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Geotechnical
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Cherry Creek Reservoir 2010 Annual Aquatic Biological Nutrient Monitoring Study and Cottonwood Creek Phosphorus Reduction Facilities Monitoring

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March 2011
Project 062450

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Executive Summary

The purpose of this report is to present the 2010 water quality data collected by GEI Consultants, Inc. (GEI), on behalf of the Cherry Creek Basin Water Quality Authority (Authority). 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 Authority's pollutant reduction facilities (PRFs) on Cottonwood Creek. Additionally, this report provides analysis of trends observed in the long-term monitoring data collected on behalf of the Authority since 1987. In spring 2010, the Authority 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, which was also the practice earlier in the monitoring program. Therefore, the presentations of inflow and loading data as well as other water quality parameters for 2010 are based on a 9-month period for this report—January to September 2010.

ES 1.1. Flow-weighted Phosphorus Concentrations and Loads

The total inflow of gaged tributary streams and ungaged surface water flows for January to September 2010 was 17,718 acre-feet per year (ac-ft/yr) and with a flow-weighted total phosphorus concentration of 218 µg/L entering the Reservoir via stream flow. This volume of water contributed 10,523 lbs of phosphorus to the Reservoir. The 9-month annual precipitation accounted for 938 acre-feet (ac-ft) of water and contributed 296 lbs of phosphorus, while the normalized alluvial inflow was 1,437 ac-ft/yr, and contributed 742 lbs of phosphorus to the Reservoir. When combined, these sources of inflow resulted in a total of 20,093 acre-feet entering the Reservoir, which contributed a total of 11,561 lbs of phosphorus in 2010. This equates to a flow-weighted total phosphorus concentration of 212 µg/L for January to September 2010 which is slightly greater than the flow-weighted goal of 200 µg/L. The long-term (1992 to 2009) annual median flow-weighted total phosphorus concentration for the Reservoir is 206 µg/L.

ES 1.2. Total Phosphorus

Total phosphorus concentrations in the upper 3 m layer of the Reservoir ranged from 61 to 128 µg/L during the July to September sampling events, with a seasonal mean of 101 µg/L. The long-term (1992 to 2010) seasonal median total phosphorus concentration for the Reservoir is 81 µg/L.

ES 1.3. Chlorophyll *a*

Chlorophyll *a* concentrations in the upper 3 m layer of the Reservoir ranged from 11.9 to 48.7 µg/L during the July to September sampling events, with a seasonal mean of 31.0 µg/L. The 2010 summer season represents the highest seasonal chlorophyll *a* level observed for the Reservoir since the monitoring program began, and highlights the propensity of algae to respond to optimal growing conditions. Despite the extreme summer time chlorophyll *a* concentrations in 2010, the Reservoir is currently in attainment of the seasonal mean chlorophyll *a* standard of 18 µg/L and its one in five year exceedance frequency.

Conditions leading up to the peak algal chlorophyll *a* level began in early June when the Reservoir began showing signs of anoxia at the water/sediment interface which facilitated the internal loading of soluble reactive phosphorus. This bioavailable phosphorus diffused upward and was circulated throughout the upper photic layer via the destratification system. By late June, the chlorophyll *a* concentration remained relatively low at 6 µg/L, and the algal assemblage was comprised primarily of green algae and diatoms. Of interest, historically the month of June consistently represents the lowest monthly mean chlorophyll *a* concentration (10.2 µg/L, 19 years) for the Reservoir as this month is a transition period from the spring algal assemblage to the summer assemblage. June represents the end of the spring runoff period, a time when the Reservoir typically receives flushing flows that bring in a higher suspended sediment load that decreases light availability for algal growth, as well as the general flushing of the reservoir. Therefore, the algal assemblage typically shows a lag-response to the internal loading component, which was no different in 2010.

On July 4th, the watershed experienced a substantial rainfall event falling over a short duration that resulted in a rapid cool down of Reservoir water temperature. This event also brought in a high suspended solid load and ―flushed" the Reservoir, essentially resetting the reservoir nutrient conditions and algal assemblage. In the following weeks, the hot summer weather quickly increased water temperatures to above 24 C. These optimal growing conditions (temperature and light) combined with the effective mixing of soluble reactive phosphorus by the destratification system, created perfect conditions for cyanobacteria (blue-green algae) production. By late July, cyanobacteria and dinoflagellates dominated the algal assemblage in terms of algal biovolume and biomass (chlorophyll *a* = 38.6 µg/L). However, by early August the internal phosphorus loading had greatly diminished which also likely triggered the cyanobacteria population to complete their life cycle and form akinetes (similar to spores) that allows the cyanobacteria to survive non-suitable conditions. Thus, cyanobacteria were essentially non-existent in the Reservoir for the remainder of the summer (density <1% of total algal cells), yet chlorophyll *a* concentrations continued to increase in the Reservoir.

In early August, algal biomass reached a peak concentration of 48.7 µg/L when the algal assemblage was primarily comprised of dinoflagellates, cryptomonads, and green algae. The summer Reservoir conditions continued to exhibit chlorophyll *a* levels greater than

25.7 µg/L, with a similar algal assemblage, including euglenoids. Individual taxa that represented these groups during the late summer were mostly flagellate species that are adept at vertically migrating through the water column to maximize production (and optimize light availability) and minimize predation, under normal reservoir conditions. Historically, the nuisance chlorophyll *a* levels (i.e., > 30 mg/l) during the summer have always been associated with cyanobacteria blooms. However, over the past few years, the operation of the destratification system appears to have provided a competitive advantage to more motile species as they have become more dominant during the late summer.

Internal phosphorus loading continued to be a large component of the late summer conditions, and thus provided a relatively constant (although decreasing) supply of bioavailable phosphorus to the algal assemblage until early September when soluble reactive phosphorus concentrations were less than method detection limits throughout the water column. At this time, internal loading had greatly subsided, and soluble reactive phosphorus was quickly being recycled through the system by algae, such that concentrations were not measurable. This condition likely resulted in phosphorus limitation, reducing algal growth to some degree although total phosphorus concentrations remained near 80 µg/L (since total phosphorus includes that contained within the algal cells).

The brief period of cyanobacteria dominance during the 2010 summer is certainly unique for the Reservoir. Prior to the operation of the destratification system, cyanobacteria were often the dominant algal group throughout the late summer period often comprising between 40% and 80% of the annual algal density. However, during the past two years, cyanobacteria have comprised only 1% (2009) and 7% (2010) of the annual algal density. The observed shift in algal composition during the late summer season, combined with the low annual density of cyanobacteria 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. Cyanobacteria are often associated with nuisance algal blooms, and can produce toxins that inhibit the growth of competing algae as well as inhibit grazing by zooplankton that rely on algae as a food source. In contrast, algal groups that were dominant in the Reservoir during 2010, such as the cryptomonads, diatoms, green algae and dinoflagellates, are the preferred food for zooplankton and some young-of-year fish. While the shift in algal composition is apparent, it is unknown whether other biological assemblages have had sufficient time to respond to these changes at the base of the food web.

ES 1.4. Temperature and Dissolved Oxygen

The winter period for many front-range reservoirs is often a time of concern, because high algal activity, followed by mortality and microbial decomposition can create optimal conditions for reservoir anoxia during ice-covered periods. This phenomenon may potentially lead to a fish kill during the ice-covered period or even during spring turnover (aka, ―winter kill"). Dissolved oxygen profiles collected in late February, during ice-covered conditions, indicated the Reservoir was well oxygenated (~10 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 early June 2010. On June 5th, the Reservoir began showing signs of brief thermal stratification lasting for approximately eight days in early June, for six days in mid-June, and six days in mid-July. During the initial stratification in early June, the dissolved oxygen concentrations at the water sediment interface decreased to levels less than 1 mg/L, yet the remainder of the water column (0 to 6m) remained well oxygenated at 9.0 mg/L. The lowest average water column dissolved oxygen concentration was 6.2 mg/L on August 24th. Evaluation of each profile revealed that the Reservoir was in attainment of the Warm 2 dissolved oxygen criteria of 5.0 mg/L.

ES 1.5. Destratification System Effectiveness

The 2010 summer season represented the third full seasonal operation of the destratification system. The additional temperature monitoring continues to show that storm events can still greatly influence water temperatures and reservoir conditions, despite the constant mixing by the aeration system. However, based on the past four years of 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 post operation, the Reservoir typically experiences approximately 20 days of stratification. This observation indicates the destratification system has been effective in reducing the periods of thermal stratification in the reservoir—which was another primary objective of the system.

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. During the past few years, there has been a slight decrease (~18 µg/L) in the seasonal mean total phosphorus concentration for the Reservoir when compared years just prior to destratification operation. This decrease is encouraging, yet like other patterns in the data, the success of the destratification system at reducing the sediment oxygen demand and internal loading will be best evaluated over a longer period.

ES 1.6. Pollutant Reduction Facility Effectiveness

The Cottonwood Creek Peoria Wetland PRF was effective in reducing the flow-weighted phosphorus concentration from 120 µg/L upstream to 106 µg/L downstream of the wetland system. Further downstream, the Cottonwood Creek Perimeter Wetland PRF showed poor nutrient removal efficiency—in fact, the flow-weighted phosphorus concentration slightly increased from 76 µg/L to 81 µg/L as flows passed through this PRF. Over the past few years this PRF (which was originally constructed 14 years ago) has shown poor function, largely due to the accumulation of sediments resulting from years of stream bank erosion along the stream reach between these two PRFs—some of which was the result of the desired channel reconstruction activities. However, once completed, 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, the annual flow-weighted total phosphorus concentration was 106 µg/L, and at the downstream end it was 76 µg/L. Since the completion of the Cottonwood Creek Stream Reclamation project in 2008, the annual flow-weighted phosphorus concentration entering the Perimeter Wetland PRF has decreased by approximately 66%. A similar reduction has been observed for the suspended solids concentrations entering the wetland PRF.

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 average of 142 µg/L to a post-project average of approximately 70 µg/L. Historically, the wetland PRFs have been effective in reducing the load and concentration of phosphorus entering the Reservoir, but the addition of the stream reclamation project on Cottonwood Creek appears to have provided a large benefit in reducing phosphorus inputs to the Reservoir.

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). This Authority 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 within a net 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 micrograms per liter (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 five 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., and continues to perform the annual monitoring duties of Cherry Creek Reservoir (GEI 2007, GEI 2008b, GEI 2009, GEI 2010). 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 assemblage.
- Evaluate relationships between the biological productivity and nutrient concentrations within Cherry Creek Reservoir and total inflows.
- Assess the effectiveness of pollutant reduction facilities (PRF) on Cottonwood Creek to reduce phosphorus loads into the Reservoir.
- Assess the effectiveness of the destratification system in controlling nuisance algae and minimizing the potential for internal loading of phosphorus.

This report presents the 2010 water quality data collected from Cherry Creek Reservoir and its three primary tributaries, Cherry Creek, Shop Creek, and Cottonwood Creek, and provides comparisons for many parameters to the long-term monitoring data collected since 1987. The report also examines the nutrient removal efficiency of the CCBWQA PRFs located on Cottonwood Creek, evaluates their effectiveness in reducing phosphorus loads to the Reservoir, and provides comparisons to historical data.

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 (385 square miles) drainage basin. The Reservoir has maintained a surface area of approximately 350 hectare (ha) (approximately 852 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 in 2010 was routinely conducted at 10 sites, including three sites in Cherry Creek Reservoir, six sites on tributary streams, and one site on Cherry Creek downstream of the Reservoir (Figure 1). 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. 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 joins Cherry Creek.

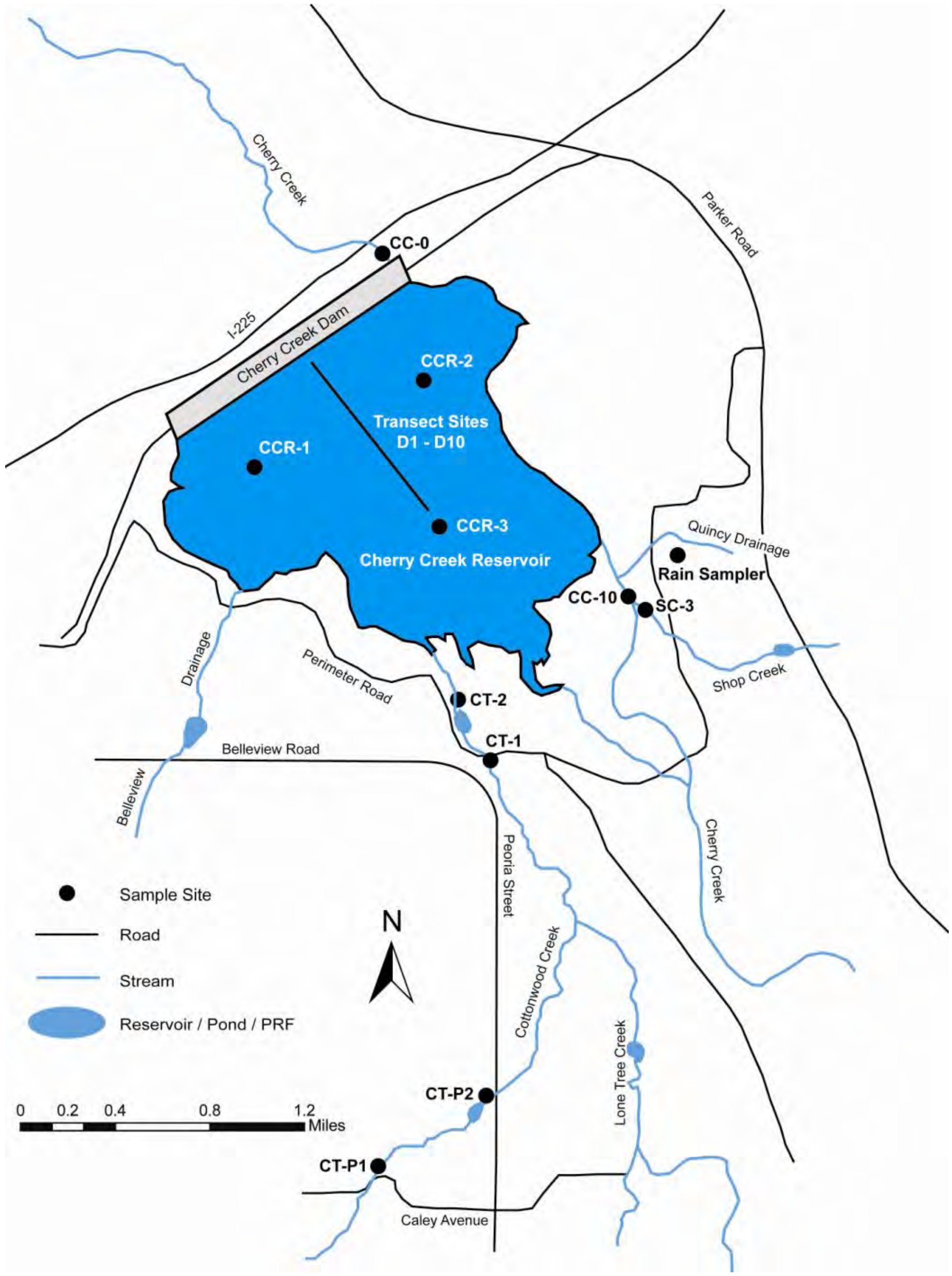

Figure 1: Sampling sites on Cherry Creek Reservoir and selected streams, 2010.

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 CC-10 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 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 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.

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 in 2010. The January 2010 and December 2010 sampling events could not be 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.

Sampling Period	Frequency	Planned Trips/Period	Actual Trips/Period
Jan – Apr	Monthly	4	3
May – Sept	Bi-Monthly	10	10
Oct – Dec	Monthly	3	2
	Total	**17**	**15**

3.1.1.1 Water Clarity

Transparency was determined using a Secchi disk and Licor 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, and chlorophyll *a* 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 Division of Wildlife (CDOW). As part of their sampling schedule to reduce mortality to a walleye brood-stock population in Cherry Creek Reservoir, CDOW has sampled fish populations every two to three years in the past. The most recent fish population survey was conducted in 2007 by the CDOW (personal communication with Harry Vermillion, CDOW). Therefore, only the 2010 fish stocking data are presented herein.

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 in order 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.

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).

Table 2: Number of storm samples collected from tributary streams to Cherry Creek Reservoir, 2010. See Appendix C for sample dates.

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

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 in 2010, with all results being reported in Appendix B.

3.2.2 Biological Laboratory Analysis

Biological analyses of the Reservoir phytoplankton samples were conducted by the Aquatic Analysts and GEI. Aquatic Analysts performed phytoplankton identification and enumeration, which provided cell counts per unit volume (cells/mL) and taxa richness, while GEI performed the chlorophyll *a* concentrations (µg/L). A change in phytoplankton analysts from the University of Colorado to Aquatic Analysts was made to expedite the identification process and ensure a timelier product. 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, 2010.

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 2010 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 were 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 SPSS 2006 or NCSS 2000 statistical software (Hintze 2001). 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 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 2010 Transparency

The whole-reservoir mean Secchi depth varied from 0.51 m in mid-October to 1.49 m in early June (Figure 2). The seasonal (July to September) whole-reservoir mean Secchi depth was 0.94 m (Figure 3). The depth at which 1% of photosynthetically active radiation (PAR) penetrated the water column (i.e., photic zone depth) ranged from 1.76 m in mid-October to a maximum depth of 4.23 m in early June (Figure 2). The greatest level of chlorophyll *a* of 48.7 µg/L was observed in early August.

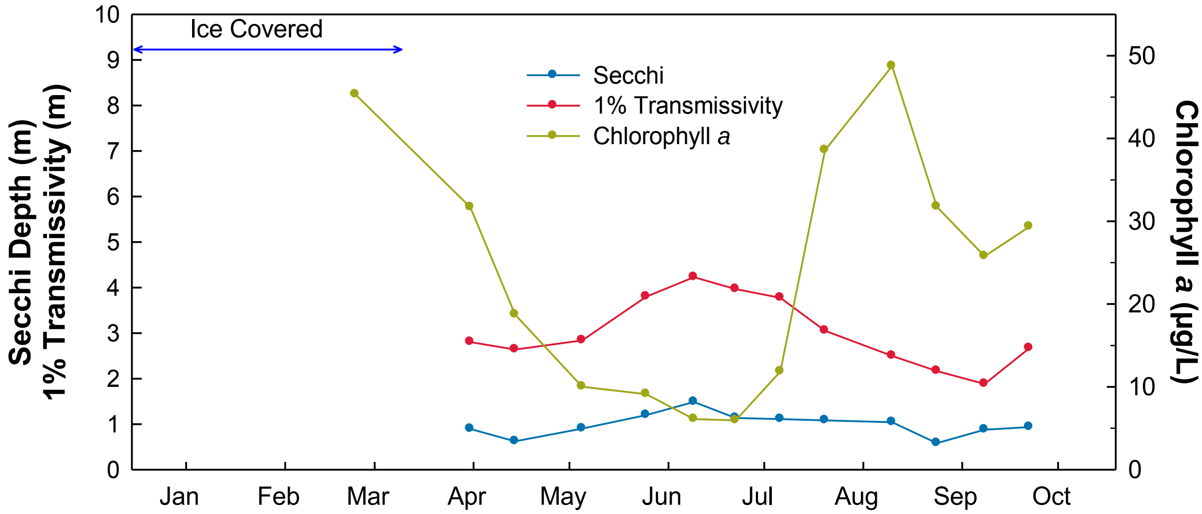

Figure 2: Annual patterns for mean whole-lake Secchi depth, 1% transmissivity, and chlorophyll *a* in Cherry Creek Reservoir, 2010.

4.1.2 Long-Term Secchi Transparency Trends in Cherry Creek Reservoir

In general, seasonal mean (July to September) Secchi depths increased from 1987 to 1996, then decreased in 1997 at which time they have become relatively stable (Figure 3). There was not, however, a statistically significant long-term upward or downward trend for seasonal mean Secchi depths over the period of record. The 2010 seasonal whole-reservoir mean Secchi depth, 0.94 m, was slightly less than the long-term (1987-present) mean value of 0.97 m.

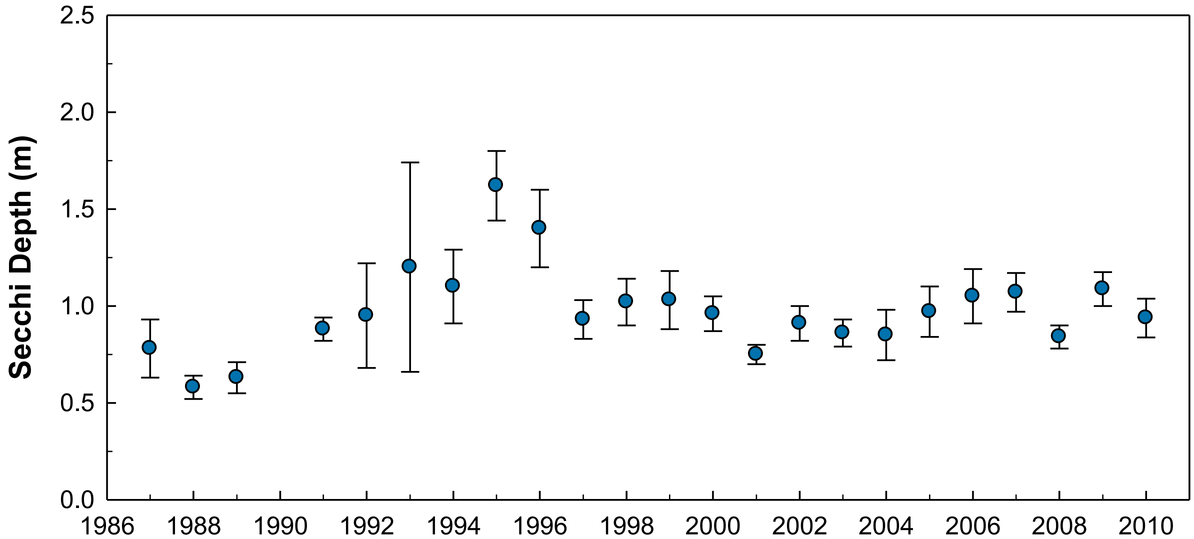

Figure 3: Whole-lake seasonal mean (July to September) Secchi depths (m) measured in Cherry Creek Reservoir, to 2010. Error bars represent a 95% confidence interval for each mean.

4.1.3 2010 Temperature and Dissolved Oxygen

Analysis of past Cherry Creek Reservoir temperature profiles indicates that stratification typically occurs when there is greater than 2°C difference between the surface and bottom water temperatures (Jones 1998). Differences of less than 1°C between the surface and bottom waters suggest 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. Using the above criteria, Cherry Creek Reservoir was evaluated for periods of potential stratification and low dissolved oxygen levels.

Measurement of routine water temperatures (i.e., Hydrolab MS5 Surveyor and Sonde) in Cherry Creek Reservoir ranged from 0.63°C at the surface in late February to 24.7°C at the surface in early August (Figure 4, Figure 6, and Figure 8). Temperature loggers were installed in early-May and showed a well mixed Reservoir until early June. By the beginning of June, the Reservoir began showing signs of thermal stratification which is also supported by dissolved oxygen profiles. During this period, dissolved oxygen concentrations were often less than 5 milligrams per liter (mg/L) at depths greater than 5 m and even less than the upper threshold (2 mg/L) conducive for internal loading. 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. Brief periods of thermal stratification were observed in the Reservoir at all lake sites (4.1.3.1).

Water column dissolved oxygen data (Figure 5, Figure 7, and Figure 9) were also compared to the table value standard (5 mg/L) for Class 1 Warm Water lakes and reservoirs. The Water Quality Control Commission established this value as the year round warm water aquatic life standard for lakes and reservoirs. During periods of stratification, the dissolved oxygen criterion is intended to apply to the epilimnion and metalimnion strata of the reservoir, (CDPHE 2007). As such, during periods of reservoir stratification (i.e., greater than a 2°C difference from surface to bottom), the 5 mg/L criteria would apply to the water column from the surface to a depth of approximately 5 m. However, during periods of whole lake mixing, the 5 mg/L standard would apply to the entire water column, except for the bottom 1 m layer. As a conservative estimate, the mean dissolved oxygen concentration for the 0 to 6 m water layer was computed for each sampling event, regardless of stratification and ranged from 6.41 to 12.82 mg/L. The reservoir was in attainment of the warm water dissolved oxygen standard of 5 mg/L during all sampling events. The uncharacteristically high dissolved oxygen content observed at the surface in late February resulted from sampling just beneath the ice layer where oxygen became saturated during the ice-covered conditions.

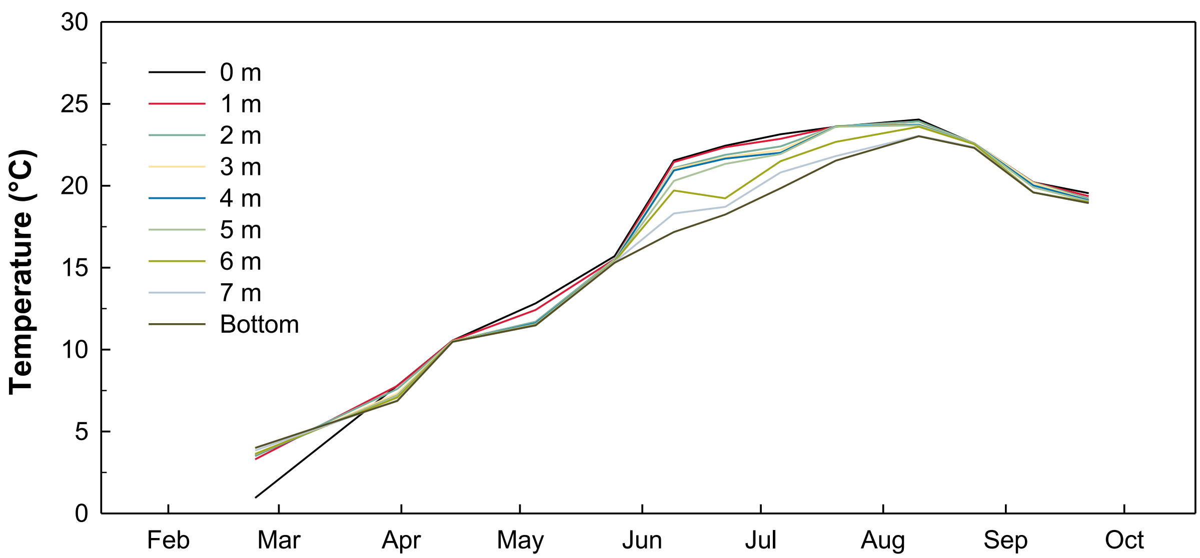

Figure 4: Temperature (°C) recorded at depth during routine monitoring at Site CCR-1 in 2010.

