% Transmittance (m)	Secchi Disk (m)
7/24/2012	0	26.71	1,075	8.18	8.32	232		
	1	25.21	1,071	7.90	8.32	240		
	2	24.69	1,074	6.23	8.18	252		
	3	24.32	1,075	5.65	8.11	257		
	4	24.17	1,076	4.32	8.01	262		
	5	23.90	1,077	2.40	7.80	271		
	6	23.48	1,078	0.51	7.59	278		
	7	23.28	1,078	0.00	7.51	96		
	--						1.93	0.70
8/7/2012	0	23.82	1,088	7.35	8.18	83		
	1	23.52	1,087	6.75	8.14	86		
	2	22.90	1,087	5.92	8.07	88		
	3	22.78	1,087	5.52	8.03	89		
	4	22.72	1,087	5.21	8.01	90		
	5	22.61	1,087	4.73	7.97	91		
	6	22.50	1,088	4.20	7.94	92		
	6.9	22.43	1,089	0.00	7.10	-180		
	--						2.30	0.68
8/23/2012	0	21.89	1,150	7.31	8.27	101		
	1	21.62	1,149	6.65	8.23	103		
	2	21.42	1,151	5.82	8.17	107		
	3	21.38	1,151	5.64	8.15	108		
	4	21.30	1,150	5.44	8.12	110		
	5	21.25	1,151	5.15	8.09	111		
	6	21.23	1,151	5.09	8.09	111		
	6.9	21.20	1,152	0.01	7.99	-134		
	--						1.90	0.65
9/11/2012	0	21.65	1,175	9.10	8.30	165		
	1	21.32	1,172	7.71	8.19	168		
	2	20.56	1,179	7.00	8.16	168		
	3	20.45	1,180	6.56	8.13	169		
	4	19.54	1,183	4.08	7.91	174		
	5	19.36	1,184	3.86	7.89	174		
	6	19.25	1,184	3.22	7.82	175		
	7	19.16	1,187	2.56	7.77	174		
	--							0.52
9/26/2012	0	18.14	1,205	6.33	8.00	222		
	1	17.86	1,204	6.25	8.00	222		
	2	17.46	1,202	5.67	7.97	222		
	3	17.24	1,200	5.56	7.97	221		
	4	17.23	1,200	5.55	7.97	221		
	5	17.22	1,200	5.44	7.97	220		
	6	17.19	1,200	5.45	7.98	219		
	6.8	17.22	1,202	5.28	7.98	218		
	--						1.60	0.50

* Denotes value obtained from within the ice layer (approximately 16.8 cm thick).
** Denotes probe malfunction, so values were obtained from water samples in the laboratory.

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
October 11, 2011
November 15, 2011
January17, 2012
March 14, 2012
April 18, 2012
May 9, 2012
May 22, 2012
June 12, 2012

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
June 27, 2012
July 11, 2012
July 24, 2012
August 7, 2012
August 23, 2012
September 11, 2012
September 26, 2012

CCR-3 Small Tables

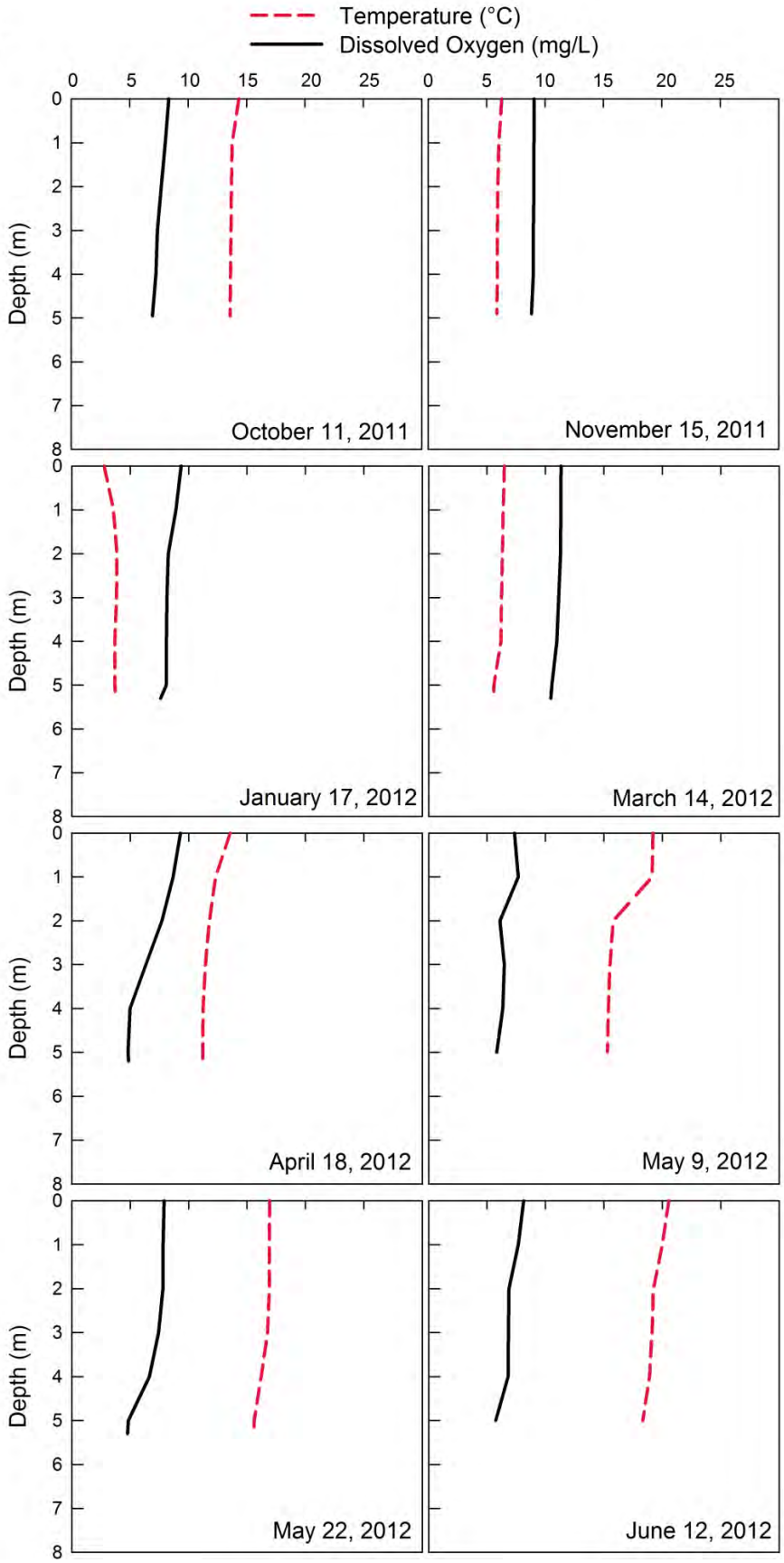
Sample Date	Depth (m)	Temperature (˚C)	Conductivity (µS/cm)	Dissolved Oxygen (mg/L)	pH	ORP (mV)	1% Transmittance (m)	Secchi Disk (m)
10/11/2011	0	14.34	963	8.34	8.08	129		
	1	13.75	962	8.04	8.43	122		
	2	13.69	963	7.69	8.26	122		
	3	13.65	964	7.37	8.13	122		
	4	13.61	964	7.24	8.08	122		
	4.95	13.58	965	6.93	8.02	123		
	--						2.00	0.58
11/15/2011	0	6.30	1,052	9.08	8.12	204		
	1	6.04	1,051	9.06	8.13	202		
	2	5.95	1,051	9.06	8.13	202		
	3	5.90	1,052	9.01	8.13	201		
	4	5.91	1,052	9.00	8.13	200		
	4.9	5.86	1,053	8.83	8.12	200		
	--						3.00	0.98
1/17/2012	0	2.76*	1,123*	9.35*	8.19**			
	1	3.55*	1,108*	8.91*	8.19**			
	2	3.85*	1,104*	8.25*	8.19**			
	3	3.81*	1,105*	8.14*	8.19**			
	4	3.67*	1,111*	8.09*				
	5	3.68*	1,115*	8.08*				
	5.3	3.72*	1,115*	7.60*				
	--						ICE	ICE
3/14/2012	0	6.46	1,121	11.33	8.18	162		
	1	6.37	1,122	11.32	8.29	160		
	2	6.29	1,120	11.29	8.21	159		
	3	6.22	1,118	11.14	8.23	158		
	4	6.18	1,119	10.98	8.22	158		
	5	5.57	1,123	10.55	8.18	155		
	5.3	5.57	1,122	10.46	8.19	152		
	--						3.10	0.97
4/18/2012	0	13.55	1,550	9.30	8.13	212		
	1	12.30	1,550	8.66	8.11	212		
	2	11.76	1,548	7.71	8.03	216		
	3	11.42	1,550	6.34	7.90	220		
	4	11.22	1,550	4.98	7.78	224		
	5	11.20	1,553	4.81	7.77	225		
	5.2	11.20	1,549	4.85	7.78	225		
	--						3.00	0.90
5/9/2012	0	19.21	1,206	7.34	8.21	253		
	1	19.13	1,200	7.67	8.23	252		
	2	15.80	1,195	6.09	8.08	258		
	3	15.53	1,196	6.47	8.12	258		
	4	15.39	1,197	6.34	8.09	259		
	5	15.31	1,198	5.82	8.04	255		
	--						2.45	0.75
5/22/2012	0	16.92	1,187	7.90	8.14	317		
	1	16.89	1,185	7.81	8.17	310		
	2	16.90	1,185	7.80	8.20	303		
	3	16.73	1,185	7.42	8.16	300		
	4	16.19	1,185	6.64	8.09	296		
	5	15.60	1,191	4.84	7.92	296		
	5.3	15.58	1,191	4.77	7.91	295		
	--						2.95	0.94

