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DRAFT
Cherry Creek Reservoir 2009 Annual Aquatic Biological Nutrient Monitoring Study and Cottonwood Creek Phosphorus Reduction Facilities Monitoring

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Executive Summary

The purpose of this report is to present the 2009 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 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 comparisons for many parameters to the long-term monitoring data collected on behalf of the Authority since 1987.

Phosphorus Loading

The total inflow of gaged tributary streams and ungaged surface water flows was 26,214 ac-ft/yr and contributed 17,425 lbs of phosphorus to the Reservoir. Annual precipitation accounted for 1,522 ac-ft of water and contributed 480 lbs of phosphorus, while the normalized alluvial inflow remained a constant 2,000 ac-ft/yr, and contributed 1,033 lbs of phosphorus to the Reservoir. These sources of inflow resulted in a total of 29,736 ac-ft entering the Reservoir, which contributed a total of 18,938 lbs of phosphorus in 2009. This equates to a flow-weighted total phosphorus concentration of 234 µg/L in 2009. The long-term (1992 to 2009) annual median flow-weighted total phosphorus concentration for the Reservoir is 206 µg/L.

Total Phosphorus

Total phosphorus concentrations in the upper 3 m layer of the Reservoir ranged from 55 to 153 µg/L during the July to September sampling events, with a seasonal mean of 98 µg/L. The long-term (1992 to 2009) seasonal median total phosphorus concentration for the Reservoir is 87 µg/L.

Chlorophyll *a*

Chlorophyll *a* concentrations in the upper 3 m layer of the Reservoir ranged from 1.1 to 25.6 µg/L during the July to September sampling events, with a seasonal mean of 13.2 µg/L. Based on the 2009 revision of the regulatory standards, the Reservoir is currently in attainment of the seasonal mean chlorophyll *a* standard of 18 µg/L and its exceedance frequency, which has been met the five previous seasons. The long-term (1992 to 2009) seasonal mean chlorophyll *a* concentration for the Reservoir is 19.3 µg/L.

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. Lake ice-cover during the 2008 to 2009 winter months was insufficient to allow monitoring of dissolved oxygen at monitoring sites. The dissolved oxygen profiles collected in early March show well oxygenated conditions (>11 mg/L) from the surface to the bottom of the Reservoir. Following spring turnover and the startup of the aeration system, the Reservoir remained well mixed and oxygenated from March to late June 2009. On June 24th, the Reservoir began showing signs of brief thermal stratification lasting for approximately eight days in late June and for four days in early July. The Reservoir was sampled for dissolved oxygen concentrations on July 1st, July 14th and July 28th, with the July 14th profiles indicating the average conditions did not meet the existing warm water criteria (5 mg/L). Concentrations on this date averaged 4.3 mg/L (0 to 6 m average), whereas on the previous and post sampling events, the average dissolved oxygen concentrations were 6.6 and 6.0 mg/L, respectively. On July 3rd, a large storm event destratified the reservoir for approximately six days, and increased the suspended sediment load and oxygen demand to the Reservoir, which resulted in the low dissolved oxygen conditions observed on July 14th. The Reservoir met the existing dissolved oxygen criteria for the remainder of the year, with the notable exception of the month of September when inaccurate data was recorded using faulty equipment. The manufacturer recalled the faulty probe.

From early July through August, Reservoir conditions were conducive for deep water anoxia (<2 mg/L) that promoted internal nutrient loading from the sediment. Soluble reactive phosphorus concentrations observed at depth provide further evidence of internal nutrient loading during this low oxygen period.

Destratification System Effectiveness

The 2009 summer season represents the second full seasonal operation of the destratification system. The continuous temperature monitoring shows that storm events greatly influence water temperatures, especially in the deeper layers because the cooler inflowing waters are more dense. These events give rise to conditions that are conducive for thermal stratification. While the destratification system was effective in circulating the upper waters of the reservoir and effective in destratifying the Reservoir following the early July storm event, the system appears to be less effective at eroding conditions in the 6 to 7 m layer near the bottom of the Reservoir.

The Reservoir continues to show periods of low dissolved oxygen levels in the deep 6 to 7 m layer, but this observation is not surprising given the historical accumulation of organic

matter in sediments. The oxygen demand at the sediment interface is likely very high and it will be a slow progression before these conditions are improved. There is evidence in 2009 that the extent of the low dissolved oxygen layer at the water/sediment boundary was less towards the end of the summer monitoring period. This may be attributed to the effectiveness of the destratification system and its ability to reduce the oxygen demand of the sediments over time, however this level of effectiveness will be best evaluated over a period of years rather than in one season.

From June to late July the Reservoir did contain a dominant assemblage of cryptomonad algae and green algae (favorable algae), and contained relatively few cyanobacteria (undesirable algae) throughout the late summer season. It is very early in the destratification monitoring to evaluate changes in patterns of algal species composition or succession, but this observation suggests that the destratification system is effective in controlling the undesirable cyanobacteria. One of the primary objectives of the destratification system is to reduce suitable habitat for cyanobacteria by vertical mixing.

Pollutant Reduction Facility Effectiveness

The Cottonwood Creek Peoria Wetland PRF was effective in reducing the flow-weighted phosphorus concentration from 134 µg/L upstream to 97 µg/L downstream of the wetland system. Further downstream, the Cottonwood Creek Perimeter Wetland PRF reduced the flow-weighted phosphorus concentration from 80 µg/L to 74 µg/L as flows entered the Reservoir. What is further evident in these data is the effectiveness of the Cottonwood Creek Stream Reclamation project, which reduced the upstream concentration from 97 µg/L to 80 µg/L along the stream reach between both wetland PRFs. Since the completion of the Cottonwood Creek Stream Reclamation project in 2008, the flow-weighted phosphorus concentration entering the Perimeter Wetland PRF has decreased by approximately 66 percent. Similar decreases have 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 74 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. Future monitoring of the existing PRF sites will provide a direct measure of the potential benefit of stream reclamation on Cottonwood Creek.

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 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 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). 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 2009 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 2009 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.

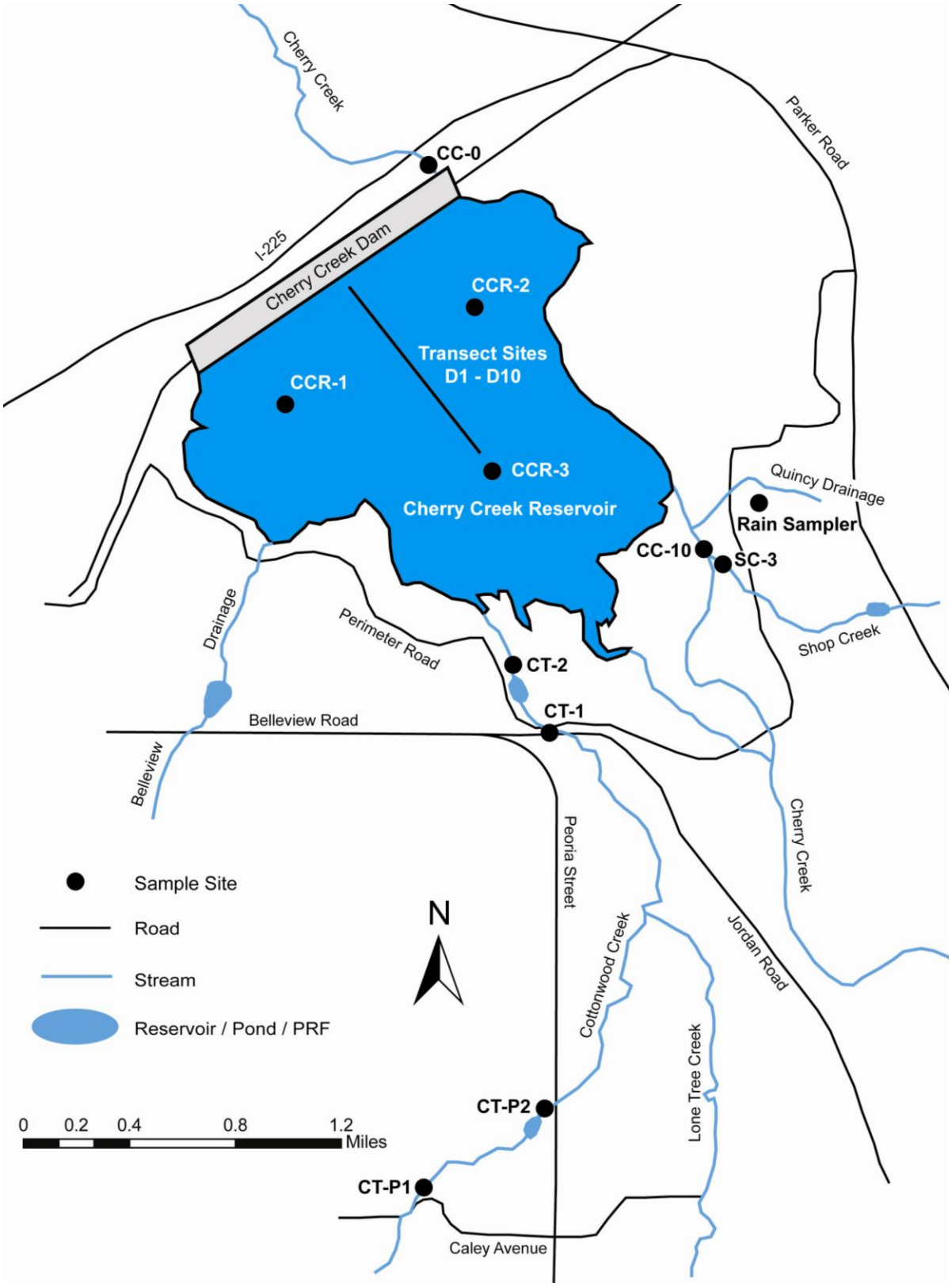

Figure 1: Sampling sites on Cherry Creek Reservoir and selected streams, 2009.

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 2009. The January 2009 and December 2009 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

Collection of dissolved oxygen, temperature, conductivity, pH, and oxidation reduction potential (ORP) measurements every meter from the surface to near the bottom of the Reservoir were used to develop depth profiles for each site during each sampling episode. From January to August, 2009, profile measurements were collected using a Yellow Springs Instrument (YSI) meter, with Model #600 XL multi-probe sonde, and in September a newly acquired Hydrolab MS5 Surveyor was used to collect the profile data. Unfortunately, problems with the luminescent dissolved oxygen (LDO) sensor led to a recall of the probe

following the two sample events in September. Therefore, the dissolved oxygen data collected in September is considered to be inaccurate. Other parameters such as temperature, pH, ORP, and conductivity were not affected by the recall of the LDO sensor. The Hydrolab sonde was used for the remainder of the sampling events in 2009. Prior to use, the water quality sondes were calibrated to ensure the accuracy of the measurements.

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 2009 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). In April 2009, a wet snow storm event resulted in runoff characteristic of a rainfall events, thus this event was also sampled. 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, 2009. See Appendix C for sample dates.

	Sites					
	CC-10	SC-3	CT-P1	CT-P2	CT-1	CT-2
Number of Storm Samples	8	8	8	9	9	9

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 2009, 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, 2009.

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 2009 and linear regression analysis (described below). Additionally, 95 percent 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 2009 Transparency

The whole-reservoir mean Secchi depth varied from 0.35 m in mid-April to 2.63 m in late May (Figure 2). The seasonal (July to September) whole-reservoir mean Secchi depth was 1.09 m (Figure 3). The depth at which 1 percent of photosynthetically active radiation (PAR) penetrated the water column (i.e., photic zone depth) ranged from 1.77 m in mid-April to a maximum depth of 5.49 m in mid-May (Figure 2). The May and mid-July sample events followed relatively large storm events which greatly affected algal biomass (chlorophyll *a*). A spring snow storm in mid-April resulted in the greatest daily precipitation event of 2009, and also represented the first "flushing" event of suspended solids and nutrients into the Reservoir following the winter deposition. Despite the greater water clarity during the May sampling event, a lag response by algae revealed a relatively low chlorophyll level (5.2 µg/L). A similar response by the algal community was evident following a large precipitation event in early July when the chlorophyll *a* concentration was 1.1 µg/L. The extremely wet summer season appears to have also affected algal biomass during other times of the year, and likely contributed to the variability in chlorophyll a concentrations. The greatest level of chlorophyll *a* of 25.6 µg/L was observed in late September.

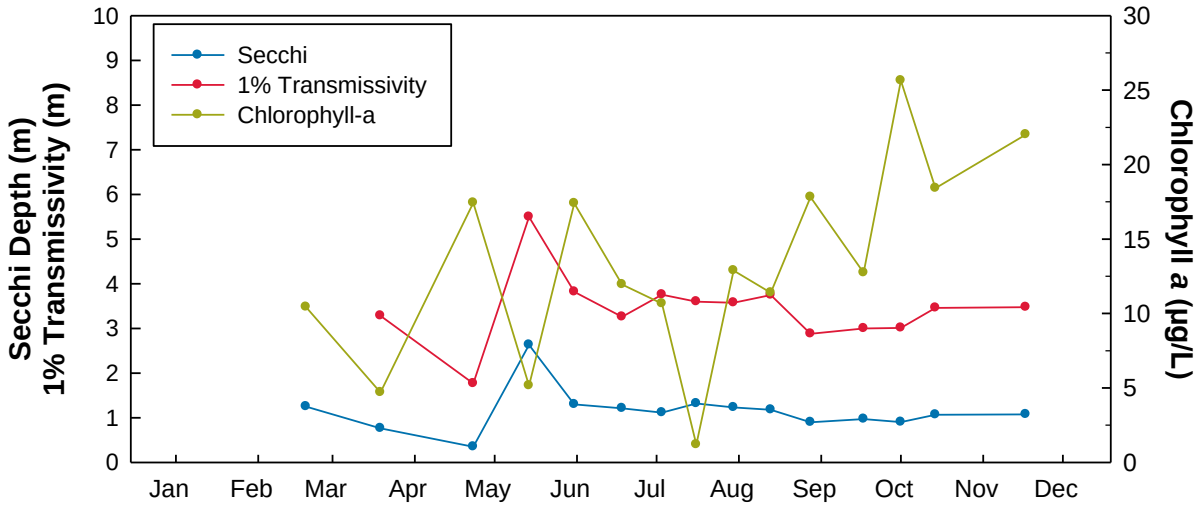

Figure 2: Annual patterns for mean whole-lake Secchi depth, 1% transmissivity, and chlorophyll *a* in Cherry Creek Reservoir, 2009.

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 2009 seasonal whole-reservoir mean Secchi depth, 1.09 m, was typical of the long-term (1992-present) mean value of 1.07 m.

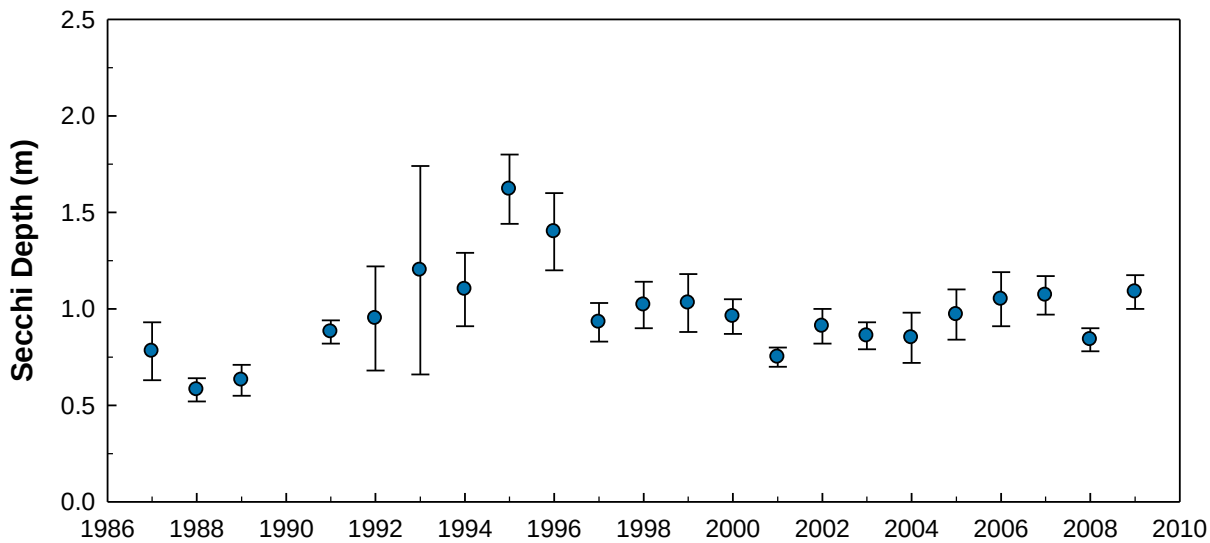

Figure 3: Whole-lake seasonal mean (July to September) Secchi depths (m) measured in Cherry Creek Reservoir, 1987 to 2009. Error bars represent a 95 percent confidence interval for each mean.

4.1.3 2009 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., YSI and Hydrolab multimeter) in Cherry Creek Reservoir ranged from 3.2 °C at the bottom in mid-February to 24.7 °C at the surface

in early July. Temperature loggers were installed in mid-May and showed a well mixed Reservoir until late June. By the end 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. Periods of thermal stratification were observed in the Reservoir at all lake sites (4.1.3.1).

Water column dissolved oxygen profiles were also compared to the table value standard (5 mg/L) for Class 1 Warm Water lakes and reservoirs (Figure 5, Figure 7, and Figure 9). The Colorado Department of Public Health and Environment ([CDPHE] 2007) 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. Following the storm event in early July, the lake-wide mean dissolved oxygen concentration of 4.3 mg/L exceeded the warm water standard. In late September, the Reservoir dissolved oxygen concentrations appeared to not meet the standard again. However, the September data are considered inaccurate because the manufacturer recalled the LDO sensor following ongoing issues with that batch of LDO sensors.

The exceedance of the standard in mid-July is considered accurate, although the underpinnings of the exceedance are solely attributed to the extreme storm event conditions in early July. This event greatly increased the suspended sediment load to the Reservoir, ultimately affecting the chemical and biological oxygen demand of the Reservoir. The July exceedance was not the result of chronic oxygen demand conditions in the Reservoir.

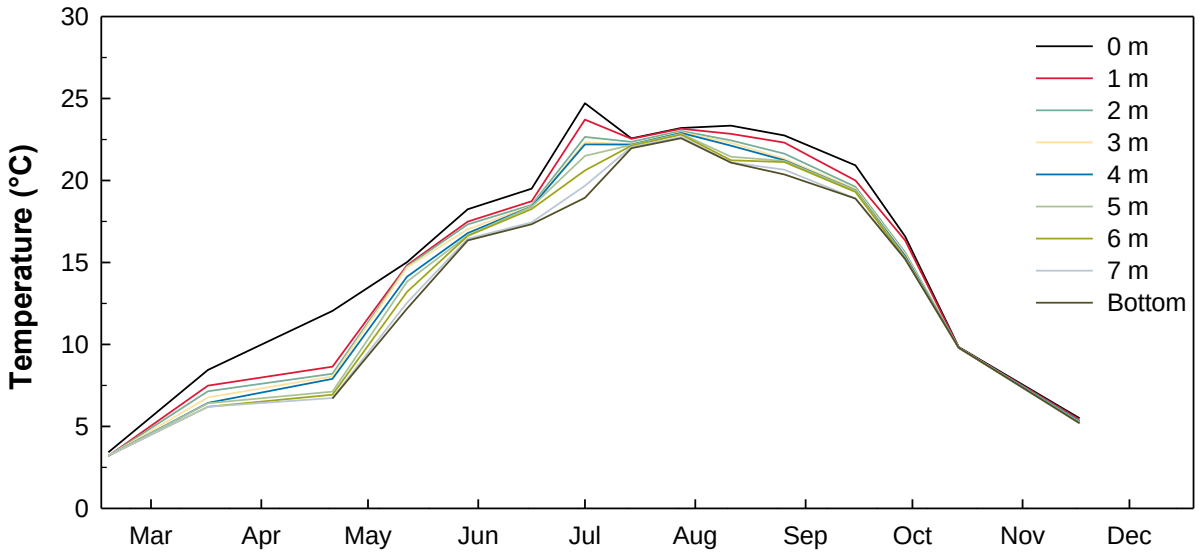

Figure 4: Temperature (°C) recorded at depth during routine monitoring at Site CCR-1 in 2009.