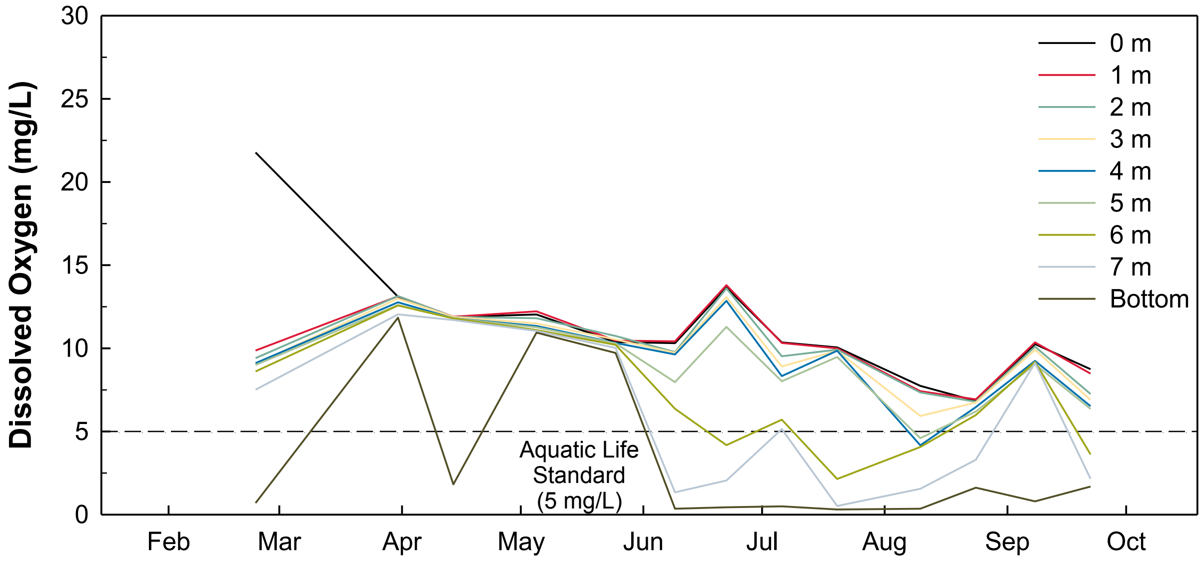

Figure 5: Dissolved oxygen (mg/L) recorded at depth during routine monitoring at Site CCR-1 in 2010. The dissolved oxygen basic standards table value for Class 2 warm water lakes and reservoirs is provided for comparison (5 mg/L).

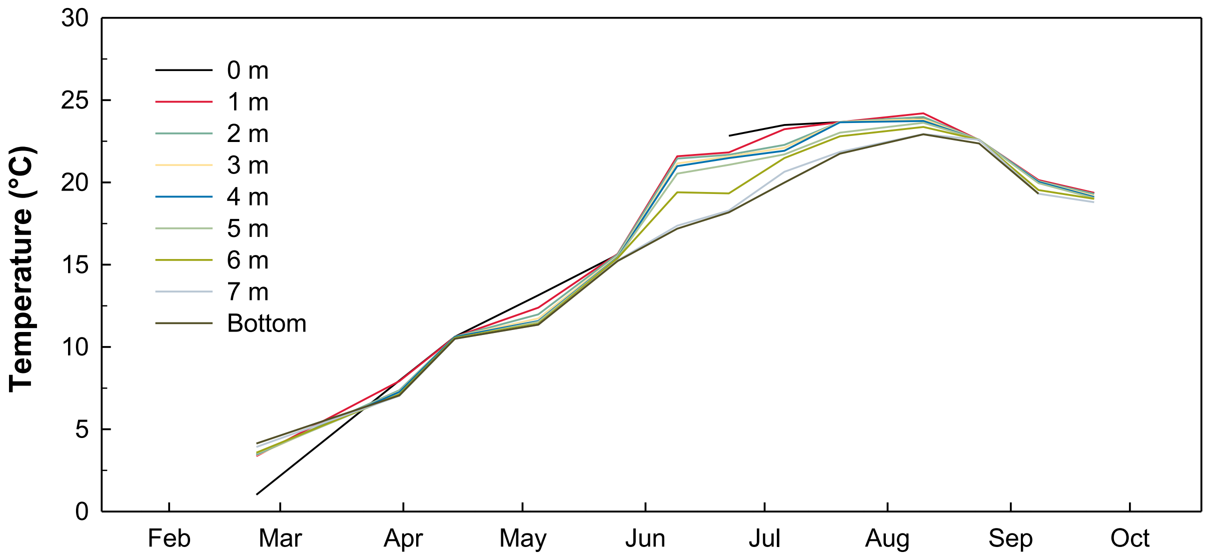

Figure 6: Temperature (°C) recorded at depth during routine monitoring at Site CCR-2 in 2010.

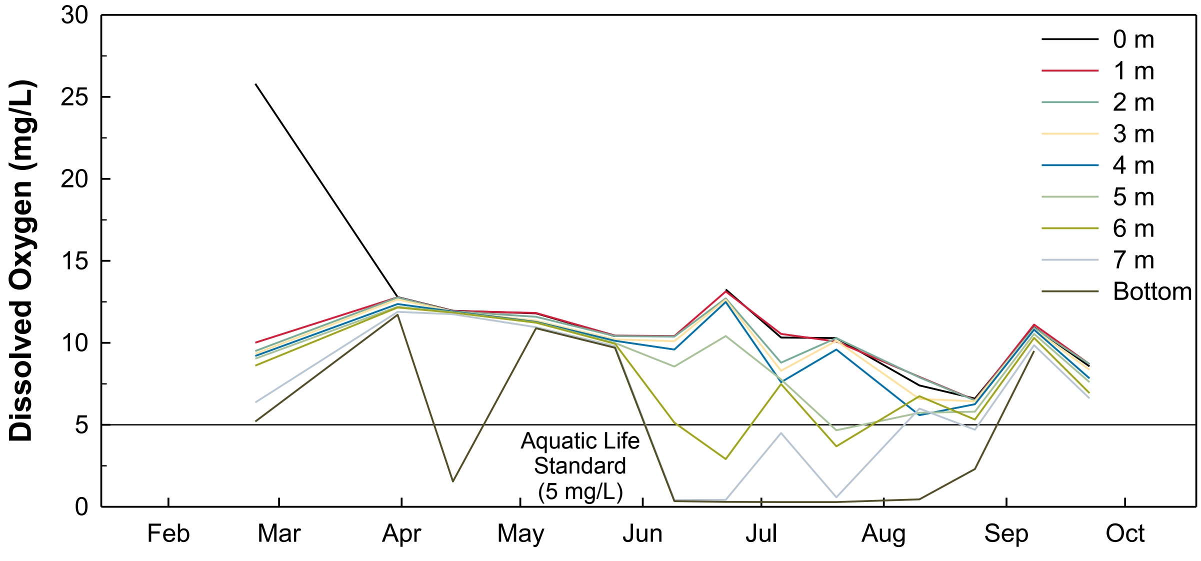

Figure 7: Dissolved oxygen (mg/L) recorded at depth during routine monitoring at Site CCR-2 in 2010. The dissolved oxygen basic standards table value for Class 2 warm water lakes and reservoirs is provided for comparison (5 mg/L).

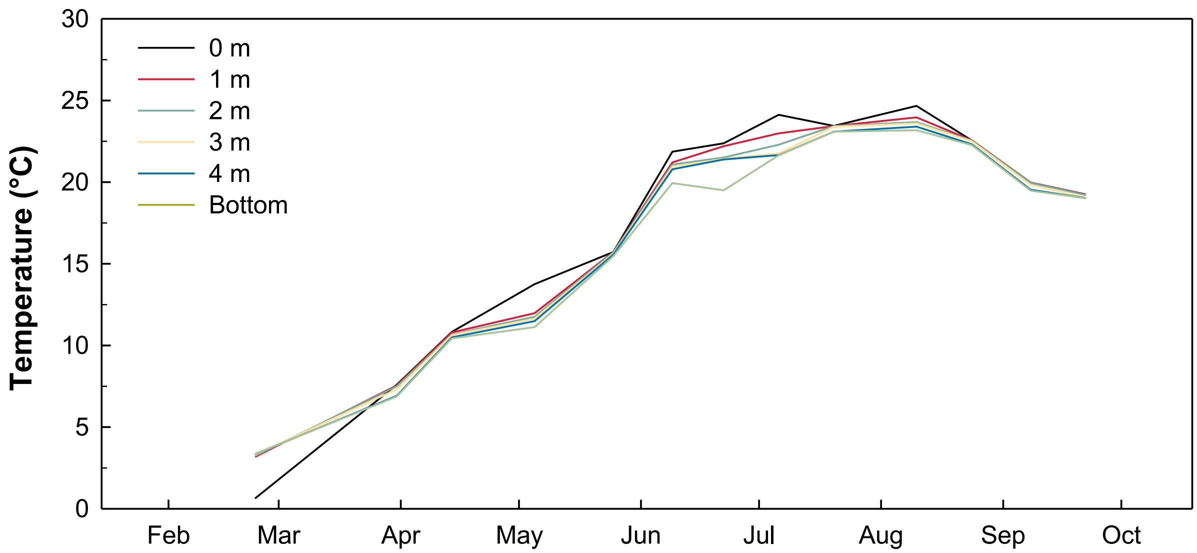

Figure 8: Temperature (°C) recorded at depth during routine monitoring at Site CCR-3 in 2010.

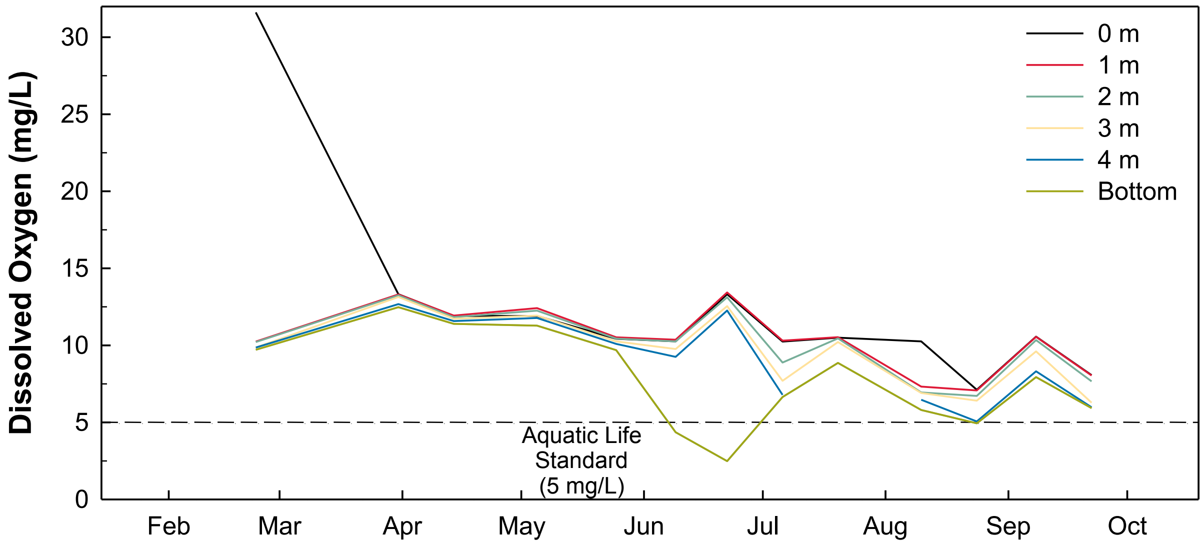

Figure 9: Dissolved oxygen (mg/L) recorded at depth during routine monitoring at Site CCR-3 in 2010. The dissolved oxygen basic standards table value for Class 2 warm water lakes and reservoirs is provided for comparison (5 mg/L).

4.1.3.1 Continuous Temperature Monitoring

In May 2010, temperature loggers were deployed for monitoring the efficiency of the destratification system at mixing the water column. From May through the beginning of June the temperature loggers revealed a very uniform water column temperature and it was not until early June before the Reservoir started showing signs of variation in water temperature (Figure 4, Figure 6, and Figure 8). 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 May 6th to October 13th (Figure 10, Figure 11, and Figure 12). On June 5th, the Reservoir began showing signs of brief thermal stratification lasting for approximately eight days in early June, for six days in mid-June, and six days in mid-July. Between these periods, storm events destratified the reservoir for a short period. During these brief stratification periods, the deeper water layers of the Reservoir revealed low dissolved oxygen concentrations.. 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).

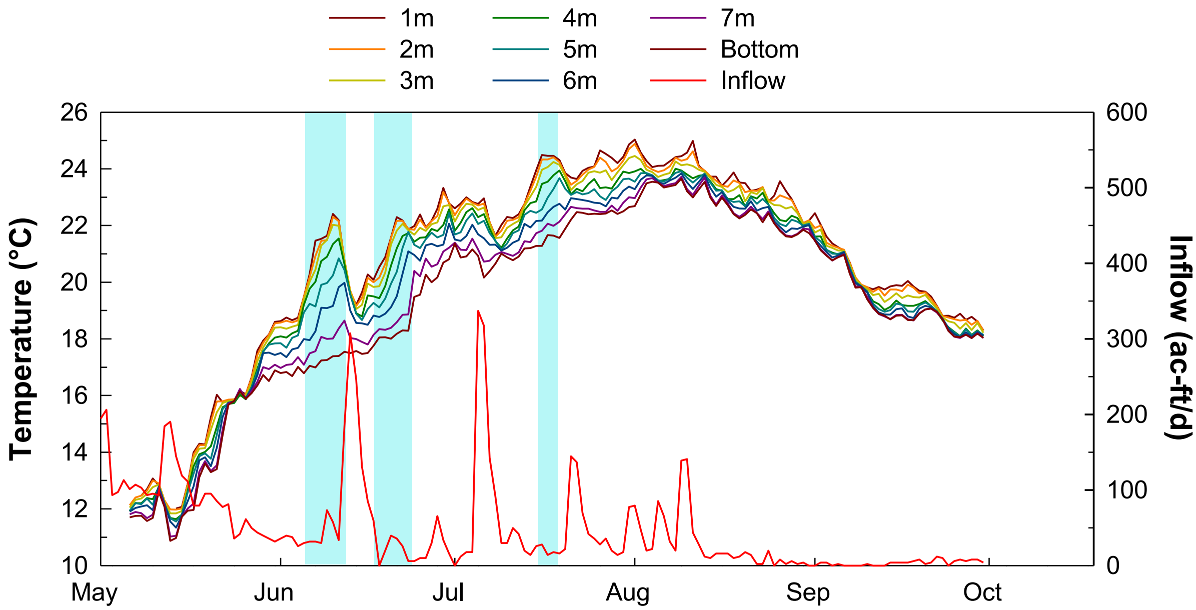

Figure 10: Daily mean temperature recorded at depth for Site CCR-1 based on 15-minute interval data collected by temperature loggers, with USACE inflow. Shaded areas denote periods of thermal stratification.

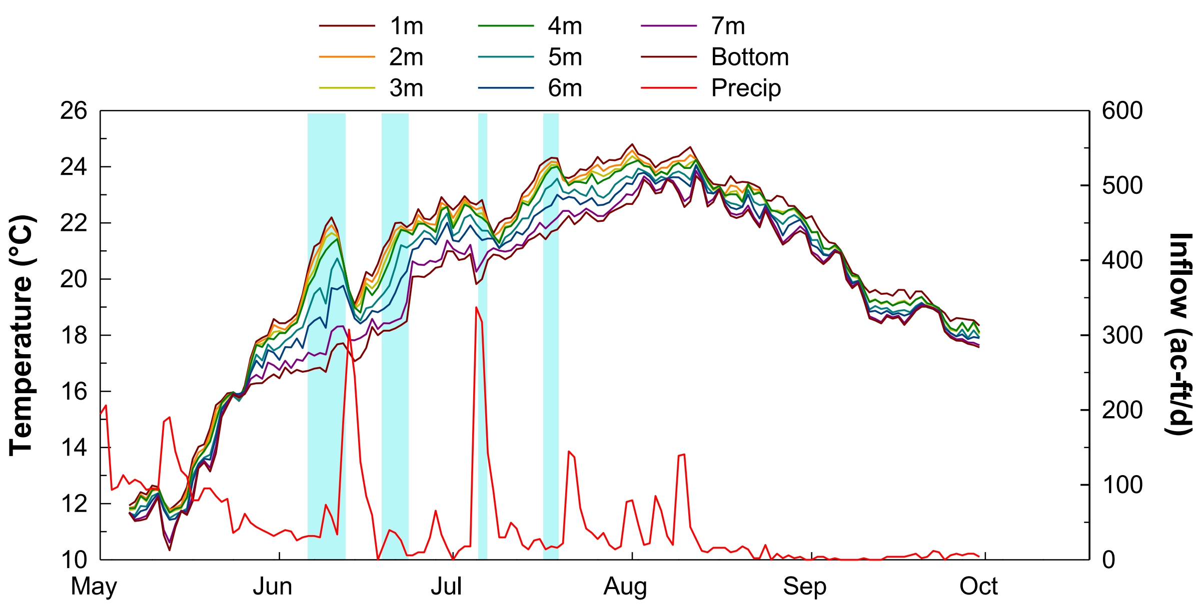

Figure 11: Daily mean temperature recorded at depth for Site CCR-2 based on 15-minute interval data collected by temperature loggers, with USACE inflow. Shaded areas denote periods of thermal stratification.

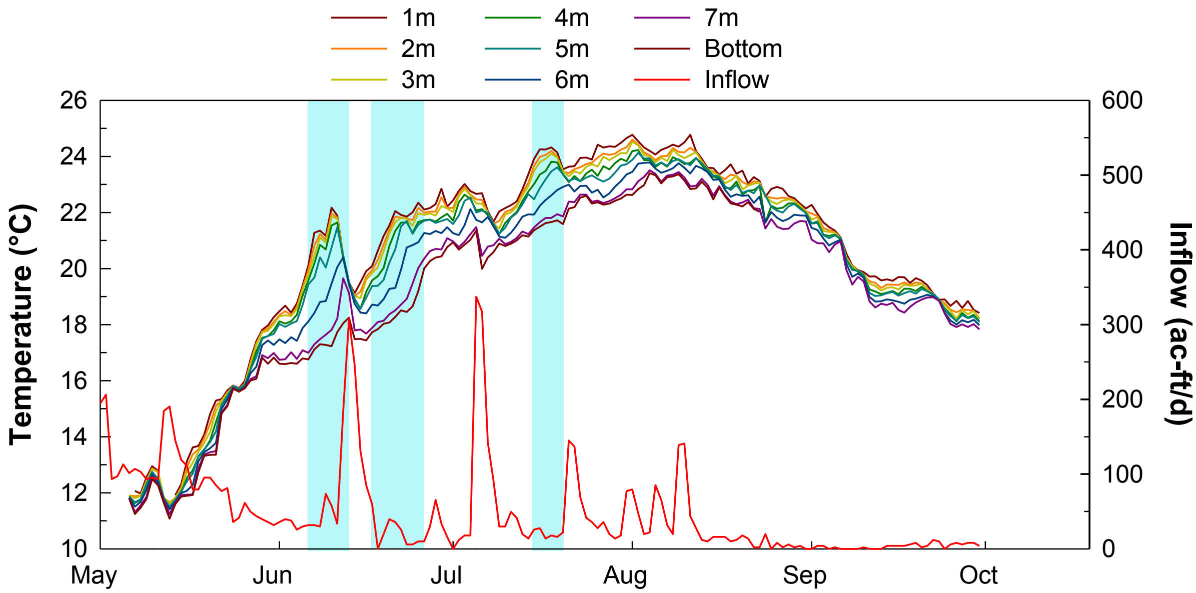

Figure 12: Daily mean temperature recorded at depth for Site CCR-3 based on 15-minute interval data collected by temperature loggers, with USACE inflow and KAPA precipitation. Shaded areas denote periods of thermal stratification.

4.1.3.2 Dissolved Oxygen and Oxidation-Reduction Potential Transect

In 2007, a 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 ten locations along the transect and the nearby Site CCR-3 location, on three sample dates (Figure 13).

During the first sample date on June 9th, the Reservoir was well oxygenated (6 to 9 mg/L DO) from the surface down to a depth of approximately 5 m. This pattern was consistent from Site D1 near the dam to Site D9, at which point the maximum Reservoir depth became shallower (5 to 6 m). These transect profiles represents a snap-shot of dissolved oxygen conditions just prior to the storm events in mid-June. Using the same criteria to evaluate compliance with dissolved oxygen concentrations as discussed above, the mean water column (0 to 6 m) concentration was 8.9 mg/L showing the Reservoir was in attainment of the warm water standard of 5 mg/L. At the 6 m depth, which was approximately 1.2 m above the water/sediment interface, the mean dissolved oxygen concentration was 4.1 mg/L (Figure 13 and Appendix B).

The oxidation-reduction potential profiles on June 9th also indicate that conditions were favorable for a reducing environment at the water/sediment interface (Figure 14). 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

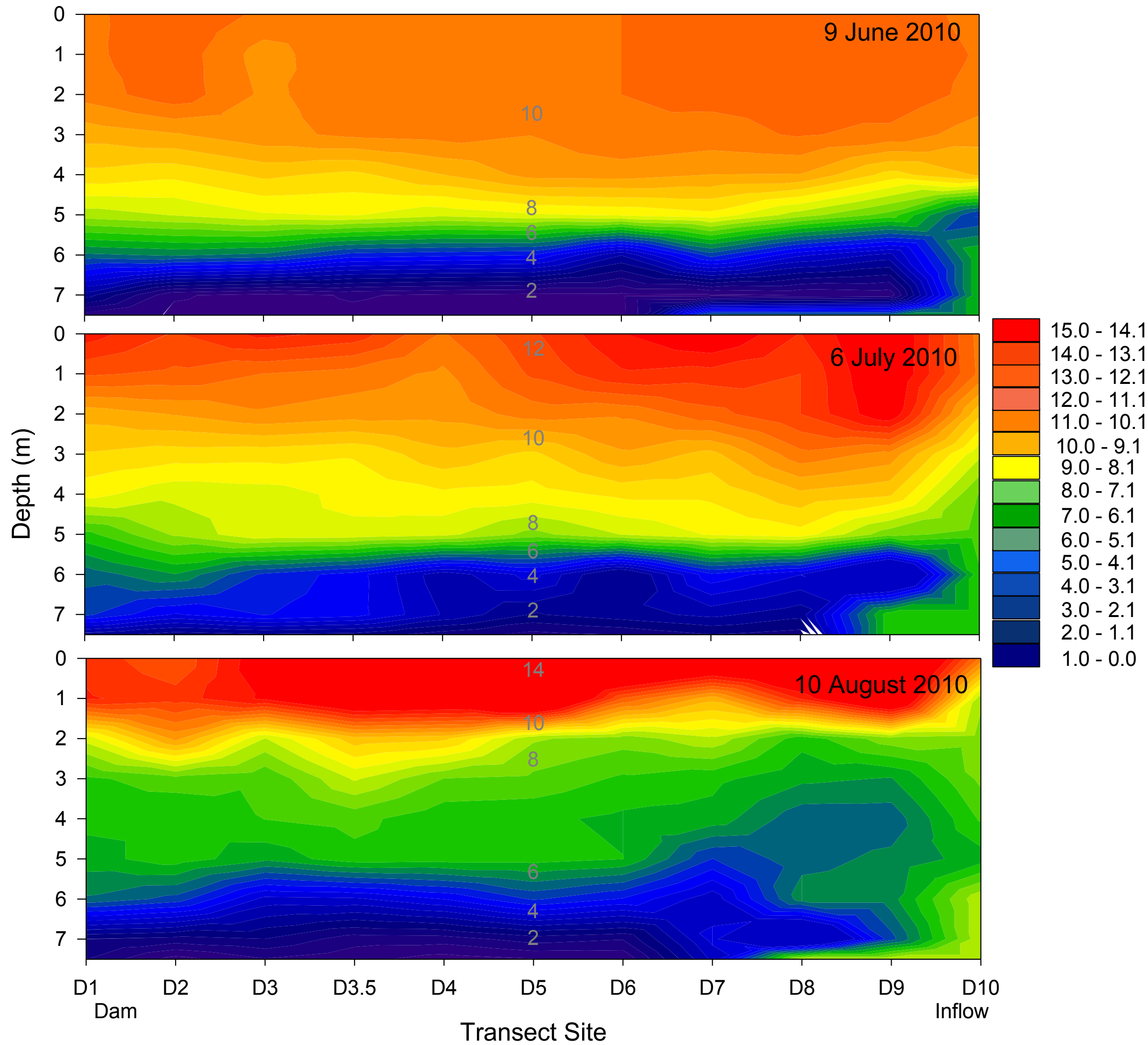

Figure 13: Dissolved oxygen conditions in Cherry Creek Reservoir for three dates based on transect profile data.

(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).