Sample Date	Depth (m)	Temperature (˚C)	Conductivity (µS/cm)	Dissolved Oxygen (mg/L)	pH	ORP (mV)	1% Transmittance (m)	Secchi Disk (m)
6/12/2012	0	20.56	1,122	8.12	8.30	264		
	1	20.01	1,116	7.66	8.25	255		
	2	19.25	1,115	6.86	8.20	253		
	3	19.13	1,115	6.82	8.20	250		
	4	18.92	1,116	6.79	8.20	247		
	5	18.34	1,122	5.73	8.05	245		
	--						2.38	0.65
6/27/2012	0	23.17	1,136	6.75	8.24	156		
	1	22.98	1,136	6.52	8.24	157		
	2	21.94	1,138	4.45	8.03	162		
	3	21.80	1,139	3.92	7.98	163		
	3.8	21.70	1,140	3.36	7.92	164		
	--						2.70	0.50
7/11/2012	0	25.90	1,115	7.78	8.18	132		
	1	23.50	1,109	8.28	8.20	133		
	2	22.92	1,111	6.20	8.05	138		
	3	22.52	1,114	3.80	7.79	145		
	4	22.26	1,106	3.37	7.73	145		
	4.9	22.11	1,102	2.91	7.68	145		
	--						1.95	0.68
7/24/2012	0	27.01	1,077	8.95	8.35	198		
	1	24.90	1,073	6.49	8.15	212		
	2	24.40	1,076	5.14	8.06	220		
	3	24.25	1,077	3.74	7.94	224		
	4	24.11	1,078	2.71	7.80	229		
	4.7	24.08	1,078	2.36	7.77	221		
	--						2.20	0.63
8/7/2012	0	24.32	1,088	8.03	8.26	69		
	1	23.53	1,086	7.59	8.25	70		
	2	22.86	1,087	5.93	8.10	74		
	3	22.77	1,088	5.10	8.03	76		
	4	22.67	1,089	4.29	7.97	76		
	4.6	22.65	1,089	4.15	7.94	68		
	--						2.30	0.71
8/23/2012	0	22.27	1,149	7.92	8.33	84		
	21	21.71	1,148	7.01	8.26	87		
	32	21.42	1,150	5.83	8.17	90		
	3	21.39	1,150	5.53	8.15	92		
	3.5	21.39	1,151	5.25	8.13	92		
	--						1.60	0.60
9/11/2012	0	21.59	1,179	8.65	8.29	180		
	1	21.24	1,176	8.57	8.30	180		
	2	20.14	1,181	6.17	8.12	185		
	3	19.89	1,182	5.68	8.07	185		
	4	19.86	1,185	5.64	8.06	186		
	4.8	19.69	1,184	4.75	7.97	187		
	--							0.70
9/26/2012	0	18.73	1,202	8.29	8.18	225		
	1	17.67	1,201	6.74	8.08	227		
	2	17.28	1,202	5.77	7.98	228		
	3	17.28	1,202	5.64	7.98	228		
	4	17.28	1,202	5.50	7.97	228		
	4.5	17.28	1,202	5.37	7.96	227		
	--						1.49	0.49

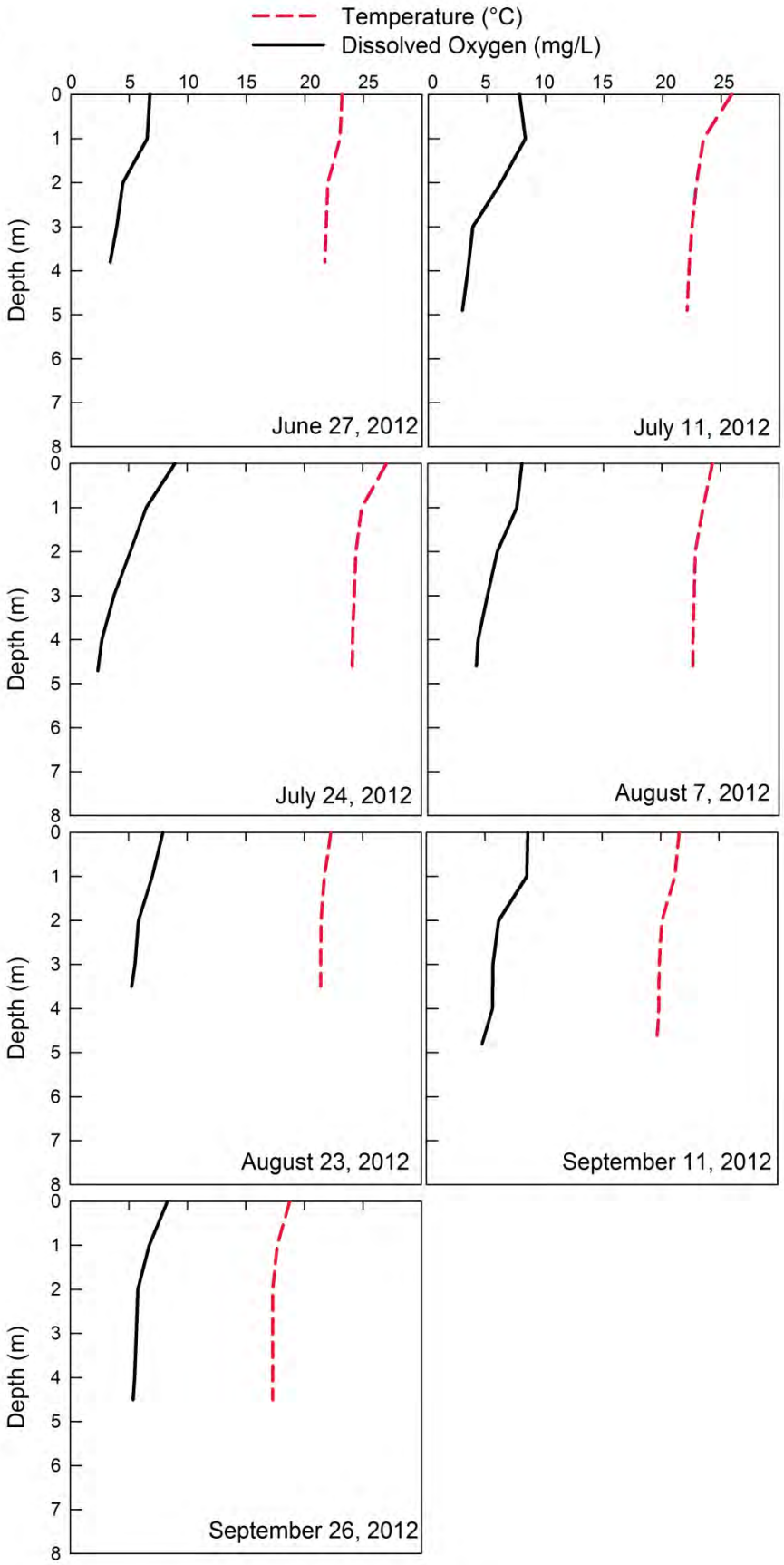
* Denotes value obtained from within the ice layer (approximately 16.8 cm thick).