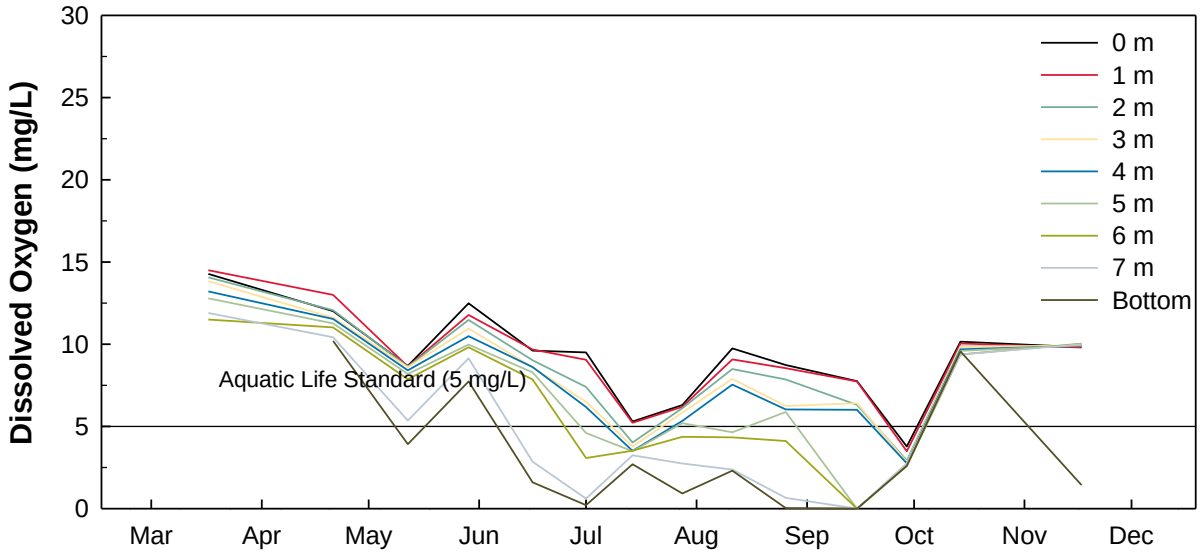

Figure 5: Dissolved oxygen (mg/L) recorded at depth during routine monitoring at Site CCR-1 in 2009. The dissolved oxygen basic standards table value for Class 2 warm water lakes and reservoirs is provided for comparison (5 mg/L).

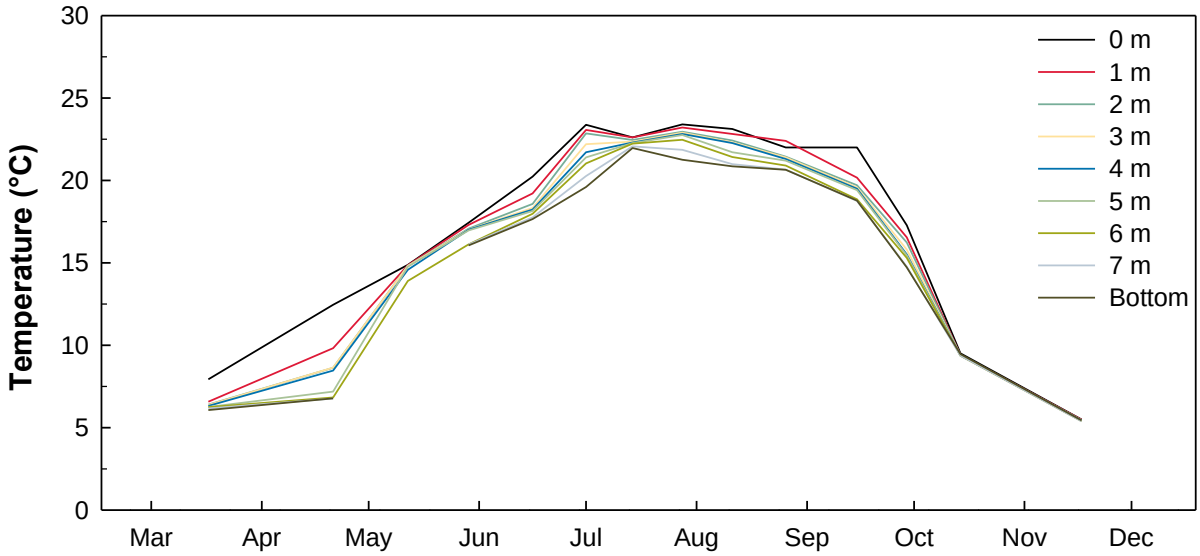

Figure 6: Temperature (°C) recorded at depth during routine monitoring at Site CCR-2 in 2009.

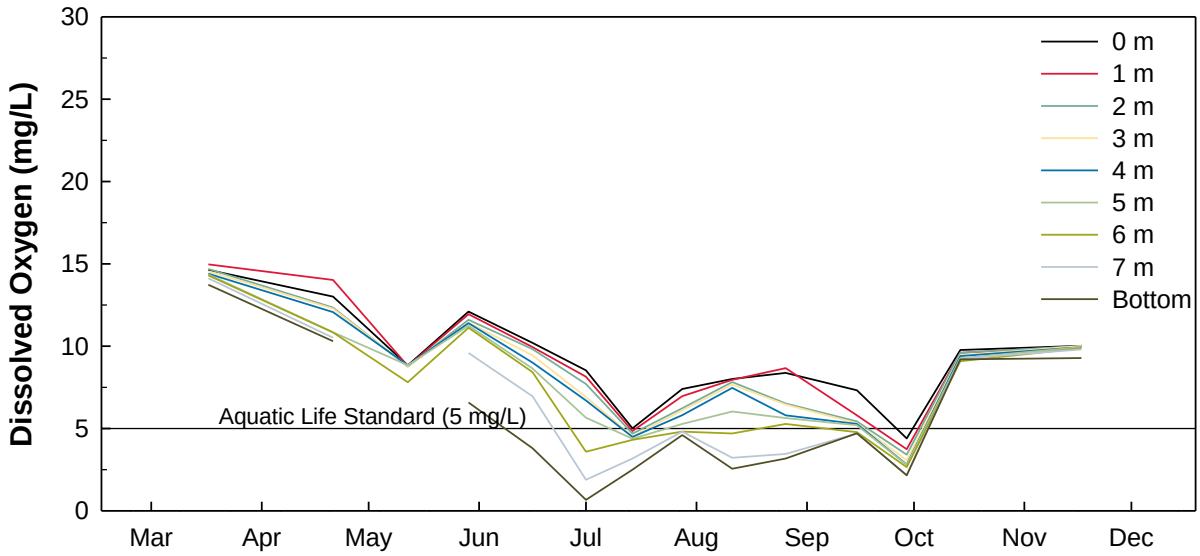

Figure 7: Dissolved oxygen (mg/L) recorded at depth during routine monitoring at Site CCR-2 in 2009. The dissolved oxygen basic standards table value for Class 2 warm water lakes and reservoirs is provided for comparison (5 mg/L).

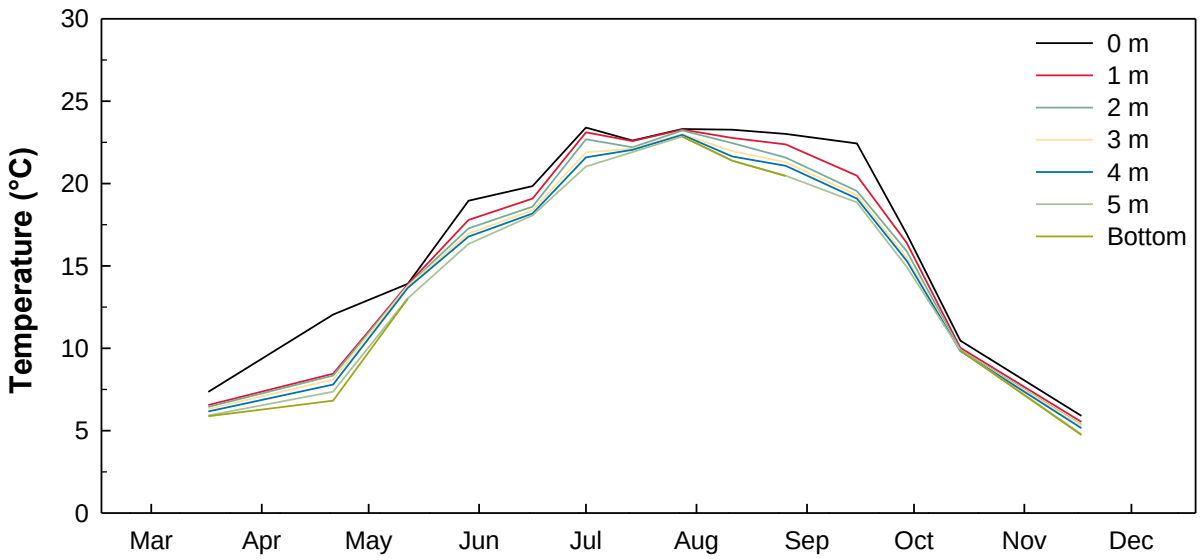

Figure 8: Temperature (°C) recorded at depth during routine monitoring at Site CCR-3 in 2009.

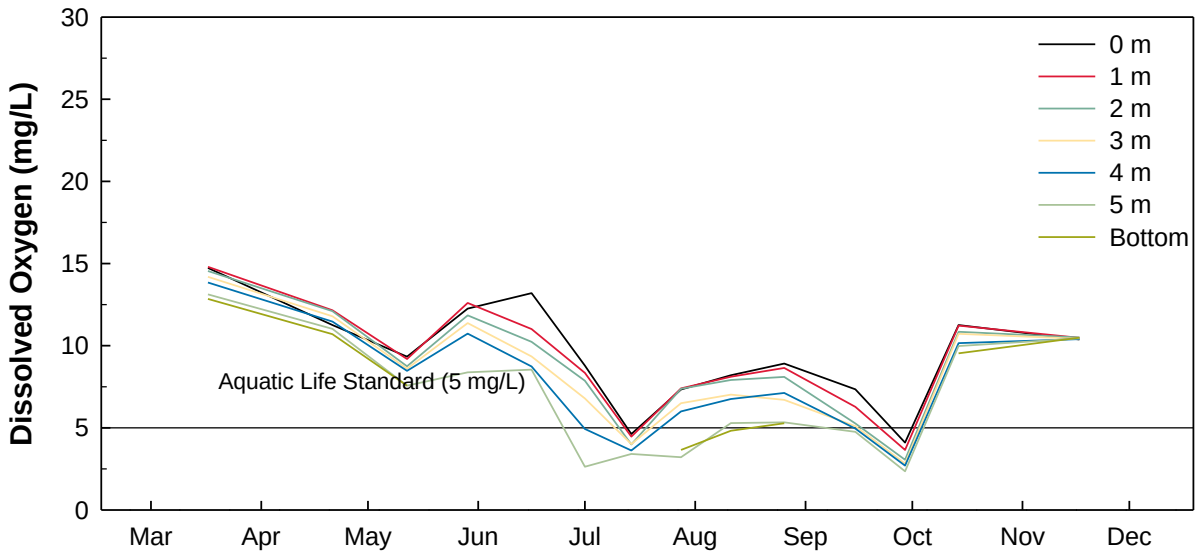

Figure 9: Dissolved oxygen (mg/L) recorded at depth during routine monitoring at Site CCR-3 in 2009. The dissolved oxygen basic standards table value for Class 2 warm water lakes and reservoirs is provided for comparison (5 mg/L).

4.1.3.1 Continuous Temperature Monitoring

In May 2009, temperature loggers were deployed for monitoring the efficiency of the destratification system at mixing the water column. From May through the end of June the temperature loggers revealed a very uniform water column temperature and it was not until late 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 14th to October 14th (Figure 10, Figure 11, and Figure 12). On June 24th, the Reservoir began showing signs of brief thermal stratification lasting for approximately eight days in late June and for four days in early July. Between these events, a storm event in early July destratified the reservoir for approximately six days. During these brief stratification periods, the deeper water layers of the Reservoir revealed low dissolved oxygen concentrations which are largely attributed to the increased oxygen demand brought on by the storm event rather than due to normal oxygen demand at the water/sediment interface. 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).

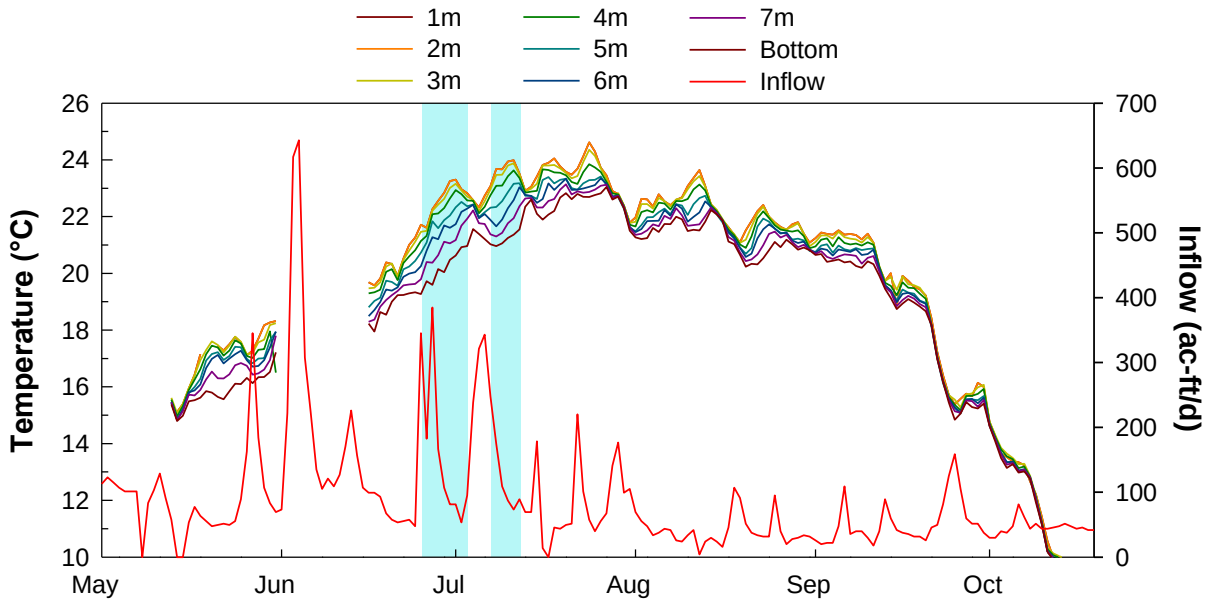

Figure 10: Daily mean temperature recorded at depth for Site CCR-1 based on 15-minute interval data collected by temperature loggers, with USACE inflow and KAPA precipitation. Shaded areas denote periods of thermal stratification and the data gap resulted from the loggers reaching maximum storage capacity.

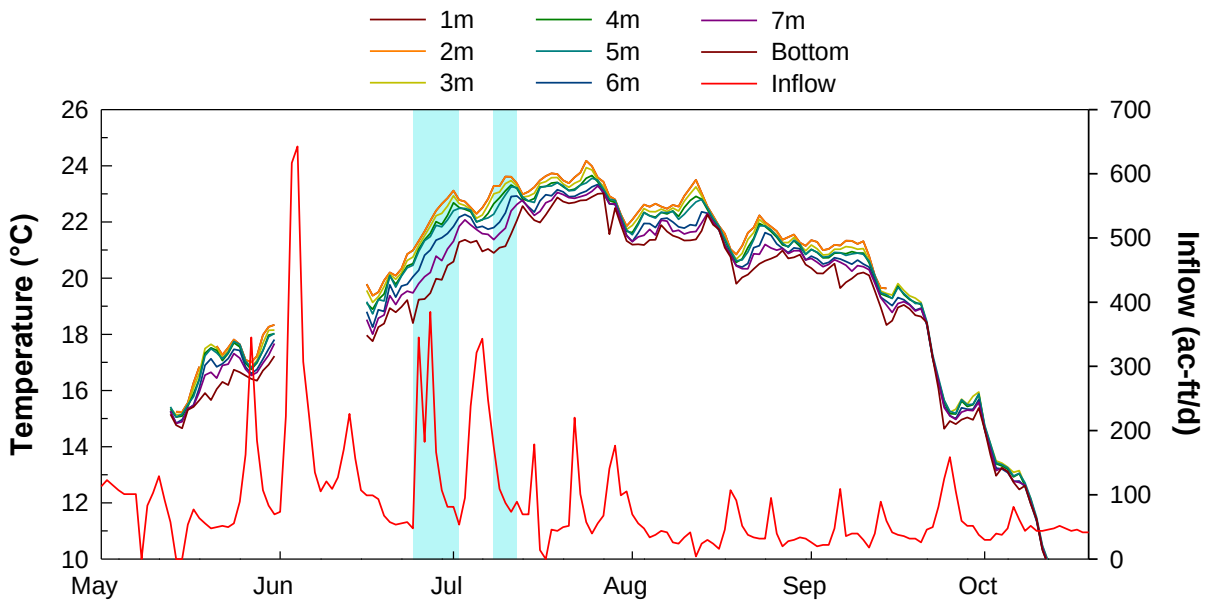

Figure 11: Daily mean temperature recorded at depth for Site CCR-2 based on 15-minute interval data collected by temperature loggers, with USACE inflow and KAPA precipitation. Shaded areas denote periods of thermal stratification and the data gap resulted from the loggers reaching maximum storage capacity.

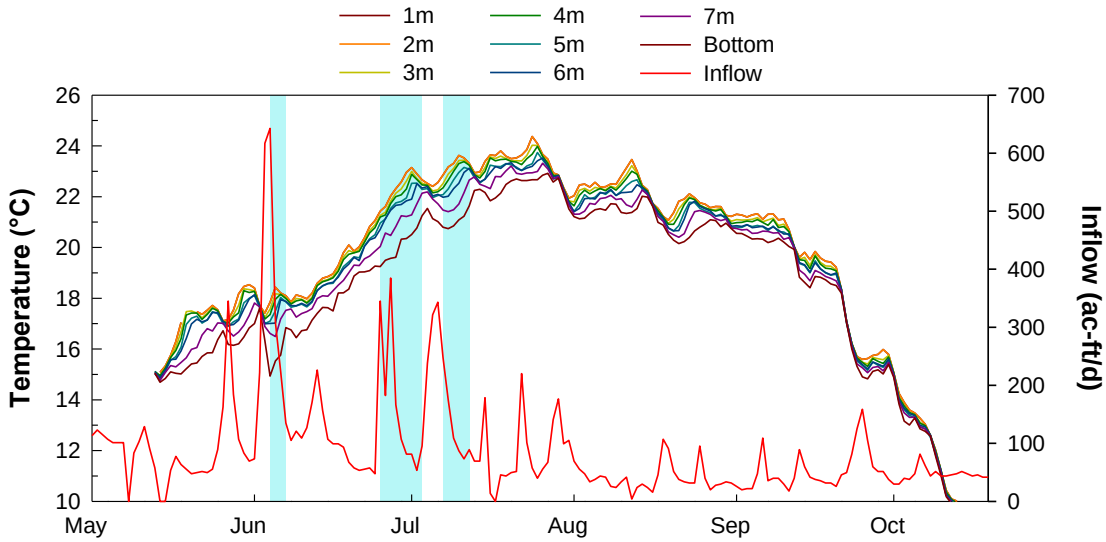

Figure 12: Daily mean temperature recorded at depth for Site CCR-3 based on 15-minute interval data collected by temperature loggers, with USACE inflow and KAPA precipitation. Shaded areas denote periods of thermal stratification.