On July 6th, the boundary layer defined by the 5 mg/L dissolved oxygen level remained at approximately the 6 m water depth across the length of the transect (Figure 13). The mean water column concentration was still 8.9 mg/L showing the Reservoir was in attainment of the warm water standard. At the 6 m depth, along the transect length, the dissolved oxygen concentration decreased to approximately 3.5 mg/L, and was similar at 7 m, with concentrations < 1 mg/L at the water/sediment interface. Similarly, the oxidation-reduction potentials at the water/sediment interface revealed favorable conditions for a reducing environment (Figure 14).

The last transect profile was collected on August 10th, when the mean water column dissolved oxygen concentration was 8.0 mg/L, again showing the Reservoir was in attainment of the warm water standard. At the 6 m depth, the dissolved oxygen concentration was 4.2 mg/L.

The three transect profiles indicate that low dissolved oxygen conditions persist near the water/sediment interface due to the oxygen demand at this boundary layer. However, the profiles show a well mixed upper layer within the reservoir, with the mean dissolved oxygen concentration in the upper 2 meters of the Reservoir ranging from 9.7 to 10.5 mg/L for the three transects. In the future, the upper 2 meter layer (excluding the surface) will be the new assessment location for the Reservoir based on the regulatory changes for assessment of dissolved oxygen made during the June 2010 Basic Standards Rulemaking Hearing.

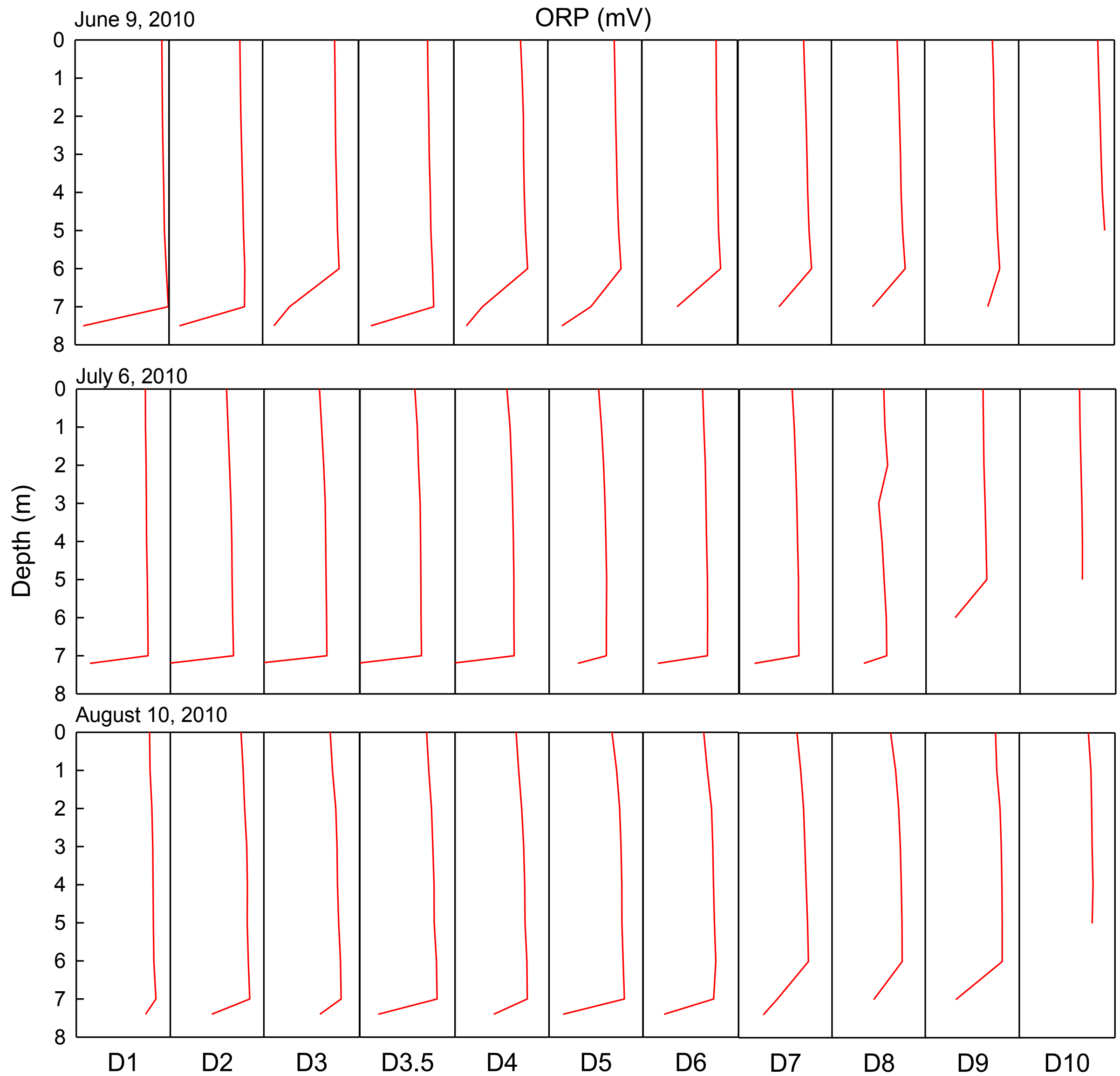

Figure 14: Oxidation reduction potentials in Cherry Creek Reservoir for three dates based on transect profile data. The ORP scales for each transect are all relative to each other within and among sampling events.

4.1.4 2010 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.

In 2010, the photic zone mean concentration of total phosphorus ranged from 61 to 128 µg/L with an overall annual mean of 98 µg/L. The seasonal photic zone mean (July to September) concentration ranged from 74 to 128 µg/L (Figure 15), with a seasonal mean of 101 µg/L. Monthly reservoir phosphorus concentrations did not correlate with monthly USACE inflow or flow-weighted phosphorus concentrations. Reservoir internal loading contributed substantially to late summer phosphorus concentrations.

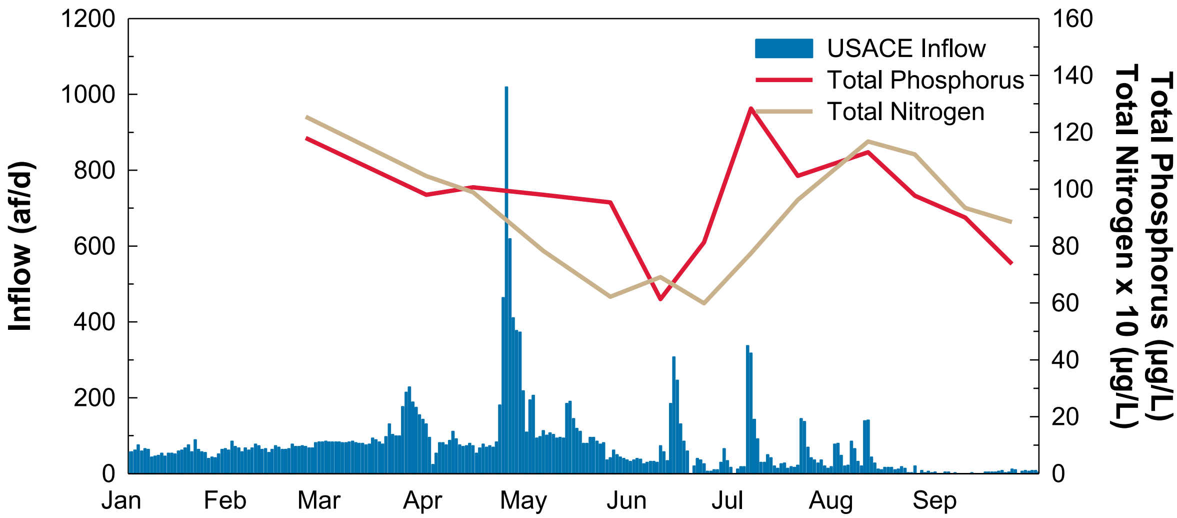

Figure 15: Annual pattern of photic zone total phosphorus, total nitrogen and USACE inflow in Cherry Creek Reservoir, 2010.

Patterns in total phosphorus concentrations collected during profile sampling at Site CCR-2 showed a well-mixed Reservoir throughout the year (Figure 16). There was an extended period of nutrient release from bottom sediments from early June through mid-August as revealed by the pattern of increasing total phosphorus concentrations for the 6 and 7 meter layers as compared with concentrations observed at the same layers during the spring and late fall periods (Figure 16). The period of internal phosphorous loading shows a substantial increase in phosphorus at the 7 m depth, 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 7.5 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 meter water layer accounted for approximately 30 to 85 of the total phosphorus content, also supporting evidence that phosphorus was being released from the sediment during that time.

Photic zone total nitrogen concentrations ranged from 599 to 1225 µg/L, with an annual average of 919 µg/L. During the July to September period, the photic zone mean total nitrogen concentration ranged from 775 to 1168 µg/L, with a mean concentration of 974 µg/L.

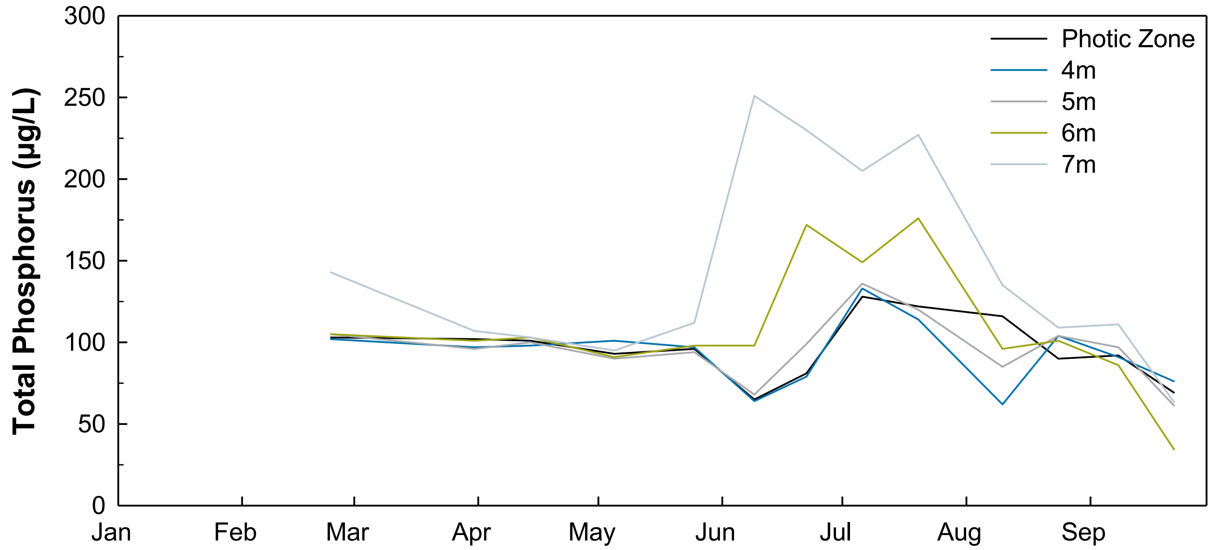

Figure 16: Total phosphorus concentrations recorded for the photic zone and at depth during routine monitoring in 2010.

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 2010 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 2010.

Routine monitoring data collected since 1987 indicates a general increasing pattern in summer mean concentrations of total phosphorus (Figure 17). In 2010, the July to September mean concentration of total phosphorus was 101 µg/L. This value is similar to last year's 98 ug/L concentration, and it is greater than the long-term median value of 81 µg/L (Table 4). Regression analyses performed on 1987 to 2010 seasonal mean TP data indicates a significant ($p < 0.01$) increasing trend.

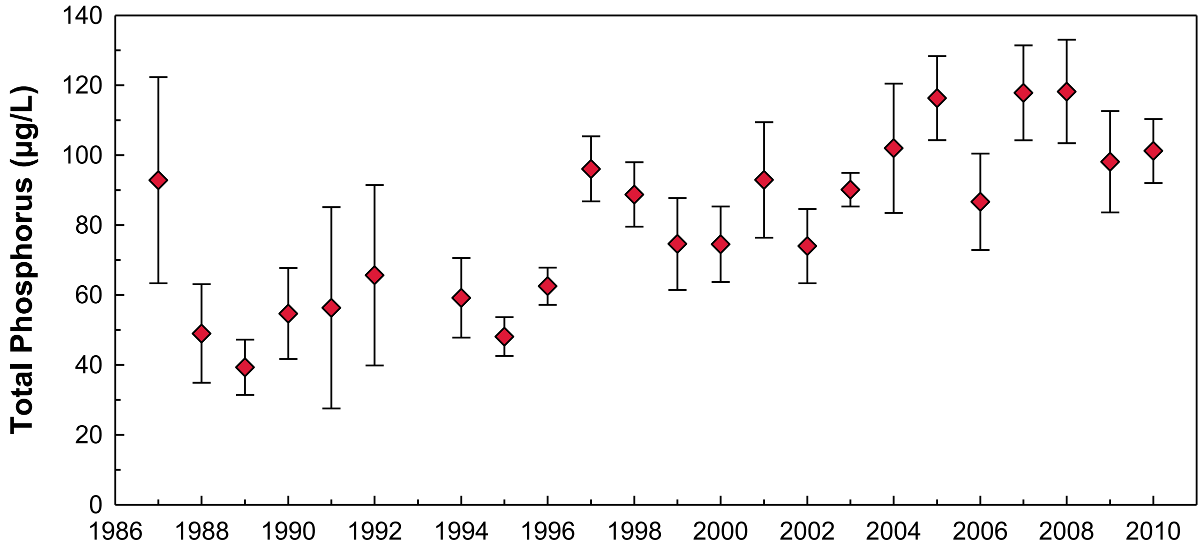

Figure 17: Seasonal mean (July to September) total phosphorus concentrations (µg/L) measured in Cherry Creek Reservoir, 1987 to 2010. Error bars represent a 95% confidence interval for each mean.

Table 4: Comparison of annual mean (monitoring period) and July to September mean phosphorus, nitrogen, and chlorophyll *a* levels in Cherry Creek Reservoir, 1992 to 2010.

Year	Total Nitrogen (µg/L)		Total Phosphorus (µg/L)		Mean Chlorophyll *a* (µg/L)	
	Annual	Jul-Sep	Annual	Jul-Sep	Annual	Jul-Sep
1992	790	970	54	66	12.2	17.4
1993	790	826	50	62	12.6	14.8
1994	1,134	1,144	56	59	11.4	15.4
1995	910	913	48	48	13.9	15.6
1996	889	944	54	62	13.8	18.2
1997	976	1,120	75	96	16.5	22.0
1998	850	880	82	89	21.7	26.5
1999	715	753	80	81	20.7	28.6
2000	784	802	81	81	21.9	25.1
2001	740	741	81	87	26.8	26.1
2002	847	858	70	74	21.7	18.8
2003	990	1,121	87	90	23.2	25.8
2004	923	977	84	102	17.0	18.4
2005	907	990	93	116	16.1	17.1
2006	897	914	81	87	15.9	14.7
2007	859	716	106	118	18.5	12.6
2008	791	800	91	118	16.1	16.6
2009	1,204	1,236	83	98	13.3	13.2
2010	908	974	97	101	24.1	31.0
Mean	**890**	**930**	**76**	**86**	**17.8**	**19.9**
Median	**889**	**914**	**81**	**87**	**16.5**	**18.2**

4.1.6 2010 Chlorophyll a Levels

The annual pattern of chlorophyll *a* concentrations was quite variable, with chlorophyll *a* less than 18 µg/l during the spring and early summer, but considerably higher during late summer and fall (Figure 18). From mid-February through September, chlorophyll *a* concentrations ranged from 6.0 µg/L to 48.7 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. Of interest was the February sampling event, which occurred during ice-covered conditions (~12 inches ice with snow cover)—yet the chlorophyll *a* level was 45.3 µg/l. The July to September seasonal mean chlorophyll *a* level of 31.0 µg/l represents the highest seasonal chlorophyll level observed for the reservoir during the monitoring program, with a peak summer reservoir mean concentration of 48.7 µg/l. The 2010 January to September mean chlorophyll *a* concentration was 24.1 µg/L.

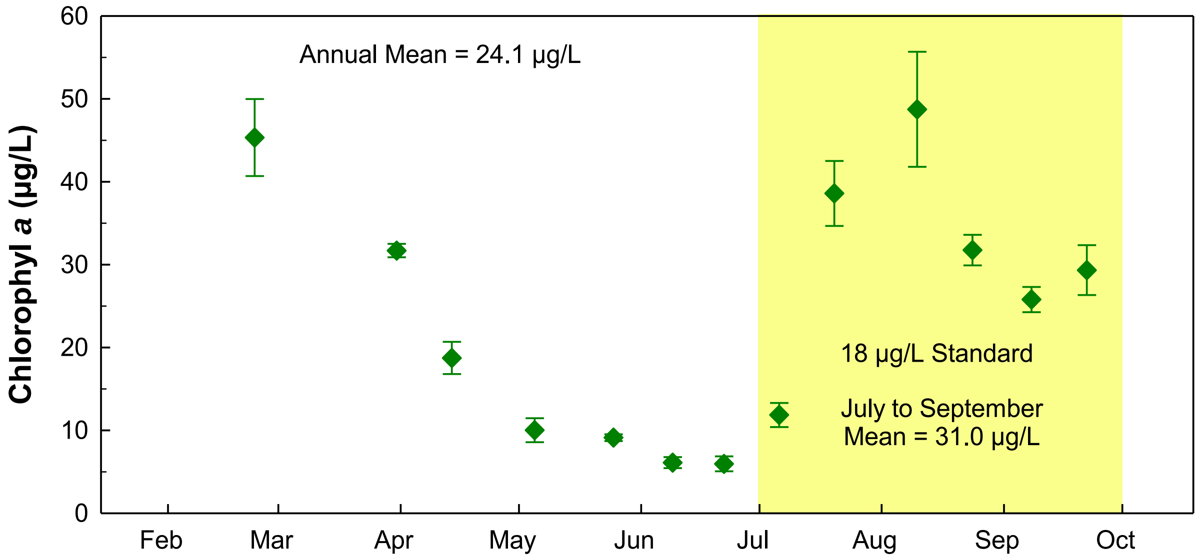

Figure 18: Concentration of chlorophyll *a* (µg/L) in Cherry Creek Reservoir, 2010. Error bars represent a 95% confidence interval around each mean. Highlighted area denotes the seasonal period for the chlorophyll *a* standard.

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 19). However, since 1999 there has been a steady decline in the seasonal mean chlorophyll *a* concentration, reaching a low level in 2007, and similarly again in 2009. However, the 2010 seasonal mean chlorophyll *a* concentration represents the highest seasonal level observed for the Reservoir since the Authority's monitoring program began, and highlights the propensity of algae to respond to optimal growing conditions. A combination of environmental conditions such as the substantial storm event followed by hot summer conditions, which coincided with the efficient mixing of the internal phosphorus load throughout the photic zone by the destratification system, lead to the optimal growing conditions for algae (i.e., water temperature, light, and nutrients). Despite this year's high seasonal chlorophyll *a* level, the reservoir is still in compliance with its one in five year exceedance frequency of the site-specific chlorophyll standard (Figure 19).

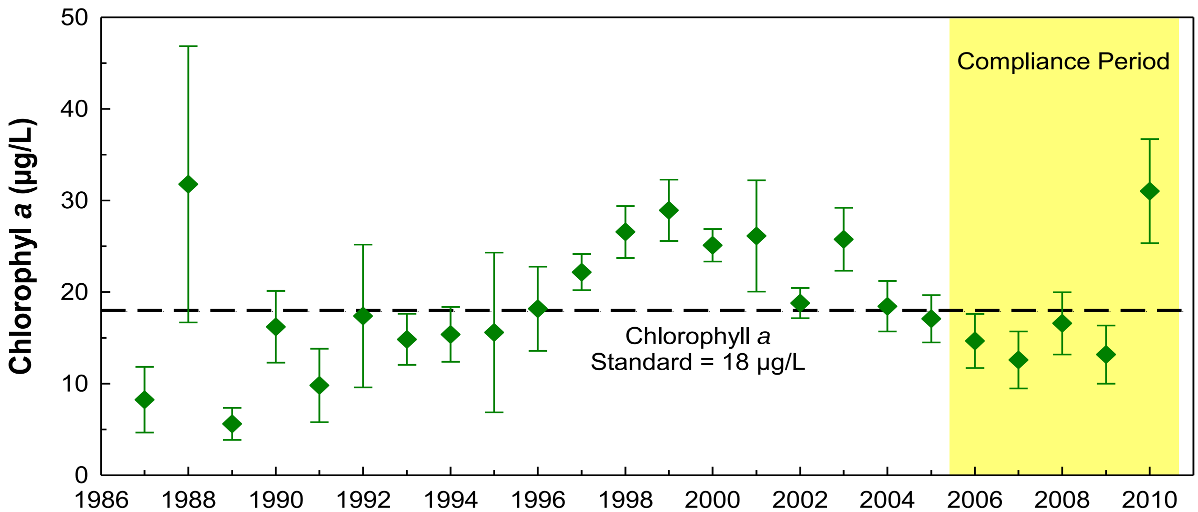

Figure 19: Seasonal mean (July to September) chlorophyll *a* concentrations measured in Cherry Creek Reservoir, 1987 to 2010. Error bars represent a 95% confidence interval around each mean.

4.2 Reservoir Biology

4.2.1 2010 Phytoplankton

Phytoplankton density in the photic zone ranged from 1,463 cells/mL on May 25th to 11,108 cells/mL on February 23rd (Table 5). The number of algal taxa present in the Reservoir ranged from 7 on February 23rd to 34 on September 8th. Annually, the assemblage was dominated in terms of density by green algae (33%), with cryptomonads and diatoms being the next most abundant taxonomic groups at 29% and 24%, respectively (Figure 20). Similar to 2009, the relative density of cyanobacteria (7%) was extremely low in 2010. Green algae were relatively abundant throughout most of the year with exception to the month of July when cryptomonads (early July) and cyanobacteria (late July) dominated the algal assemblage in terms of density.

When the size (i.e., biovolume) of each algae is considered, the diatoms were the most dominant algal group (29%) observed over the course of the year, followed by green algae (22%) then cyanobacteria (19%) (Figure 21). The dinoflagellates and cryptomonads each accounted for approximately 14% 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 dominant in early/mid-summer as well as dinoflagellates in late summer, then diatoms comprising most of the assemblage during the fall. 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.

Table 5: Density (cells/mL) of phytoplankton and total number of taxa collected from all three sites on Cherry Creek Reservoir 2010.

Taxa	23-Feb	31-Mar	14-Apr	10-May	25-May	9-Jun	22-Jun
Diatoms							
Centrics	--	103	202	79	80	105	28
Pennates	--	51	58	158	186	631	284
Green algae	6,264	794	434	534	319	511	1,064
Cyanobacteria	--	--	14	--	27	210	71
Golden-brown algae	251	154	116	--	--	--	--
Euglenoids	--	26	29	20	--	--	--
Dinoflagellates	84	51	--	--	--	15	14
Cryptomonads	4,510	1,794	665	1,385	851	150	99
Total Density	**11,108**	**2,973**	**1,518**	**2,176**	**1,463**	**1,624**	**1,560**
Total Taxa	**7**	**17**	**22**	**18**	**18**	**16**	**18**
Taxa	**6-Jul**	**20-Jul**	**10-Aug**	**24-Aug**	**8-Sep**	**22-Sep**	**--**
Diatoms							--
Centrics	--	--	176	823	1,195	925	--
Pennates	127	235	176	397	887	424	--
Green algae	152	294	2,466	879	1,118	1,889	--
Cyanobacteria	229	3,377	59	57	--	--	--
Golden-brown algae	--	--	--	--	--	--	--
Euglenoids	25	--	--	57	116	--	--
Dinoflagellates	25	147	1,703	170	154	193	--
Cryptomonads	3,174	206	1,879	993	347	540	--
Total Density	**3,733**	**4,257**	**6,460**	**3,375**	**3,816**	**3,970**	**--**
Total Taxa	**13**	**17**	**18**	**26**	**34**	**25**	**--**

In the late winter and early spring the flagellated green algae (*Chlamydomonas* sp.) were more abundant than the nonmotile green algae forms (e.g., *Scendesmus* sp., *Oocystis* sp.); although, the cryptomonads were the dominant algal group in terms of density in the spring. The cryptomonads are also a biflagellated algae, and similar to the flagellated green algae are motile and likely gain a competitive advantage given the constant mixing conditions of the destratification system in the spring. Similarly the dinoflagellates observed during late summer conditions may gain some preferential advantage of the constant mixing provided by the destratification system. The flagellated algae, which are motile and can vertically migrate through the water column to optimize production, represented 49% and 41% of the total assemblage in terms of density and biovolume, respectively.

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 very rare in terms of annual density (7%), although this group did have a late July bloom when they comprised approximately 80% of the assemblage for a brief period. The development of this late July cyanobacteria bloom began in early July as indicated by their relative biovolume despite their low density (Figures 20 and 21). This late July 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. A key aspect in the algal successional patterns is that cyanobacteria were only dominant during a few weeks in late July. Ten days after this cyanobacteria bloom was observed on July 20th, this group comprised less than 1% of the assemblage in terms of density and less than 3% in terms of biovolume. Historically, cyanobacteria were the most dominant group throughout much of the summer period and often extending into the fall.