** Denotes probe malfunction, so values were obtained from water samples in the laboratory.

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 11, 2011
November 15, 2011
January 17, 2012
March 14, 2012
April 18, 2012
May 9, 2012
May 22, 2012
June 12, 2012

CCR-3


Temperature (°C)
Dissolved Oxygen (mg/L)
Depth (m)
June 27, 2012
July 11, 2012
July 24, 2012
August 7, 2012
August 23, 2012
September 11, 2012
September 26, 2012

Cherry Creek Transect ORP Data

Sample Date	Depth	Transect ORP (mV)										
		D1	D2	D3	D3.5	D4	D5	D6	D7	D8	D9	D10
6/27/2012	0	103	97	109	97	102	92	119	200	204	211	224
	1	107	102	113	104	106	97	121	201	204	212	219
	2	113	106	117	109	109	103	123	203	208	215	222
	3	116	111	121	113	114	107	127	203	209	216	223
	4	121	113	123	116	116	109	130	204	210	217	223
	5	122	115	124	117	118	111	131	205	210	217	--
	6	124	117	126	120	120	114	134	206	211	217	--
	7	139	121	129	122	122	81	--	62	--	--	--
	Bottom	--	98	70	97	68	--	50	--	203	214	223

Sample Date	Depth	Transect ORP (mV)										
		D1	D2	D3	D3.5	D4	D5	D6	D7	D8	D9	D10
7/31/2012	0	378	222	68	55	64	108	41	48	32	48	20
	1	369	224	72	58	65	104	44	50	38	51	25
	2	362	226	74	60	67	105	48	53	42	56	29
	3	357	228	76	62	69	105	51	54	44	56	31
	4	353	230	80	64	70	105	53	56	46	57	33
	5	346	232	82	65	70	106	55	58	48	58	--
	6	339	234	85	67	69	106	56	60	49	59	--
	7	292	154	85	67	32	--	--	--	--	--	--
	Bottom	178	-217	-218	-228	-156	-205	-117	-189	-114	-221	31

Sample Date	Depth	Transect ORP (mV)										
		D1	D2	D3	D3.5	D4	D5	D6	D7	D8	D9	D10
8/23/2012	0	130	52	59	42	30	33	24	27	41	30	52
	1	131	59	61	49	36	41	33	34	47	37	55
	2	132	62	62	51	40	46	36	38	49	43	61
	3	134	63	64	52	42	47	37	41	50	44	62
	4	134	65	65	54	43	48	38	42	52	45	63
	5	134	65	66	55	45	49	39	43	53	60	--
	6	134	68	67	55	45	51	39	45	54	61	--
	7	135	15	14	36	-165	-185	--	--	--	--	--
	Bottom	-139	-202	-115	-128	--	--	-77	-15	-72	44	-71

Cherry Creek Transect DO Data

Sample Date	Depth	Dissolved Oxygen (mg/L)										
		D1	D2	D3	D3.5	D4	D5	D6	D7	D8	D9	D10
6/27/2012	0	7.16	7.73	7.76	7.68	7.45	6.91	6.44	6.27	6.97	8.11	6.92
	1	6.87	6.96	6.72	7.40	7.31	6.80	6.39	5.80	6.87	7.41	7.24
	2	5.95	6.07	5.65	6.01	6.49	6.21	6.27	5.05	4.73	5.36	5.07
	3	5.32	5.08	4.80	4.75	4.65	4.70	4.78	4.53	4.34	4.67	4.33
	4	4.25	4.79	4.49	4.45	4.30	4.30	4.24	4.28	4.24	4.29	3.90
	5	4.00	4.40	4.33	4.16	3.91	4.09	3.85	3.99	3.94	3.96	--
	6	3.64	3.95	3.68	3.51	3.46	3.34	3.28	3.39	3.55	3.63	--
	7	2.50	2.68	2.98	2.74	2.78	2.87	2.83	2.72	--	--	--
	Bottom	--	2.57	2.69	2.58	2.74	--	6.44	--	3.79	3.25	3.40

Sample Date	Depth	Dissolved Oxygen (mg/L)										
		D1	D2	D3	D3.5	D4	D5	D6	D7	D8	D9	D10
7/31/2012	0	5.00	5.11	5.20	5.20	6.75	6.66	6.96	6.59	7.21	7.57	7.08
	1	5.00	5.13	5.15	5.18	6.80	6.74	7.00	6.58	7.21	7.32	6.97
	2	4.96	5.10	5.17	5.14	6.46	6.11	6.29	6.28	5.85	5.57	5.75
	3	4.95	5.07	5.14	5.13	5.22	5.88	5.93	6.31	5.65	5.45	5.57
	4	4.96	5.10	5.16	5.14	4.67	5.70	5.72	6.10	5.40	5.33	5.30
	5	4.96	5.08	5.16	5.12	4.34	5.33	5.49	5.68	5.18	4.53	--
	6	4.96	5.03	5.15	4.94	4.21	4.72	4.91	4.92	4.61	4.12	--
	7	4.75	4.62	4.86	4.73	3.66	--	--	--	--	--	--
	Bottom	4.62	0.03	0.01	0.01	0.04	0.02	0.04	0.00	0.09	0.00	4.99