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 July 1st, 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 (4 to 5 m). These transect profiles represents a snap-shot of dissolved oxygen conditions just prior to the storm events in early July. Using the same criteria to evaluate compliance with dissolved oxygen concentrations as discussed above, the mean water column (0 to 6 m) concentration was 6.8 mg/L which met the warm water standard. This average value represents conditions along the transect length when the water depth was greater than 6 m (i.e., 10 of 12 sites sampled). At the 6 m depth, which was approximately 1.2 m above the water/sediment interface, the mean dissolved oxygen concentration was 5.3 mg/L (Figure 13 and Appendix B).

The oxidation-reduction potential profiles on July 1st 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 (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 percent of the cumulative total phosphorus load from 1992 to 2006 (Nürnberg and LaZerte 2008).

By July 28th, the boundary layer defined by the 5 mg/L dissolved oxygen level migrated slightly downward to approximately the 6 m water depth across the length of the transect (Figure 13). The mean water column concentration was 5.8 mg/L which met the warm water standard. At the 6 m depth, along the transect length, the dissolved oxygen concentration was 5.1 mg/L, which decreased considerably at depths greater than 7 m, with concentrations less than 1 mg/L at the water/sediment interface. Similarly, the oxidation-reduction potentials at the water/sediment interface were favorable for a reducing environment (Figure 14).

The last transect profile was collected on August 26th, when the mean water column dissolved oxygen concentration was 6.6 mg/L, which met the warm water standard. At the 6 m depth, the dissolved oxygen concentration was 5.4 mg/L. On this date, the coverage of

the anoxic zone appeared to be considerably less than observed during the previous two sampling events(Figure 13).

The oxidation-reduction profiles also indicate that conditions were becoming less favorable for a reducing environment following the storm event (Figure 14).

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 6.2 to 7.9 mg/L.

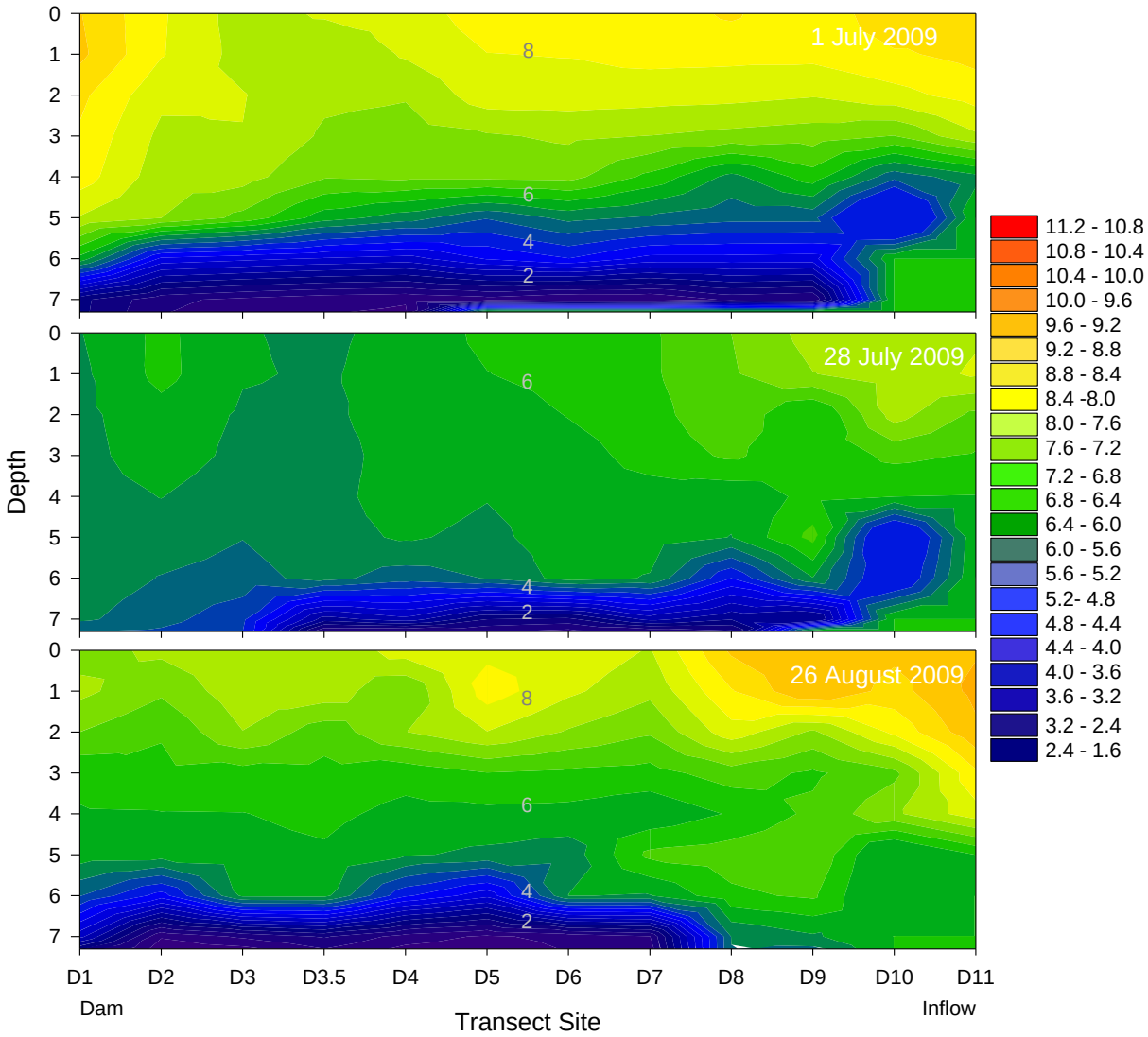

Figure 13: Dissolved oxygen conditions in Cherry Creek Reservoir for three dates based on transect profile data.

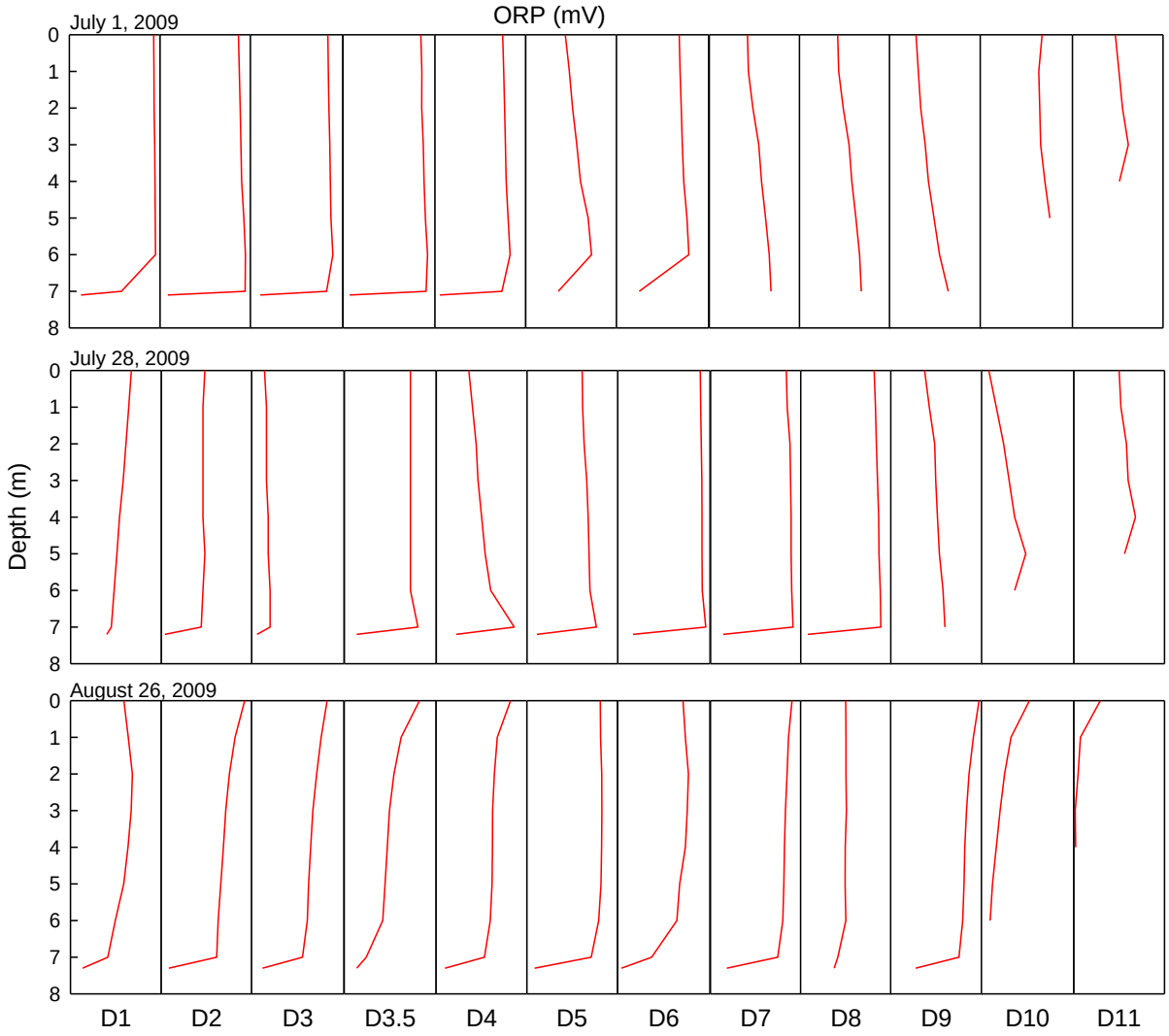

Figure 14: Oxidation reduction potentials in Cherry Creek Reservoir for three dates based on transect profile data. The ORP (mV) scales for each profile within each sample event panel are all relative to each other, but are different with respect to the three sample events. Oxidation-reduction potentials (mV) are provided in Appendix B.

4.1.4 2009 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 2009, the photic zone mean concentration of total phosphorus ranged from 51 to 153 µg/L with an overall annual mean of 83 µg/L. The seasonal photic zone mean (July-to-September)

concentration ranged from 55 to 153 µg/L, with a seasonal mean of 98 µg/L (Figure 15). Monthly reservoir phosphorus concentrations did not correlate with monthly USACE inflow or phosphorus loads. The annual phosphorus pattern indicates that the April snow storm contributed to the spring peak phosphorus concentration in the Reservoir, and that internal loading contributed substantially to summer phosphorus concentrations.

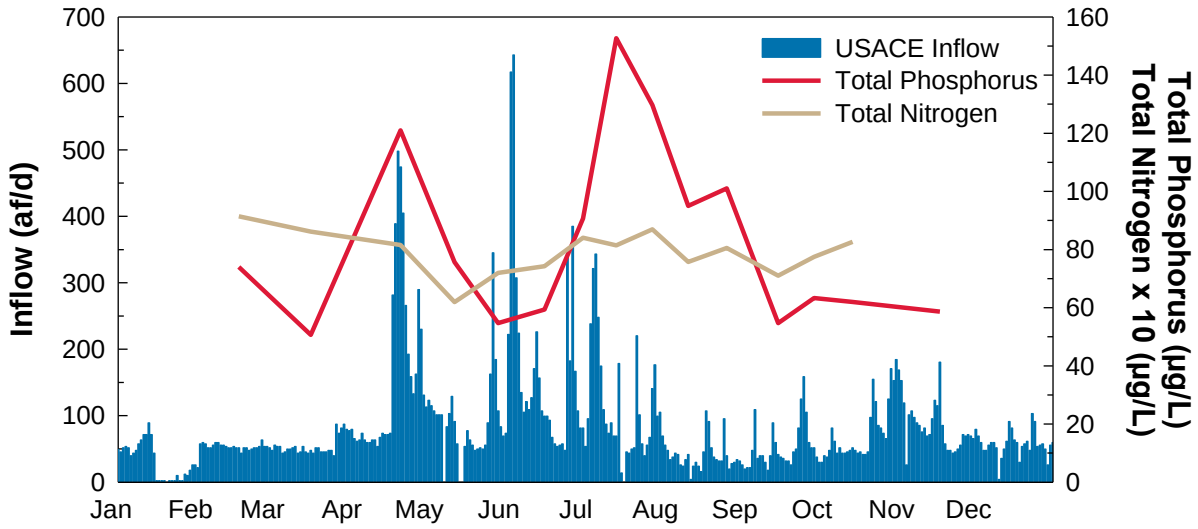

Figure 15: Annual pattern of photic zone total phosphorus, total nitrogen and USACE inflow in Cherry Creek Reservoir, 2009.

Patterns in total phosphorus concentrations collected along depth profiles at Site CCR-2 showed a well-mixed Reservoir throughout the year (Figure 16). There were periods of nutrient release from bottom sediments from June through September as evidenced by increasing total phosphorus concentrations as compared with concentrations observed 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 diffusion of phosphorus between the 6 and 7 m layers, and the eventual circulation within the upper layers resulting from the aeration system. In terms of nutrient concentrations, the aeration system appears to create a well mixed layer from the surface down to approximately 6 m, which is slightly above the aerator heads (approximately 0.75 m above the sediment). During the June to September period, the total dissolved phosphorus fraction in the 7 meter water layer accounted for approximately 40 to 70 percent 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 619 to 2,199 µg/L, with an annual average of 1,204 µg/L. During the July-to-September period, the photic zone mean total nitrogen concentration ranged from 666 to 2,017 µg/L, with a mean concentration of

1,236 µg/L. These annual and seasonal nitrogen values represent some of the greatest concentrations observed in the Reservoir, and despite the lack of correlation with inflow, these concentrations are likely the result of the extremely wet year experienced by the watershed.

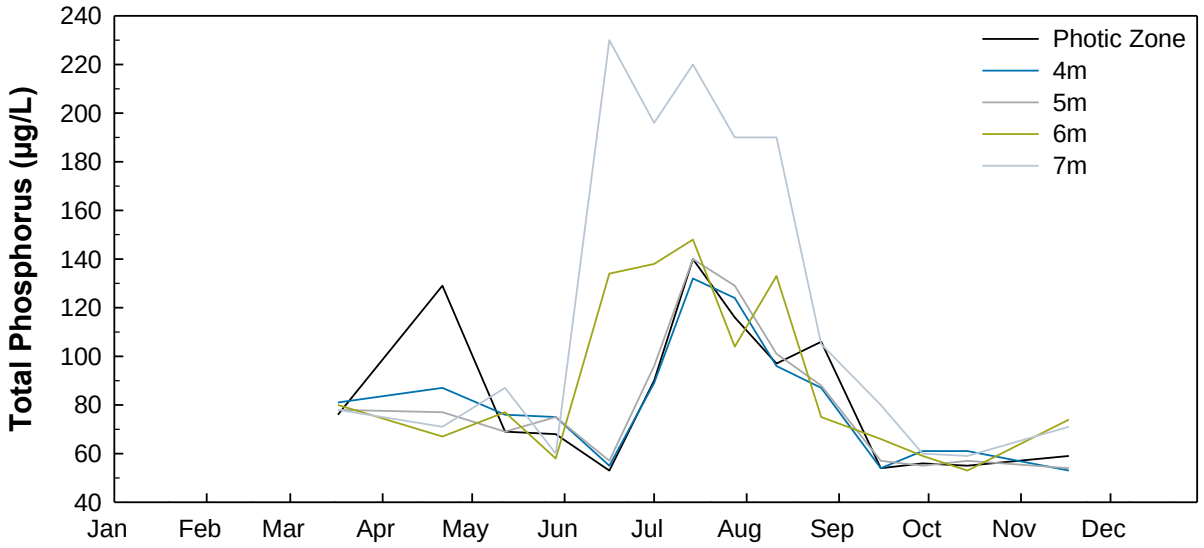

Figure 16: Total phosphorus concentrations recorded for the photic zone and at depth during routine monitoring in 2009.

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 2009 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 2009.

Routine monitoring data collected since 1987 indicates a general increasing pattern in summer mean concentrations of total phosphorus (Figure 17). In 2009, the July to September mean concentration of total phosphorus was 98 µg/L. Although this value is substantially

lower than last year's 118 ug/L concentration, it is still greater than the long-term median value of 81 µg/L (Table 4). Regression analyses performed on 1987 to 2009 seasonal mean TP data indicates a significant ($p < 0.01$) increasing trend.

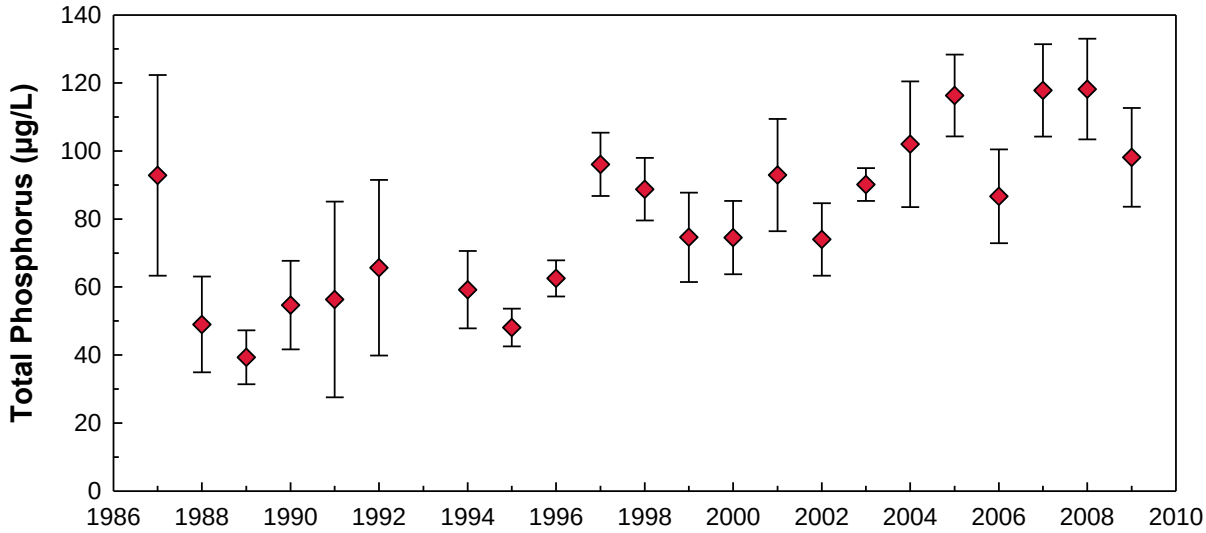

Figure 17: Seasonal mean (July to September) total phosphorus concentrations (µg/L) measured in Cherry Creek Reservoir, 1987 to 2009. Error bars represent a 95 percent confidence interval for each mean.

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 2009.