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 occurred and phosphorus was quickly mixed throughout the water column by the destratification system. Following the early July storm event, the Reservoir was likely ―flushed" of the non-motile green algae or diatoms, 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 early July likely provided a competitive edge to the cyanobacteria (e.g., *Aphanizomenon flos-aquae* and *Anabaena flos-aquae)* and dinoflagellate (*Ceratium hirundinella* and *Glenodinium* sp.) populations that dominated the assemblage in terms of biovolume during July. Both algal groups typically dominate late summer algal assemblages (Whitton and Potts 2000, James et al. 1992, Padisák 1985, Konopka and Brock 1978, Pollingher 1987). The constant mixing by the destratification system also enhances the bottom-up factors by providing a soluble phosphorus-rich photic zone environment which allows algae to maximize their production during the summer. However, the sudden decline of cyanobacteria in early August is likely a result of reduced internal phosphorus loading at this time combined with the efficient mixing of the destratification system. The constant mixing reduces the favorable habitat for the non-motile cyanobacteria. One of the primary objectives of the destratification system was to reduce the favorable habitat conditions for cyanobacteria (AMEC 2005) and given their low relative abundance during the past few years, the system appears to be effective with respect to this goal. Interestingly, the constant mixing by destratification system also appears to have provided more suitable habitat for flagellated algae. These algae are motile and typically move up and down in the water column to maximize production while minimizing grazing pressure.

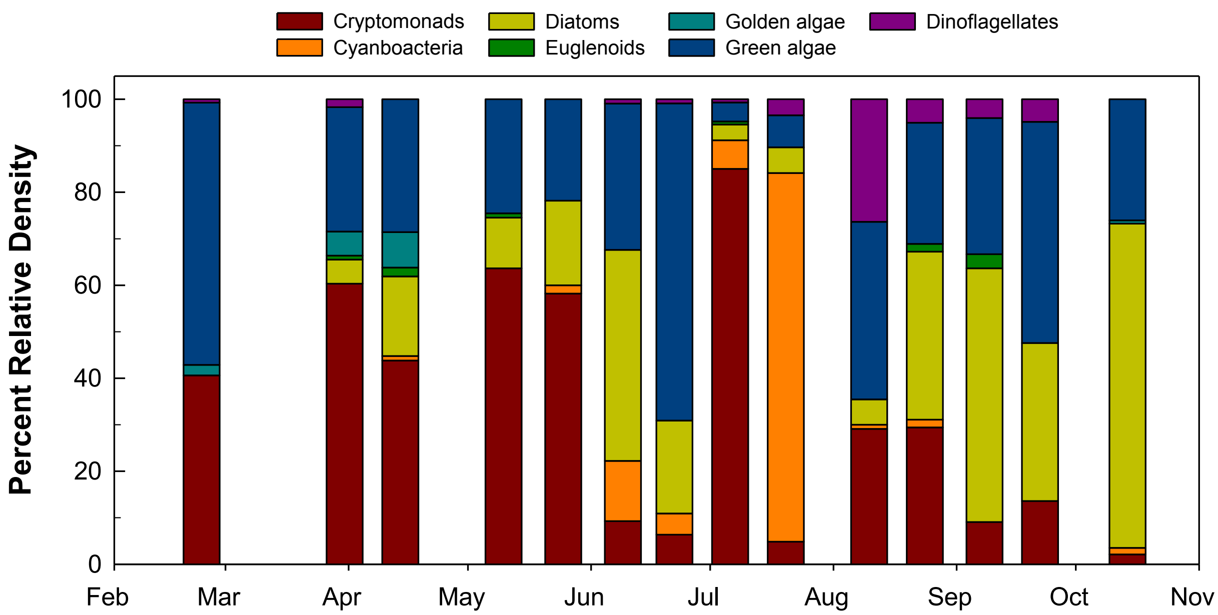

Figure 20: Percent relative density of algal groups by sample date in Cherry Creek Reservoir, 2010.

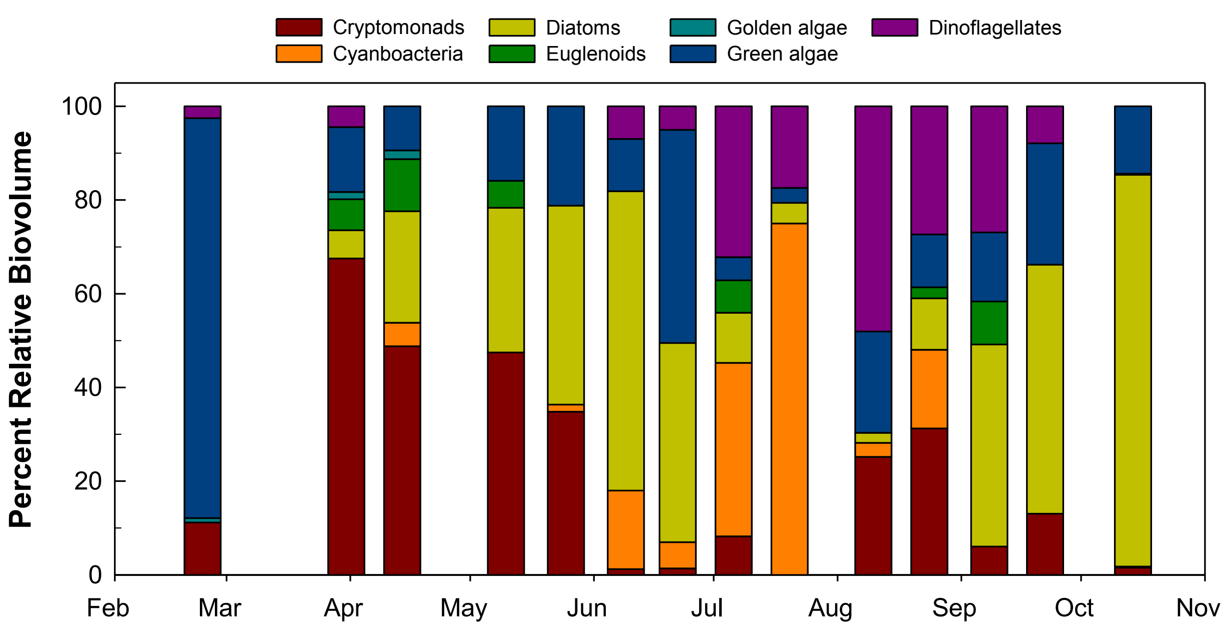

Figure 21: Percent relative biovolume of algal groups by sample date in Cherry Creek Reservoir, 2010.

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 unclear whether the zooplankton population was able to effectively control the algal population during the summer 2010 conditions. It is possible, that given the large gizzard shad (forage fish) population in the Reservoir, these fish could be exerting a heavy grazing pressure on 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). 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, cyptomonads, and green algae (Vanni and Temte 1990).

In 2010, the Reservoir exhibited extremely high chlorophyll levels at various periods throughout the year. In late winter and early spring, the high chlorophyll levels of 45 µg/L and 31 µg/L were associated with an abundance of *Chlamydomonas* sp. (green algae), *Rhodomonas minuta* (cryptomonad) and *Cryptomonas erosa* (cryptomonad). All three are flagellated algae that provide optimal or near optimal food resources for zooplankton (Stemberger and Gilbert 1985, Sarnelle 1993). The high summer levels that ranged from 25 µg/L to 48.7 µg/L were associated with a variety of algae. In July, both cyanobacteria and dinoflagellates contributed to the high levels of chlorophyll *a*. The highest summer chlorophyll *a* concentration of 48.7 µg/L was primarily due to dinoflagellates, with both cryptomonads and green algae contributing to the high levels. As discussed earlier, cyanobacteria were not associated with the summer maximum chlorophyll *a* concentration. This is a unique condition for the Reservoir, because historically the peak chlorophyll *a* concentration was associated with cyanobacteria. The high chlorophyll *a* concentrations of the late summer and fall were primarily due to diatoms, dinoflagellates, and green algae.

4.2.2 Long-Term Phytoplankton

Historically, the cyanobacteria have been the most abundant algae in the Reservoir, especially during the late summer season, but in both 2009 and 2010, this taxonomic group comprised 1% and 7% of the algal assemblage in terms of overall density. The considerable reduction in the relative density of cyanobacteria appears to be related to the effectiveness of the destratification system.

One of the primary objectives of the destratification system was to reduce the suitable habitat conditions for 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 mg/l) during the summer have always been associated with cyanobacteria blooms. However, during the past two years the reservoir has exhibited a shift in the algal species composition such that cyanobacteria have been a very small component of the assemblage (Figure 22). Prior to the operation of the destratification system, cyanobacteria represented between 40 and 80 percent of assemblage in terms of density (cells/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, in both 2009 and 2010, the cyanobacteria population has been greatly reduced, representing between 1 and 7 percent of the algal assemblage in terms of density (Figure 22). Cryptomonads, diatoms, and green algae have become the dominant algal types, all of which are a better food source for zooplankton and fish.

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 allowed them to maximize their productivity. As a result, the reservoir exhibited extremely high chlorophyll *a* levels in 2010 which exceeded the chlorophyll threshold of 18 µg/L.

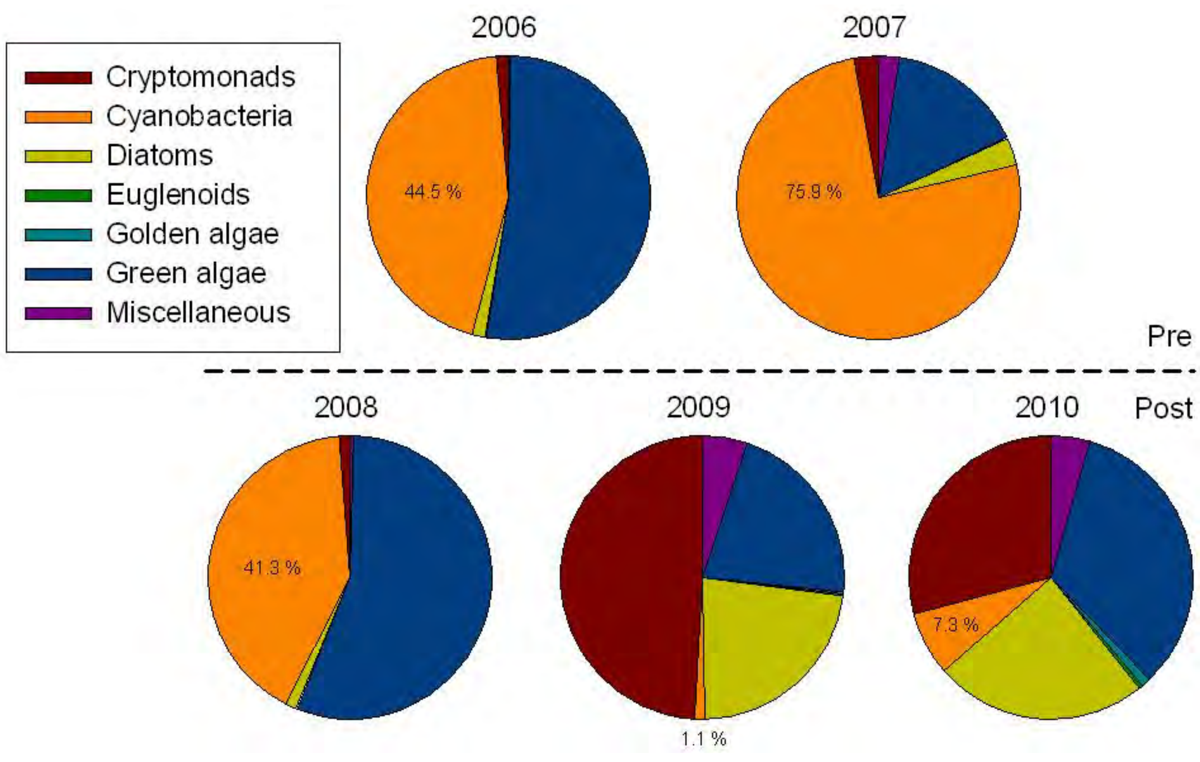

Figure 22: Percent algal density of major taxonomic groups in Cherry Creek Reservoir, 2010, pre- and post-operation of the destratification system.

4.2.3 Fish 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 Division of Wildlife (CDOW) shows that 11 species and 3 hybrids have been stocked in Cherry Creek Reservoir from 1985 to 2009 (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 2010, the CDOW did not stock any fish in the Reservoir nor did they perform population surveys.

4.3 Stream Water Quality

4.3.1 2010 Phosphorus Concentrations in Streams

The median annual total phosphorus concentration for base flow conditions ranged from 53 µg/L at CT-P1 to 241 µg/L at CC-10 (Table 6). At most stream sites, the median seasonal (July to September) base flow concentration was similar to the annual median concentration. The seasonal median concentration of total phosphorus ranged from 43 µg/L at Site CT-2 to 250 µg/L at Site CC-10. At most stream sites, the storm flow TP concentration was greater than concentrations during base flow conditions. The annual median storm flow concentration ranged from 93 µg/L at Site CT-1 to 307 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, 2010.

	Base Flow				Storm Flow	
	Summer		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	250	15	241	19	307	97
CC-O	128	20	124	17	--	--
Cottonwood Creek						
CT-1	58	23	57	23	93	21
CT-2	43	13	57	20	97	28
CT-P1	86	22	53	17	178	35
CT-P2	86	20	54	15	148	40
Shop Creek						
SC-3	155	24	134	8	130	14

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

Long-term patterns (1995-2010) 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 (CC-10) and Shop Creek (SC-3) are 210 µg/L and 102 µg/L, respectively (Table 7), with storm flow concentrations being approximately 67% greater (Table 8). In Cottonwood Creek (CT-2), the long-term median annual base flow total phosphorus concentration is 81 µg/L; however, the long-term median storm flow concentration is approximately 160% greater. Soluble reactive phosphorus fractions for base flows in Cherry Creek and Shop Creek were approximately 78% and 68%, respectively, of the total phosphorus concentrations, while soluble reactive phosphorus fractions in Cottonwood Creek (CT-2) have been approximately 15% of total phosphorus concentrations.

Table 7: Comparison of base flow median annual total phosphorus and soluble reactive phosphorus concentrations for Sites CC-10, SC-3, and CT-2 from 1995 to 2010.

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	177	148	83	63	--	--
1996	145[a]	155[a]	77	70	100	78
1997	202	184	104	83	108	62
1998	264	229	78	71	105	66
1999	258	195	99	60	87	37
2000	284	195	156	125	87	24
2001	222	165	164	126	74	18
2002	193	147	160	125	72	11
2003	205	162	81	66	93	14
2004	214	154	163	105	81	8
2005	216	176	140	80	81	12
2006	157	134	128	63	64	7
2007	217	177	69	43	81	9
2008	188	137	45	21	63	5
2009	189	144	63	29	54	5
2010[b]	241	187	134	70	57	6
Median	**210**	**164**	**102**	**70**	**81**	**12**

[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.

[b] Based on 9 months of data.

Table 8: Comparison of storm flow median annual total phosphorus and soluble reactive phosphorus concentrations for Sites CC-10, SC-3, and CT-2 from 1995 to 2010.

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	25
2010	307	178	130	101	97	24
Median	351	201	171	101	208	35

Base flow total phosphorus and soluble reactive phosphorus concentrations revealed no trends over time at both sites CC-10 and SC-3 (Figures 23 through 26). However, at Site CT-2, both the total phosphorus and soluble reactive phosphorus concentrations reveal a significant ($p < 0.05$) decreasing trend (Figure 27 and Figure 28) during base flow conditions. The observed decreasing trend and greatly reduced variability in soluble reactive phosphorus concentrations at Site CT-2 from 1995 to 2010 is the result of the effectiveness of the PRFs near the Perimeter Road and Peoria Street, along with 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.

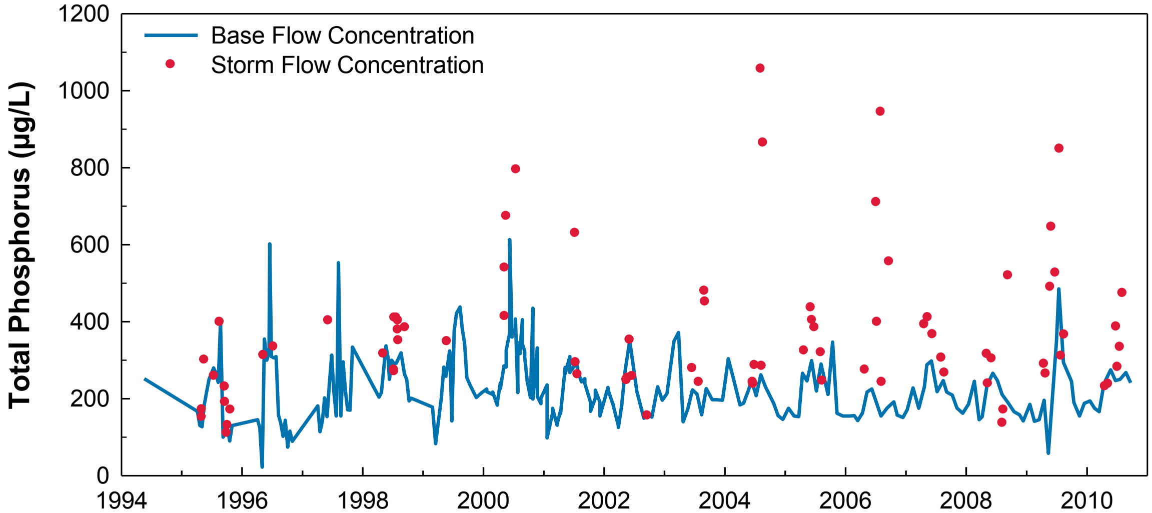

Figure 23: Base flow and storm flow total phosphorus concentrations measured in Site CC-10, 1994 to 2010.

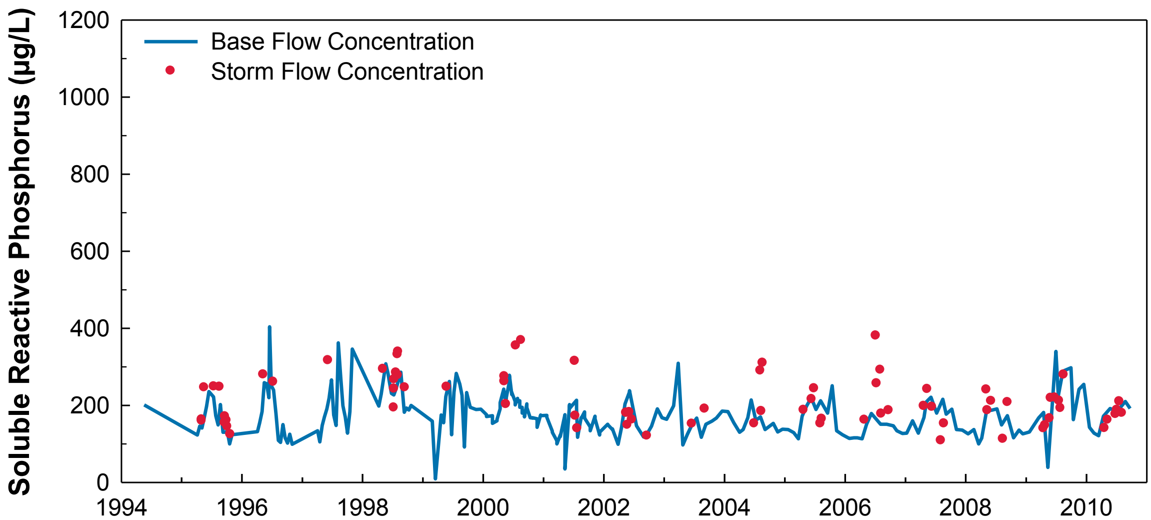

Figure 24: Base flow and storm flow soluble reactive phosphorus concentrations measured in Site CC-10, 1994 to 2010.

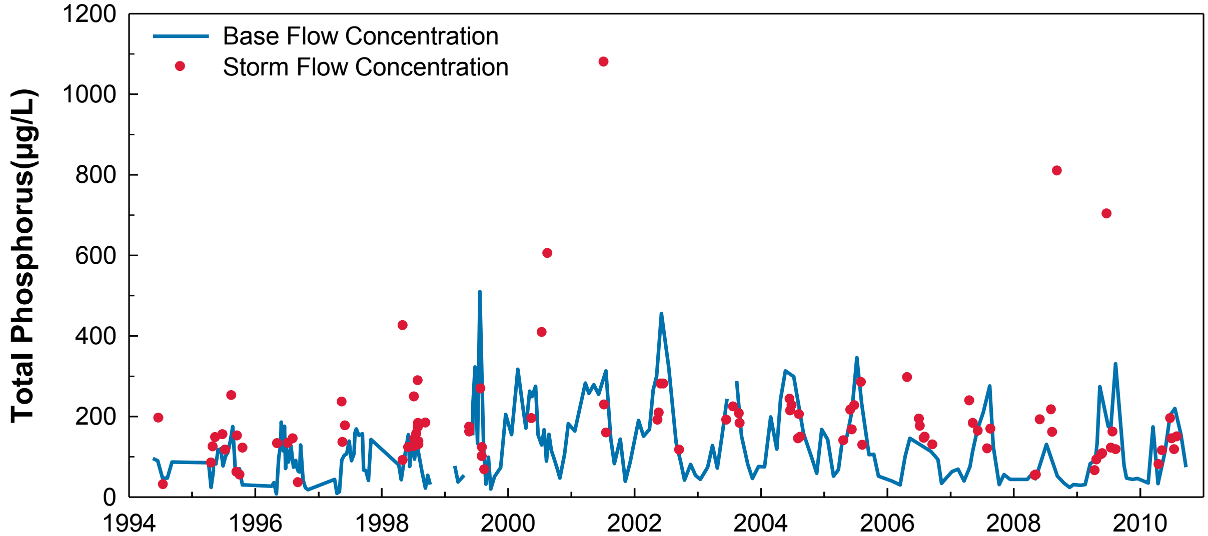

Figure 25: Base flow and storm flow total phosphorus concentrations measured in Site SC-3, 1994 to 2010.

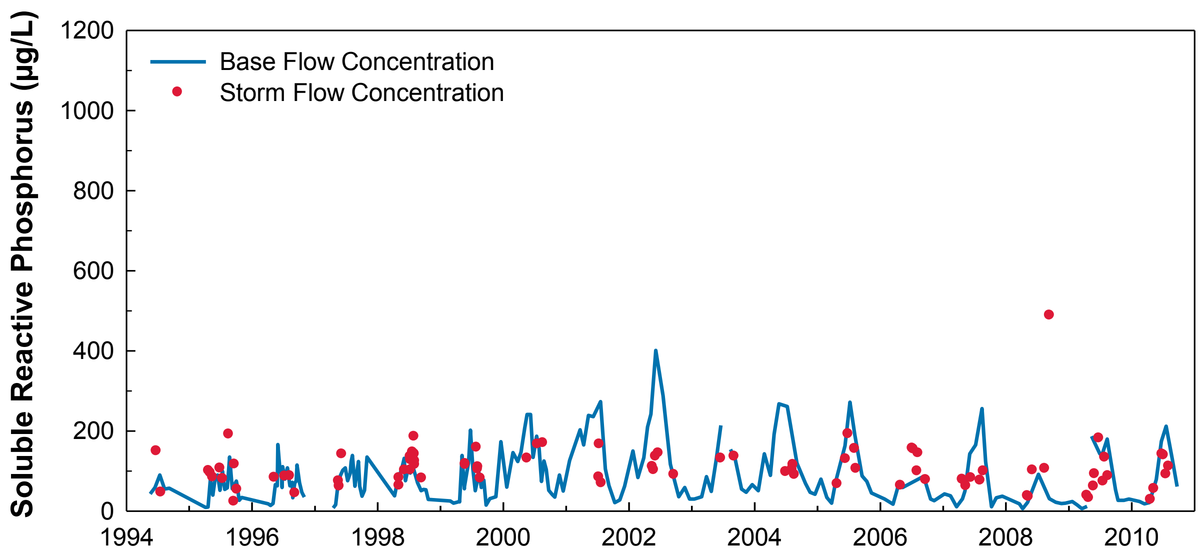

Figure 26: Base flow and storm flow soluble reactive phosphorus concentrations measured in Site SC-3, 1994 to 2010.

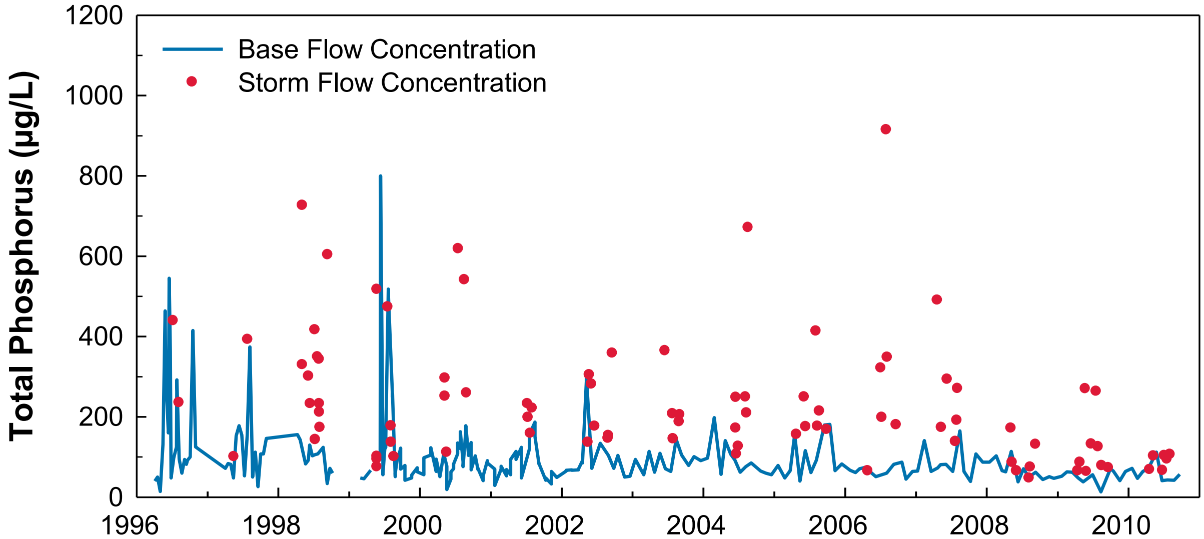

Figure 27: Base flow and storm flow total phosphorus concentrations measured in Site CT-2, 1996 to 2010.