Sample Date	Depth	Dissolved Oxygen (mg/L)										
		D1	D2	D3	D3.5	D4	D5	D6	D7	D8	D9	D10
8/23/2012	0	7.31	7.94	6.13	8.28	8.01	9.83	9.17	7.64	8.68	9.13	8.99
	1	6.90	6.22	5.56	5.98	6.63	8.93	7.41	6.99	6.01	7.28	8.87
	2	6.21	5.23	5.46	5.38	5.83	5.84	5.98	5.82	5.61	5.48	5.46
	3	5.64	4.75	5.01	5.16	5.24	5.48	5.38	5.38	5.45	5.17	5.15
	4	5.53	4.52	4.62	4.80	4.92	5.05	5.28	5.19	5.28	4.97	4.24
	5	5.39	5.24	4.34	4.26	4.61	4.91	4.79	5.00	4.32	4.08	--
	6	5.32	4.53	4.21	4.27	4.42	4.70	4.55	3.33	2.51	2.98	--
	7	4.56	4.10	3.32	3.20	0.01	0.00	--	--	--	--	--
	Bottom	0.01	0.00	0.00	0.00	--	--	3.63	2.61	2.23	2.34	3.90

Appendix C

2012 WY Stream Water Quality and Precipitation Data

CC-10 Water Chemistry Data									
Detection Limits	2	2	2	2	2	2	3	4	4
Sample Date	**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**	**TSS mg/L**	**TVSS mg/L**
10/11/2011	209	153	165	954	845	548	25	18.4	4.4
11/15/2011	141	110	108	1403	1308	1079	19	14.2	
12/13/2011	171	126	127	1535	1483	1259	57	21	
1/18/2012	149	112	123	1878	1735	1520	59	21.6	5.6
2/21/2012	135	103	106	1442	1424	1147	36	15.2	
3/14/2012	150	122	121	1046	964	692	28	21.4	4.2
4/18/2012	191	139	140	880	801	428	28	24.8	
5/14/2012	161	140	154	1144	1077	635	52	11.8	
6/5/2012	216	185	194	731	705	339	36	4.9	
7/19/2012	238	199	210	650	629	319	42	8.8	
8/7/2012	236	177	183	657	530	183	22	20.4	
9/11/2012	223	190	199	592	503	306	31	13.4	4.4
Storm Events									
4/4/2012	336	167	170	1723	1399	918	69	94.5	12
5/7/2012	242	164	167	1105	1028	566	54	25.4	5
5/24/2012	445	184	177	1479	1159	466	78	152	19
6/7/2012	3110	272	263	2818	1425	589	233	1660	145
7/8/2012	786	233	211	2594	1758	622	473	494	51
9/12/2012	471	314	292	2491	2153	958	429	109	12.5
9/26/2012	487	291	278	1071	885	493	32	110	14.5

CC-Out @ I225 Water Chemistry Data									
Detection Limits	2	2	2	2	2	2	3	4	4
Sample Date	**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**	**TSS mg/L**	**TVSS mg/L**
10/11/2011	146	48	49	1040	691	28	175	32.8	8.8
1/18/2012	61	32	26	839	651	95	147	8.4	9.2
2/21/2012	71	17	8	859	514	6	17	10.2	5.2
3/14/2012	62	11	5	1077	652	5	28	12.6	6.4
4/18/2012	90	18	9	936	518		7	17.6	4.4
5/9/2012	140	39	27	1145	670	10	20	42.8	9.4
6/12/2012	185	58	56	1112	579	15	28	44.8	9.2
7/19/2012	206	67	65	1061	519	7	34	67.2	9
9/26/2012	128	37	28	634	353	10	39	26.4	5.8

CT-1 Water Chemistry Data									
Detection Limits	2	2	2	2	2	2	3	4	4
Sample Date	**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**	**TSS mg/L**	**TVSS mg/L**
10/11/2011	79	19	8	1161	936	511	26	39.4	8
11/15/2011	126	15	9	1787	1448	907	81	84.2	10.6
12/13/2011	72	31	20	1930	1737	1341	63	37.6	5
1/18/2012	56	23	26	2005	1907	1577	34	20.8	4.4
2/21/2012	55	27	18	1626	1610	1165	26	19	
3/14/2012	61	11	6	1942	1785	1202	34	35.4	5.8
4/18/2012	66	23	16	1110	942	401	45	18.6	
5/14/2012	51	19	9	1078	875	242	106	18.8	
6/5/2012	60	24	17	697	618	34	47	25.6	4.8
7/19/2012	46	27	21	854	779	250	38	15.8	
8/7/2012	54	20	13	991	810	242	37	16	
9/11/2012	64	16	6	2327	1930	1391	53	38.6	5
Storm Events									
4/4/2012	81	19	11	1556	1272	707	71	34	10
5/7/2012	63	20	8	1128	930	153	249	32.8	7.6
5/24/2012	115	20	19	1271	1056	365	77	48	11
6/7/2012	2933	27	16	2967	1178	341	265	1336.7	136.7
7/8/2012	116	19	7	1998	1556	493	80	64	20
9/12/2012	103	14	8	1851	1552	1040	72	70	9.5
9/26/2012	131	38	26	953	808	490	46	47	9

CT-2 Water Chemistry Data									
Detection Limits	2	2	2	2	2	2	3	4	4
Sample Date	**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**	**TSS mg/L**	**TVSS mg/L**
10/11/2011	72	10	5	1088	834	367	27	36.8	7.6
11/15/2011	76	13	8	1440	1295	812	73	58.2	8.6
12/13/2011	87	12	13	2299	2019	1590	69	67.6	6.6
1/18/2012	56	17	11	2545	2442	2104	38	38	9.2
2/21/2012	49	21	11	1782	1736	1290	49	23.4	
3/14/2012	156	6	4	2226	1958	1096	159	123.8	8.8
4/18/2012	45	8	7	1236	1079	319	126	14.6	
5/14/2012	65	12	5	767	621	18	19	25.2	5.2
6/5/2012	36	14	6	596	492	8	14	11.8	5
7/19/2012	41	13	4	672	528	8	17	14.2	
8/7/2012	48	15	2	1994	1792	1166	29	21.6	4
9/11/2012	72	10	5	1088	834	367	27	36.8	7.6
Storm Events									
4/4/2012	82	29	20	1584	1356	715	124	20.7	6.7
5/7/2012	48	17	3	925	846	85	137	22.6	8
5/24/2012	99	34	19	1509	1304	516	126	33	9
6/7/2012	889	172	165	2099	1259	447	354	442.5	60
7/8/2012	213	70	50	1598	1030	334	23	54	19
9/12/2012	112	20	6	1991	1651	1072	31	49.5	6.5
9/26/2012	110	12	3	967	643	260	18	55.5	10.5

CT-P1 Water Chemistry Data									
Detection Limits	2	2	2	2	2	2	3	4	4
Sample Date	**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**	**TSS mg/L**	**TVSS mg/L**
10/11/2011	34	28	26	1027	803	381	26	17	5.6
11/15/2011	22	10	8	848	781	347	76	8.2	
12/13/2011	22	6	7	1229	1095	785	38	7.4	
1/18/2012	139	47	57	605	473	283	91	56.4	7.6
2/21/2012	23	7	5	800	717	438	19	6.2	
3/14/2012	41	5	3	766	481	124	11	14.6	5.6
4/18/2012	39	14	7	750	600	190	47	9.2	
5/14/2012	60	14	3	993	745	231	72	11.6	
6/5/2012	110	20	21	1114	921	264	93	42.6	10.4
7/19/2012	79	24	17	929	629	157	24	19.8	6.2
8/7/2012	85	11	5	959	567	87	24	24.6	6.2
9/11/2012	62	21	9	1121	939	505	91	24.8	5.6
Storm Events									
4/4/2012	276	38	23	1807	1238	452	244	114	25
5/7/2012	205	31	12	1573	1192	383	170	94.6	18
5/24/2012	312	24	11	1876	1299	399	248	154	28
6/7/2012	2235	43	34	2821	1458	555	346	1052.5	122.5
7/8/2012	234	84	69	1332	863	296	34	85	21
9/12/2012	460	69	58	2486	1763	753	434	272.5	30
9/26/2012	405	41	30	1819	1465	611	236	287	26