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
Mean	**889**	**928**	**75**	**85**	**17.4**	**19.3**
Median	**874**	**914**	**81**	**87**	**16.3**	**17.8**

4.1.6 2009 Chlorophyll a Levels

From mid-February through mid November, chlorophyll *a* concentrations ranged from 1.1 to 25.6 µg/L (Figure 18). The 2009 annual mean chlorophyll *a* concentration was 13.3 µg/L, and the July to September mean chlorophyll *a* concentration was 13.2 µg/L, which met the new chlorophyll *a* standard of 18 µg/L.

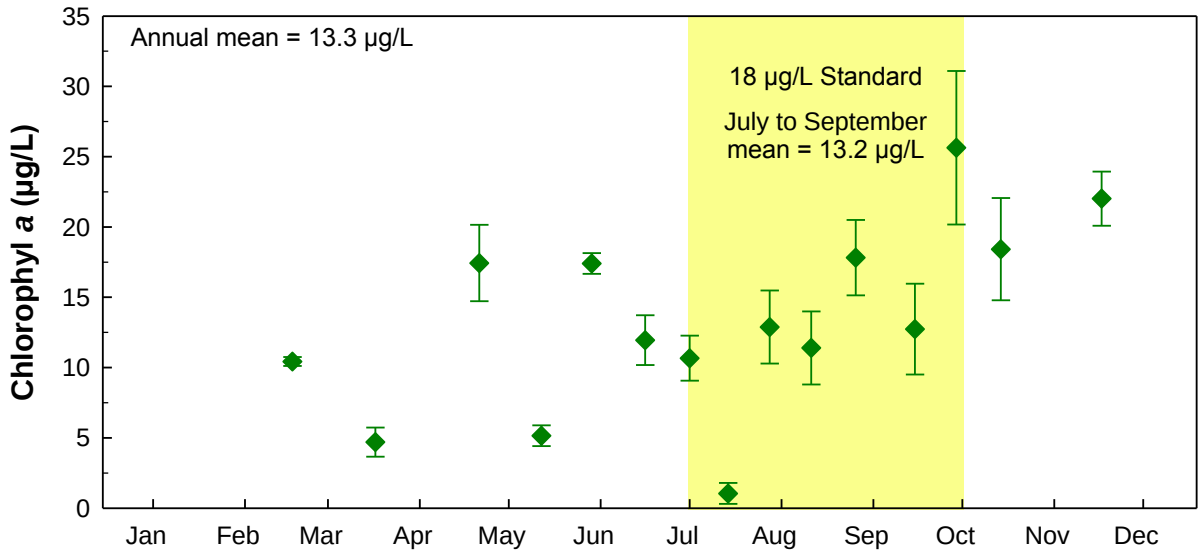

Figure 18: Concentration of chlorophyll *a* (µg/L) in Cherry Creek Reservoir, 2009. Error bars represent 95 percent confidence interval around each mean. Highlighted area denotes the seasonal period for the chlorophyll *a* standard.

4.1.7 Long-term Chlorophyll a Trends in Cherry Creek Reservoir

Based on the 2009 revision of the regulatory standards, the Reservoir is currently in attainment of the seasonal mean chlorophyll *a* standard of 18 µg/L and its exceedance frequency, which has been met the five previous years (Figure 19). 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 low levels in 2009.

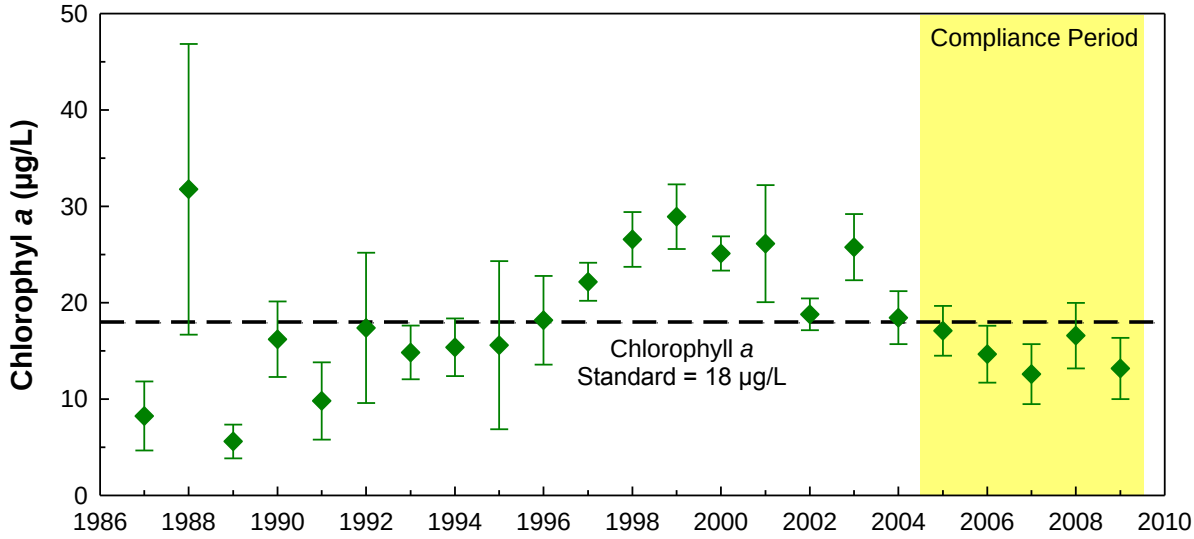

Figure 19: Seasonal mean (July to September) chlorophyll *a* concentrations measured in Cherry Creek Reservoir, 1987 to 2009. Error bars represent 95 percent confidence interval around each mean.

4.2 Reservoir Biology

4.2.1 2009 Phytoplankton

Phytoplankton density in the photic zone ranged from 806 cells/ml on May 12th to 10,877 cells/mL on February 17th (Table 5). The number of algal taxa present in the Reservoir ranged from 9 on February 17th to 24 on September 15th. Annually, the assemblage was dominated in terms of density by cryptomonads, with green algae being the second most abundant taxonomic groups (Figure 20). In 2009, the relative density of blue-green algae was extremely low as compared to previous years data.

Table 5: Density (cells/mL) of phytoplankton and total number of taxa collected from all three sites on Cherry Creek Reservoir 2009.

Taxa	17-Feb	17-Mar	21-Apr	12-May	29-May	16-Jun	1-Jul
Diatoms							
Centrics	88	1744	247	22	570	587	36
Pennates	354	2165	129	29	847	385	291
Green Algae	2,211	1,082	634	87	259	293	837
Blue-Green Algae	--	--	--	--	--	128	--
Golden-Brown Algae	--	--	--	--	--	--	--
Euglenoids							
Dinoflagellates	531	421	21	29	--	92	109
Cryptomonads	6,279	541	107	625	173	422	7,602
Microflagellates	1,415	661	--	15	17	92	--
Total Density	**10,877**	**6,615**	**1,138**	**806**	**1,866**	**1,998**	**8,875**
Total Taxa	**9**	**13**	**20**	**12**	**15**	**19**	**15**
Taxa	**14-Jul**	**28-Jul**	**11-Aug**	**26-Aug**	**15-Sep**	**29-Sep**	**14-Oct**
Diatoms							
Centrics	--	1260	1149	586	339	44	111
Pennates	--	66		167	73	153	166
Green Algae	389	1,426	1,396	726	202	656	536
Blue-Green Algae	111	--	27	56	9	--	--
Golden-Brown Algae	--	--	--	--	18	44	92
Euglenoids	--	--	--	--	64	--	18
Dinoflagellates	37	133	27	726	--	87	37
Cryptomonads	2,411	497	301	530	266	1,508	1,017
Microflagellates		33		84		22	
Total Density	**2,949**	**3,416**	**2,901**	**2,875**	**972**	**2,513**	**1,978**
Total Taxa	**11**	**16**	**18**	**23**	**24**	**14**	**19**

Regression analysis revealed no significant correlation between cryptomonads or green algal density with monthly total or soluble reactive phosphorus concentrations during 2009. Additionally, no significant relationship was observed between phytoplankton density and chlorophyll *a*. Monthly average chlorophyll *a* concentrations did not correlate with either monthly average total phosphorus concentrations nor monthly average total nitrogen. However, there is a corresponding time lag response showing an increase in green algal density and following an increase in photic zone total phosphorus concentrations.

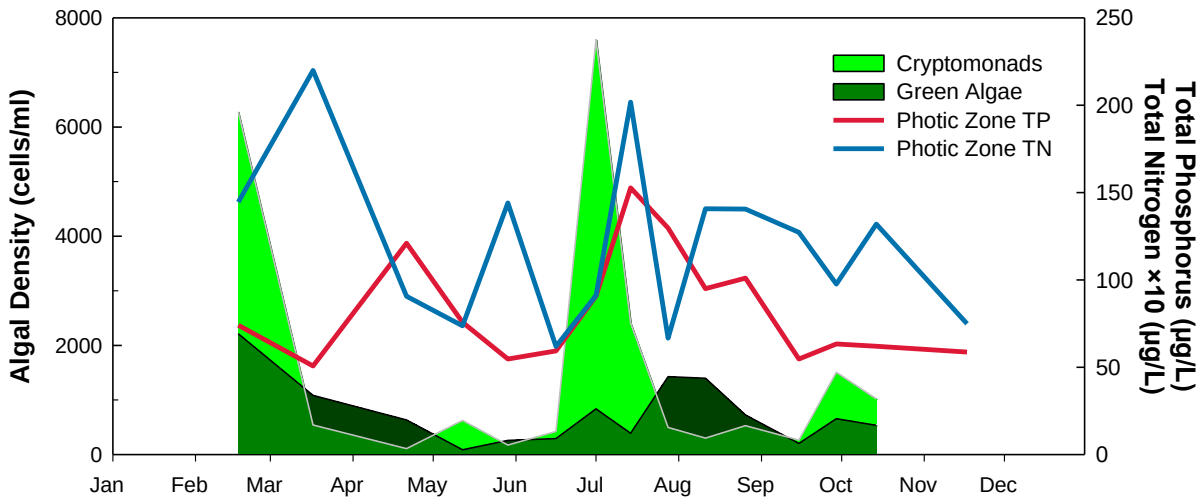

Figure 20: Annual pattern of blue-green and green algal densities and photic zone total phosphorus and total nitrogen concentrations in Cherry Creek Reservoir, 2009.

4.2.2 Long-Term Phytoplankton

In 2009, the phytoplankton assemblage was dominated, in terms of density, by cryptomonads (45 percent) and diatoms (23 percent), and green algae (22 percent; Table 5). Historically, the cyanobacteria have been the most abundant algae, especially during the late summer season, but in 2009, this taxonomic group comprised less than 1 percent in terms of overall density. The considerable reduction in the relative density cyanobacteria appears to related to the effectiveness of the destratification system (Appendix E). One of the primary objectives of the destratification system is to reduce suitable habitat for cyanobacteria by vertical mixing.

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 2009, four fish taxa were stocked (Appendix E): approximately four million walleye fry, thirty thousand catchable rainbow trout, five thousand black crappie, and four thousand channel catfish.

4.3 Stream Water Quality

4.3.1 2009 Phosphorus Concentrations in Streams

The median annual total phosphorus concentration for base flow conditions ranged from 35 µg/L at CT-P1 to 189 µg/L at CC-10 (Table 6). At most stream sites, the median seasonal (July-to-September) base flow concentration was greater than the annual median concentration. The seasonal median concentration of total phosphorus ranged from 42 µg/L at Site CT-2 to 294 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 78 µg/L at Site CT-2 to 378 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, 2009.

Stream, Site	Base Flow				Storm Flow	
	Summer		Annual		Annual	
	TP (µg/L)	TSS (mg/L)	TP (µg/L)	TSS (mg/L)	TP (µg/L)	TSS (mg/L)
Cherry Creek						
CC-10	294	54	189	34	378	150
CC-O	101	24	82	14	--	--
Cottonwood Creek						
CT-1	47	21	71	24	97	38
CT-2	42	19	54	30	78	32
CT-P1	104	17	35	13	182	53
CT-P2	75	15	49	18	122	27
Shop Creek						
SC-3	171	18	63	15	111	18

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

Long-term patterns (1995-2009) 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 205 µg/L and 99 µg/L, respectively (Table 7), with storm flow concentrations being approximately 70 percent 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 percent greater. Soluble reactive phosphorus fractions for base flows in Cherry Creek and Shop Creek were approximately 79 percent and 71 percent, respectively, of the total phosphorus concentrations, while soluble reactive phosphorus fractions in Cottonwood Creek (CT-2) have been approximately 16 percent 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 2009.

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*	155*	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
Median	**205**	**162**	**99**	**70**	**81**	**13**

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

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 2009.

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**
Median	**354**	**207**	**175**	**101**	**209**	**35**

Base flow total phosphorus and soluble reactive phosphorus concentrations revealed no trends over time at both sites CC-10 and SC-3 (Figures 21 through 24). However, at Site CT-2, both the total phosphorus and soluble reactive phosphorus concentrations reveal a significant ($p < 0.05$) decreasing trend (Figure 25 and Figure 26) during base flow conditions. The observed decreasing trend and greatly reduced variability in soluble reactive phosphorus concentrations at Site CT-2 from 1995 to 2009 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.

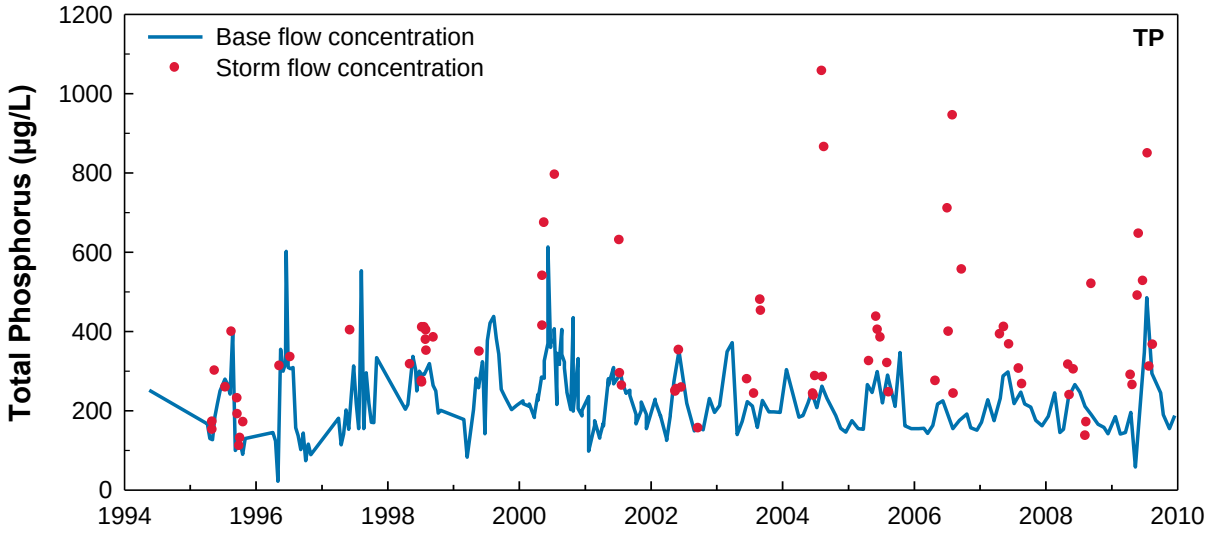

Figure 21: Base flow and storm flow total phosphorus concentrations measured in Site CC-10, 1994 to 2009.

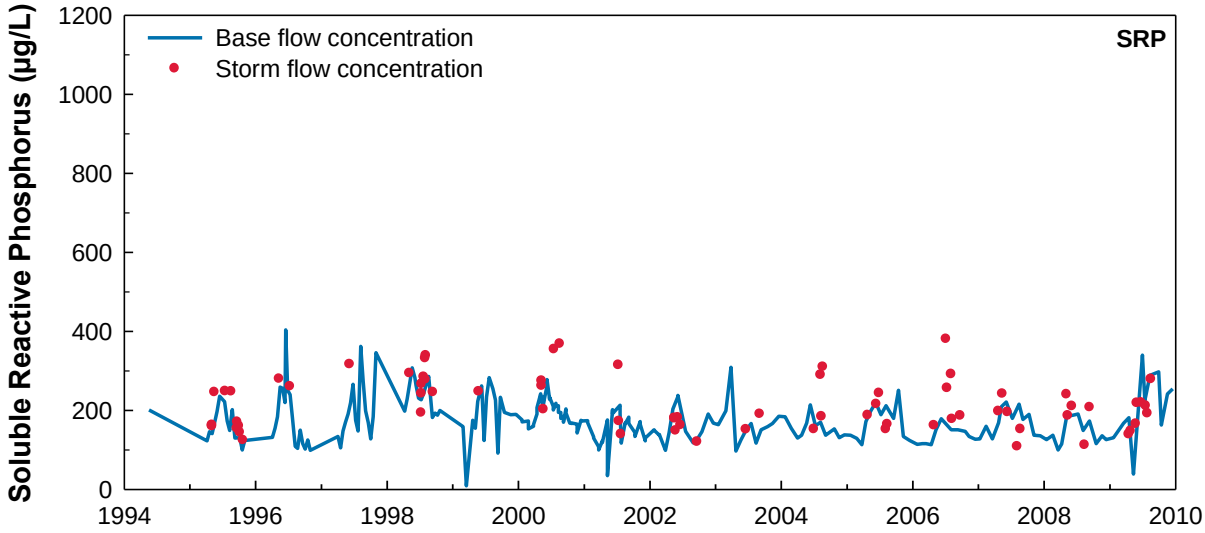

Figure 22: Base flow and storm flow soluble reactive phosphorus concentrations measured in Site CC-10, 1994 to 2009.

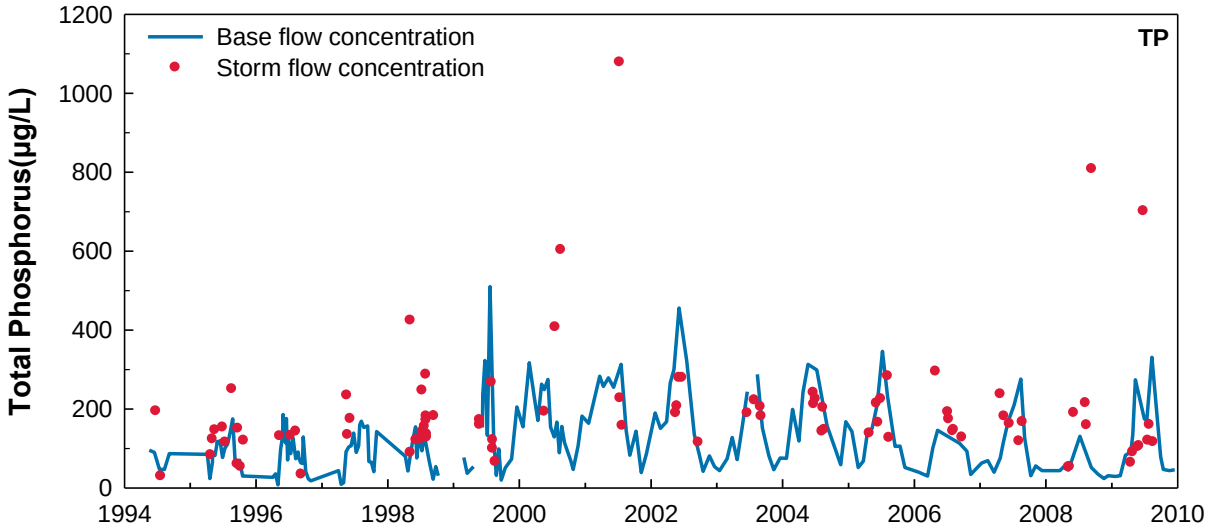

Figure 23: Base flow and storm flow total phosphorus concentrations measured in Site SC-3, 1994 to 2009.