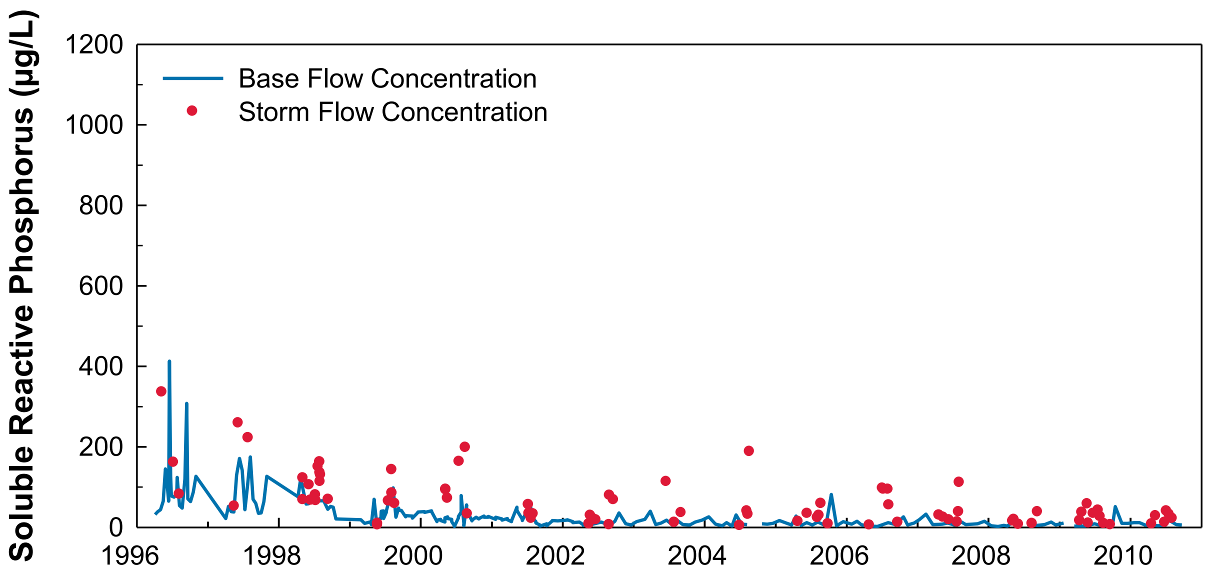

Figure 28: Base flow and storm flow soluble reactive phosphorus concentrations measured in Site CT-2, 1996 to 2010.

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

Alluvial phosphorus data were obtained from Halepaska & Associates for Site MW-9, and are used to estimate the alluvial phosphorus load component, as summarized in Appendix D (JCHA 2001 through 2010). 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 slight, but significant ($p < 0.05$), increasing trend over time (1994 to 2010) at Site MW-9 (Figure 29).

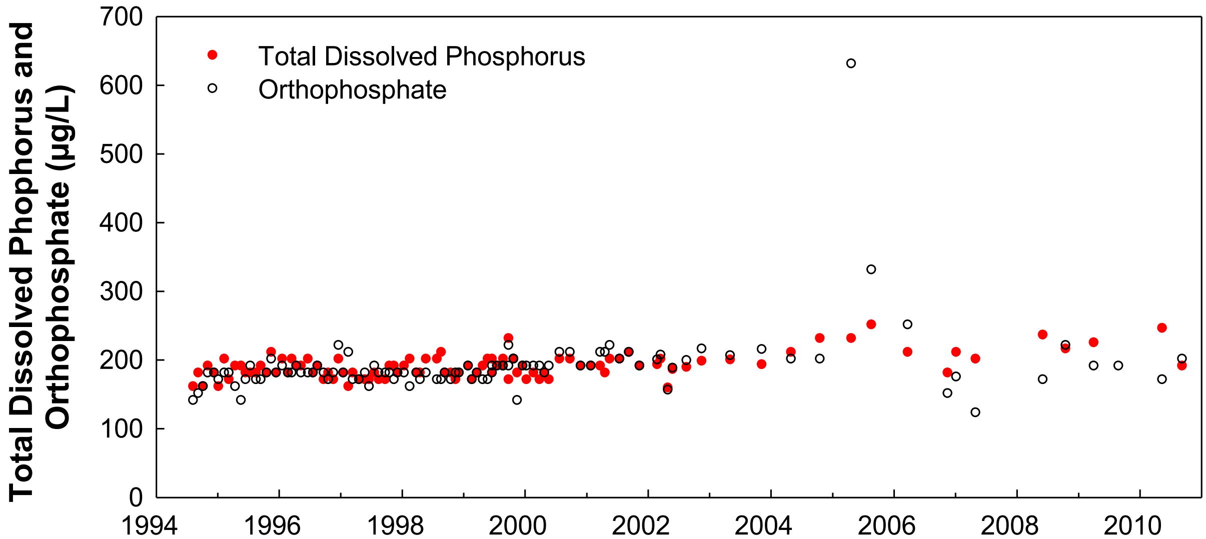

Figure 29: Total dissolved phosphorus and soluble reactive phosphorus concentrations measured at Site MW-9 (1994 to 2010).

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 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. Of note in 2010, the total phosphorus loads for the period of 2007 through 2009 were revised using the median storm flow concentration for each stream source rather than the mean storm flow concentration. Therefore, the normalized loads have slightly changed for the various sources when compared to previous monitoring reports.

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 (84%) of the normalized total phosphorus load to the Reservoir was from Cherry Creek mainstem flows (9,549 lbs). Because Cherry Creek is monitored downstream of Shop Creek, the 145 lbs (<1%) contributed by Shop Creek has been subtracted from the normalized total load calculated for Site CC-10. Cottonwood Creek accounted for 7% of the phosphorus load, or 829 lbs. In 2010, the total phosphorus load to Cherry Creek Reservoir from tributary streams was 10,523 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 19,038 acre-feet in 2010 (Appendix D). Monthly total phosphorus data collected from Site CC-O near the dam outlet was used to estimate the phosphorus export (6,755 lbs/yr) leaving the Reservoir in 2010 (Table 9).

Table 9: Normalized phosphorus loads and export (lbs/year) for Cherry Creek Reservoir, 1992 to 2010.

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	3,142	408	3,925	1,010	429	5,364	1,443	3,921
1993	1,524	179	1,773	1,027	314	3,114	928	2,186
1994	2,437	164	2,700	857	227	3,785	1,055	2,730
1995	2,251	1,402	4,160	1,015	561	5,736	1,434	4,302
1996	2,467	599	3,161	916	349	4,425	1,323	3,102
1997	3,110	884	4,139	1,033	487	5,659	1,599	4,060
1998	9,963	1,633	11,840	1,033	449	13,322	4,010	9,311
1999	11,788	1,314	16,167	1,033	471	17,672	6,759	10,913
2000	10,714	1,644	12,357	1,033	398	13,788	4,426	9,362
2001	5,642	1,820	7,707	1,033	359	9,099	4,697	4,402
2002	1,815	505	2,320	916	288	3,525	1,843	1,681
2003	6,337	974	7,934	1,033	423	9,390	4,673	4,717
2004	5,710	1,753	7,486	1,033	454	8,974	3,421	5,553
2005	7,843	1,502	9,345	1,033	346	10,725	3,644	7,080
2006	3,813	1,272	5,084	1,033	375	6,492	3,287	3,206
2007	16,602	1,976	18,712	1,033	331	20,076	8,042	12,034
2008	6,744	717	7,462	1,015	250	8,727	4,828	3,899
2009	15,038	999	16,100	1,033	480	17,613	9,935	7,678
2010	9,694	829	10,523	742	296	11,561	6,755	4,806
Median	**5,710**	**999**	**7,486**	**1,033**	**375**	**8,974**	**3,644**	**4,402**

4.4.3 Phosphorus Load from Precipitation

In 2010, a total of 13.2 inches of precipitation was recorded at the KAPA meteorological station located at Centennial Airport (as of 09/30/10). When scaled to the areal extent of the Reservoir (852 acres), precipitation accounted for a total of 938 acre-feet of inflow to the Reservoir. The long-term (1995 to 2005) median total phosphorus concentration of 116 µg/L was used to calculate the 2010 annual total phosphorus load of 296 lbs/yr. This long-term median TP 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 2010 is 375 lbs (Table 9).

4.4.4 Phosphorus Load from Alluvium

In 2010, the alluvial inflow quantity was set as a constant 1,496 acre-feet per year (ac-ft/yr; Note only 9 months of data are used in 2010) with the rationale being summarized in Appendix D. Extremely low flows reported by the USACE for September 2010 substantially reduced the measured stream flows to ZERO for sites CC-10 and CT-2, and reduced alluvial flows during the normalization process to 1,437 ac-ft/yr (see Appendix D). The long-term

(1994 to 2006) 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 742 lbs in 2010 (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.

In 2010, the USACE calculated inflow was 20,093 ac-ft/yr, while the GEI calculated stream inflow was 16,022 ac-ft/yr (Appendix D). To compare these two inflow values, the USACE inflow was adjusted for precipitation (938 ac-ft/yr) and alluvial inflows (1,437 ac-ft/yr), which resulted in an adjusted USACE inflow of 17,659 ac-ft/yr. The difference between the adjusted USACE inflow and the GEI stream inflow was 1,637 acre-feet of water. This water volume difference was reapportioned between Cherry Creek (72%), Cottonwood Creek (28%), and Ungaged Inflow (0%). Flow-weighted total phosphorus concentrations for Cherry Creek and Cottonwood Creek were used to calculate the combined reapportioned load of 1,112 lbs.

Following the water balance normalization process, flow from the two tributary streams accounted for a total phosphorus load of 10,523 lbs to the Reservoir in 2010 (Figure 30). The alluvial inflow contributed 742 lbs of phosphorus, with precipitation events contributing 296 lbs to the Reservoir. The total external load of phosphorus to the Reservoir in 2010 was 11,561 lbs (Figure 28).

The Reservoir outflow phosphorus load was estimated to be 6,755 lbs. The flow-weighted total phosphorus concentration for all external sources of inflow to the Reservoir is 212 µg/L and the flow-weighted export concentration for the Reservoir is 130 µg/L (Table 10). The difference of 82 µg/L was retained by the Reservoir. The net external phosphorus load to the Reservoir was 4,806 lbs in 2010.

Table 10: Flow-weighted phosphorus concentrations (µg/L) for Cherry Creek Reservoir, 1992 to 2010.

Year	Cherry Creek Flow-weighted Concentration	Cottonwood Creek Flow-weighted Concentration	Inflow Flow-weighted Concentration	Outflow Flow-weighted Concentration
1992	264	179	214	93
1993	251	155	196	93
1994	250	90	199	76
1995	189	202	179	63
1996	238	339	213	94
1997	261	162	200	80
1998	275	172	234	81
1999	267	132	235	97
2000	348	150	272	95
2001	239	136	194	125
2002	227	98	173	112
2003	284	138	231	143
2004	225	146	192	87
2005	261	126	213	84
2006	230	133	187	107
2007	285	147	250	114
2008	202	70	170	104
2009	271	64	218	140
2010	254	83	212	130
Median	**254**	**138**	**212**	**95**

The effectiveness of the Authority's efforts in reducing flow-weighted phosphorus concentrations entering the Reservoir is illustrated by the concentrations observed along Cottonwood Creek (Figure 28). 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 (CT-P1), the annual flow-weighted total phosphorus concentration was 120 µg/L. The phosphorus level in Cottonwood Creek flow was greatly reduced by the Cottonwood Creek Peoria Wetland System, and reduced further by time flow reached the Cottonwood Creek Perimeter Pond. The normalized flow-weighted concentration of 83 µg/L at Site CT-2 is still on the low end of the observed inflow concentrations for Cottonwood Creek since 1992.

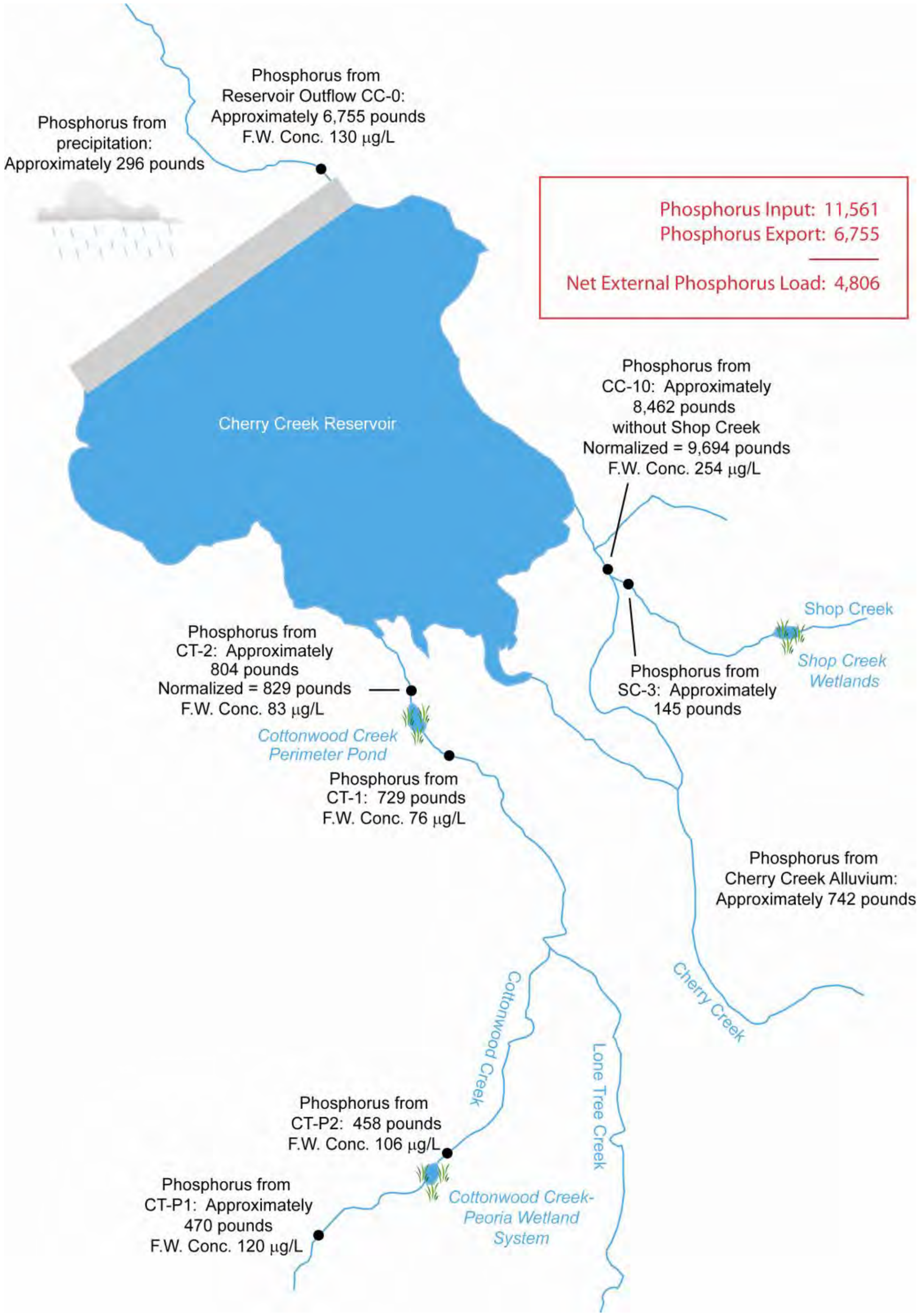

Figure 30: Mass balance diagram of phosphorus loading in Cherry Creek Reservoir, 2010. Note the 2010 loads and concentrations are based on a 9-month period (January through September).

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 (TSS), and 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 32% in 2010, with the long-term average showing a 16% reduction. The flow-weighted total phosphorus concentration upstream and downstream of the PRF was 120 µg/L and 106 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 15% reduction in the flow-weighted total phosphorus concentration at the downstream site.

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 2010.

Parameter	Year	Sampling Sites		Difference	Percent Change Downstream
		CT-P1	CT-P2		
Mean Total Suspended Solids (mg/L)	2002	66	79	13	20
	2003	31	34	3	-0
	2004	87	53	- 34	-39
	2005	47	51	4	9
	2006	38	47	9	24
	2007	79	42	-37	-47
	2008*	37	35	-2	-5
	2009	48	28	-20	-42
	2010	37	25	-12	-32
	Mean	**52**	**44**	**-8**	**-16**
Flow-weighted Total Phosphorus Concentration (µg/L)	2002	114	72	-42	-37
	2003	107	109	2	2
	2004	144	134	-10	-7
	2005	132	129	-3	-2
	2006	142	135	-7	-5
	2007	160	116	-44	-28
	2008*	112	84	-28	-25
	2009	111	83	-28	-25
	2010	120	106	-14	-12
	Mean	**127**	**108**	**-19**	**-15**

* 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 2010, this PRF continues to show poor removal efficiency of both total suspended solids and total phosphorus. Prior to the stream reclamation project, the years of bank erosion in the reach between sites CT-P2 and CT-1 resulted in much of the sediment accumulating in this PRF and reducing its ability to function properly. This PRF is tentatively scheduled for sediment removal and maintenance in 2011. In 2010, the mean concentration of TSS slightly increased from 31 mg/L upstream to 34 mg/L downstream of the PRF (Table 12). The flow-weighted total phosphorus concentration also increased downstream of the PRF by 9%, with the flow-weighted concentration entering the Reservoir from Cottonwood Creek being 81 µg/L.

Since the completion of the Cottonwood Creek Reclamation Project, the flow-weighted total phosphorus concentrations at both sites CT-1 and CT-2 have decreased by approximately 66 and 50%, respectively. Similar reductions have occurred in the suspended solids concentrations at these sites. Prior to the reclamation project, the mean flow-weighted total phosphorus concentration for Cottonwood Creek was 142 µg/L, whereas the flow-weighted concentration has been less than 81 µg/L for the past three years. The decrease in suspended solids and total phosphorus concentrations is likely attributed to the relocation of Cottonwood Creek into a wide, shallow channel that slows the velocity of the water and dissipates the hydraulic energy of the flows, reducing the erosion potential through this reach. In addition, the redesigned drop structures along Cottonwood Creek have reduced the erosion potential that has historically occurred within this reach. These data support the Authority's premise that stream stabilization/reclamation provides a water quality benefit to the Cherry Creek Watershed and Reservoir by reducing the amount of suspended solids and phosphorus due to stream bank erosion.

Table 12: Historical total phosphorus and total suspended solids concentrations and total phosphorus loads upstream and downstream of the Cottonwood Creek Perimeter Pond (1997-2010).

Parameter	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	130	79	-51	-39
	2003	84	62	-22	-26
	2004	155	77	-78	-50
	2005	126	66	-60	-48
	2006	86	95	9	10
	2007	81	71	-10	-12
	2008*	30	56	26	87
	2009	34	32	-2	-6
	2010	31	34	3	6
	Mean	123	69	-54	-44
Flow-weighted Total Phosphorus Concentration (µg/L)	1997	467	166	-301	-64
	1998	217	161	-56	-26
	1999	143	132	-11	-8
	2000	284	161	-123	-43
	2001	158	145	-13	-8
	2002	121	112	-9	-7
	2003	192	126	-66	-34
	2004	192	140	-52	-27
	2005	148	128	-20	-14
	2006	172	135	-37	-22
	2007	162	147	-15	-9
	2008*	60	69	9	15
	2009	76	63	-13	-17
	2010	76	81	5	6
	Mean	176	126	-50	-28

* Nine months of operation.

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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.

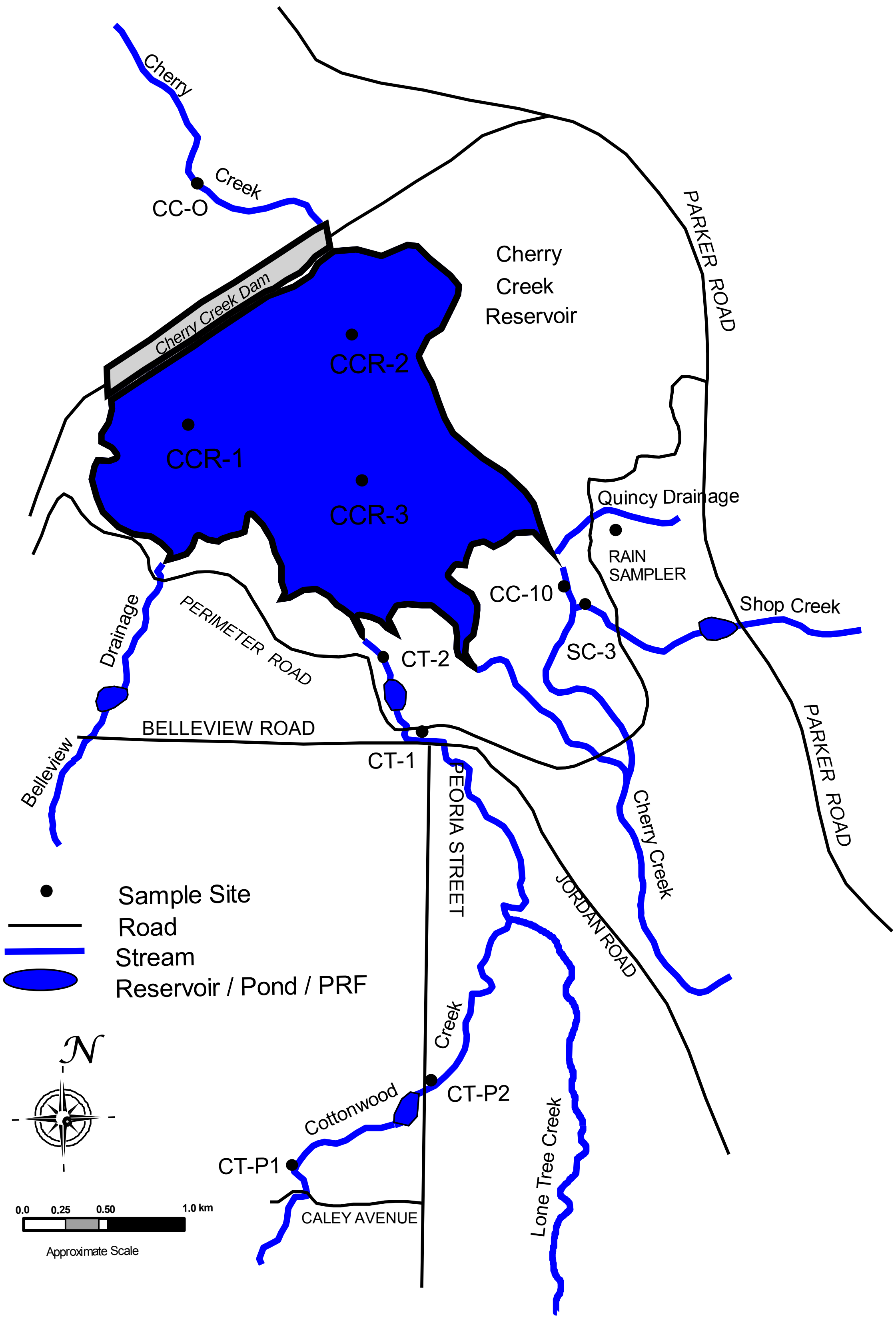

Figure 1: Sampling sites on Cherry Creek Reservoir and selected streams.

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

4.5.3 Storm Flow Sampling

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

4.5.4 Precipitation Sampling

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

4.6 Field Methodologies

4.6.1 Reservoir Sampling

4.6.1.1 Transparency

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

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

4.6.1.2 Depth Profile Measurements

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

4.6.1.3 Continuous Temperature Monitoring

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

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

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

4.6.1.4 Water Samples

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

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

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

Table 4: Number of reservoir samples collected.

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

4.6.2 Water Quality Analyses

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

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

4.7 Stream Sampling

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

4.7.1 Automatic Sampler

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

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

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

4.7.2 Storm Event Sampling

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

4.8 Precipitation Sampling

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

5.0 Laboratory Procedures

5.1 Chemical Laboratory Analysis

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

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

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

5.2 Biological Laboratory Analysis

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

5.3 Laboratory Quality Assurance/Quality Control Protocols

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

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

6.0 Data Verification, Reduction, and Reporting

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

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

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

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

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

7.0 References

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

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

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

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

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Appendix B

2010 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)**
2/23/2010	CCR-1 Photic	103	39	23	1,123	626	106	95	42.3
3/31/2010	CCR-1 Photic	94	18	7	1,017	534	--	13	30.6
4/14/2010	CCR-1 Photic	105	20	14	1,106	615	--	16	18.6
5/5/2010	CCR-1 Photic	97	53	42	808	487	29	38	11.1
5/25/2010	CCR-1 Photic	94	55	45	681	428	2	23	8.9
6/9/2010	CCR-1 Photic	60	25	20	785	537	--	29	5.3
6/22/2010	CCR-1 Photic	78	34	29	588	425	--	9	5.0
7/6/2010	CCR-1 Photic	133	77	69	905	556	2	21	13.9
7/20/2010	CCR-1 Photic	81	64	60	932	465	--	20	35.7
8/10/2010	CCR-1 Photic	120	31	8	1,231	664	2	35	51.8
8/24/2010	CCR-1 Photic	97	25	13	1,151	740	--	16	31.7
9/8/2010	CCR-1 Photic	90	14	--	935	501	--	15	25.4
9/22/2010	CCR-1 Photic	81	16	7	906	586	4	43	28.2

-- Denotes result less than MDL.