CT-P2 Water Chemistry Data									
Detection Limits	2	2	2	2	2	2	3	4	4
Sample Date	**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**	**TSS mg/L**	**TVSS mg/L**
10/11/2011	68	19	16	1,238	989	579	22	19	5.2
11/15/2011	79	10	8	1,295	1,125	745	75	63.8	7.6
12/13/2011	30	10	9	1,535	1,446	1,119	29	11.8	4.2
1/18/2012	37	6	8	1,175	1,133	911	24	9.2	--
2/21/2012	36	9	5	991	919	613	14	14.8	--
3/14/2012	33	4	4	848	696	333	19	16.6	4.6
4/18/2012	48	13	5	933	782	371	49	20.4	--
5/14/2012	44	14	6	1,092	957	396	96	8.6	--
6/5/2012	72	26	15	1,100	931	423	77	27.8	7.6
7/19/2012	119	27	23	1,101	851	394	42	31.6	7.4
8/7/2012	94	15	8	1,158	819	302	22	27	6.6
9/11/2012	45	13	7	1,251	1,080	590	72	20.4	4.2
Storm Events									
4/4/2012	239	48	44	2,152	1,741	628	545	89	25
5/7/2012	110	28	11	1,787	1,510	485	336	40	11.3
5/24/2012	174	58	40	1,955	1,662	506	316	49	12
6/7/2012	863	69	57	2,491	1,533	597	393	388.3	61.7
7/8/2012	242	84	71	1,445	985	326	39	73	24
9/12/2012	279	114	102	2,747	2,340	1,128	433	83	15.5
9/26/2012	192	58	46	1,659	1,424	684	172	59	10.5

SC-3 Water Chemistry Data									
Detection Limits	2	2	2	2	2	2	3	4	4
Sample Date	**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**	**TSS mg/L**	**TVSS mg/L**
10/11/2011	82	64	65	361	253	31	8	13.2	--
3/14/2012	65	35	37	509	371	138	11	10.4	--
4/18/2012	49	39	37	302	255	12	6	--	--
5/14/2012	56	64	55	527	537	136	14	4	--
Storm Events									
4/4/2012	73	48	44	1137	1096	665	16	8.7	4.2
5/7/2012	124	73	86	879	812	226	22	26.3	7.7
5/24/2012	231	136	118	976	716	162	18	94	12
6/7/2012	143	75	68	1095	987	408	224	16.6	--
7/8/2012	459	216	187	3573	2818	897	843	126	19
9/12/2012	529	409	373	3620	3121	1634	537	118.5	10.5
9/26/2012	265	183	163	1801	1636	1161	60	84	9

Appendix D

2012 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 2012 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 or three stage rating curve (Site SC-3) was developed to more accurately estimate low or high flows at these sites. A multi-level weir equation is used to estimate flows at both sites CT-P2 and CT-2 located in the outlet structure for each pond. The weir equations for sites CT-P2 and CT-2 (Table D-2) were provided by Muller Engineering (unpublished data, 2004).

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). Additionally, the sediment removal project at the Cottonwood PRF resulted in Site CT-2 being offline for approximately 65 percent of the year. 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. In the 2012 WY, Site CC-10 contained one water level data gap, but revealed no strong relations with any of the GEI monitored stream sites. Therefore a model was developed with the USGS Cherry Creek gage near Parker (#393109104464500), using data from December 27, 2011 to January 5, 2012, to estimate periods of missing levels for Site CC-10.

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 2012.

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
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
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

Site	Year	Date	Staff Gage Level (ft)	Transducer Level (ft)	Discharge (cfs)
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-1	2011	1-Mar-11	0.40	0.378	1.53
CT-1	2011	31-Mar-11	0.40	0.420	2.29
CT-1	2011	27-Apr-11	0.58	0.579	6.34
CT-1	2011	11-May-11	0.80	0.814	15.69
CT-1	2011	20-Jun-11	1.80	1.637	119.77
CT-1	2011	4-Aug-11	1.06	1.060	1.31
CT-1	2011	27-Sep-11	1.02	1.013	1.41
CT-1	2012	6-Jan-12	0.90	0.782	2.23
CT-1	2012	24-Jan-12	0.92	0.893	2.25
CT-1	2012	6-Mar-12	1.00	1.000	2.78
CT-1	2012	16-Apr-12	1.10	1.105	7.58
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

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)/0.7317)	0.75
	> 0.93	Q = EXP((H+9.5512)/2.7825)-38.6997	0.89
SC-3	< 0.25	Q = EXP((H-0.6231)/0.1141)	0.70
	0.25 – 1.2	Q = EXP((H-0.4107)/0.3306)+1.4970	0.89
	> 1.2	Q = (H-0.2732)/0.1397)	0.86
CT-P1	<1.75	Q = EXP(H-1.5052)/0.2841	0.81
	>1.75	Q = EXP(H)-4.2425/0.2551	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	<1.0	Q = EXP((H-0.7782)/0.2902)	0.86
CT-1	>1.0	Q = EXP((H+1.386)/0.7675)-19.6503	0.98
CT-2	< 0.95	Q = ((3.3)*(2)*(H)^(1.5))	
	0.95 - 1.35	Q = ((7.2)+(3.3)*(2)*(H)^(1.5))	
	> 1.35	Q = ((7.2)+(3.3)*(2)*(H)^(1.5))+((3.3)*(2)*(H-1.0)^(1.5))+((3.3)*(2)*(H-0.50)^(1.5))	

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 = 1.1778*(Parker Level) – 2.7183	0.84	3%
SC-3	SC-3 Level = 0.2623*(CC-10 Level) - 0.1672	0.40	7%
CT-P1	CT-P1 Level = 1.1107*(CT-1 Level) + 0.3589	0.75	1%
CT-P2	CT-P2 Level = 4.7149*(CT-1 Level) – 3.6224	0.85	1%
CT-1, Oct to Nov	CT-1 Level = 0.1356*(CT-P2 Level) + 0.9615	0.94	3%
CT-1, May to June	CT-1 Level = 0.1342*(CT-P2 Level) + 0.8902	0.88	6%
CT-2	No estimates were made due to construction at the site		

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 2012, 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 2011.

Site	90th Percentile (cfs)
CC-10 Oct-Jun	21.132
CC-10 Jul-Sep	8.260
SC-3	1.601
CT-1	5.966
CT-2	--
CT-P1	1.949
CT-P2	3.5

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 2012.

Month	CC-O	CC-10	SC-3	CT-P1	CT-P2	CT-1	CT-2
October 2011	146	209	82	34	68	79	72
November 2011	75	141	49	22	79	126	76
December 2011	60	171	76	22	30	72	87
January 2012	61	149	75	139	37	56	56
February 2012	71	135	72	23	36	55	49
March 2012	62	150	65	41	33	61	156
April 2012	90	191	49	39	48	66	70
May 2012	140	161	56	60	44	51	45
June 2012	185	216	155	110	72	60	65
July 2012	206	238	143	79	119	46	36
August 2012	167	236	152	85	94	54	41
September 2012	128	223	84	62	45	64	48
Water Year Storm Flow Median	--	471	231	312	239	115	110

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 2012 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 2012 (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 2012 alluvial component was defined as a constant source of water to the reservoir that accounted for 1,972 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.