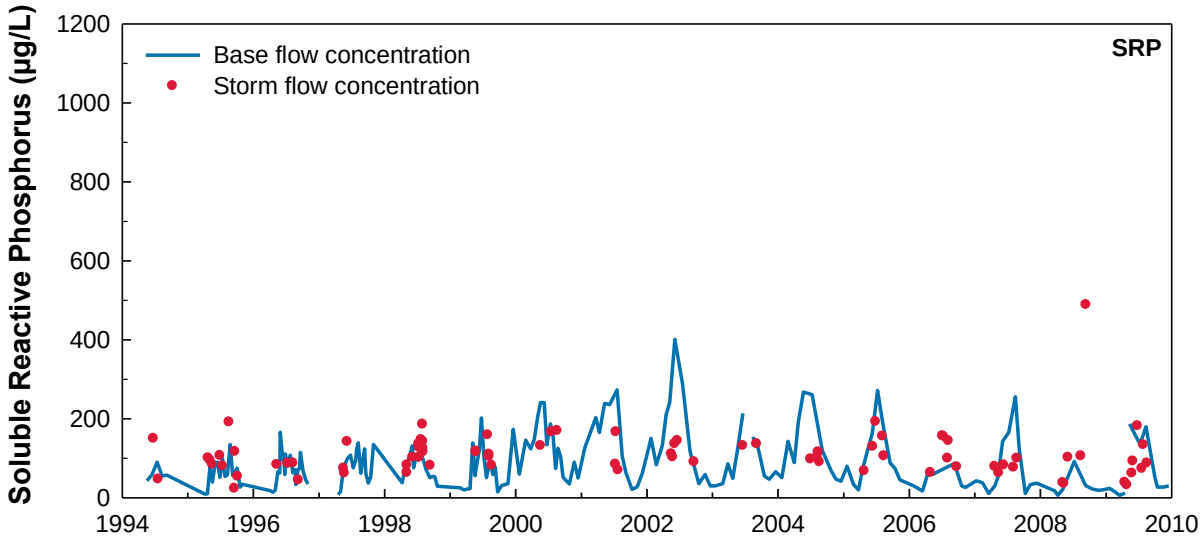

Figure 24: Base flow and storm flow soluble reactive phosphorus concentrations measured in Site SC-3, 1994 to 2009.

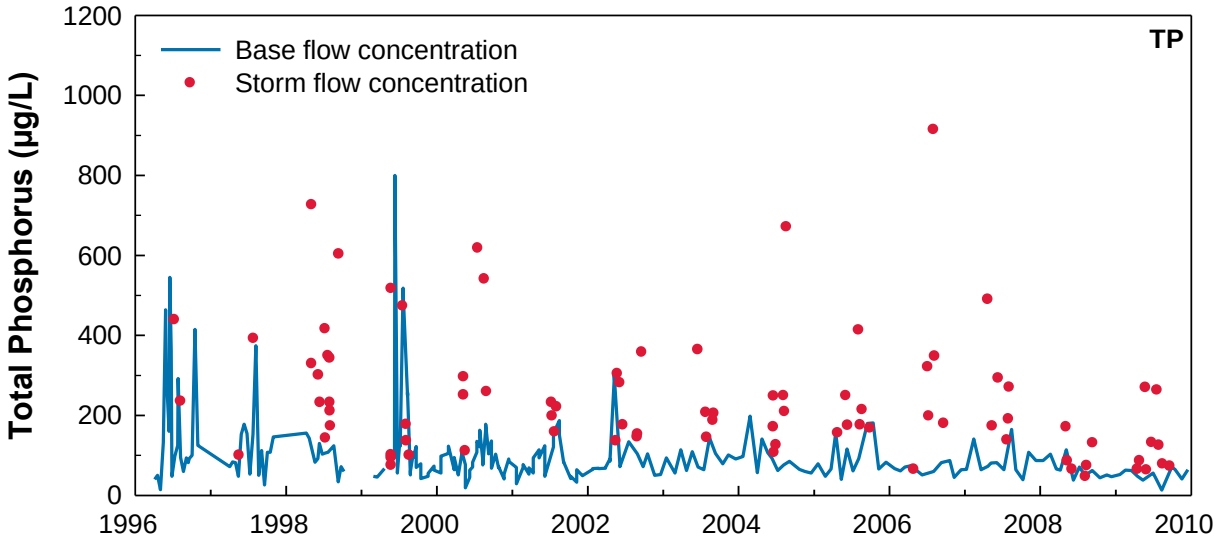

Figure 25: Base flow and storm flow total phosphorus concentrations measured in Site CT-2, 1996 to 2009.

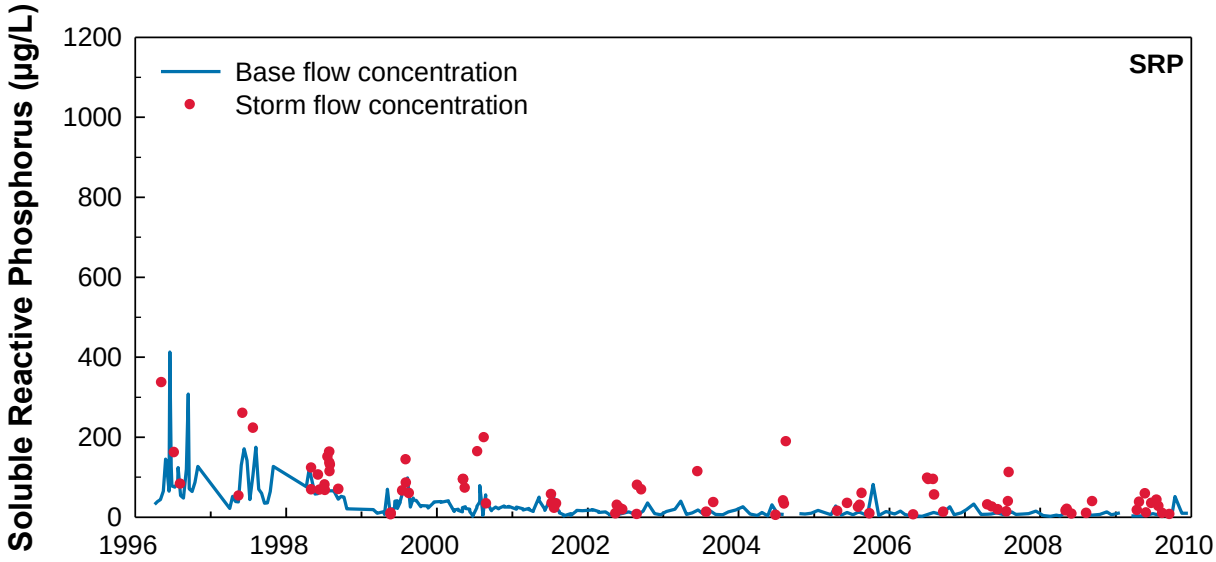

Figure 26: Base flow and storm flow soluble reactive phosphorus concentrations measured in Site CT-2, 1996 to 2009.

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 2009). 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 2009) at Site MW-9 (Figure 27).

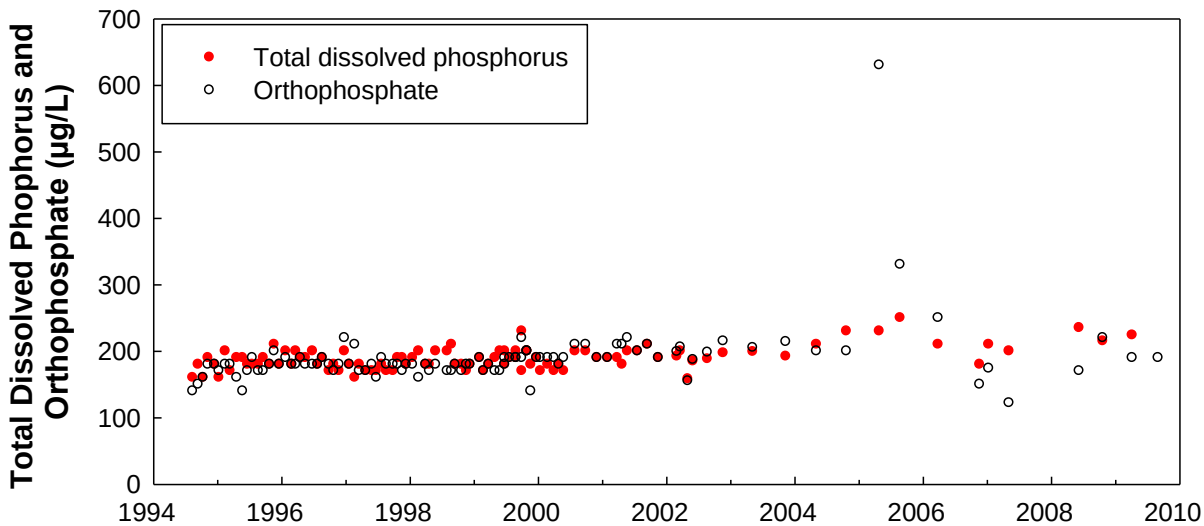

Figure 27: Total dissolved phosphorus and soluble reactive phosphorus concentrations measured at Site MW-9 (1994 to 2009).

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 1,900 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.

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 percent) of the total phosphorus load to the Reservoir was from Cherry Creek mainstem flows (16,002 lbs). Because Cherry Creek is monitored downstream of Shop Creek, the 185 lbs (<1 percent) contributed by Shop Creek has been subtracted from the total load calculated for Site CC-10. Cottonwood Creek accounted for 6 percent of the phosphorus load, or 1,167 lbs. In 2009, the total phosphorus load to Cherry Creek Reservoir from tributary streams was 17,425 lbs and includes 70 lbs of ungaged residual phosphorus load (Table 9).

4.4.2 Phosphorus Export from Reservoir Outflow

The total outflow from Cherry Creek Reservoir as measured by the USACE was 26,124 ac-ft in 2009 (Appendix D). Monthly total phosphorus data collected from Site CC-O near the dam outlet was used to estimate the phosphorus export (9,935 lbs/yr) leaving the Reservoir in 2009 (Table 9).

Table 9: Normalized phosphorus loads and export (lbs/year) for Cherry Creek Reservoir, 1992 to 2009.

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	16,142	2,133	18,408	1,033	331	19,772	8,042	11,730
2008	6814	778	7,592	1,015	250	8,857	4,828	4,029
2009	16,187	1,167	17,425	1,033	480	18,938	9,935	9,003
Median	**5,676**	**1,220**	**7,539**	**1,033**	**387**	**8,916**	**3,533**	**4,352**

4.4.3 Phosphorus Load from Precipitation

In 2009, a total of 21.4 inches of precipitation was recorded at the KAPA meteorological station located at Centennial Airport. When scaled to the areal extent of the Reservoir (852 acres), precipitation accounted for a total of 1,522 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 2009 annual total phosphorus load of 480 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 2009 is 387 lbs (Table 9).

4.4.4 Phosphorus Load from Alluvium

In 2009, the alluvial inflow quantity was set as a constant 2,000 acre-feet per year (ac-ft/yr) with the rationale being summarized in 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 1,033 lbs in 2009 (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 2009, the USACE calculated inflow was 29,736 ac-ft/yr, while the GEI calculated stream inflow was 22,430 ac-ft/yr (Appendix D). To compare these two inflow values, the USACE inflow was adjusted for precipitation (1,522 ac-ft/yr) and alluvial inflows (2,000 ac-ft/yr), which resulted in an adjusted USACE inflow of 26,214 ac-ft/yr. The difference between the adjusted USACE inflow and the GEI stream inflow was 3,784 ac-ft of water. This water volume difference was reapportioned between Cherry Creek (75 percent), Cottonwood Creek (23 percent), and Ungaged Inflow (2 percent). Flow-weighted total phosphorus concentrations for Cherry Creek and Cottonwood Creek were used to calculate the combined reapportioned load of 2,204 lbs.

Following the water balance normalization process, flow from the two tributary streams accounted for a total phosphorus load of 17,169 lbs to the Reservoir in 2009 (Figure 28). The alluvial inflow contributed 1,033 lbs of phosphorus, with precipitation events contributing 480 lbs to the Reservoir. The total external load of phosphorus to the Reservoir in 2009 was 18,938 lbs (Figure 28).

The Reservoir outflow phosphorus load was estimated to be 9,935 lbs. The flow-weighted total phosphorus concentration for all external sources of inflow to the Reservoir is 234 µg/L and the flow-weighted export concentration for the Reservoir is 140 µg/L. The difference of 94 µg/L was retained by the Reservoir. The net external phosphorus load to the Reservoir was 9,003 lbs in 2009.

Table 10: Flow-weighted phosphorus concentrations (µg/L) for Cherry Creek Reservoir, 1992 to 2009.

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	277	159	246	114
2008	204	76	173	104
2009	292	75	234	140
Median	**256**	**142**	**206**	**94**

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 completion of the Cottonwood Reclamation Project and the 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 134 µg/L. This concentration was greatly reduced by the Cottonwood Creek Peoria Wetland System, and reduced further by time flows reached the Cottonwood Creek Perimeter Pond. The normalized flow-weighted concentration of 75 µg/L at Site CT-2 represents the lowest observed inflow concentration for Cottonwood Creek since 1992.

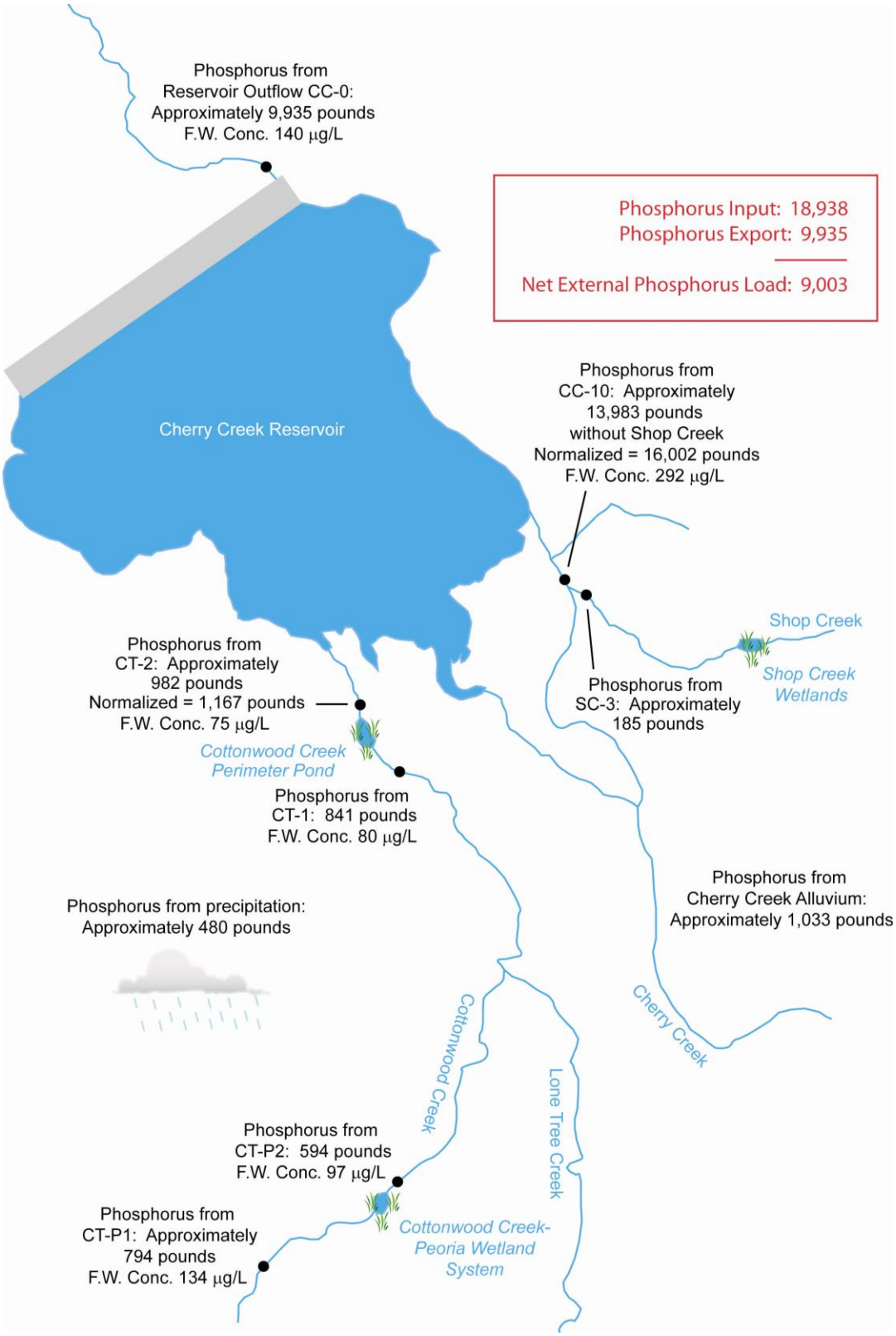

Figure 28: Mass balance diagram of phosphorus loading in Cherry Creek Reservoir, 2009.

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. From mid March to the first part of May, a cofferdam was placed on the stream and flows were rerouted to allow for the construction of the new drop structure immediately downstream of Site CT-P1. This project pooled the water at the ISCO which affected level monitoring during this period of construction.

Despite the maintenance and an expected increase in sediment transport downstream of Site CT-P1, both the suspended solids data and the flow-weighted phosphorus concentration showed a decrease downstream of the PRF (Table 11). The flow-weighted total phosphorus concentration upstream and downstream of the PRF was 134 µg/L and 97 µg/L, respectively, which indicates a high efficiency in removing phosphorus from flow.

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 2009.

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
	Mean	54	46	-8	-15
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	177	131	-46	-26
	2008*	116	86	-30	-26
	2009	134	97	-37	-28
	Mean	133	112	-22	-16

* Eight months of operation.

4.5.2 Cottonwood Creek Perimeter Pond

The effectiveness of the Cottonwood Creek storm water Perimeter Pond in reducing phosphorus loads to the Reservoir is similarly gaged by comparing data from sites upstream and downstream of the PRF (Table 12). In 2009, the mean concentration of TSS slightly decreased from 34 mg/L upstream to 32 mg/L downstream of the PRF (Table 12). The flow-weighted total phosphorus concentration also decreased downstream of the pond by 8 percent, with the concentration entering the Reservoir from Cottonwood Creek being 74 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 percent, 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 74 µg/L for the past two 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.

Table 12: Historical total phosphorus and total suspended solids concentrations and total phosphorus loads upstream and downstream of the Cottonwood Creek Perimeter Pond (1997-2009).

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
	Mean	130	71	-59	-45

Parameter	Year	Sampling Sites		Difference	Percent Change Downstream
		CT-1	CT-2		
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	216	158	-58	-27
	2008*	73	74	1	1
	2009	80	74	-6	-8
	Mean	190	132	-58	-30

* Nine months of operation.

5.0 References

Advanced Sciences, Inc. 1994a. *Cherry Creek Basin, Annual Water-Quality Monitoring Report, 1993 Water Year*. Project No. 8970. Prepared for the Cherry Creek Basin Water Quality Authority.

Advanced Sciences, Inc. 1994b. 1993 Cherry Creek Basin Water Quality Authority Contract: Project 8790. Exhibits A through H (amended).

AMEC, Earth and Environmental, Inc., Alex Horne Associates, and Hydrosphere Resource Consultants, Inc. 2005. *Cherry Creek Reservoir Destratification*. Feasibility report prepared for the Cherry Creek Basin Water Quality Authority.