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)**
2/23/2010	CCR-2 Photic	103	45	39	1169	709	192	141	41.2
2/23/2010	CCR-2 4m	102	55	53	954	763	223	190	--
2/23/2010	CCR-2 5m	105	66	54	979	777	220	190	--
2/23/2010	CCR-2 6m	105	73	59	952	812	223	210	--
2/23/2010	CCR-2 7m	143	109	90	1,068	903	231	402	--
3/31/2010	CCR-2 Photic	102	19	8	1,071	507	--	13	32.3
3/31/2010	CCR-2 4m	97	16	7	996	491	--	10	--
3/31/2010	CCR-2 5m	96	17	8	990	491	--	16	--
3/31/2010	CCR-2 6m	101	17	7	950	470	--	9	--
3/31/2010	CCR-2 7m	107	17	9	978	455	--	7	--
4/14/2010	CCR-2 Photic	101	16	11	964	490	--	--	21.1
4/14/2010	CCR-2 4m	98	16	13	919	465	--	--	--
4/14/2010	CCR-2 5m	100	15	10	938	445	--	--	--
4/14/2010	CCR-2 6m	103	16	8	960	460	--	--	--
4/14/2010	CCR-2 7m	103	18	7	965	476	--	--	--
5/5/2010	CCR-2 Photic	93	49	40	758	460	20	37	8.9
5/5/2010	CCR-2 4m	101	50	40	750	464	20	43	--
5/5/2010	CCR-2 5m	90	51	39	737	443	20	39	--
5/5/2010	CCR-2 6m	91	48	40	715	471	20	48	--
5/5/2010	CCR-2 7m	95	51	40	714	470	23	49	--
5/25/2010	CCR-2 Photic	96	56	45	603	398	2	23	9.7
5/25/2010	CCR-2 4m	97	53	45	594	398	2	20	--
5/25/2010	CCR-2 5m	94	53	45	598	377	2	16	--
5/25/2010	CCR-2 6m	98	58	45	591	388	--	25	--
5/25/2010	CCR-2 7m	112	53	44	607	354	3	40	--
6/9/2010	CCR-2 Photic	65	25	18	687	472	--	21	6.5
6/9/2010	CCR-2 4m	64	26	22	616	447	--	21	--
6/9/2010	CCR-2 5m	68	34	30	611	426	--	27	--
6/9/2010	CCR-2 6m	98	57	53	630	439	3	20	--
6/9/2010	CCR-2 7m	251	165	171	776	479	--	81	--
6/22/2010	CCR-2 Photic	81	37	33	604	438	--	11	6.5
6/22/2010	CCR-2 4m	79	36	34	595	412	--	9	--

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)**
6/22/2010	CCR-2 5m	99	49	46	633	438	3	8	--
6/22/2010	CCR-2 6m	172	103	99	776	553	11	134	--
6/22/2010	CCR-2 7m	230	161	153	900	686	7	263	--
7/6/2010	CCR-2 Photic	128	84	66	725	422	--	10	11.8
7/6/2010	CCR-2 4m	133	96	74	697	460	2	31	--
7/6/2010	CCR-2 5m	136	96	75	655	436	--	31	--
7/6/2010	CCR-2 6m	149	98	80	749	477	2	38	--
7/6/2010	CCR-2 7m	205	116	111	818	566	66	52	--
7/20/2010	CCR-2 Photic	122	60	55	1,010	448	--	19	44.7
7/20/2010	CCR-2 4m	114	64	59	824	434	--	21	--
7/20/2010	CCR-2 5m	120	118	116	787	633	5	171	--
7/20/2010	CCR-2 6m	176	136	130	980	650	5	198	--
7/20/2010	CCR-2 7m	227	189	190	916	731	2	332	--
8/10/2010	CCR-2 Photic	116	31	8	1,198	603	2	26	55.7
8/10/2010	CCR-2 4m	62	26	13	944	580	2	47	--
8/10/2010	CCR-2 5m	85	30	16	951	599	3	45	--
8/10/2010	CCR-2 6m	96	37	22	1,045	589	6	56	--
8/10/2010	CCR-2 7m	135	50	39	990	560	32	53	--
8/24/2010	CCR-2 Photic	90	24	11	1,148	701	--	19	34.2
8/24/2010	CCR-2 4m	104	22	8	1,127	690	--	11	--
8/24/2010	CCR-2 5m	104	24	9	1,097	657	--	14	--
8/24/2010	CCR-2 6m	101	24	12	1,018	678	--	19	--
8/24/2010	CCR-2 7m	109	44	32	974	650	--	44	--
9/8/2010	CCR-2 Photic	92	14	--	997	534	--	29	24.5
9/8/2010	CCR-2 4m	91	14	--	845	475	--	12	--
9/8/2010	CCR-2 5m	97	12	--	842	447	--	14	--
9/8/2010	CCR-2 6m	86	14	--	834	452	--	11	--
9/22/2010	CCR-2 Photic	69	17	7	878	560	3	38	33.9
9/22/2010	CCR-2 4m	76	18	7	803	551	--	66	--
9/22/2010	CCR-2 5m	61	19	7	836	556	2	69	--
9/22/2010	CCR-2 6m	34	13	6	776	538	3	60	--
9/22/2010	CCR-2 7m	63	14	8	782	542	4	56	--

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)
2/23/2010	CCR-3 Photic	148	58	38	1,383	769	238	103	52.5
3/31/2010	CCR-3 Photic	98	18	7	1,051	503	--	11	32.3
4/14/2010	CCR-3 Photic	96	19	11	898	434	--	--	16.5
5/5/2010	CCR-3 Photic	104	53	40	783	494	18	31	10.2
5/25/2010	CCR-3 Photic	96	58	45	582	376	2	45	8.8
6/9/2010	CCR-3 Photic	59	24	19	600	424	--	18	6.5
6/22/2010	CCR-3 Photic	85	35	31	604	433	--	7	6.4
7/6/2010	CCR-3 Photic	124	71	67	696	474	--	40	9.9
7/20/2010	CCR-3 Photic	111	56	50	943	446	--	10	35.4
8/10/2010	CCR-3 Photic	103	28	10	1,076	676	2	22	38.8
8/24/2010	CCR-3 Photic	106	23	14	1,068	651	--	14	29.4
9/8/2010	CCR-3 Photic	88	13	--	869	544	--	20	27.6
9/22/2010	CCR-3 Photic	71	15	7	869	556	4	57	26.0

-- Denotes result less than MDL.

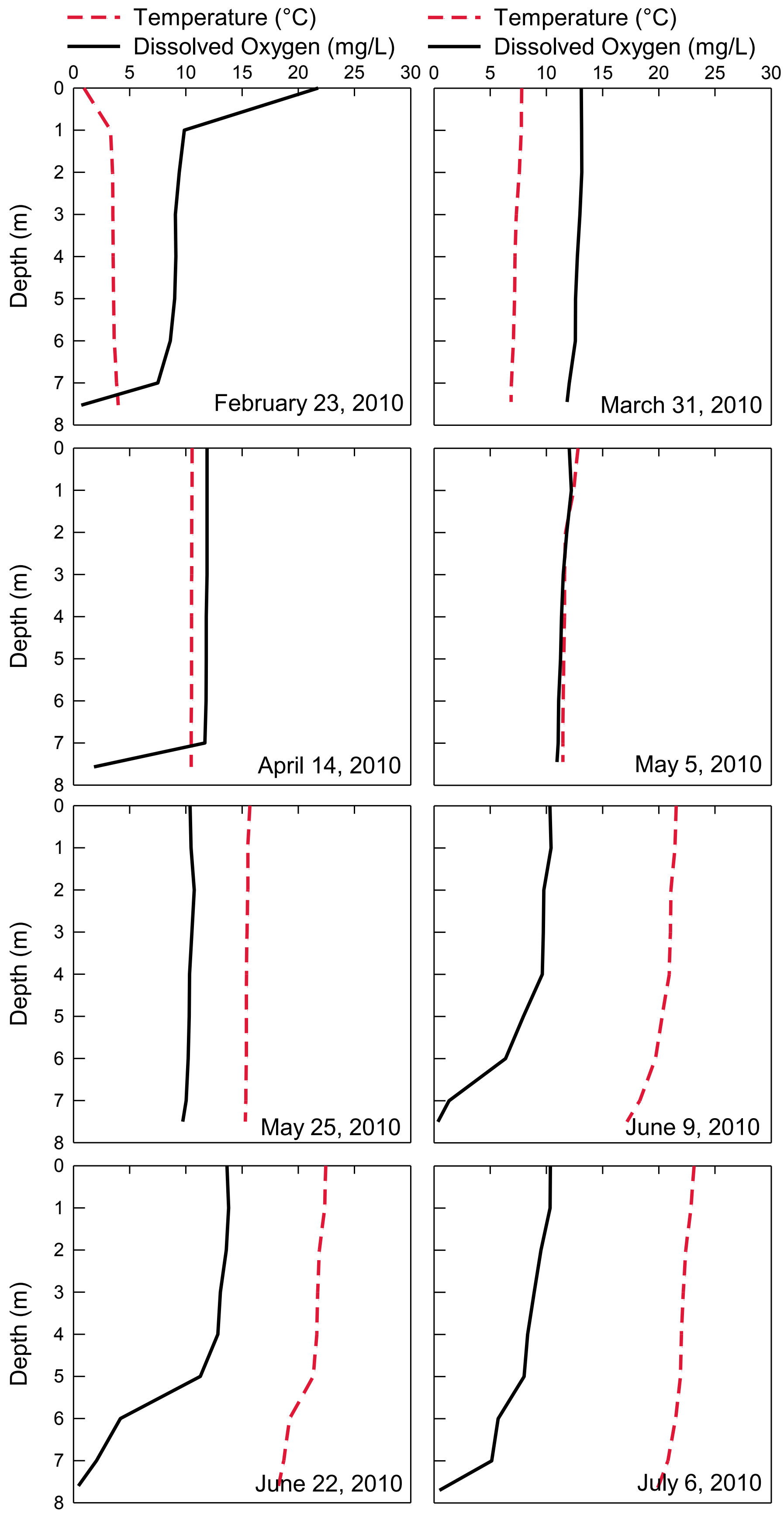
Site CCR-1 Small Tables

Sample Date	Depth	Temperature	Conductivity	Dissolved Oxygen	pH	ORP	1% Transmittance	Secchi Disk
2/23/2010	0	0.94	965	21.77	8.37	396		
	1	3.30	1022	9.86	7.86	410		
	2	3.48	1025	9.41	7.87	410		
	3	3.52	1029	9.07	7.87	410		
	4	3.54	1030	9.11	7.86	411		
	5	3.57	1034	9.00	7.84	412		
	6	3.63	1043	8.61	7.83	412		
	7	3.84	1094	7.51	7.70	417		
	7.53	4.00	1140	0.70	7.59	380		
	--						--	--
3/31/2010	0	7.80	916	13.10	8.10	483		
	1	7.78	915	13.13	8.11	483		
	2	7.59	913	13.14	8.15	483		
	3	7.32	908	12.98	8.22	483		
	4	7.20	910	12.76	8.21	487		
	5	7.18	910	12.59	8.20	484		
	6	7.07	910	12.57	8.20	484		
	7	6.89	913	12.04	8.16	484		
	7.45	6.86	912	11.84	8.15	484		
	--						2.94	0.91
4/14/2010	0	10.55	935	11.88	8.43	352		
	1	10.55	935	11.89	8.46	341		
	2	10.52	935	11.88	8.47	338		
	3	10.52	935	11.88	8.47	336		
	4	10.50	936	11.81	8.48	335		
	5	10.51	936	11.81	8.48	334		
	6	10.50	935	11.79	8.49	334		
	7	10.47	935	11.69	8.48	333		
	7.57	10.47	933	1.82	7.62	147		
	--						2.77	0.63
5/5/2010	0	12.82	865	12.03	8.25	248		
	1	12.42	864	12.22	8.29	249		
	2	11.70	862	11.81	8.22	252		
	3	11.61	861	11.49	8.20	253		
	4	11.61	860	11.34	8.20	254		
	5	11.55	861	11.26	8.19	255		
	6	11.50	861	11.09	8.20	256		
	7	11.47	862	11.04	8.20	256		
	7.45	11.47	862	10.94	8.20	252		
	--						3.00	0.87
5/25/2010	0	15.69	886	10.37	8.37	172		
	1	15.52	887	10.46	8.42	184		
	2	15.51	887	10.74	8.43	184		
	3	15.44	886	10.53	8.44	183		
	4	15.39	886	10.32	8.43	183		
	5	15.38	886	10.30	8.44	183		
	6	15.38	886	10.21	8.44	183		
	7	15.34	887	10.02	8.43	183		
	7.5	15.29	887	9.72	8.42	183		
	--						4.00	1.29

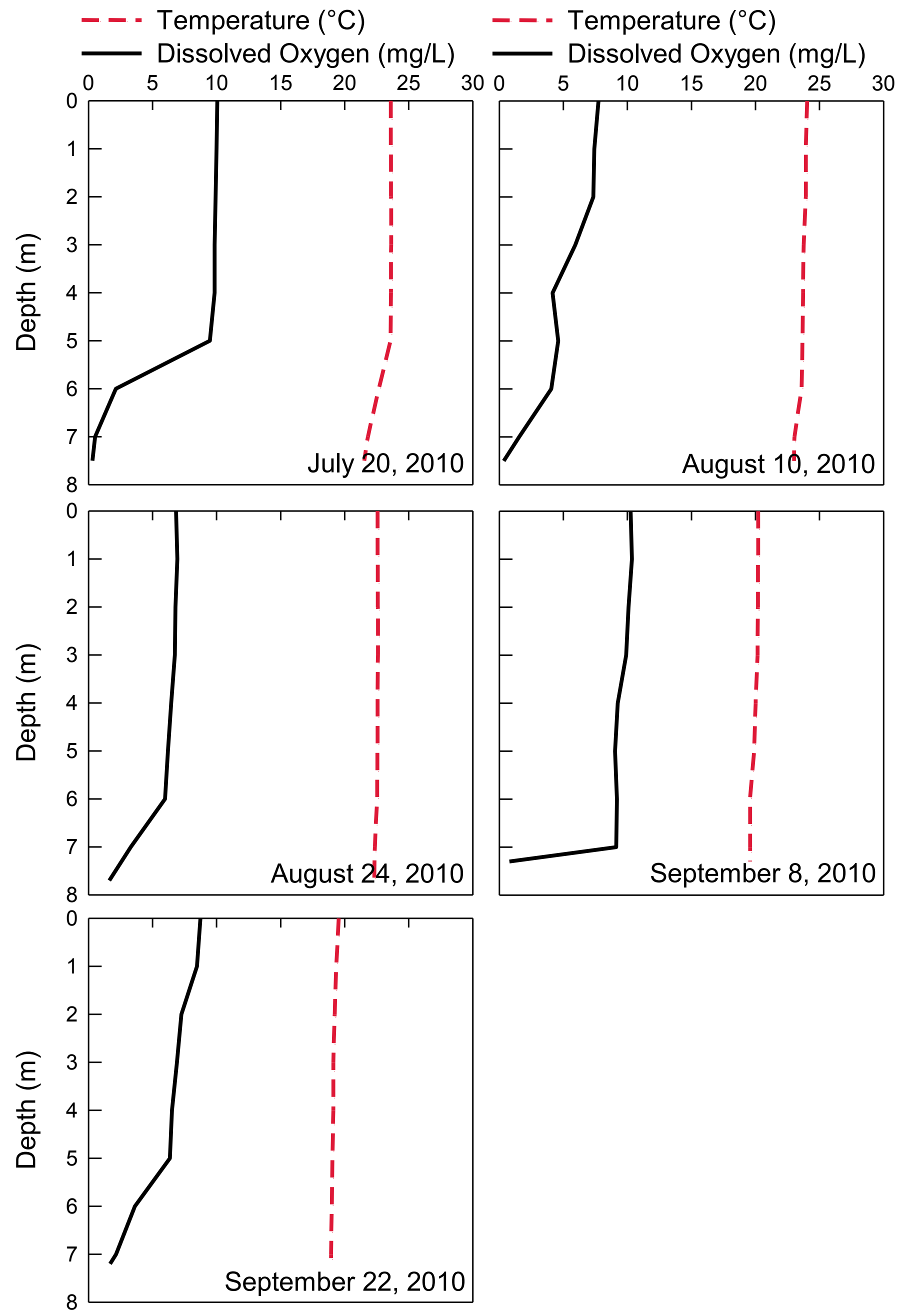
Sample Date	Depth	Temperature	Conductivity	Dissolved Oxygen	pH	ORP	1% Transmittance	Secchi Disk
6/9/2010	0	21.54	874	10.31	8.47	173		
	1	21.44	874	10.42	8.47	180		
	2	21.08	874	9.77	8.43	187		
	3	21.04	874	9.73	8.42	191		
	4	20.93	873	9.63	8.41	194		
	5	20.30	876	7.96	8.28	202		
	6	19.71	878	6.36	8.17	208		
	7	18.31	878	1.34	7.65	224		
	7.5	17.17	879	0.35	7.52	16		
	--						4.45	1.48
6/22/2010	0	22.44	896	13.65	8.30	171		
	1	22.35	897	13.80	8.31	169		
	2	21.88	895	13.60	8.28	169		
	3	21.73	896	13.07	8.27	168		
	4	21.65	896	12.85	8.25	168		
	5	21.33	896	11.28	8.14	170		
	6	19.23	896	4.17	7.62	184		
	7	18.71	895	2.05	7.46	187		
	7.6	18.24	896	0.44	7.39	-141		
	--						3.50	1.10
7/6/2010	0	23.14	922	10.35	8.22	242		
	1	22.86	922	10.32	8.22	239		
	2	22.40	920	9.52	8.16	239		
	3	22.17	919	8.91	8.11	239		
	4	22.01	918	8.33	8.07	239		
	5	21.93	918	8.02	8.05	238		
	6	21.50	895	5.71	7.85	241		
	7	20.81	848	5.14	7.75	243		
	7.7	19.84	773	0.49	6.90	-186		
	--						3.75	1.13
7/20/2010	0	23.60	824	10.05	8.36	242		
	1	23.61	824	10.00	8.36	236		
	2	23.63	824	9.92	8.36	228		
	3	23.63	824	9.85	8.36	224		
	4	23.62	824	9.85	8.36	218		
	5	23.59	824	9.47	8.33	215		
	6	22.67	831	2.14	7.68	229		
	7	21.81	835	0.52	7.37	-186		
	7.5	21.53	838	0.31	7.21	-237		
	--						2.95	1.15
8/10/2010	0	24.04	854	7.74	8.08	336		
	1	23.93	854	7.42	8.20	331		
	2	23.93	854	7.34	8.04	333		
	3	23.76	855	5.93	7.89	338		
	4	23.72	855	4.16	7.83	339		
	5	23.68	855	4.59	7.76	342		
	6	23.60	855	4.06	7.67	344		
	7	23.04	833	1.55	7.41	349		
	7.5	23.02	834	0.35	7.13	-202		
	--						2.75	1.25

Sample Date	Depth	Temperature	Conductivity	Dissolved Oxygen	pH	ORP	1% Transmittance	Secchi Disk
8/24/2010	0	22.57	870	6.83	7.98	115		
	1	22.58	870	6.93	7.99	110		
	2	22.59	870	6.78	7.98	107		
	3	22.59	871	6.74	7.94	107		
	4	22.57	871	6.46	7.96	106		
	5	22.56	871	6.20	7.93	105		
	6	22.53	871	5.98	7.89	105		
	7	22.35	873	3.30	7.66	109		
	7.7	22.31	874	1.62	7.49	-23		
	--						2.25	0.75
9/8/2010	0	20.21	864	10.25	8.03	240		
	1	20.21	864	10.35	8.06	236		
	2	20.20	864	10.09	8.06	235		
	3	20.16	864	9.91	8.04	234		
	4	20.02	865	9.24	7.97	234		
	5	19.90	864	9.04	7.95	234		
	6	19.58	865	9.18	7.95	233		
	7	19.59	865	9.12	7.95	231		
	7.3	19.58	864	0.79	7.92	152		
	--						1.65	1.00
9/22/2010	0	19.54	894	8.74	8.16	216		
	1	19.36	895	8.47	8.10	219		
	2	19.22	896	7.25	8.01	225		
	3	19.12	897	6.90	7.97	227		
	4	19.11	897	6.52	7.94	229		
	5	19.05	897	6.35	7.92	230		
	6	18.99	900	3.62	7.62	241		
	7	18.94	902	2.15	7.50	244		
	7.2	18.94	902	1.68	7.45	158		
	--						2.75	1.00

CCR-1


Temperature (°C)
Dissolved Oxygen (mg/L)
Depth (m)
0 5 10 15 20 25 30
February 23, 2010
March 31, 2010
April 14, 2010
May 5, 2010
May 25, 2010
June 9, 2010
June 22, 2010
July 6, 2010

CCR-1


Temperature (°C)
Dissolved Oxygen (mg/L)
Temperature (°C)
Dissolved Oxygen (mg/L)
0 5 10 15 20 25 30
Depth (m)
July 20, 2010
August 10, 2010
August 24, 2010
September 8, 2010
September 22, 2010

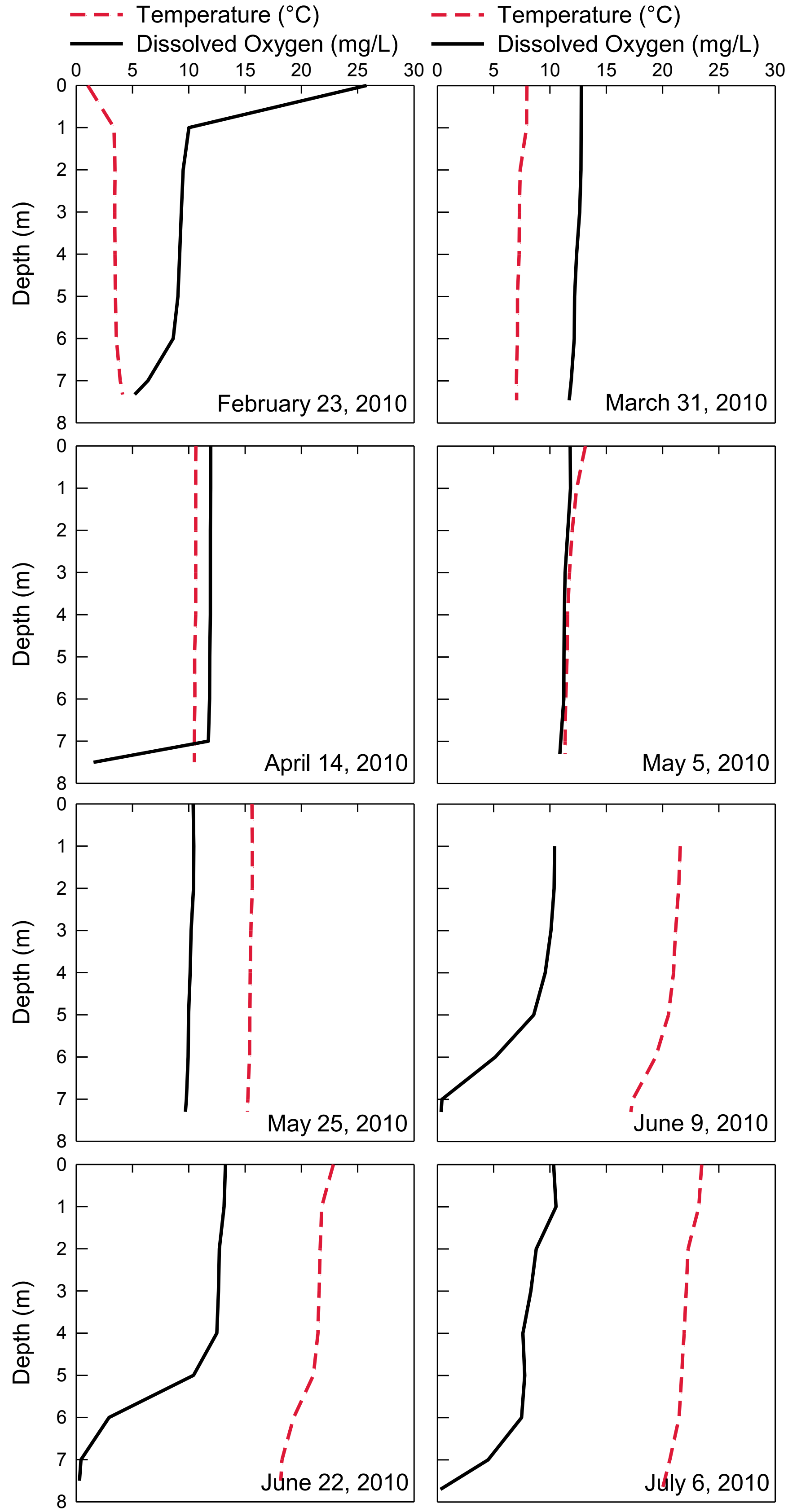
CCR-2 Small Tables

Sample Date	Depth	Temperature	Conductivity	Dissolved Oxygen	pH	ORP	1% Transmittance	Secchi Disk
2/23/2010	0	1.02	956	25.79	8.75	380		
	1	3.36	1027	10.01	7.92	401		
	2	3.46	1029	9.50	7.92	402		
	3	3.42	1030	9.33	7.92	402		
	4	3.46	1031	9.19	7.92	403		
	5	3.49	1031	9.03	7.92	404		
	6	3.57	1033	8.61	7.90	405		
	7	3.92	1049	6.36	7.71	411		
	7.33	4.13	1057	5.20	7.64	414		
	--						--	--
3/31/2010	0	7.95	903	12.78	8.31	444		
	1	7.92	903	12.77	8.29	444		
	2	7.36	911	12.76	8.26	444		
	3	7.29	911	12.64	8.24	445		
	4	7.26	912	12.36	8.21	445		
	5	7.12	913	12.19	8.20	446		
	6	7.12	913	12.15	8.20	446		
	7	7.03	911	11.88	8.19	446		
	7.46	7.05	912	11.71	8.15	329		
	--						2.75	0.85
4/14/2010	0	10.62	935	11.95	8.55	325		
	1	10.61	935	11.94	8.53	324		
	2	10.62	935	11.92	8.53	324		
	3	10.61	935	11.91	8.58	325		
	4	10.61	935	11.91	8.57	325		
	5	10.52	935	11.86	8.55	326		
	6	10.55	935	11.84	8.55	326		
	7	10.49	935	11.74	8.53	327		
	7.5	10.49	935	1.54	8.49	221		
	--						2.50	0.59
5/5/2010	0	13.14	864	11.79	8.32	243		
	1	12.38	864	11.82	8.30	244		
	2	11.97	865	11.58	8.27	245		
	3	11.73	866	11.35	8.26	246		
	4	11.57	866	11.27	8.25	246		
	5	11.53	866	11.24	8.26	246		
	6	11.41	867	11.23	8.25	247		
	7	11.35	868	10.95	8.24	247		
	7.3	11.35	868	10.88	8.24	247		
	--						2.75	0.96
5/25/2010	0	15.61	887	10.39	8.48	184		
	1	15.65	886	10.44	8.49	184		
	2	15.63	887	10.41	8.49	185		
	3	15.51	887	10.21	8.47	186		
	4	15.45	887	10.12	8.47	186		
	5	15.42	887	9.98	8.46	187		
	6	15.39	887	9.94	8.46	187		
	7	15.25	887	9.79	8.44	188		
	7.3	15.22	887	9.70	8.45	187		
	--						3.60	1.11