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
October 2011	746	464	409	29	170	144	367	116	98	170	252	226
November 2011	1,148	132	629	7	112	121	294	0	61	164	629	294
December 2011	1,129	1,077	595	7	80	88	153	0	34	170	735	189
January 2012	1,313	1,118	779	1	77	74	94	0	13	169	1,008	122
February 2012	1,615	1,608	854	100	132	122	177	0	52	158	1,163	241
March 2012	1,172	785	857	42	75	69	122	0	0	169	878	125
April 2012	1,450	986	1,280	42	142	126	195	0	60	164	1,064	162
May 2012	918	999	1,013	13	124	107	183	199	94	169	555	100
June 2012	2,307	2,291	1,384	62	237	92	573	28	204	164	1,372	567
July 2012	1,027	884	537	7	66	97	140	503	182	169	536	140
August 2012	171	128	164	0	30	53	82	184	28	142	0	0
September 2012	728	390	209	10	157	173	280	1404	171	164	168	225
Water Year Total	**13,724**	**10,862**	**8,710**	**320**	**1,402**	**1,266**	**2,660**	**2,434**	**997**	**1,972**	**8,360**	**2,391**

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
October 2011	--	184	266	9	95	59	97	30	31	88	164	60
November 2011	--	27	279	4	54	52	97	0	19	85	279	97
December 2011	--	176	277	1	12	12	30	0	11	88	342	37
January 2012	--	185	316	0	29	7	14	0	4	88	408	19
February 2012	--	311	314	41	60	33	32	0	16	82	427	44
March 2012	--	132	430	25	8	6	20	0	0	88	441	21
April 2012	--	241	1,257	12	82	47	45	0	19	85	1,045	37
May 2012	--	380	491	4	65	39	38	24	30	88	269	21
June 2012	--	1,152	1,469	36	178	37	167	5	64	85	1,456	166
July 2012	--	495	570	3	35	43	29	109	58	88	569	29
August 2012	--	58	122	0	7	14	12	21	9	73	0	0
September 2012	--	136	181	5	111	88	76	396	54	85	145	61
Water Year Total	**--**	**3,477**	**5,972**	**140**	**736**	**437**	**657**	**585**	**315**	**1,023**	**5,545**	**592**

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-2 (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 2011	478	776	-298	53%	47%	-158	-140	0	-139	-102	-37	0
November 2011	923	923	0	68%	32%	0	0	0	0	0	0	0
December 2011	925	748	176	80%	20%	141	35	0	72	65	7	0
January 2012	1,130	873	257	89%	11%	229	28	0	97	93	4	0
February 2012	1,404	1,031	373	83%	17%	310	63	0	125	113	12	0
March 2012	1,003	979	24	88%	12%	21	3	0	11	11	0	0
April 2012	1,226	1,475	-249	87%	13%	-217	-32	0	-220	-212	-8	0
May 2012	655	1,195	-541	85%	15%	-460	-81	0	-239	-222	-17	0
June 2012	1,939	1,957	-18	71%	29%	-13	-5	0	-15	-13	-2	0
July 2012	676	677	-2	79%	21%	-0.8	-0.2	0	-1	-1	0	0
August 2012	-27	246	-273	67%	33%	-183	-90	0	-134	-122	-12	0
September 2012	393	489	-96	43%	57%	-41	-55	0	-51	-36	-15	0
Water Year Total	**10,725**	**11,369**	**-647**	**77%**	**23%**	**-372**	**-274**	**0**	**-494**	**-426**	**-68**	**0**

Appendix E

2012 WY Biological Data

Table E-1: Quantity and size of fish stocked in Cherry Creek Reservoir, 1985 to 1995.

	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Black crappie											
Size (inches)	5	--	--	--	--	--	--	--	--	--	--
Number	7,234	--	--	--	--	--	--	--	--	--	--
Blue catfish											
Size (inches)	--	--	--	--	--	--	--	3	--	3	--
Number	--	--	--	--	--	--	--	9,000	--	21,000	--
Bluegill											
Size (inches)	--	1	0.2	--	--	--	--	--	--	--	--
Number	--	111,968	70,000	--	--	--	--	--	--	--	--
Channel catfish											
Size (inches)	2 to 8	4	4	3	3	3.5	3	4	4	4	4
Number	116,784	25,594	25,600	16,000	10,316	25,599	13,500	13,500	13,500	23,625	18,900
Cutthroat trout											
Size (inches)	--	6	--	--	--	--	--	--	--	9	--
Number	--	52,228	--	--	--	--	--	--	--	9,089	--
Flathead catfish											
Size (inches)	--	--	--	--	--	--	--	--	--	1	--
Number	--	--	--	--	--	--	--	--	--	148	--
Largemouth bass											
Size (inches)	--	--	5	5	6	--	--	--	--	--	--
Number	--	--	10,000	10,000	8,993	--	--	--	--	--	--
Rainbow trout											
Size (inches)	8 to 12	2 to 18	2 to 26	9.5	8 to 22	9 to 15	9 to 10	9.5	9.5	9 to 18	9 to 20
Number	75,753	414,136	129,715	293,931	79,919	74,986	79,571	101,656	92,601	62,615	139,242
Tiger musky											
Size (inches)	--	5.5	7	8	--	8	5 to 8	7	9	8	8
Number	--	4,723	4,000	4,500	--	2,001	6,500	4,940	4,500	900	4,500
Walleye											
Size (inches)	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Number	2,346,000	1,734,000	1,760,000	1,760,000	1,352,000	1,400,000	1,300,000	2,600,000	2,600,000	2,600,000	2,600,000
Wiper											
Size (inches)	--	0.2	--	--	0.2	1	1	10	1	1 to 4	1
Number	--	80,000	--	--	99,000	8,996	9,000	15,520	9,003	26,177	4,500
Yellow perch											
Size (inches)	2	--	--	--	--	--	--	--	--	--	--
Number	90,160	--	--	--	--	--	--	--	--	--	--

Table E-2: Quantity and size of fish stocked in Cherry Creek Reservoir, 1996 to 2006.

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Black crappie											
Size (inches)	--	--	--	--	--	--	--	--	--	--	2.5
Number	--	--	--	--	--	--	--	--	--	--	300
Channel catfish											
Size (inches)	3	3	4	3.5	4.1	3.5	--	2.5	2.5	2.2	2.8
Number	8,100	13,500	7,425	13,500	13,500	13,500	--	33,669	13,500	14	13,500
Cutthroat trout											
Size (inches)	9.5	3 to 9	--	--	--	--	--	--	--	--	--
Number	85,802	22,907	--	--	--	--	--	--	--	--	--
Largemouth bass											
Size (inches)	--	--	--	--	--	--	--	--	--	--	2.1
Number	--	--	--	--	--	--	--	--	--	--	195
Northern pike											
Size (inches)	--	--	--	--	--	--	--	--	--	--	--
Number	--	--	--	--	46	--	--	--	--	--	--
Rainbow × cutthroat hybrid											
Size (inches)	--	--	--	--	--	--	--	--	--	--	10.6
Number	--	--	--	--	5,600	--	--	--	--	--	7,895
Rainbow trout											
Size (inches)	4 to 22	10 to 24	11	10 to 19	--	10 to 19	10	10.5	10.5	10.4	10.8
Number	163,007	74,525	59,560	32,729	--	23,065	13,900	30,111	43,553	43,248	47,150
Snake River cutthroat											
Size (inches)	--	--	--	--	--	--	--	--	--	--	16.1
Number	--	--	--	--	--	--	--	--	--	--	204
Tiger musky											
Size (inches)	7	6	7	7	8	7	7	--	--	--	--
Number	3,500	4,500	4,000	3,000	4,086	4,000	4,000	--	--	--	--
Walleye											
Size (inches)	0.2	0.2	1.5	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.2
Number	3,202,940	2,600,000	40,000	2,400,000	2,400,000	2,400,000	2,519,660	4,136,709	2,874,100	2,579,939	2,788,825
Wiper											
Size (inches)	1	1	1.3	1.3	--	--	--	--	--	0.2	2.1
Number	8,938	9,000	9,000	9,000	--	--	--	--	--	200,000	5,000

Table E-3: Quantity and size of fish stocked in Cherry Creek Reservoir, 2007 to 2012.