American Public Health Association (APHA). 1998. *Standard Methods for the Examination of Water and Wastewater*, 20th Edition. Prepared and published jointly by the American Public Health Association, American Water Works Association, and Water Pollution Control Federation, Washington, DC.

Carpenter, S. R., J. F. Kitchell, and J. R. Hodgson. 1985. Cascading trophic interactions and lake productivity. *Bioscience* 35:634-639.

Chadwick Ecological Consultants, Inc.(CEC). 1995. *Cherry Creek Reservoir Annual Aquatic Biological and Nutrient Monitoring Study, 1994*. Prepared for the Cherry Creek Basin Water Quality Authority.

Chadwick Ecological Consultants, Inc. (CEC). 1996. *Cherry Creek Reservoir Annual Aquatic Biological and Nutrient Monitoring Study, 1995*. Prepared for the Cherry Creek Basin Water Quality Authority.

Chadwick Ecological Consultants, Inc. (CEC). 1997. *Cherry Creek Reservoir Annual Aquatic Biological and Nutrient Monitoring Study, 1996*. Prepared for the Cherry Creek Basin Water Quality Authority.

Chadwick Ecological Consultants, Inc. (CEC). 1998a. *Analysis of Phosphorus Loads to Cherry Creek Reservoir*. Prepared for the Cherry Creek Basin Water Quality Authority.

Chadwick Ecological Consultants, Inc. (CEC). 1998b. *Cherry Creek Reservoir Annual Aquatic Biological and Nutrient Monitoring Study, 1997*. Prepared for the Cherry Creek Basin Water Quality Authority.

Chadwick Ecological Consultants, Inc. (CEC). 1999. *Cherry Creek Reservoir 1998 Annual Aquatic Biological and Nutrient Monitoring Study*. Prepared for the Cherry Creek Basin Water Quality Authority.

Chadwick Ecological Consultants, Inc. (CEC). 2000. *Cherry Creek Reservoir 1999 Annual Aquatic Biological and Nutrient Monitoring Study*. Prepared for the Cherry Creek Basin Water Quality Authority.

Chadwick Ecological Consultants, Inc. (CEC). 2001. *Cherry Creek Reservoir 2000 Annual Aquatic Biological and Nutrient Monitoring Study*. Prepared for the Cherry Creek Basin Water Quality Authority.

Chadwick Ecological Consultants, Inc. (CEC). 2002. *Cherry Creek Reservoir 2001 Annual Aquatic Biological and Nutrient Monitoring Study*. Prepared for the Cherry Creek Basin Water Quality Authority.

Chadwick Ecological Consultants, Inc. (CEC). 2003a. *Cherry Creek Reservoir 2002 Annual Aquatic Biological and Nutrient Monitoring Study and Cottonwood Creek Phosphorus Reduction Facility Monitoring*. Prepared for the Cherry Creek Basin Water Quality Authority.

Chadwick Ecological Consultants, Inc. (CEC). 2004. *Cherry Creek Reservoir 2003 Annual Aquatic Biological and Nutrient Monitoring Study and Cottonwood Creek Phosphorus Reduction Facility Monitoring*. Prepared for the Cherry Creek Basin Water Quality Authority.

Chadwick Ecological Consultants, Inc. (CEC). 2005. *Cherry Creek Reservoir 2004 Annual Aquatic Biological and Nutrient Monitoring Study and Cottonwood Creek Phosphorus Reduction Facility Monitoring*. Prepared for the Cherry Creek Basin Water Quality Authority.

Chadwick Ecological Consultants, Inc. (CEC). 2006. *Cherry Creek Reservoir 2005 Annual Aquatic Biological and Nutrient Monitoring Study and Cottonwood Creek Phosphorus Reduction Facility Monitoring*. Prepared for the Cherry Creek Basin Water Quality Authority.

Cole, G. A. 1979. *Textbook of Limnology*, 2nd Edition. The C.V. Mosby Company, St. Louis, MO.

Colorado Department of Public Health and Environment (CDPHE). 2007. *The Basic Standards and Methodologies for Surface Water* (5 CCR 1002-31). Regulation No. 31. Water Quality Control Division, Denver, CO.

Cooke, D. C., E. B. Welch, S. A. Peterson, and P.R. Newroth. 1993. *Restoration & Management of Lakes & Reservoirs*, 2nd Edition. Lewis Publishers, Boca Raton, FL.

Denver Regional Council of Governments (DRCOG). 1984. *Cherry Creek Reservoir Clean Lakes Study*. Denver Regional Council of Governments, Denver, CO.

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

GEI Consultants, Inc. (GEI). 2007. *Cherry Creek Reservoir 2006 Annual Aquatic Biological and Nutrient Monitoring Study and Cottonwood Creek Phosphorus Reduction Facility Monitoring*. Prepared for the Cherry Creek Basin Water Quality Authority.

GEI Consultants, Inc. (GEI). 2008a. *Cherry Creek Reservoir Aquatic Biological and Nutrient Sampling and Laboratory Analyses, Sampling, Analysis, and Quality Assurance Work Plan. April 2008.* Prepared for the Cherry Creek Basin Water Quality Authority.

GEI Consultants, Inc. (GEI). 2008b. *Cherry Creek Reservoir 2006 Annual Aquatic Biological and Nutrient Monitoring Study and Cottonwood Creek Phosphorus Reduction Facility Monitoring*. Prepared for the Cherry Creek Basin Water Quality Authority.

Horne, A. J. and C. R. Goldman. 1994. *Limnology*. McGraw-Hill Company, NY.

Hintze, J. L. 2001. NCSS and PASS. Number Cruncher Statistical Systems, Kaysville, UT.

In-Situ, Inc. 1986 (as amended). *Cherry Creek Reservoir and Cherry Creek Basin Monitoring Program, Southeastern Denver Metropolitan Area, Colorado: Proposal No. 4405*. Prepared for the Cherry Creek Basin Authority, December 3 (with later modifications).

John C. Halepaska & Associates, Inc. (JCHA). 1999. *1998 Annual Report, Phase I Baseline Water Quality Data Collection Study for the Upper Cherry Creek Basin*. Prepared for the Cherry Creek Basin Water Quality Authority, Project No. 5601:6.

John C. Halepaska & Associates, Inc. (JCHA). 2000. *1999 Annual Report, Phase I Baseline Water Quality Data Collection Study for the Upper Cherry Creek Basin*. Prepared for the Cherry Creek Basin Water Quality Authority.

John C. Halepaska & Associates, Inc. (JCHA). 2001. *2000 Annual Report, Baseline Water Quality Data Collection Study for the Upper Cherry Creek Basin*. Prepared for the Cherry Creek Basin Water Quality Authority.

John C. Halepaska & Associates, Inc. (JCHA). 2002. *2001 Annual Report, Baseline Water Quality Data Collection Study for the Upper Cherry Creek Basin*. Prepared for the Cherry Creek Basin Water Quality Authority.

John C. Halepaska & Associates, Inc. (JCHA). 2003. *2002 Annual Report, Baseline Water Quality Data Collection Study for the Upper Cherry Creek Basin*. Prepared for the Cherry Creek Basin Water Quality Authority.

John C. Halepaska & Associates, Inc. (JCHA). 2004. *2003 Annual Report, Baseline Water Quality Data Collection Study for the Upper Cherry Creek Basin*. Prepared for the Cherry Creek Basin Water Quality Authority.

John C. Halepaska & Associates, Inc. (JCHA). 2005. *2004 Annual Report, Baseline Water Quality Data Collection Study for the Upper Cherry Creek Basin*. Prepared for the Cherry Creek Basin Water Quality Authority.

John C. Halepaska & Associates, Inc. (JCHA). 2006. *2005 Annual Report, Baseline Water Quality Data Collection Study for the Upper Cherry Creek Basin*. Prepared for the Cherry Creek Basin Water Quality Authority.

John C. Halepaska & Associates, Inc. (JCHA). 2007. *2006 Annual Report, Baseline Water Quality Data Collection Study for the Upper Cherry Creek Basin*. Prepared for the Cherry Creek Basin Water Quality Authority.

John C. Halepaska & Associates, Inc. (JCHA). 2008. *2007 Annual Report, Baseline Water Quality Data Collection Study for the Upper Cherry Creek Basin*. Prepared for the Cherry Creek Basin Water Quality Authority.

John C. Halepaska & Associates, Inc. (JCHA). 2009. *2008 Annual Report, Baseline Water Quality Data Collection Study for the Upper Cherry Creek Basin*. Prepared for the Cherry Creek Basin Water Quality Authority.

Jones, J. R. 1994. *Report on Cherry Creek Reservoir, Summer 1993*. Report to Cherry Creek Basin Water Quality Authority.

Jones, J. R. 1995. *Report on Cherry Creek Reservoir, Summer 1994*. Report to Cherry Creek Basin Water Quality Authority.

Jones, J. R. 1996. *Report on Cherry Creek Reservoir, 1995 Sampling Season*. Report to Cherry Creek Basin Water Quality Authority.

Jones, J. R. 1997. *Report on Cherry Creek Reservoir, 1996 Sampling Season*. Report to Cherry Creek Basin Water Quality Authority.

Jones, J. R. 1998. *Report on Cherry Creek Reservoir, 1997 Sampling Season*. Report to Cherry Creek Basin Water Quality Authority.

Jones, J. R. 1999. *Report on Cherry Creek Reservoir, 1998 Sampling Season*. Report to Cherry Creek Basin Water Quality Authority.

Jones, J. R. 2001. *Report on Cherry Creek Reservoir, 1992-2001 and Historical Data*. Report to Cherry Creek Basin Water Quality Authority.

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

Lewis, W. M., and J. F. Saunders. 2002. *Review and Analysis of Hydrologic Information on cherry Creek Watershed and Cherry Creek Reservoir*. Prepared for the Cherry Creek Basin Water Quality Authority.

Lewis, W. M., J. F. Saunders, and J. H. McCutchan. 2004. *Studies of Phytoplankton Response to Nutrient Enrichment in Cherry Creek Reservoir, Colorado.* Prepared for Colorado Department of Public Health and Environment, Water Quality Control Division.

Lewis, W. M., J. H. McCutchan, and J. F. Saunders. 2005. *Estimation of Groundwater Flow into Cherry Creek Reservoir and its Relationship to the Phosphorous Budget of the Reservoir*. Prepared for the Cherry Creek Basin Water Quality Authority.

Nürnberg, G., and LaZerte, B. 2008. *Cherry Creek Reservoir Model and Proposed Chlorophyll Standard*. Prepared for the Cherry Creek Basin Water Quality Authority.

SPSS, 2006. SPSS 15.0 for Windows. Release 15.0.0 (6 Sep 2006).

Vanni, M. J., and C. D. Layne. 1996. Nutrient recycling and herbivory as mechanisms in the top-down effect of fish on algae in lakes. *Ecology* 78:21-40.

Vanni, M. J., C. D. Layne, and S. E. Arnott. 1996. Top-down trophic interactions in lakes: effects of fish on nutrient dynamics. *Ecology* 78:1-20.

Wetzel, R. G. 2001. *Limnology*, 3rd Edition. Academic Press, San Diego, CA.

Appendix A

Cherry Creek Reservoir Sampling and Analysis Plan

GEI Consultants

Geotechnical
Water Resources
Environmental and
Ecological Services

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

Submitted to:
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April 2008
Project 062450

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1.0 Introduction

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

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

2.0 Project Description

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

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

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

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

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

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

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

3.0 Project Organization and Responsibilities

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

3.1 Project Manager

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

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

3.2 Quality Assurance Manager

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

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

3.3 Analytical and Biological Laboratory Managers

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

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

3.4 Sampling Crew

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

4.0 Aquatic Biological and Nutrient Sampling

4.1 Reservoir Monitoring Sites

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

4.1.1 Cherry Creek Reservoir

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

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

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

4.2 Stream Monitoring Sites

4.2.1 Cherry Creek

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

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

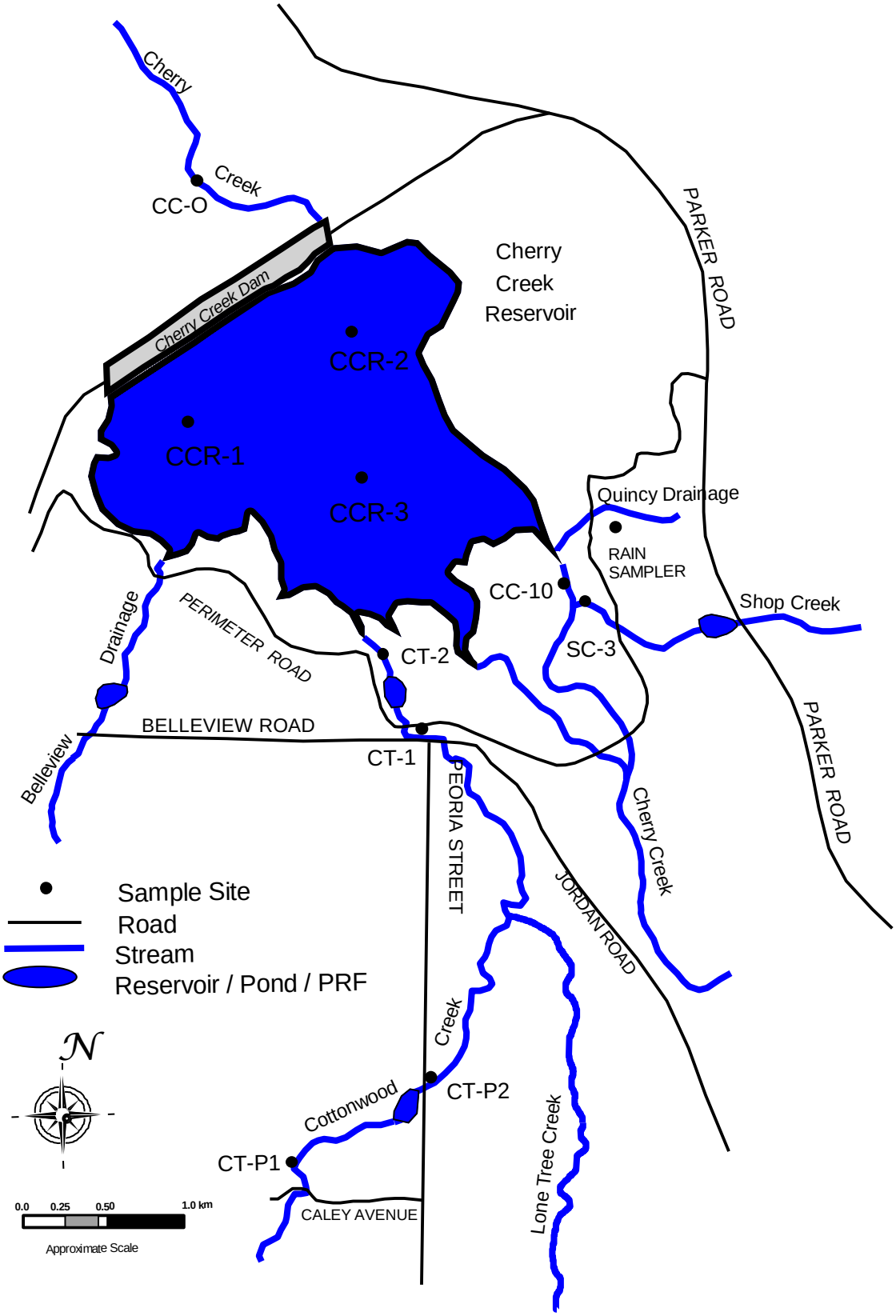


Figure 1: Sampling sites on Cherry Creek Reservoir and selected streams.

4.2.2 Cottonwood Creek

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

4.3 PRF Monitoring Sites

4.3.1 Shop Creek

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

4.3.2 Cottonwood Creek

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

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

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

4.3.3 Precipitation Sampling Site

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

4.4 Analyte List

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

Table 1: Standard methods for sample analysis.

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

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

4.5 Sampling Schedule

4.5.1 Reservoir Sampling

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

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

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

4.5.2 PRF Sampling

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

Table 3: PRF sampling.

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

4.5.3 Storm Flow Sampling

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

4.5.4 Precipitation Sampling

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

4.6 Field Methodologies

4.6.1 Reservoir Sampling

4.6.1.1 Transparency

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

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

4.6.1.2 Depth Profile Measurements

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

4.6.1.3 Continuous Temperature Monitoring

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

The temperature arrays would be deployed using the State Park's buoy system, beginning in March/April and operated through October, with periodic downloading of data to minimize

potential loss of data. This deployment schedule would overlap with the proposed operational schedule of the destratification system.

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

4.6.1.4 Water Samples

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

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

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

Table 4: Number of reservoir samples collected.

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

4.6.2 Water Quality Analyses

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

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

4.7 Stream Sampling

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

4.7.1 Automatic Sampler

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

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

The USACE also reports daily inflow to Cherry Creek Reservoir as a function of storage, based on changes in reservoir level. This daily inflow value incorporates information regarding measured outflow, precipitation, and evaporation. GEI monitors inflow to the Reservoir using gaging stations on Cherry Creek, Cottonwood Creek, and Shop Creek (the three main surface inflows) to provide a daily surface inflow record. Given the differences in

the two methods for determining inflow, combined with the potential of unmonitored alluvial and surface flows that may result in greater seepage through the adjacent wetlands during storm events, and other unmonitored surface inflows (i.e., Belleview and Quincy drainages) an exact match between USACE and GEI calculated inflows is not expected. Therefore, GEI normalizes their streamflow data to match the USACE computed inflow value.

4.7.2 Storm Event Sampling

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

4.8 Precipitation Sampling

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

5.0 Laboratory Procedures

5.1 Chemical Laboratory Analysis

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

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

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

5.2 Biological Laboratory Analysis

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

5.3 Laboratory Quality Assurance/Quality Control Protocols

Analytical equipment calibrations are performed every time new standards are prepared (minimum of once per week). Instrument values are compared to known standard concentration and if the correlation coefficient of the standard curve is less than 0.999, the instrument is recalibrated or standards are remade, with the process being completed until the instrument passes the test. Pseudo-replicate analyses are performed on each sample analyzed (i.e., sample analyzed twice) and the percent difference must be within 10 percent, if the resultant concentration is above the minimum detection limit. If the difference of the

pseudo-replicate analyses are >10 percent, a new analytical sample is placed in a clean test tube and analyzed. During a sample analysis run, check standards are analyzed between every 5 samples (or 10 replicates). The check standards consist of one high range standard, one mid range standard, and the control blank (zero). Check standards analyzed before and after each group of samples must be within 10 percent of the theoretical value. If standards are outside of this range, new analytical samples and standards are placed in clean test tubes and analyzed to try to determine the source of the error. Sample values are not accepted until the problem has been resolved and all check standards pass the QC criteria. One matrix spike is run for every 10 samples analyzed (or 20 replicates). The percent recovery for matrix spikes must be ± 20 percent.