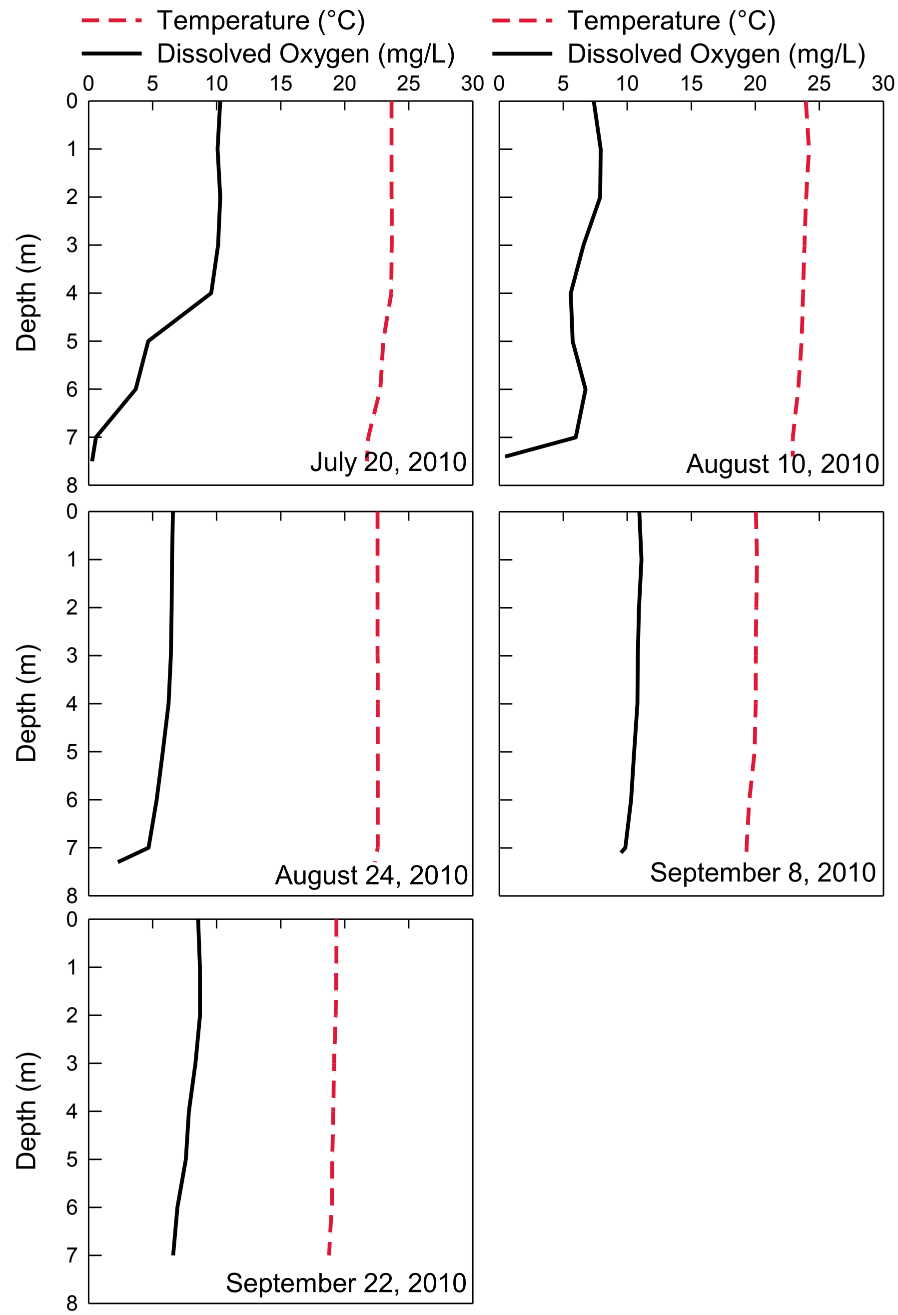
Sample Date	Depth	Temperature	Conductivity	Dissolved Oxygen	pH	ORP	1% Transmittance	Secchi Disk
6/9/2010	0	--	--	--	--	--		
	1	21.58	874	10.41	8.48	124		
	2	21.44	874	10.37	8.48	132		
	3	21.15	874	10.09	8.46	145		
	4	20.98	874	9.58	8.42	152		
	5	20.53	875	8.55	8.33	156		
	6	19.39	879	5.13	8.04	169		
	7	17.36	880	0.41	7.60	174		
	7.3	17.18	880	0.34	7.54	-19		
	--						4.23	1.40
6/22/2010	0	22.83	897	13.25	8.28	69		
	1	21.82	895	13.13	8.26	71		
	2	21.67	896	12.71	8.23	74		
	3	21.57	895	12.63	8.23	75		
	4	21.47	895	12.48	8.22	76		
	5	21.06	897	10.41	8.07	81		
	6	19.33	898	2.91	7.58	95		
	7	18.28	895	0.42	7.41	97		
	7.5	18.17	891	0.29	6.82	-199		
	--						4.15	1.25
7/16/2010	0	23.48	922	10.32	8.23	50		
	1	23.23	921	10.54	8.24	55		
	2	22.27	919	8.78	8.12	60		
	3	22.10	920	8.30	8.08	62		
	4	21.92	913	7.60	8.02	65		
	5	21.70	908	7.76	8.04	65		
	6	21.47	879	7.48	7.98	68		
	7	20.64	788	4.50	7.62	76		
	7.7	19.98	759	0.28	7.06	-215		
	--						3.82	0.95
7/20/2010	0	23.66	823	10.28	8.35	14		
	1	23.66	823	10.07	8.38	22		
	2	23.67	823	10.28	8.38	26		
	3	23.67	823	10.12	8.35	30		
	4	23.65	824	9.58	8.29	33		
	5	23.02	833	4.66	7.90	38		
	6	22.79	838	3.68	7.83	38		
	7	21.85	836	0.57	7.47	-232		
	7.5	21.74	837	0.28	7.44	-248		
	--						2.50	1.10
8/10/2010	0	23.94	852	7.39	8.08	82		
	1	24.20	851	7.92	8.15	89		
	2	23.97	854	7.88	8.16	94		
	3	23.84	855	6.57	8.02	100		
	4	23.73	855	5.58	7.90	104		
	5	23.62	848	5.73	7.88	106		
	6	23.36	842	6.74	7.99	107		
	7	22.93	836	5.98	7.88	110		
	7.4	22.92	836	0.45	7.84	-13		
	--						2.50	1.00

Sample Date	Depth	Temperature	Conductivity	Dissolved Oxygen	pH	ORP	1% Transmittance	Secchi Disk
8/24/2010	0	22.56	870	6.59	7.92	89		
	1	22.57	870	6.51	7.93	86		
	2	22.57	870	6.48	7.94	85		
	3	22.58	870	6.43	7.93	84		
	4	22.58	870	6.25	7.92	84		
	5	22.59	870	5.79	7.86	85		
	6	22.58	871	5.32	7.81	86		
	7	22.58	872	4.69	7.72	88		
	7.3	22.36	873	2.29	7.54	-17		
	--						2.40	0.40
9/8/2010	0	20.05	863	10.94	8.12	178		
	1	20.14	863	11.11	8.15	178		
	2	20.07	863	10.91	8.13	179		
	3	20.05	863	10.82	8.13	180		
	4	20.03	863	10.79	8.12	181		
	5	19.95	863	10.54	8.10	182		
	6	19.53	864	10.29	8.06	184		
	7	19.31	865	9.85	8.02	185		
	7.1	19.31	866	9.50	7.99	38		
	--						2.25	0.75
9/22/2010	0	19.35	894	8.56	8.18	197		
	1	19.36	895	8.69	8.19	200		
	2	19.29	894	8.70	8.19	203		
	3	19.17	894	8.35	8.15	207		
	4	19.11	894	7.83	8.09	212		
	5	19.04	895	7.60	8.07	215		
	6	19.00	895	6.93	8.01	219		
	7	18.79	897	6.61	8.00	218		
	--						2.75	1.00

CCR-2


Temperature (°C)
Dissolved Oxygen (mg/L)
Depth (m)
February 23, 2010
March 31, 2010
April 14, 2010
May 5, 2010
May 25, 2010
June 9, 2010
June 22, 2010
July 6, 2010

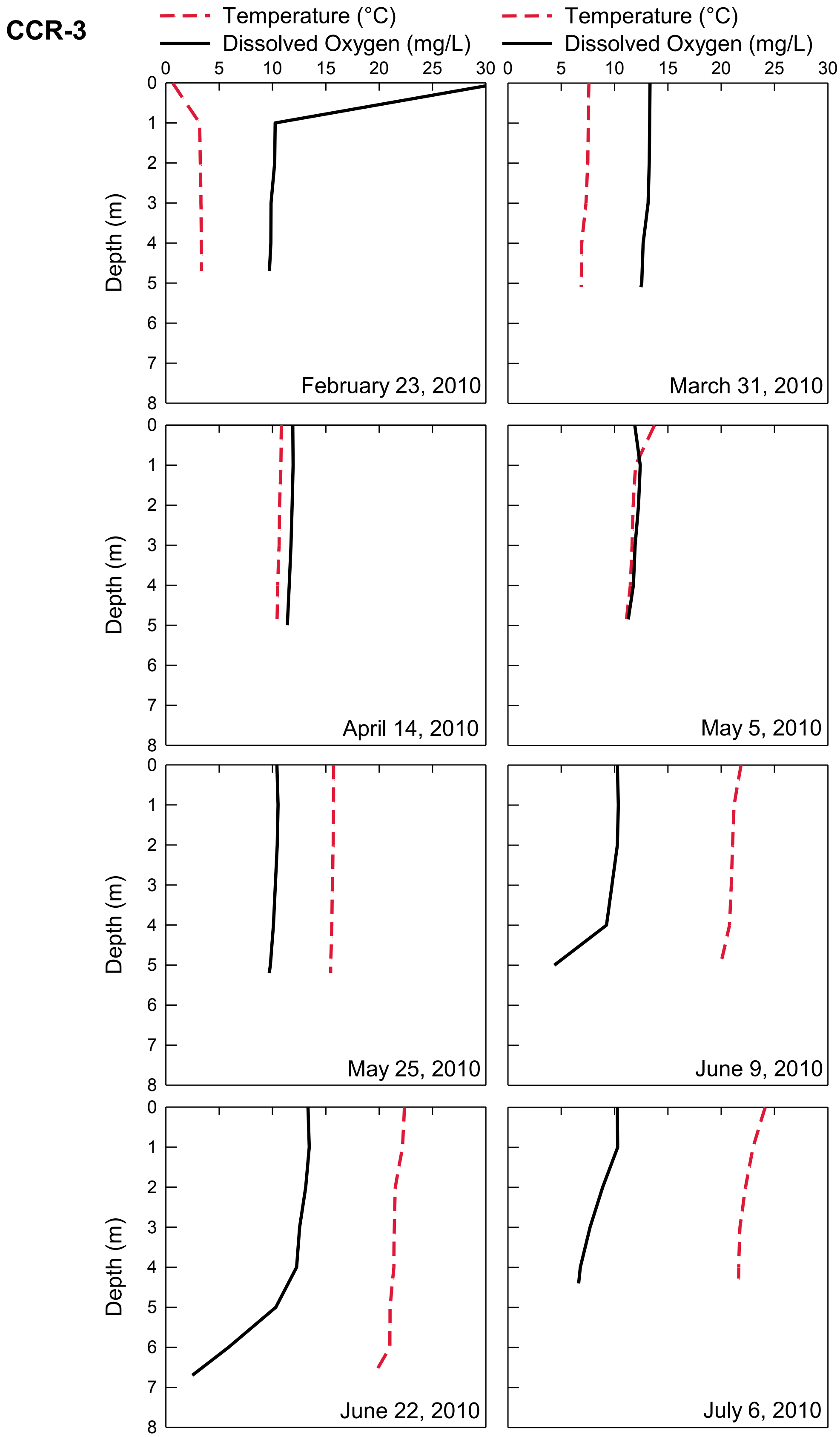
CCR-2


Temperature (°C)
Dissolved Oxygen (mg/L)
Temperature (°C)
Dissolved Oxygen (mg/L)
0 5 10 15 20 25 30
Depth (m)
0 1 2 3 4 5 6 7 8
July 20, 2010
August 10, 2010
August 24, 2010
September 8, 2010
September 22, 2010

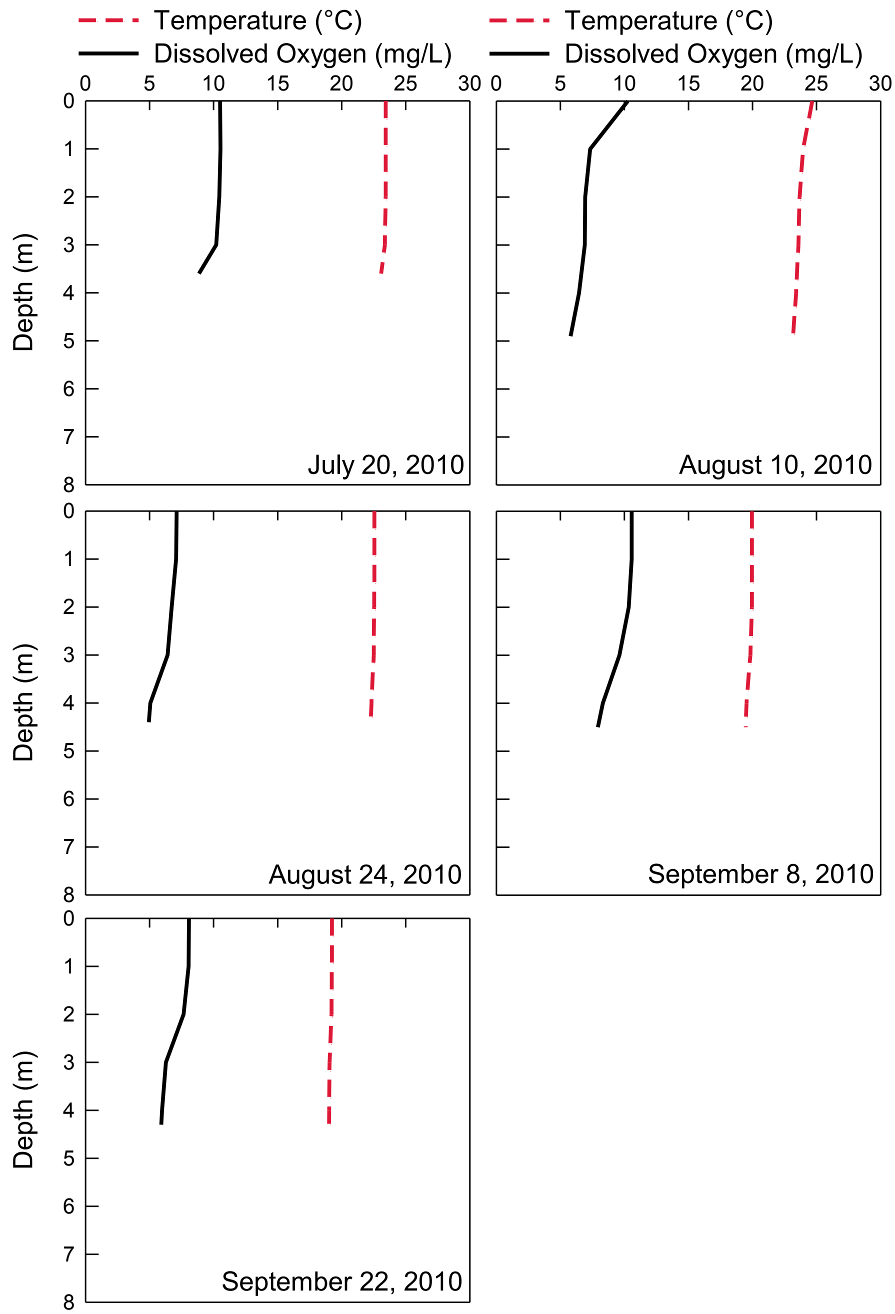
CCR-3 Small Tables

Sample Date	Depth	Temperature	Conductivity	Dissolved Oxygen	pH	ORP	1% Transmittance	Secchi Disk
2/23/2010	0	0.63	947	31.62	8.88	364		
	1	3.17	1012	10.25	7.89	390		
	2	3.24	1016	10.21	7.87	391		
	3	3.30	1025	9.86	7.88	391		
	4	3.34	1043	9.85	7.88	391		
	4.7	3.35	1409	9.71	7.77	398		
	--						--	--
3/31/2010	0	7.60	909	13.32	8.37	377		
	1	7.55	909	13.30	8.35	377		
	2	7.49	909	13.25	8.33	378		
	3	7.32	909	13.14	8.30	379		
	4	6.92	910	12.68	8.26	381		
	5	6.89	909	12.55	8.25	383		
	5.1	6.87	910	12.47	8.24	383		
	--						2.72	0.92
4/14/2010	0	10.83	938	11.90	8.53	348		
	1	10.79	938	11.93	8.54	347		
	2	10.67	938	11.84	8.54	346		
	3	10.63	937	11.73	8.53	345		
	4	10.49	937	11.57	8.53	345		
	5	10.43	936	11.39	8.51	345		
	--						2.65	0.65
5/5/2010	0	13.75	868	11.90	8.34	236		
	1	11.97	864	12.41	8.36	236		
	2	11.75	866	12.25	8.33	237		
	3	11.64	866	11.93	8.32	237		
	4	11.48	866	11.77	8.30	238		
	4.85	11.12	871	11.28	8.26	239		
	--						2.76	0.88
5/25/2010	0	15.72	887	10.42	8.48	207		
	1	15.72	886	10.52	8.49	207		
	2	15.70	886	10.44	8.50	207		
	3	15.62	885	10.26	8.48	207		
	4	15.56	885	10.09	8.48	207		
	5	15.47	887	9.80	8.46	207		
	5.2	15.46	887	9.69	8.46	207		
	--						--	1.19
6/9/2010	0	21.86	875	10.26	8.48	131		
	1	21.21	874	10.36	8.49	135		
	2	21.07	873	10.26	8.48	140		
	3	20.95	874	9.76	8.44	145		
	4	20.78	875	9.25	8.40	150		
	5	19.94	876	4.35	8.00	160		
	--						4.00	1.58
6/22/2010	0	22.37	897	13.32	8.29	47		
	1	22.20	897	13.44	8.28	49		
	2	21.51	895	13.11	8.24	54		
	3	21.42	896	12.54	8.21	56		
	4	21.38	895	12.26	8.21	59		

Sample Date	Depth	Temperature	Conductivity	Dissolved Oxygen	pH	ORP	1% Transmittance	Secchi Disk
6/22/2010	5	21.03	897	10.31	8.10	64		
	6	21.01	898	5.88	7.80	-40		
	6.7	19.50	867	2.48	7.30	-167		
	--						4.25	1.05
7/6/2010	0	24.12	927	10.25	8.24	49		
	1	22.98	922	10.30	8.24	51		
	2	22.28	923	8.88	8.15	55		
	3	21.76	921	7.70	8.05	59		
	4	21.65	920	6.78	7.97	61		
	4.4	21.64	920	6.64	7.97	61		
	--						3.75	1.25
7/20/2010	0	23.44	824	10.50	8.40	22		
	1	23.43	824	10.53	8.40	27		
	2	23.43	824	10.45	8.40	30		
	3	23.38	825	10.21	8.38	33		
	3.6	23.08	831	8.86	8.30	34		
	--						3.70	1.00
8/10/2010	0	24.66	850	10.26	8.35	89		
	1	23.96	850	7.32	8.05	100		
	2	23.67	851	6.94	8.05	103		
	3	23.59	849	6.90	8.04	105		
	4	23.40	835	6.46	7.97	109		
	4.9	23.17	813	5.80	7.86	105		
	--						2.25	0.88
8/24/2010	0	22.55	870	7.12	7.97	98		
	1	22.56	870	7.07	7.98	95		
	2	22.54	870	6.72	7.96	94		
	3	22.50	870	6.41	7.92	93		
	4	22.32	873	5.06	7.81	94		
	4.4	22.26	873	4.94	7.82	93		
	--						1.85	0.60
9/8/2010	0	19.96	863	10.57	8.07	148		
	1	19.97	863	10.56	8.08	149		
	2	19.95	863	10.34	8.05	151		
	3	19.83	864	9.61	7.98	154		
	4	19.53	865	8.32	7.87	158		
	4.5	19.47	866	7.93	7.86	160		
	--						1.75	0.88
9/22/2010	0	19.24	896	8.07	8.12	209		
	1	19.24	896	8.04	8.13	213		
	2	19.21	896	7.66	8.08	218		
	3	19.05	897	6.27	7.91	225		
	4	19.02	897	5.98	7.89	229		
	4.3	19.01	898	5.92	7.89	228		
	--						2.50	0.80


CCR-3
Temperature (°C)
Dissolved Oxygen (mg/L)
Temperature (°C)
Dissolved Oxygen (mg/L)
0 5 10 15 20 25 30
0 5 10 15 20 25 30
Depth (m)
0 1 2 3 4 5 6 7 8
February 23, 2010
March 31, 2010
April 14, 2010
May 5, 2010
May 25, 2010
June 9, 2010
June 22, 2010
July 6, 2010

CCR-3


Temperature (°C)
Dissolved Oxygen (mg/L)
Temperature (°C)
Dissolved Oxygen (mg/L)
0 5 10 15 20 25 30
0 5 10 15 20 25 30
Depth (m)
0 1 2 3 4 5 6 7 8
July 20, 2010
August 10, 2010
August 24, 2010
September 8, 2010
September 22, 2010

Cherry Creek Transect ORP Data

Collection Date	Depth	Transect ORP (mV)										
		D1	D2	D3	D3.5	D4	D5	D6	D7	D8	D9	D10
6/9/2010	0	179	102	101	90	84	83	82	111	80	85	131
	1	180	104	103	92	91	86	85	112	85	90	135
	2	181	106	104	95	96	89	88	113	90	92	140
	3	184	110	106	97	97	93	91	116	94	96	145
	4	187	114	110	101	100	96	94	118	97	100	150
	5	190	117	113	104	105	102	99	121	103	106	160
	6	198	123	120	111	114	112	109	130	114	115	--
	7	207	122	-87	116	-78	-17	-59	-52	-25	65	--
	Bottom	-164	-156	-153	-148	-146	-140	-142	--	--	--	--

Collection Date	Depth	Transect ORP (mV)										
		D1	D2	D3	D3.5	D4	D5	D6	D7	D8	D9	D10
7/6/2010	0	80	39	32	31	20	11	30	25	17	40	49
	1	81	46	41	41	34	23	36	34	22	42	51
	2	84	52	50	46	40	32	43	40	34	44	55
	3	85	58	56	53	45	38	46	45	-4	49	59
	4	86	62	58	55	48	42	49	48	10	53	61
	5	90	63	60	56	50	45	53	52	19	56	--
	6	92	66	62	57	50	44	54	52	28	--	--
	7	93	69	63	59	51	44	53	54	30	--	--
	Bottom	-185	-206	-223	-212	-212	-78	-181	-135	-68	-77	61

Collection Date	Depth	Transect ORP (mV)										
		D1	D2	D3	D3.5	D4	D5	D6	D7	D8	D9	D10
8/10/2010	0	112	102	78	81	60	68	54	49	50	96	89
	1	114	111	87	90	71	88	69	65	71	101	100
	2	122	117	101	101	84	101	87	77	84	115	103
	3	126	126	106	107	92	107	92	83	91	120	105
	4	127	129	108	112	97	110	95	88	95	123	109
	5	128	128	113	113	98	111	99	94	98	124	--
	6	130	133	121	122	106	116	105	98	99	124	--
	7	139	139	123	125	108	121	96	-37	-22	-71	--
	Bottom	95	-23	35	-122	-35	-140	-112	-95	--	--	105

Cherry Creek Transect DO Data

Collection Date	Depth	Dissolved Oxygen (mg/L)										
		D1	D2	D3	D3.5	D4	D5	D6	D7	D8	D9	D10
6/9/2010	0	10.28	10.72	10.32	10.15	10.27	10.35	10.40	10.59	10.61	10.64	10.26
	1	10.30	10.67	9.81	10.35	10.28	10.37	10.40	10.49	10.65	10.69	10.36
	2	10.16	10.67	9.92	10.20	9.98	10.22	10.40	10.50	10.52	10.70	10.26
	3	9.35	9.56	9.88	10.08	10.16	10.01	10.38	10.26	10.44	10.28	9.76
	4	8.68	8.50	8.89	8.68	9.19	9.74	9.76	9.59	9.58	8.64	9.25
	5	7.39	7.62	7.95	8.03	7.71	7.94	8.05	8.27	7.39	6.63	4.35
	6	5.11	5.26	5.09	4.22	4.11	4.01	2.42	4.59	3.28	2.65	--
	7	2.21	0.45	0.26	0.44	0.32	0.27	0.28	0.32	0.41	0.50	--
	Bottom	0.27	0.26	0.24	0.30	0.22	0.25	0.25	--	--	--	--