	2007	2008	2009	2010	2011	2012
Black crappie						
Size (inches)	--	--	1.4	--	1.1 to 1.2	0.7 to 1.8
Number	--	--	5,000	--	97,399	41,541
Channel catfish						
Size (inches)	3	--	3.3	2.7	3.4	2.5 to 6.6
Number	9,360	--	3,780	13,500	9,450	11,750
Cutthroat trout						
Size (inches)	--	--	--	12.5 to 14.7	15.1	--
Number	--	--	--	1,562	200	--
Rainbow × cutthroat trout						
Size (inches)	--	9.7	--	--	--	--
Number	--	4,001	--	--	--	--
Rainbow trout						
Size (inches)	10	10.1	4.8	9.6 to 17.7	10.1 to 10.9	10.1 to 17.0
Number	37,709	11,588	12,287	11,038	28,029	29,872
Size (inches)	12	--	10.2	9.8 to 10.2	10.6	--
Number	4,800	--	29,759	39,200	1,737	--
Size (inches)	--	--	13.6	--	--	--
Number	--	--	109	--	--	--
Walleye						
Size (inches)	0.3	0.2	0.2	0.2 to 1.1	0.2	0.23
Number	4,300,000	3,992,572	4,012,800	4,264,512	4,001,400	4,001,400
Size (inches)	1	--	1.3	--	--	1
Number	7,998	--	14,998	--	--	15,000
Wiper						
Size (inches)	1.5	--	--	1.6	--	--
Number	4,600	--	--	8,000	--	--

Table E-4: 2012 Cherry Creek Reservoir phytoplankton data represented in cells per mililter (cells/mL).

	2012 Water Year														
	11-Oct	15-Nov	17-Jan	14-Mar	18-Apr	9-May	22-May	12-Jun	27-Jun	11-Jul	24-Jul	7-Aug	23-Aug	11-Sep	26-Sep
Bacillariophyta															
Centrales															
Cyclotella comta	--	--	--	--	--	--	--	--	--	--	--	--	48	--	135
Cyclotella meneghiniana	--	--	--	--	--	106	--	39	--	--	--	--	--	311	--
Cyclotella stelligera	66	107	--	--	--	--	--	--	--	--	--	--	287	104	67
Stephanodiscus astraea minutula	265	54	--	--	--	--	--	117	679	443	368	104	573	622	404
Stephanodiscus hantzschii	862	1,020	--	--	7	317	161	233	600	253	1,062	334	382	1,140	269
Synedra radians	--	--	--	--	--	--	121	156	--	32	--	--	--	104	34
Pennate															
Achnanthes lanceolata	--	--	--	--	--	--	--	--	--	--	--	--	--	--	34
Achnanthes lewisiana	--	--	--	--	--	--	--	--	--	--	--	--	48	--	--
Achnanthes linearis	--	--	--	5,977	--	--	--	--	--	--	--	21	48	--	--
Achnanthes minutissima	--	--	--	815	--	--	--	--	--	--	--	--	669	--	--
Asterionella formosa	--	54	--	--	--	--	--	--	--	--	--	--	--	--	--
Cocconeis placentula	--	--	--	--	--	--	--	--	--	--	--	--	143	--	--
Cymbella meneghiniana	--	--	--	--	--	--	--	--	--	--	--	--	191	--	--
Cymbella microcephala	--	--	--	109	--	--	--	--	--	--	--	--	382	--	--
Cymbella minuta	--	--	--	489	--	--	--	--	--	--	--	--	48	--	--
Fragilaria construens	--	--	--	--	--	--	--	--	26	--	41	--	--	--	34
Fragilaria construens venter	--	--	--	--	14	--	40	39	26	--	--	--	--	52	--
Gomphonema angustatum	--	--	--	--	--	--	--	--	--	--	--	--	334	--	--
Melosira ambigua	--	--	--	--	--	35	40	--	52	95	82	21	--	--	--
Melosira distans alpigena	--	--	--	--	--	--	--	--	26	--	--	--	--	--	34
Melosira granulata	--	107	--	--	--	--	--	--	--	--	--	--	--	--	--
Melosira granulata angustissima	--	--	--	--	--	--	--	--	--	--	--	104	--	--	--
Melosira italica	--	--	--	--	7	--	--	--	--	--	--	--	--	--	--
Navicula capitata	--	--	--	--	--	--	--	--	--	--	--	--	48	--	--
Navicula cryptocephala veneta	--	--	--	--	--	--	--	--	--	--	--	--	--	52	--
Navicula decussis	--	--	--	--	--	--	--	--	--	--	--	--	--	--	34
Navicula minima	--	--	--	--	--	--	--	--	--	--	--	--	96	--	--
Navicula minuscula	--	--	--	--	--	--	--	--	--	--	--	21	--	--	--
Nitzschia acicularis	265	215	--	--	--	35	--	117	--	--	41	--	--	--	--
Nitzschia capitellata	66	--	--	--	--	--	--	39	--	--	--	--	--	--	34
Nitzschia communis	--	--	--	--	--	--	--	--	--	--	--	--	48	--	--
Nitzschia fruticosa	--	--	--	--	--	35	--	156	--	--	41	--	--	52	--
Nitzschia palea	--	54	--	--	--	--	--	--	--	--	--	--	48	--	--
Nitzschia paleacea	66	--	--	54	--	--	--	78	--	32	--	--	--	--	34
Rhoicosphenia curvata	--	--	--	--	--	--	--	--	--	--	--	--	48	--	--
Chlorophyta															
Ankistrodesmus falcatus	1,525	859	638	54	--	106	201	505	130	222	123	125	191	207	202
Chlamydomonas sp.	265	376	170	--	--	--	81	117	78	63	654	292	860	622	67
Chodatella wratislawiensis	--	--	--	--	--	--	--	--	--	--	--	21	--	52	--
Closteriopsis longissima	66	--	--	--	--	--	--	78	--	--	--	--	--	52	--
Crucigenia crucifera	--	--	--	--	--	--	--	--	--	63	--	63	--	--	--
Crucigenia quadrata	133	54	43	54	126	247	40	--	26	127	82	63	96	104	202
Crucigenia tetrapedia	66	161	--	--	--	35	40	39	--	95	--	--	48	--	101
Oocystis lacustris	199	107	--	--	7	70	--	--	--	--	--	--	--	--	--
Oocystis pusilla	133	--	43	--	42	141	1,208	272	209	95	123	84	--	207	168
Pediastrum boryanum	--	--	--	--	--	35	--	--	26	--	41	21	--	--	--
Pediastrum duplex	66	--	--	--	--	--	--	--	26	--	41	--	--	--	--
Pediastrum tetras	--	--	--	--	--	--	--	--	--	--	41	--	--	--	--
Scenedesmus abundans	66	--	--	--	--	70	40	78	26	--	41	--	--	--	34
Scenedesmus acuminatus	265	54	--	--	--	35	40	78	--	32	--	--	--	--	--
Scenedesmus quadricauda	597	376	--	54	28	317	121	389	365	412	899	167	96	363	438
Schroderia sp.	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Selenastrum minutum	199	376	213	--	--	141	201	272	52	63	163	63	96	259	337
Sphaerocystis schroeteri	265	54	--	--	7	70	--	--	26	32	--	104	96	--	34
Tetraedron minimum	66	--	--	--	--	211	121	--	104	32	82	--	--	52	--
Tetraedron regulare	--	--	--	--	7	--	--	39	--	--	--	--	--	--	34
Tetrastrum staurogeniaforme	66	--	--	--	--	--	--	--	--	32	--	--	--	52	--
Chrysophyta															
Chrysococcus rufescens	--	161	638	--	21	--	--	--	--	--	--	--	--	--	--
Kephyrion littorale	--	--	--	109	7	--	--	39	--	--	--	--	--	--	--
Kephyrion sp.	--	54	--	54	--	106	--	--	--	32	--	--	--	--	--
Cyanobacteria															
Anabaena flos-aquae	66	--	--	--	--	--	--	78	130	222	--	63	143	--	--
Aphanizomenon flos-aquae	--	--	--	--	--	--	--	78	78	158	368	940	287	104	--
Euglenophycota															
Euglena sp.	--	--	--	--	--	35	--	39	--	--	41	--	--	--	--
Trachelomonas acanthostoma	--	--	--	--	--	35	--	--	--	--	--	--	--	--	--