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

6.0 Data Verification, Reduction, and Reporting

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

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

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

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

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

7.0 References

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

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

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

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

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

Appendix B

2009 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)**
2/17/2009	CCR-1 Photic	77	17	6	1,179	690	2	25	10
3/17/2009	CCR-1 Photic	53	11	5	992	498		25	6
4/21/2009	CCR-1 Photic	93	16	13	928	485	12	10	17
5/12/2009	CCR-1 Photic	80	45	39	758	532	29	71	4
5/29/2009	CCR-1 Photic	68	10	2	877	509		26	17
6/16/2009	CCR-1 Photic	62	29	21	612	427		22	13
7/1/2009	CCR-1 Photic	85	39	30	888	736		17	9
7/14/2009	CCR-1 Photic	140	117	97	770	600	9	123	0
7/28/2009	CCR-1 Photic	135	99	77	604	464		17	12
8/11/2009	CCR-1 Photic	98	49	35	707	460		17	10
8/26/2009	CCR-1 Photic	92	37	24	763	460		9	15
9/15/2009	CCR-1 Photic	56	17	14	681	504	9	20	13
9/29/2009	CCR-1 Photic	63	13	6	801	478		13	21
10/14/2009	CCR-1 Photic	66	22	5	736	494		12	21
11/17/2009	CCR-1 Photic	50	15	6	789	360		16	20

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)**
2/17/2009	CCR-2 Photic	79	15	9	916	470	56	5	10
3/17/2009	CCR-2 Photic	76	13	5	795	402		9	4
3/17/2009	CCR-2 4m	81	12	6	837	401		9	
3/17/2009	CCR-2 5m	78	13	5	796	476		6	
3/17/2009	CCR-2 6m	80	14	5	830	405		7	
3/17/2009	CCR-2 7m	78	19	7	805	430		19	
4/21/2009	CCR-2 Photic	129	38	30	887	494	42	5	20
4/21/2009	CCR-2 4m	87	19	14	746	402	9	4	
4/21/2009	CCR-2 5m	77	16	9	740	451		13	
4/21/2009	CCR-2 6m	67	15	11	728	538	3	15	
4/21/2009	CCR-2 7m	71	13	9	730	405	5	12	
5/12/2009	CCR-2 Photic	69	49	37	691	511	33	56	6
5/12/2009	CCR-2 4m	76	44	38	628	496	33	54	
5/12/2009	CCR-2 5m	69	50	40	625	489	34	66	
5/29/2009	CCR-2 Photic	68	14	2	697	494		32	17
5/29/2009	CCR-2 4m	75	15	3	766	427		32	
5/29/2009	CCR-2 5m	75	18	4	536	446		26	
5/29/2009	CCR-2 6m	77	13	2	777	445		28	
5/29/2009	CCR-2 7m	87	11	4	776	458		19	
6/16/2009	CCR-2 Photic	53	27	20	537	398		17	10
6/16/2009	CCR-2 4m	55	28	20	512	374		13	
6/16/2009	CCR-2 5m	57	29	20	541	419		18	
6/16/2009	CCR-2 6m	58	28	21	505	382		13	
6/16/2009	CCR-2 7m	60	27	21	539	401		22	
7/1/2009	CCR-2 Photic	90	41	32	918	555		18	12
7/1/2009	CCR-2 4m	89	39	33	757	495	2	18	
7/1/2009	CCR-2 5m	96	39	34	777	483	3	16	
7/1/2009	CCR-2 6m	134	69	61	882	546	32	70	
7/1/2009	CCR-2 7m	230	160	118	1,057	772	43	311	
7/14/2009	CCR-2 Photic	140	109	93	791	614	20	120	1
7/14/2009	CCR-2 4m	132	89	93	718	538	56	118	
7/14/2009	CCR-2 5m	140	110	93	763	561	20	127	

CCR-2 GEI Water Chemistry Data									
Analytical Detection Limits		2	2	2	2	2	2	3	0.1
Sample Date	**Sample Name/ Location**	**Total Phosphorous µg/L**	**Total Dissolved Phosphorous µg/L**	**Ortho-phosphate µg/L**	**Total Nitrogen µg/L**	**Total Dissolved Nitrogen µg/L**	**Nitrate+ Nitrite µg/L**	**Ammonia µg/L**	**Average Chlorophyll *a* (mg/m^3)**
7/14/2009	CCR-2 6m	138	108	93	705	544	20	121	
7/14/2009	CCR-2 7m	196	138	123	940	681	16	221	
7/28/2009	CCR-2 Photic	116	78	65	616	422	2	11	11
7/28/2009	CCR-2 4m	124	84	70	608	465	2	38	
7/28/2009	CCR-2 5m	129	90	73	664	498	3	65	
7/28/2009	CCR-2 6m	148	86	78	758	525	12	84	
7/28/2009	CCR-2 7m	220	118	110	962	614	128	81	
8/11/2009	CCR-2 Photic	97	50	37	928	574		25	14
8/11/2009	CCR-2 4m	96	48	37	637	639		12	
8/11/2009	CCR-2 5m	101	52	40	1,201	420		11	
8/11/2009	CCR-2 6m	104	55	47	608	397		18	
8/11/2009	CCR-2 7m	190	80	71	784	601	6	91	
8/26/2009	CCR-2 Photic	106	38	23	781	438		16	20
8/26/2009	CCR-2 4m	87	40	27	676	427		10	
8/26/2009	CCR-2 5m	88	40	26	704	429		19	
8/26/2009	CCR-2 6m	133	56	43	769	484	58	20	
8/26/2009	CCR-2 7m	190	78	65	911	497	69	40	
9/15/2009	CCR-2 Photic	54	13	13	719	526	4	27	10
9/15/2009	CCR-2 4m	54	15	16	651	496	5	26	
9/15/2009	CCR-2 5m	57	19	18	650	473	8	33	
9/15/2009	CCR-2 6m	75	29	25	739	512	33	70	
9/15/2009	CCR-2 7m	105	28	28	868	562	28	113	
9/29/2009	CCR-2 Photic	56	18	6	927	463		7	25
9/29/2009	CCR-2 4m	61	18	10	750	463	11	29	
9/29/2009	CCR-2 5m	55	9	10	722	464	14	29	
9/29/2009	CCR-2 6m	66	13	12	649	469	20	40	
9/29/2009	CCR-2 7m	80	26	28	791	564	74	96	
10/14/2009	CCR-2 Photic	55	19	6	728	466		12	15
10/14/2009	CCR-2 4m	61	19	6	694	480		9	
10/14/2009	CCR-2 5m	57	18	6	718	450		7	
10/14/2009	CCR-2 6m	59	18	7	750	496		10	
10/14/2009	CCR-2 7m	60	20	7	725	446		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)**
11/17/2009	CCR-2 Photic	59	17	6	681	346		14	22
11/17/2009	CCR-2 4m	53	14	5	672	325		7	
11/17/2009	CCR-2 5m	54	15	6	690	343		6	
11/17/2009	CCR-2 6m	53	19	5	709	335		28	
11/17/2009	CCR-2 7m	59	17	7	688	367	3	17	

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)**
2/17/2009	CCR-3 Photic	66	10	6	823	443		6	11
3/17/2009	CCR-3 Photic	23	10	5	889	397		8	4
4/21/2009	CCR-3 Photic	141	47	44	904	529	75	7	15
5/12/2009	CCR-3 Photic	78	52	46	760	550	50	76	5
5/29/2009	CCR-3 Photic	28	15	4	795	449		42	18
6/16/2009	CCR-3 Photic	63	31	19	707	414		24	13
7/1/2009	CCR-3 Photic	97	33	27	925	539		24	11
7/14/2009	CCR-3 Photic	178	114	97	1,133	835	13	151	2
7/28/2009	CCR-3 Photic	138	78	64	779	496		13	16
8/11/2009	CCR-3 Photic	90	48	35	696	500	2	18	10
8/26/2009	CCR-3 Photic	105	36	20	879	521		21	18
9/15/2009	CCR-3 Photic	54	16	12	705	467		38	16
9/29/2009	CCR-3 Photic	71	18	7	1,198	749	4	26	31
10/14/2009	CCR-3 Photic	65	17	4	728	442		7	19
11/17/2009	CCR-3 Photic	67	20	6	775	373	2	28	24

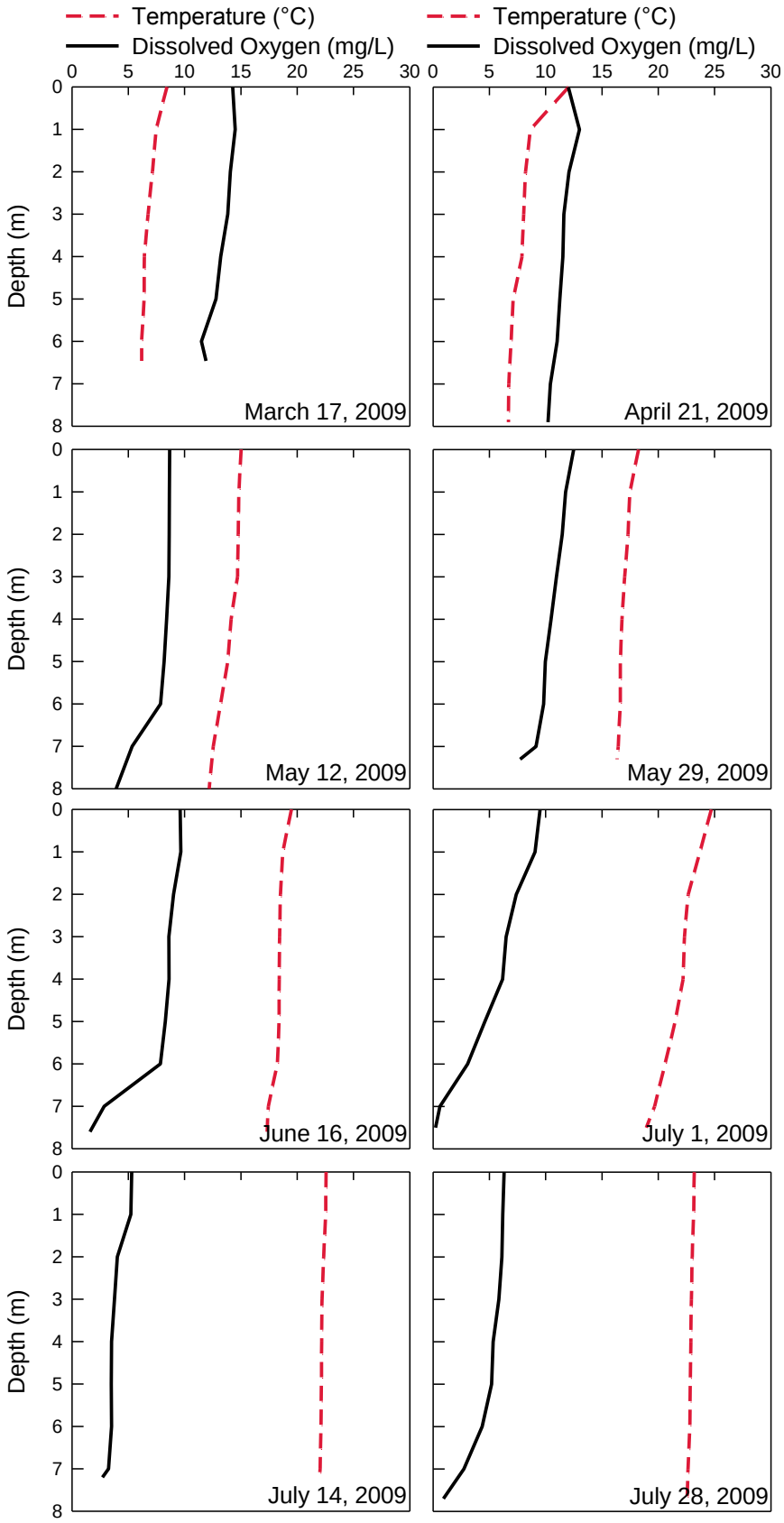
Site CCR-1 Small Tables

Sample Date	Depth	Temperature	Conductivity	Dissolved Oxygen	pH	ORP	1% Transmittance	Secchi Disk
2/17/2009	0	3.42	611		8.09			
	1	3.19	612		8.07			
	2	3.21	612		8.01			
	3	3.21	610		7.97			
	4	3.21	616		7.97			
	5	3.21	611		7.94			
	6	3.21	612		7.96			
	7	3.22	614		7.94			
	7.3	--	--		--			
	--						--	1.25
3/17/2009	0	8.44	686	14.27	7.71	35.8		
	1	7.48	668	14.50	7.71	36.8		
	2	7.14	662	14.06	7.72	33.7		
	3	6.76	656	13.83	7.70	33.4		
	4	6.43	650	13.21	7.69	33.8		
	5	6.41	664	12.78	7.70	32.8		
	6	6.19	649	11.49	7.79	62.5		
	6.46	6.19	642	11.90	7.75	--		
	--						3.27	0.80
4/21/2009	0	12.04	669	12.01	7.64	159.6		
	1	8.64	623	12.99	7.49	164.6		
	2	8.21	614	12.06	7.36	168.7		
	3	8.05	610	11.61	7.34	168.0		
	4	7.89	606	11.53	7.34	166.4		
	5	7.12	605	11.26	7.31	166.1		
	6	6.93	602	11.02	7.31	164.5		
	7	6.73	600	10.42	7.27	164.0		
	7.9	6.69	599	10.20	7.33	147.4		
	--						2.35	0.47
5/12/2009	0	15.02	750	8.67	7.79	287.0		
	1	14.83	752	8.64	7.75	281.3		
	2	14.77	751	8.63	7.77	276.0		
	3	14.70	750	8.60	7.80	269.9		
	4	14.13	739	8.41	7.87	263.3		
	5	13.83	736	8.18	7.80	265.2		
	6	13.21	722	7.86	7.83	268.9		
	7	12.54	712	5.35	7.77	255.7		
	8	12.18	708	3.92	7.64	100.7		
	--						5.98	3.09
5/29/2009	0	18.24	763	12.48	8.83	162.7		
	1	17.48	753	11.77	8.82	167.8		
	2	17.32	750	11.47	8.80	170.4		
	3	17.02	744	10.95	8.77	173.2		
	4	16.78	741	10.48	8.73	176.2		
	5	16.64	740	9.97	8.71	177.4		
	6	16.62	740	9.81	8.69	178.6		
	7	16.44	738	9.14	8.34	57.0		
	7.3	16.34	727	7.73	7.82	-78.7		
	--						3.79	1.31

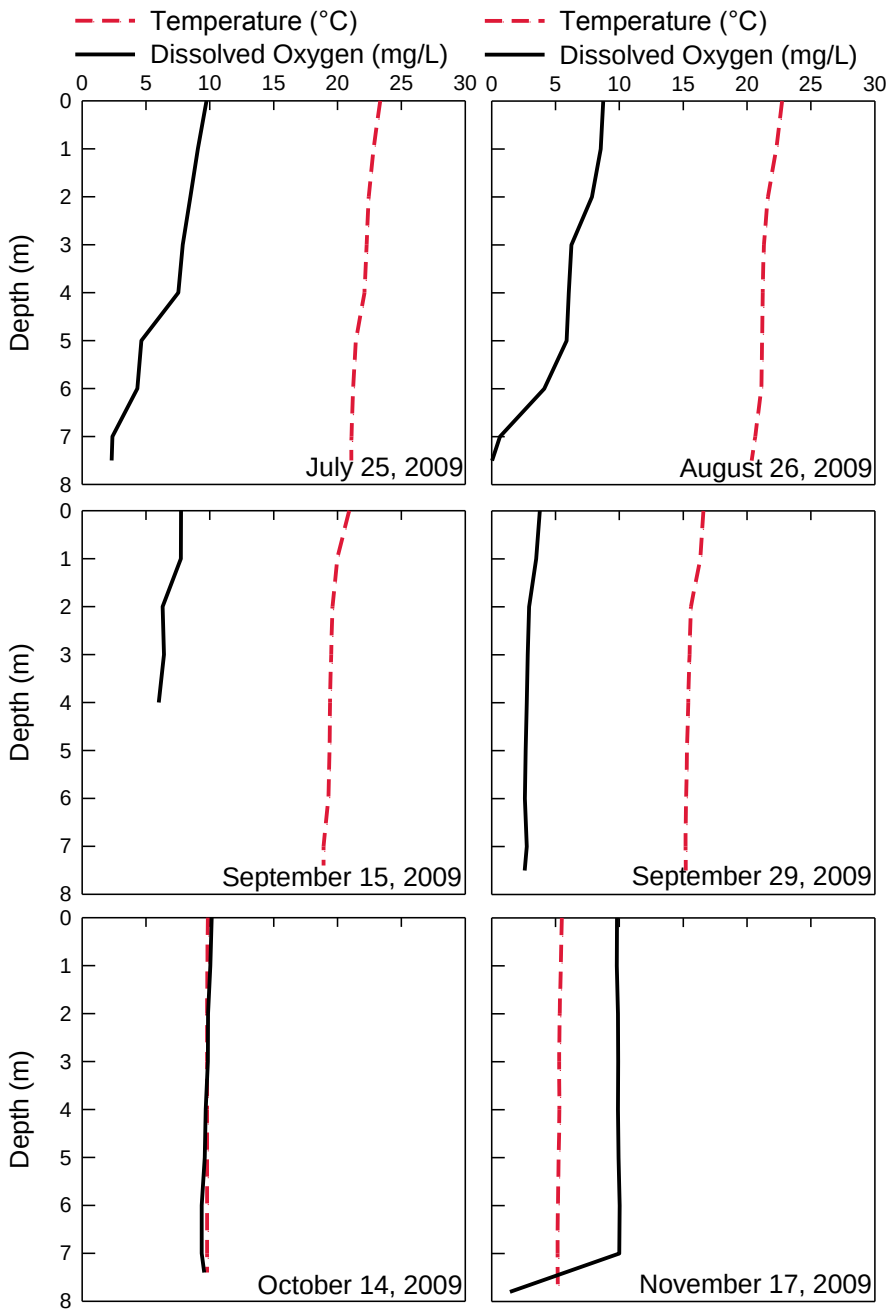
Sample Date	Depth	Temperature	Conductivity	Dissolved Oxygen	pH	ORP	1% Transmittance	Secchi Disk
6/16/2009	0	19.49	762	9.61	8.68	88.8		
	1	18.73	748	9.67	8.73	81.6		
	2	18.51	746	9.02	8.68	78.2		
	3	18.44	745	8.60	8.65	76.9		
	4	18.41	744	8.61	8.66	74.5		
	5	18.39	744	8.28	8.63	75.2		
	6	18.25	741	7.85	8.60	74.9		
	7	17.44	723	2.85	8.15	74.0		
	7.6	17.33	722	1.60	8.10	39.0		
	--						3.45	1.40
7/1/2009	0	24.71	861	9.50	8.58	246.5		
	1	23.71	860	9.05	8.55	251.5		
	2	22.65	861	7.39	8.41	255.4		
	3	22.33	862	6.49	8.33	257.9		
	4	22.20	862	6.17	8.29	258.9		
	5	21.50	862	4.59	8.10	259.9		
	6	20.60	863	3.07	7.93	260.7		
	7	19.67	843	0.61	7.74	261.1		
	7.5	18.94	841	0.21	7.62	61.3		
	--						3.90	1.04
7/14/2009	0	22.56	794	5.30	8.11	116.0		
	1	22.54	794	5.22	8.13	116.9		
	2	22.35	792	4.02	8.09	117.5		
	3	22.21	790	3.77	8.08	116.1		
	4	22.18	790	3.51	8.05	115.3		
	5	22.16	790	3.48	8.04	115.4		
	6	22.12	790	3.52	8.03	115.1		
	7	22.04	789	3.24	8.03	113.6		
	7.2	21.96	788	2.70	7.62	-145.8		
	--						3.80	1.60
7/28/2009	0	23.19	848	6.30	8.97	-313.0		
	1	23.15	848	6.18	8.98	-317.0		
	2	23.02	847	6.11	8.96	-317.0		
	3	22.94	847	5.84	8.94	-319.0		
	4	22.89	847	5.33	8.88	-318.0		
	5	22.85	847	5.20	8.90	-319.0		
	6	22.80	848	4.36	8.80	-318.0		
	7	22.64	852	2.74	8.64	-316.0		
	7.7	22.57	853	0.92	7.86	-574.0		
	--						3.92	1.52
8/11/2009	0	23.34	816	9.74	8.48	113.4		
	1	22.84	807	9.07	8.48	114.9		
	2	22.44	801	8.48	8.42	116.2		
	3	22.28	799	7.88	8.40	115.5		
	4	22.12	797	7.54	8.36	115.1		
	5	21.44	791	4.64	8.11	113.6		
	6	21.23	789	4.33	8.06	113.5		
	7	21.09	788	2.37	7.90	111.1		