Collection Date	Depth	Dissolved Oxygen (mg/L)										
		D1	D2	D3	D3.5	D4	D5	D6	D7	D8	D9	D10
7/6/2010	0	11.81	11.16	11.73	11.47	10.36	11.13	11.97	12.54	11.59	12.65	10.25
	1	10.86	10.71	10.39	10.22	9.91	10.87	11.54	11.42	11.20	12.63	10.30
	2	9.35	9.62	9.94	9.77	9.73	10.17	10.06	10.65	11.20	12.42	8.88
	3	8.76	8.60	8.56	8.44	9.09	8.70	9.54	9.06	10.28	9.86	7.70
	4	8.16	7.71	7.81	8.12	8.31	8.24	8.49	8.49	9.09	8.86	6.78
	5	6.25	7.26	7.95	7.90	7.73	7.06	7.61	8.04	8.24	6.92	--
	6	4.95	5.57	4.31	3.81	2.52	3.37	1.66	3.90	3.21	--	--
	7	4.50	3.55	4.02	3.79	2.77	1.96	2.23	2.51	2.13	--	--
	Bottom	0.32	0.32	0.22	0.24	0.23	0.32	0.45	0.85	0.85	0.87	6.64

Collection Date	Depth	Dissolved Oxygen (mg/L)										
		D1	D2	D3	D3.5	D4	D5	D6	D7	D8	D9	D10
8/10/2010	0	11.47	10.81	12.46	13.37	14.70	14.65	15.06	14.01	13.82	15.04	10.26
	1	11.65	11.40	12.09	13.35	13.19	14.60	10.75	9.33	11.68	13.90	7.32
	2	7.76	9.73	7.58	9.05	8.90	7.26	6.98	7.51	6.15	7.06	6.94
	3	6.30	6.66	6.45	7.66	6.79	6.70	6.33	6.11	5.70	5.57	6.90
	4	6.12	5.92	6.41	6.53	6.12	6.09	5.91	5.85	4.92	4.95	6.46
	5	5.82	6.23	5.71	6.27	6.20	6.19	6.01	4.39	5.04	5.31	--
	6	5.14	4.65	3.05	3.12	3.61	4.46	3.96	2.90	5.43	5.43	--
	7	1.60	1.45	1.59	0.97	1.00	1.39	1.23	3.34	1.05	4.65	--
	Bottom	1.21	0.22	0.78	0.54	0.20	0.38	0.46	2.89	--	--	5.80

Appendix C

2010 Stream Water Quality and Precipitation Data

GEI Water Chemistry Data

Site/Sample Date	Total Phosphorus (µg/L)	Total Dissolved Phosphorus (µg/L)	Ortho-phosphate (µg/L)	Total Nitrogen (µg/L)	Total Dissolved Nitrogen (µg/L)	Nitrate+ Nitrite (µg/L)	Ammonia (µg/L)	Total Suspended Solids (mg/L)	Total Volatile Suspended Solids (mg/L)
Analytical Detection Limits	2	2	2	2	2	2	3	4	4
CC-10									
1/19/2010	194	138	143	1784	1655	1282	200	28	4
2/16/2010	175	121	128	1855	1773	1437	37	18	--
3/16/2010	166	126	121	1445	1310	1005	27	19	--
4/14/2010	239	180	172	1080	967	606	14	33	7
5/24/2010	275	201	192	1098	986	627	39	44	5
6/22/2010	247	187	187	1084	1050	739	32	27	5
7/20/2010	250	192	192	971	855	567	39	19	--
8/24/2010	268	218	210	928	854	294	55	15	4
9/22/2010	241	182	192	614	544	256	55	13	5
CC-10 Storm									
4/22/2010	231	150	140	1540	1354	987	66	42	6
5/12/2010	237	164	161	1375	1101	641	113	93	6
6/28/2010	386	201	176	1445	1088	669	51	100	10
7/7/2010	281	179	187	1227	974	625	46	70	9
7/21/2010	333	191	209	1696	1209	572	37	107	22
8/5/2010	473	171	179	1465	1036	737	32	197	17
CC-Out @ I225									
1/19/2010	82	55	48	1006	834	223	208	7	--
2/16/2010	144	113	107	1243	1065	150	459	7	--
3/16/2010	92	55	49	972	791	190	188	9	--
4/14/2010	93	15	7	868	423	--	--	18	8
5/24/2010	95	54	44	694	456	7	30	13	5
6/22/2010	278	184	171	999	757	10	410	28	8
7/6/2010	298	188	182	1109	816	127	180	22	8
7/20/2010	316	268	259	1079	930	29	487	8	4
8/10/2010	127	58	42	1033	626	15	80	19	5
8/24/2010	121	39	29	1023	669	12	62	21	6
9/8/2010	129	45	36	1424	1038	297	189	26	5
9/22/2010	86	40	36	1267	1045	171	318	17	6

GEI Water Chemistry Data									
Analytical Detection Limits	2	2	2	2	2	2	3	4	4
Site/Sample Date	Total Phosphorus (µg/L)	Total Dissolved Phosphorus (µg/L)	Ortho-phosphate (µg/L)	Total Nitrogen (µg/L)	Total Dissolved Nitrogen (µg/L)	Nitrate+ Nitrite (µg/L)	Ammonia (µg/L)	Total Suspended Solids (mg/L)	Total Volatile Suspended Solids (mg/L)
CT-1									
1/19/2010	84	30	21	1866	1721	971	139	38	5
2/16/2010	55	28	21	1680	1547	726	362	15	--
3/16/2010	89	18	11	1490	1218	715	153	32	5
4/14/2010	56	11	3	1212	1032	330	5	28	5
5/24/2010	53	15	9	1562	1392	621	64	19	5
6/22/2010	35	17	12	934	842	194	49	12	--
7/20/2010	58	29	20	971	863	235	48	13	--
8/24/2010	57	24	13	1386	1222	479	30	23	5
9/22/2010	63	16	9	1711	1524	973	40	30	8
CT-1 Storm									
4/22/2010	75	18	10	1471	1246	690	106	20	5
5/12/2010	111	38	34	1897	1569	900	147	21	--
6/28/2010	72	15	13	1076	836	294	48	12	--
7/7/2010	65	36	28	818	672	192	41	22	11
7/21/2010	146	40	34	2334	1745	798	90	72	26
8/5/2010	246	44	22	1776	1270	663	14	100	18
CT-2									
1/19/2010	72	22	12	2030	1877	1026	128	35	5
2/16/2010	47	19	12	1962	1791	826	434	15	4
3/16/2010	64	12	6	1422	1211	652	81	20	5
4/14/2010	72	10	5	972	732	153	--	41	8
5/24/2010	112	11	4	1516	1156	410	94	71	12
6/22/2010	41	13	6	907	802	114	50	13	--
7/20/2010	43	27	17	1022	782	114	51	10	--
8/24/2010	42	18	7	1316	1178	316	52	13	4
9/22/2010	57	10	6	1603	1096	759	59	34	10
CT-2 Storm									
4/22/2010	67	16	7	1452	1235	670	114	16	5
5/12/2010	101	34	27	2187	1971	1108	193	26	5
6/28/2010	65	23	11	1117	952	341	53	12	4
7/7/2010	102	52	39	829	630	133	14	29	11
7/21/2010	93	35	31	2491	2060	1013	247	42	25
8/5/2010	105	32	21	1600	1215	764	55	127	30

GEI Water Chemistry Data									
Analytical Detection Limits	2	2	2	2	2	2	3	4	4
Site/Sample Date	Total Phosphorus (µg/L)	Total Dissolved Phosphorus (µg/L)	Ortho-phosphate (µg/L)	Total Nitrogen (µg/L)	Total Dissolved Nitrogen (µg/L)	Nitrate+ Nitrite (µg/L)	Ammonia (µg/L)	Total Suspended Solids (mg/L)	Total Volatile Suspended Solids (mg/L)
CT-P1									
1/19/2010	24	10	6	1312	1233	855	44	7	--
2/16/2010	15	8	7	1314	1225	929	28	4	--
3/16/2010	46	10	4	1510	1255	820	67	8	--
4/14/2010	39	10	5	855	710	119	--	8	4
5/24/2010	53	8	3	878	701	201	82	17	5
6/22/2010	83	22	18	1066	926	324	87	23	6
7/20/2010	86	28	40	1120	928	428	92	17	--
8/24/2010	96	54	45	1199	1036	371	94	22	5
9/22/2010	81	14	9	1167	884	343	80	22	9
CT-P1 Storm									
4/22/2010	401	56	52	1459	934	392	249	234	26
5/12/2010	112	11	8	1196	1103	414	221	23	5
6/28/2010	138	52	29	1356	1059	376	158	27	5
7/7/2010	146	58	48	1133	795	328	26	38	8
7/21/2010	209	19	15	2285	1229	491	78	91	28
8/5/2010	318	30	18	1607	846	361	19	32	9
CT-P2									
1/19/2010	30	11	7	1485	1411	1102	38	15	--
2/16/2010	18	8	6	1661	1555	1215	30	5	--
3/16/2010	42	8	3	1385	1145	692	64	7	--
4/14/2010	53	11	7	971	880	426	--	22	7
5/24/2010	55	7	3	1174	966	494	56	35	7
6/22/2010	54	25	20	1306	1197	654	80	10	--
7/20/2010	58	38	34	1416	1179	658	121	8	4
8/24/2010	93	48	38	1598	1446	802	135	20	5
9/22/2010	86	10	6	1432	1129	622	75	21	6
CT-P2 Storm									
4/22/2010	158	44	34	1653	1324	618	242	42	10
5/12/2010	138	25	20	1725	1369	520	257	42	8
6/28/2010	192	58	37	1615	1176	558	113	29	7
7/7/2010	109	56	48	1243	1010	506	59	27	10
7/21/2010	110	43	40	2313	1555	667	155	39	13
8/5/2010	213	59	46	1512	863	445	63	48	14

GEI Water Chemistry Data									
Analytical Detection Limits	2	2	2	2	2	2	3	4	4
Site/Sample Date	Total Phosphorus (µg/L)	Total Dissolved Phosphorus (µg/L)	Ortho-phosphate (µg/L)	Total Nitrogen (µg/L)	Total Dissolved Nitrogen (µg/L)	Nitrate+ Nitrite (µg/L)	Ammonia (µg/L)	Total Suspended Solids (mg/L)	Total Volatile Suspended Solids (mg/L)
SC-3									
2/16/2010	35	28	24	3958	3611	3414	19	4	--
3/16/2010	174	30	18	3281	2645	2495	6	10	6
4/14/2010	33	22	21	344	292	7	--	5	--
5/24/2010	113	91	79	538	480	33	38	8	4
6/22/2010	203	183	174	401	387	11	9	6	--
7/20/2010	220	210	212	425	332	--	8	--	--
8/24/2010	155	135	132	453	446	--	8	41	--
9/22/2010	74	57	61	310	280	--	28	8	--
SC-3 Storm									
4/22/2010	79	42	28	1899	1684	1198	31	17	5
5/12/2010	113	65	55	1866	1678	1147	135	15	--
6/28/2010	193	170	141	688	597	189	63	8	--
7/7/2010	143	136	139	366	353	74	13	16	6
7/21/2010	116	91	91	1323	1097	611	23	5	8
8/5/2010	148	109	111	759	624	324	21	14	5
Rain Gauge									
6/28/2010	155	102	71	1947	1664	514	734	12	9
7/21/2010	1482	529	551	8522	7787	922	2044	--	--
8/5/2010	34	19	16	1095	981	464	439	--	--

Appendix D

2010 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, CT-P2, 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 2010 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 combined with the 2010 data.

Rating curves were developed for CC-10, SC-3, CT-P1, and CT-1 by fitting a nonlinear regression model to the data (Table D-2). For sites CC-10, SC-3, and CT-P1 a two-stage rating curve was developed to more accurately estimate flows at these sites. A multi-level weir equation is used to estimate flows at both the CT-P2 and CT-2 sites located in the outlet structure for each pond. The weir equations for sites CT-P2 and Site 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, icing, or flooding (Table D-3). To estimate mean daily water levels for periods of missing data, stage relationships were evaluated among nearby sites, with the best-fit linear regression model being used to estimate the missing level data. In 2010, Site CC-10 contained one water level data gap at the first part of the year. In 2010, Site CC-10 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 January 20, 2010 to March 8, 2010, to estimate periods of missing levels for CC-10 in January and early February.

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 2010.

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)
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
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-1	2008	26-Jun-08	0.39	--	0.45
CT-1	2008	3-Jul-08	0.46	0.458	0.35
CT-1	2008	15-Aug-08	0.75	--	11.29
CT-1	2008	11-Dec-08	0.63	0.650	2.98
CT-1	2009	24-Mar-09	0.60	0.598	1.51
CT-1	2009	16-Apr-09	0.60	0.608	2.86
CT-1	2009	26-May-09	1.59	1.515	94.12
CT-1	2009	23-Jun-09	0.57	0.565	2.06
CT-1	2009	08-Dec-09	0.60	0.590	2.28
CT-1	2009	18-Aug-09	0.86	0.862	11.18
CT-1	2009	20-Nov-09	0.73	0.727	4.90
CT-1	2010	26-Jan-10	0.66	--	3.09
CT-1	2010	15-Apr-10	0.64	0.637	2.61
CT-1	2010	29-Jun-10	0.66	0.673	2.93
CT-1	2010	10-Aug-10	0.90	0.905	12.69
CT-1	2010	8-Sep-10	0.55	0.525	1.71

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	< 1.0	Q = EXP((H+0.4080)/0.8205)	0.77
	> 1.0	Q = EXP((H+9.0167)/2.6882)-35.4637	0.90
SC-3	< 1.2	Q = EXP((H-0.6749)/0.2043)-0.0045	0.98
	> 1.2	Q = (H-0.3313)/0.1205)	0.79
CT-P1	<2.2	Q = EXP((H-0.9677)/0.4035)-2.6058	0.96
	>2.2	Q = EXP(H-1.4703)/0.0394	0.93
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		Q = EXP((-0.0768+SQRT((0.0768^2)-(4*0.0339*(0.4992-H))))/(2*0.0339))	0.97
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, Jan to Feb	CC-10 Level = 1.2389*(Parker Level) -2.9475	0.91	6%
SC-3, Mar	SC-3 Level = 0.3086*(CC-10 Level) - 0.2106	0.60	7%
CT-P1, Jan to Feb	CT-P1 Level = 0.1722(CT-P2 Level) + 1.4359	0.76	7%
CT-P2, Feb	CT-P2 Level = (CT-P1 Level -1.4359)/0.1722	0.84	6%
CT-1, Jan, Mar, Apr	CT-1 Level = 0.1335*(CT-P2 Level) + 0.5686	0.84	13%
CT-2, Feb to Mar	CT-2 Level = 1.0449*(CT-P1 Level) + 0.888	0.84	4%
CT-2,Jan, Mar,Apr	CT-2 Level = 0.3533*(CT-P2 Level) + 0.4165	0.56	17%

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 (CC-10 and CT-2 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 acre-feet, then the first 1,000 acre-feet 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 MW-9 (1995-2006, 190 µg/L). Notably, flow and loads for sites upstream of 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 annual 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 annual value (Table D-4), then the flow was categorized as storm flow. Flows less than the 90th percentile were categorized as base flows.

Table D-4: Threshold flow value used to categorize base flows and storm flows in 2010.

Site	90th Percentile (cfs)
CC-10, Jan-May & Oct-Nov; Jun-Sep	38.27; 19.91
SC-3	0.48
CT-1	7.86
CT-2	14.03
CT-P1	4.34
CT-P2	4.90

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 inflow 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 annual 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 2010.

Month	CC-O	CC-10	SC-3	CT-P1	CT-P2	CT-1	CT-2
January	82	194	41	24	30	84	72
February	144	175	35	15	18	55	47
March	92	166	174	46	42	89	64
April	93	239	33	39	53	56	72
May	95	275	113	53	55	53	112
June	278	247	203	83	54	35	41
July	307	250	220	86	58	58	43
August	124	268	155	96	93	57	42
September	108	241	74	81	86	63	57
Annual storm flow median	--	307	130	178	148	93	97

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 2010 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 2010 (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 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 2010 alluvial component was defined as a constant source of water to the reservoir that accounted for 1,437 ac-ft/yr with no seasonal fluctuations. The long-term (1994-2005) median total dissolved phosphorus concentration for MW-9 (190 µg/L) was used to estimate the alluvial load component (Equation 3).

EQUATION 3:

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

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

In 2010, 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 enter 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 values.

Additionally, when the redistributed inflow is greater than 1,000 ac-ft/mo, the first 1,000 acre-feet 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-2
January	1,789	1,670	1,199	11	80	71	229	207	8	170	1,374	238
February	1,960	1,951	1,158	3	77	70	204	181	62	153	1,508	236
March	3,425	3,199	2,062	10	218	222	383	562	111	170	2,471	673
April	5,338	4,872	3,660	202	323	293	833	697	190	164	4,186	798
May	2,979	3,254	1,798	120	137	151	349	325	54	170	2,334	422
June	1,738	1,375	883	35	186	274	442	466	166	164	921	486
July	1,864	1,590	1,011	30	189	218	507	515	213	170	982	500
August	891	1,107	405	6	177	227	424	530	131	170	256	334
September	109	21	208	2	57	61	136	154	4	164	0	0
Annual Total	**20,093**	**19,039**	**12,384**	**419**	**1,444**	**1,587**	**3,507**	**3,637**	**939**	**1,495**	**14,032**	**3,687**
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-2**
January	--	372	632	1	5	6	52	41	2	88	725	47
February	--	764	551	0	3	3	30	23	20	79	718	30
March	--	800	1,253	4	75	68	95	131	35	88	1,501	157
April	--	1,232	2,875	70	127	94	191	170	60	85	3,288	195
May	--	841	1,396	42	34	37	59	94	17	88	1,812	122
June	--	1,039	671	14	68	89	77	93	52	85	700	97
July	--	1,327	781	12	75	67	111	112	67	88	758	109
August	--	373	305	2	71	80	91	116	41	88	192	73
September	--	6	144	0	12	14	23	24	1	85	0	0
Annual Total	**--**	**6,754**	**8,608**	**145**	**470**	**458**	**729**	**804**	**295**	**774**	**9,694**	**830**

Table D-7: Calculation of the monthly redistributed inflow and load values and the apportioning of these data to sites CC-10 and CT-2.

Month	Adjusted USACE Inflow (USACE Precip Alluvium)	GEI Inflow CC-10 +CT-2 (ac-ft/mo)	Redist-ributed Inflow (ac-ft/mo)	CC-10 Percent of GEI Inflow	CT-2 Percent of GEI Inflow	CC-10 Redistri-buted Flow (ac-ft/mo)	CT-2 Redistri-buted Flow (ac-ft/mo)	Ungaged Residual Flow (ac-ft/mo)	Redistri-buted Load (lbs/mo)	CC-10 Redistri-buted Load (lbs/mo)	CT-2 Redistri-buted Load (lbs/mo)	Ungaged Residual Load (lbs/mo)
January	1,611	1,406	206	85%	15%	175	31	0	99	93	6	0
February	1,744	1,339	405	86%	14%	348	57	0	174	167	7	0
March	3,145	2,624	520	79%	21%	411	109	0	274	248	26	0
April	4,984	4,358	626	84%	16%	526	100	0	438	413	25	0
May	2,755	2,123	632	85%	15%	537	95	0	444	416	28	0
June	1,407	1,349	58	65%	35%	38	20	0	33	29	4	0
July	1,482	1,526	-44	66%	34%	-29	-15	0	-26	-23	-3	0
August	590	935	-345	43%	57%	-148	-197	0	-156	-113	-43	0
September	-59	362	-421	57%	43%	-240	-181	0	-168	-144	-24	0
Annual Total	**17,659**	**16,022**	**1,637**	**--**	**--**	**1,618**	**19**	**0**	**1,112**	**1,086**	**26**	**0**

Appendix E

2010 Biological Data

Table E-1: Quantity and size of fish stocked in Cherry Creek Reservoir, 1985 to 2010.

Year	Species	Size (inches)	Number
1985	Black crappie	5.0	7,234
	Channel catfish	2 to 8	116,784
	Rainbow trout	8 to 12	75,753
	Walleye	0.3	2,346,000
	Yellow perch	2.0	90,160
1986	Bluegill	1.0	111,968
	Channel catfish	4.0	25,594
	Cutthroat trout	6.0	52,228
	Rainbow trout	2 to 18	414,136
	Tiger musky	5.5	4,723
	Walleye	0.3	1,734,000
	Wiper	0.2	80,000
1987	Bluegill	0.2	70,000
	Channel catfish	4.0	25,600
	Largemouth bass	5.0	10,000
	Rainbow trout	2 to 26	129,715
	Tiger musky	7.0	4,000
	Walleye	0.2	1,760,000
1988	Channel catfish	3.0	16,000
	Largemouth bass	5.0	10,000
	Rainbow trout	9.5	293,931
	Tiger musky	8.0	4,500
	Walleye	0.2	1,760,000
1989	Channel catfish	3.0	10,316
	Largemouth bass	6.0	8,993
	Rainbow trout	8 to 22	79,919
	Walleye	0.2	1,352,000
	Wiper	0.2	99,000
1990	Channel catfish	3.5	25,599
	Rainbow trout	9 to 15	74,986
	Tiger musky	8.0	2,001
	Walleye	0.2	1,400,000
	Wiper	1.0	8,996
1991	Channel catfish	3.0	13,500
	Rainbow trout	9 to 10	79,571
	Tiger musky	5 to 8	6,500
	Walleye	0.2	1,300,000
	Wiper	1.0	9,000
1992	Blue catfish	3.0	9,000
	Channel catfish	4.0	13,500
	Rainbow trout	9.5	101,656
	Tiger musky	7.0	4,940
	Walleye	0.2	2,600,000
	Wiper	10.0	15,520

Year	Species	Size (inches)	Number
1993	Channel catfish	4.0	13,500
	Rainbow trout	9.5	92,601
	Tiger musky	9.0	4,500
	Walleye	0.2	2,600,000
	Wiper	1.0	9,003
1994	Blue catfish	3.0	21,000
	Channel catfish	4.0	23,625
	Cutthroat trout	9.0	9,089
	Flathead catfish	1.0	148
	Rainbow trout	9 to 18	62,615
	Tiger musky	8.0	900
	Walleye	0.2	2,600,000
	Wiper	1 to 4	26,177
1995	Channel catfish	4.0	18,900
	Rainbow trout	9 to 20	139,242
	Tiger musky	8.0	4,500
	Walleye	0.2	2,600,000
	Wiper	1.0	4,500
1996	Channel catfish	3.0	8,100
	Cutthroat trout	9.5	85,802
	Rainbow trout	4 to 22	163,007
	Tiger musky	7.0	3,500
	Walleye	0.2	3,202,940
	Wiper	1.0	8,938
1997	Channel catfish	3.0	13,500
	Cutthroat trout	3 to 9	22,907
	Rainbow trout	10 to 24	74,525
	Tiger musky	6.0	4,500
	Walleye	0.2	2,600,000
	Wiper	1.0	9,000
1998	Channel catfish	4.0	7,425
	Rainbow trout	11.0	59,560
	Tiger musky	7.0	4,000
	Walleye	1.5	40,000
	Wiper	1.3	9,000
1999	Channel catfish	3.5	13,500
	Rainbow trout	10 to 19	32,729
	Tiger musky	7.0	3,000
	Walleye	0.2	2,400,000
	Wiper	1.3	9,000
2000	Channel catfish	4.1	13,500
	Northern pike	--	46
	Rainbow trout	4 to 20	180,166
	Rainbow × cutthroat hybrid	--	5,600
	Tiger musky	8.0	4,086
	Walleye	0.2	2,400,000

Year	Species	Size (inches)	Number
2001	Channel catfish	3.5	13,500
	Rainbow trout	10 to 19	23,065
	Tiger musky	7.0	4,000
	Walleye	0.2	2,400,000
2002	Rainbow trout	10.0	13,900
	Tiger musky	7.0	4,000
	Walleye	0.2	2,519,660
2003	Channel catfish	2.5	33,669
	Rainbow trout	10.5	30,111
	Walleye	0.3	4,136,709
2004	Channel catfish	2.5	13,500
	Rainbow trout	10.5	43,553
	Walleye	0.3	2,874,100
2005	Channel catfish	2.2	14
	Rainbow trout	10.4	43,248
	Walleye	0.3	2,579,939
	Wiper	0.2	200,000
2006	Black crappie	2.5	300
	Channel catfish	2.8	13,500
	Largemouth bass	2.1	195
	Rainbow × cutthroat hybrid	10.6	7,895
	Rainbow trout	10.8	47,150
	Snake River cutthroat	16.1	204
	Walleye	0.2	2,788,825
	Wiper	2.1	5,000
2007	Channel Catfish	3.0	9,360
	Rainbow trout	12.0	4,800
	Rainbow trout	10.0	37,709
	Walleye	1.0	7,998
	Walleye	0.3	4,300,000
	Wiper	1.5	4,600
2008	Rainbow trout	10.1	11,588
	Rainbow × cutthroat trout	9.7	4,001
	Walleye	0.2	3,992,572
2009	Black crappie	1.4	5,000
	Channel catfish	3.3	3,780
	Rainbow trout	4.8	12,287
	Rainbow trout	10.2	29,759
	Rainbow trout	13.6	109
	Walleye	0.2	4,012,800
	Walleye	1.3	14,998