Trachelomonas hispida	--	--	43	--	--	70	40	--	--	32	--	21	--	--	--
Trachelomonas scabra	66	107	--	--	7	106	40	156	26	63	41	21	--	52	202
Trachelomonas sp.	--	--	--	--	--	--	--	--	--	32	--	--	--	--	--
Trachelomonas volvocina	--	--	--	--	7	--	--	--	--	--	--	--	--	--	--
Pyrrophycophyta															
Ceratium hirundinella	--	--	--	--	--	--	--	--	--	--	--	--	--	--	34
Glenodinium sp.	862	644	43	--	--	35	--	--	--	--	41	--	48	52	168
Cryptophyta															
Cryptomonas erosa	66	537	383	--	--	740	564	311	--	127	163	84	--	570	269
Rhodomonas minuta	464	591	2,383	--	--	1,022	1,611	311	26	127	286	--	48	881	168
Unidentified flagellate	--	--	43	--	--	--	--	--	--	--	--	--	--	52	--
Total Density (cells/mL)	7,097	6,121	4,638	7,770	286	4,158	4,711	3,849	2,740	2,914	4,861	2,735	5,446	6,117	3,568
Total Taxa	26	22	10	10	13	25	18	26	21	25	23	21	28	23	26

Table E-5: Total reservoir phytoplankton density (cells/mL) and number of taxa in Cherry Creek Reservoir, 1984 to 2012

	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 (cells/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-5: Total reservoir phytoplankton density (cells/mL) and number of taxa in Cherry Creek Reservoir, 1984 to 2012 (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 (cells/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-5: Total reservoir phytoplankton density (cells/mL) and number of taxa in Cherry Creek Reservoir, 1984 to 2012 (cont.)

	2009	2010	2011	2012	Long-term Median
Blue-Green Algae					
Density	332	4,177	1,136	2,648	**69,138**
Taxa	3	6	3	2	**11**
Green Algae					
Density	10,733	19,202	26,055	23,851	**19,189**
Taxa	20	22	23	20	**25**
Diatoms					
Density	11,609	13,975	39,654	24,186	**4,012**
Taxa	25	30	21	34	**21**
Golden-Brown Algae					
Density	246	587	1,895	1,304	**248**
Taxa	4	3	4	3	**4**
Euglenoids					
Density	83	272	570	1,802	**255**
Taxa	3	4	4	5	**4**
Dinoflagellates					
Density	4,497	2,556	6,253	1,158	**57**
Taxa	4	3	1	2	**3**
Cryptomonads					
Density	22,277	16,794	14,850	12,130	**1,601**
Taxa	2	2	2	2	**3**
Miscellaneous					
Density	--	--	--	94	**1,969**
Taxa	--	--	--	1	**5**
Total Density (cells/ml)	49,777	57,563	90,413	67,173	**103,346**
Total Number of Taxa	61	70	58	68	**70**

Table E-6: 2012 Cherry Creek Reservoir zooplankton.

	2012													
	14-Mar	**18-Apr**	**9-May**	**22-May**	**12-Jun**	**27-Jun**	**11-Jul**	**24-Jul**	**7-Aug**	**23-Aug**	**11-Sep**	**23-Sep**	**16-Oct**	**13-Nov**
Cladocera														
Bosmina longirostris	210.6	31.1	15.9	28.3	44.6	35.4	16.6	41.1	64.0	93.8	132.5	13.6	3.7	0.2
Daphnia galeata mendotae	--	1.3	2.7	2.3	5.8	9.6	--	19.0	6.7	8.8	8.1	0.1	0.2	--
Daphnia lumholtzi	--	--	--	--	--	--	--	0.4	24.8	0.4	--	--	--	--
Daphnia parvula	--	--	--	--	--	--	--		--	--	--	--	--	--
Daphnia pulicaria	0.3	--	--	--	--	--	--	4.9	1.4	0.9	0.5	--	--	--
Diaphanosoma leuchtenbergianum	--	--	--	--	--	--	--		--	--	--	--	--	--
Copepod														
Diacyclops thomasi	29.1	27.8	20.7	4.1	2.1	2.1	1.1	1.3	0.4	0.7	3.0	3.4	4.0	2.1
Immature instar (copepodid)	66.3	93.1	18.8	12.6	8.5	4.2	0.2	4.9	5.7	5.3	3.2	2.5	0.8	--
Mesocyclops edax	--	--	--	4.4	5.3	3.7	1.4	0.4	1.1	0.2	0.2	1.6	0.4	--
Nauplius	--	61.9	28.3	40.7	81.4	75.2	23.4	121.6	69.0	73.0	78.7	8.4	3.5	13.3
Skistodiaptomus pallidus	7.0	0.7	0.5	3.4	3.7	8.0	0.9	2.7	14.5	4.2	5.0	--	--	0.1
Rotifer														
Asplanchna sp.	1.7	--	--	--	--	--	--	--	--	--	1.8	--	--	--
Bdelloid rotifers	--	--	--	--	--	--	--	--	--	--	4.4	--	--	--
Brachionus angularis	--	--	--	--	--	--	--	17.7	39.8	--	5.3	0.9	--	--
Brachionus calyciflorus	--	--	--	--	--	--	--	--	--	28.8	--	--	--	--
Gastropus sp.	--	--	--	--	--	--	--	--	69.0	--	0.4	--	--	--
Keratella cochlearis	8.4	211.0	262.7	132.7	32.7	29.2	1.3	1.8	17.7	0.9	18.6	--	34.0	105.2
Polyarthra sp.	--	--	--	--	--	--	--	--	--	--	24.3	15.0	--	--
Trichocerca sp.	--	--	--	--	--	--	--	--	--	--	0.4	--	--	--
Total Concentration (#/L)	323.5	426.9	349.6	228.4	184.2	167.4	44.9	215.9	314.0	216.9	286.0	45.5	46.6	120.9
Total Number of Taxa	7	7	7	8	8	8	7	11	12	11	15	8	7	5