Sample Date	Depth	Temperature	Conductivity	Dissolved Oxygen	pH	ORP	1% Transmittance	Secchi Disk
8/26/2009	0	22.74	801	8.73	8.69	72.4		
	1	22.30	796	8.54	8.65	48.5		
	2	21.63	783	7.85	8.62	36.3		
	3	21.32	781	6.24	8.48	30.0		
	4	21.23	778	6.03	8.45	21.9		
	5	21.18	778	5.87	8.43	19.2		
	6	21.12	780	4.11	8.22	18.0		
	7	20.65	775	0.65	7.81	11.0		
	7.5	20.36	773	0.03	7.62	-140.8		
	--						2.90	0.98
9/15/2009	0	20.92	917	7.75	8.47	378.0		
	1	19.99	915	7.73	8.52	378.0		
	2	19.61	916	6.31	8.40	382.0		
	3	19.50	916	6.41	8.37	383.0		
	4	19.41	917	6.01	8.35	385.0		
	5	19.39	916	--	8.35	385.0		
	6	19.30	916	--	8.36	385.0		
	7	18.90	919	--	8.17	389.0		
	7.4	18.90	919	--	8.16	321.0		
	--						3.10	0.97
9/29/2009	0	16.58	915	3.77	8.49	432.0		
	1	16.34	914	3.48	8.54	430.0		
	2	15.61	914	2.93	8.44	432.0		
	3	15.50	916	2.83	8.35	430.0		
	4	15.40	918	2.75	8.32	434.0		
	5	15.31	919	2.66	8.15	439.0		
	6	15.23	918	2.60	8.10	440.0		
	7	15.19	920	2.75	8.04	442.0		
	7.5	15.21	922	2.59	7.94	221.0		
	--						3.03	0.95
10/14/2009	0	9.84	877	10.15	7.38	201.9		
	1	9.81	876	10.04	7.32	202.6		
	2	9.79	876	9.86	7.23	203.4		
	3	9.79	876	9.84	7.23	202.2		
	4	9.79	876	9.68	7.21	201.4		
	5	9.78	877	9.60	7.22	198.5		
	6	9.78	877	9.37	7.24	196.0		
	7	9.79	877	9.37	7.28	193.5		
	7.4	9.80	876	9.56	7.25	190.6		
	--						3.55	1.05
11/17/2009	0	5.49	904	9.82	8.15	323.0		
	1	5.42	903	9.80	8.15	325.0		
	2	5.33	903	9.89	8.16	328.0		
	3	5.28	903	9.91	8.18	330.0		
	4	5.31	903	9.89	8.18	333.0		
	5	5.26	903	9.93	8.19	335.0		
	6	5.19	903	10.03	8.24	339.0		
	7	5.17	902	10.00	8.23	341.0		
	7.8	5.19	902	1.43	8.18	331.0		
	--						3.60	1.13

CCR-1


Temperature (°C)
Dissolved Oxygen (mg/L)
Depth (m)
March 17, 2009
April 21, 2009
May 12, 2009
May 29, 2009
June 16, 2009
July 1, 2009
July 14, 2009
July 28, 2009

CCR-1


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 25, 2009
August 26, 2009
September 15, 2009
September 29, 2009
October 14, 2009
November 17, 2009

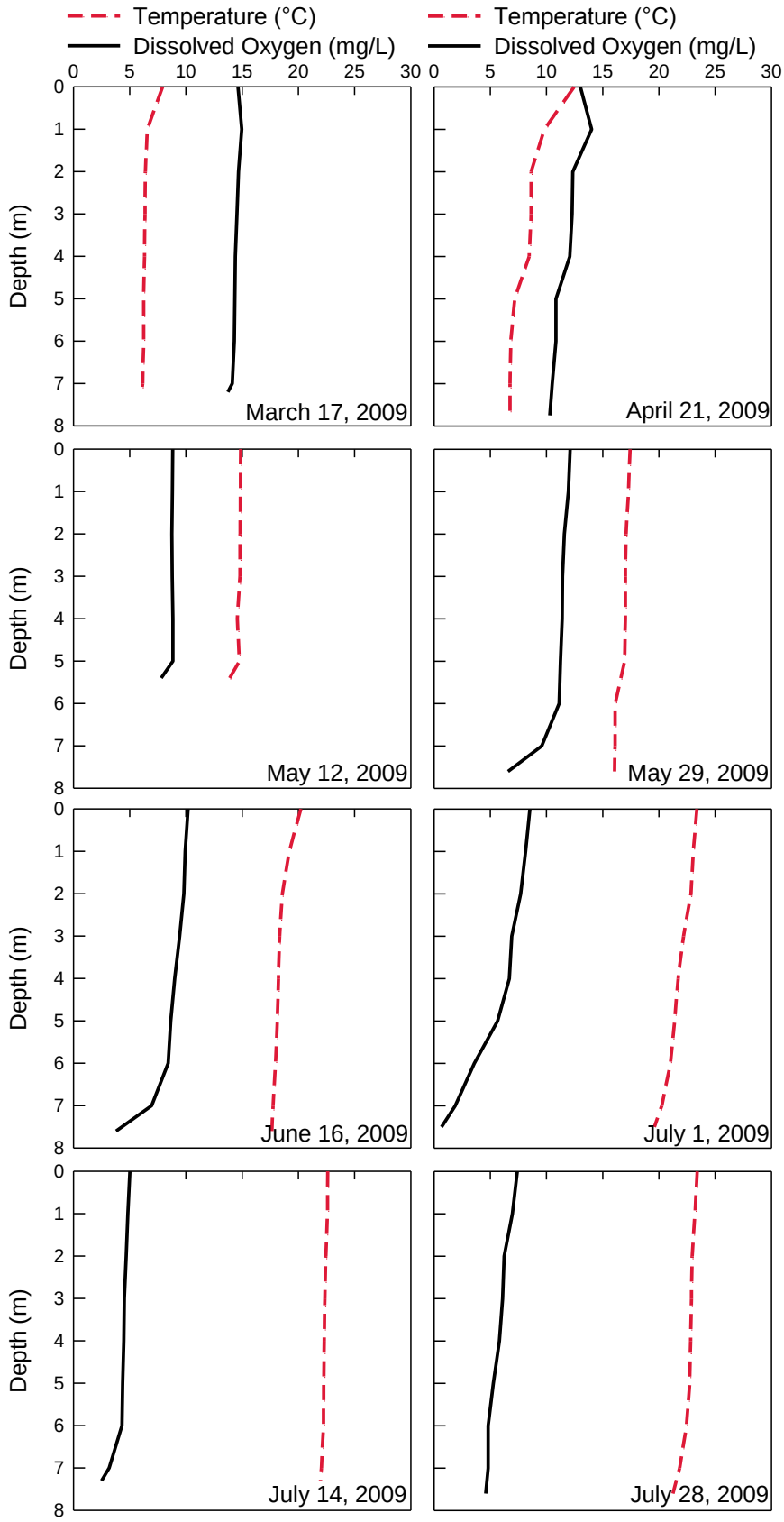
CCR-2 Small Tables

Sample Date	Depth	Temperature	Conductivity	Dissolved Oxygen	pH	ORP	1% Transmittance	Secchi Disk
2/17/2009	0	3.22	612		7.94			
	1	3.23	612		7.93			
	2	3.25	609		7.94			
	--						--	--
3/17/2009	0	7.93	692	14.63	7.86	100.3		
	1	6.57	652	14.96	7.83	94.4		
	2	6.40	650	14.68	7.82	90.2		
	3	6.37	649	14.54	7.80	88.3		
	4	6.32	647	14.39	7.82	86.0		
	5	6.25	647	14.35	7.83	84.4		
	6	6.24	646	14.30	7.83	84.0		
	7	6.16	645	14.12	7.84	83.0		
	7.2	6.06	643	13.73	7.84	79.7		
	--						3.35	0.75
4/21/2009	0	12.45	657	13.01	7.85	151.5		
	1	9.82	604	14.02	7.81	148.4		
	2	8.63	587	12.34	7.59	155.2		
	3	8.64	619	12.27	7.65	152.8		
	4	8.46	612	12.06	7.56	155.6		
	5	7.18	605	10.84	7.44	159.0		
	6	6.83	598	10.83	7.44	156.7		
	7	6.76	597	10.51	7.43	155.4		
	7.75	6.77	597	10.30	7.42	109.5		
	--						1.72	0.35
5/12/2009	0	14.87	752	8.83	8.13	166.6		
	1	14.85	752	8.80	8.10	166.4		
	2	14.82	751	8.75	8.11	164.7		
	3	14.81	752	8.78	8.13	163.7		
	4	14.57	746	8.84	8.15	163.0		
	5	14.76	750	8.84	8.15	162.3		
	5.4	13.89	736	7.81	8.07	167.3		
	--						5.75	2.85
5/29/2009	0	17.43	750	12.10	8.87	142.6		
	1	17.30	748	11.94	8.83	163.4		
	2	17.07	745	11.59	8.78	178.9		
	3	17.02	744	11.42	8.77	185.0		
	4	17.01	744	11.39	8.77	188.1		
	5	16.96	744	11.24	8.77	192.4		
	6	16.12	740	11.12	8.77	198.8		
	7	16.10	731	9.58	8.65	175.7		
	7.6	16.05	718	6.57	8.15	-27.4		
	--						3.90	1.35
6/16/2009	0	20.23	775	10.19	8.69	70.7		
	1	19.21	756	9.94	8.71	71.0		
	2	18.57	744	9.82	8.75	70.8		
	3	18.33	740	9.44	8.72	72.1		
	4	18.23	739	9.00	8.71	73.0		
	5	18.14	737	8.64	8.68	73.8		

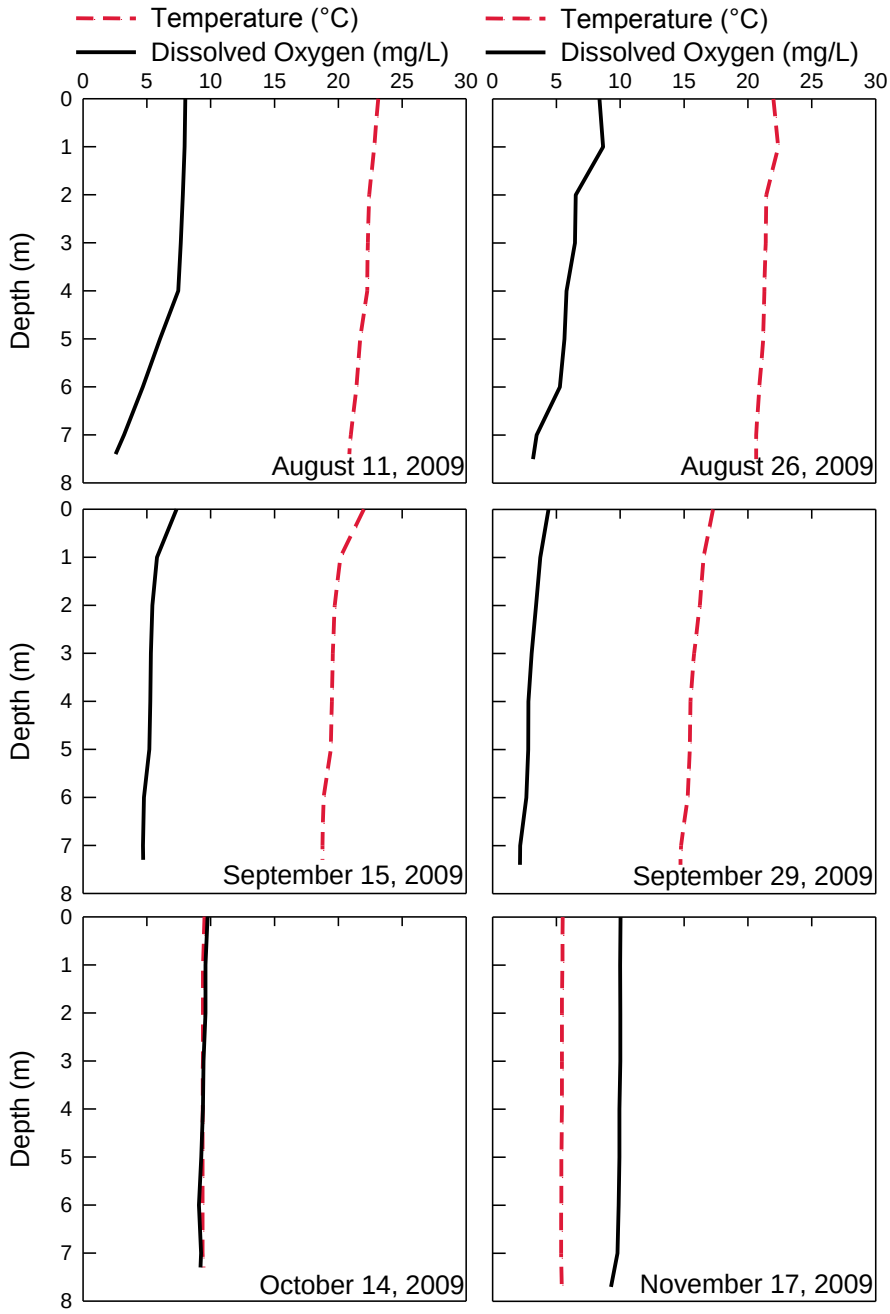
Sample Date	Depth	Temperature	Conductivity	Dissolved Oxygen	pH	ORP	1% Transmittance	Secchi Disk
6/16/2009	6	17.97	734	8.42	8.69	74.0		
	7	17.75	731	6.95	8.58	74.0		
	7.6	17.65	730	3.79	8.44	-21.1		
	--						3.42	1.15
7/1/2009	0	23.37	860	8.53	8.49	239.1		
	1	23.06	860	8.14	8.47	239.7		
	2	22.85	861	7.70	8.42	241.0		
	3	22.19	863	6.91	8.35	242.8		
	4	21.71	865	6.70	8.30	244.7		
	5	21.39	871	5.65	8.17	245.7		
	6	21.03	867	3.58	7.96	247.8		
	7	20.26	862	1.88	7.79	243.2		
	7.5	19.59	862	0.66	7.41	22.6		
	--						3.78	1.05
7/14/2009	0	22.61	800	5.01	8.20	18.8		
	1	22.60	800	4.84	8.20	23.4		
	2	22.45	798	4.68	8.20	27.5		
	3	22.35	797	4.52	8.17	35.6		
	4	22.29	795	4.48	8.18	35.1		
	5	22.26	795	4.37	8.17	36.1		
	6	22.23	795	4.31	8.16	37.0		
	7	22.06	791	3.17	8.07	37.4		
	7.3	21.96	789	2.49	7.94	-96.4		
	--						3.60	1.23
7/28/2009	0	23.40	840	7.40	9.10	-319.0		
	1	23.21	840	6.96	9.09	-318.0		
	2	22.95	840	6.23	9.00	-315.0		
	3	22.90	841	6.09	8.99	-315.0		
	4	22.82	841	5.81	8.97	-314.0		
	5	22.75	842	5.27	8.91	-312.0		
	6	22.46	808	4.81	8.84	-310.0		
	7	21.85	754	4.81	8.75	-308.0		
	7.6	21.25	710	4.60	8.51	-535.0		
	--						3.55	1.12
8/11/2009	0	23.12	813	8.01	8.44	66.6		
	1	22.82	806	7.95	8.44	68.5		
	2	22.42	801	7.82	8.45	69.7		
	3	22.31	800	7.66	8.43	71.5		
	4	22.26	799	7.46	8.41	72.7		
	5	21.71	793	6.03	8.31	72.5		
	6	21.42	790	4.69	8.21	71.7		
	7	20.98	789	3.22	8.11	70.5		
	7.4	20.85	791	2.55	7.88	-68.7		
	--						3.80	1.10
8/26/2009	0	21.99	788	8.37	8.53	37.1		
	1	22.39	794	8.66	8.61	21.1		
	2	21.44	781	6.52	8.43	13.9		
	3	21.40	781	6.45	8.40	11.9		
	4	21.29	780	5.79	8.35	8.7		
	5	21.20	780	5.63	8.32	7.7		
	6	20.90	771	5.27	8.24	6.7		

Sample Date	Depth	Temperature	Conductivity	Dissolved Oxygen	pH	ORP	1% Transmittance	Secchi Disk
8/26/2009	7	20.65	766	3.45	8.03	4.0		
	7.5	20.64	766	3.17	8.00	-0.6		
	--						2.97	0.90
9/15/2009	0	22.00	918	7.32	8.51	384.0		
	1	20.16	917	5.80	8.42	388.0		
	2	19.71	916	5.43	8.40	389.0		
	3	19.57	917	5.32	8.36	390.0		
	4	19.49	917	5.27	8.35	391.0		
	5	19.41	917	5.20	8.32	391.0		
	6	18.85	921	4.77	8.18	396.0		
	7	18.75	923	4.70	8.14	396.0		
	7.3	18.77	923	4.71	8.13	392.0		
	--						2.90	0.96
9/29/2009	0	17.27	916	4.39	8.57	226.0		
	1	16.54	913	3.74	8.60	231.0		
	2	16.23	911	3.41	8.62	235.0		
	3	15.79	912	3.06	8.52	241.0		
	4	15.50	916	2.81	8.37	249.0		
	5	15.45	917	2.79	8.34	252.0		
	6	15.29	918	2.65	8.29	255.0		
	7	14.76	926	2.17	8.12	260.0		
	7.3					233.0		
	7.4	14.72	927	2.15	8.10			
	--						3.00	0.75
10/14/2009	0	9.51	877	9.76	7.58	151.7		
	1	9.41	877	9.59	7.68	154.3		
	2	9.39	877	9.59	7.70	155.7		
	3	9.39	877	9.44	7.72	157.8		
	4	9.38	877	9.40	7.75	158.1		
	5	9.37	877	9.26	7.75	157.7		
	6	9.36	877	9.08	7.77	157.9		
	7	9.36	877	9.24	7.76	157.6		
	7.3	9.46	876	9.20	7.61	140.8		
	--						3.58	1.05
11/17/2009	0	5.49	903	10.02	8.34	415.0		
	1	5.48	902	10.00	8.34	414.0		
	2	5.44	902	10.01	8.34	414.0		
	3	5.45	902	10.01	8.35	413.0		
	4	5.44	902	9.94	8.36	412.0		
	5	5.41	902	9.94	8.36	412.0		
	6	5.39	902	9.87	8.36	412.0		
	7	5.38	902	9.79	8.35	411.0		
	7.7	5.44	901	9.27	8.21	361.0		
	--						3.70	0.97

CCR-2


Temperature (°C)
Dissolved Oxygen (mg/L)
Depth (m)
March 17, 2009
April 21, 2009
May 12, 2009
May 29, 2009
June 16, 2009
July 1, 2009
July 14, 2009
July 28, 2009

CCR-2


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
August 11, 2009
August 26, 2009
September 15, 2009
September 29, 2009
October 14, 2009
November 17, 2009

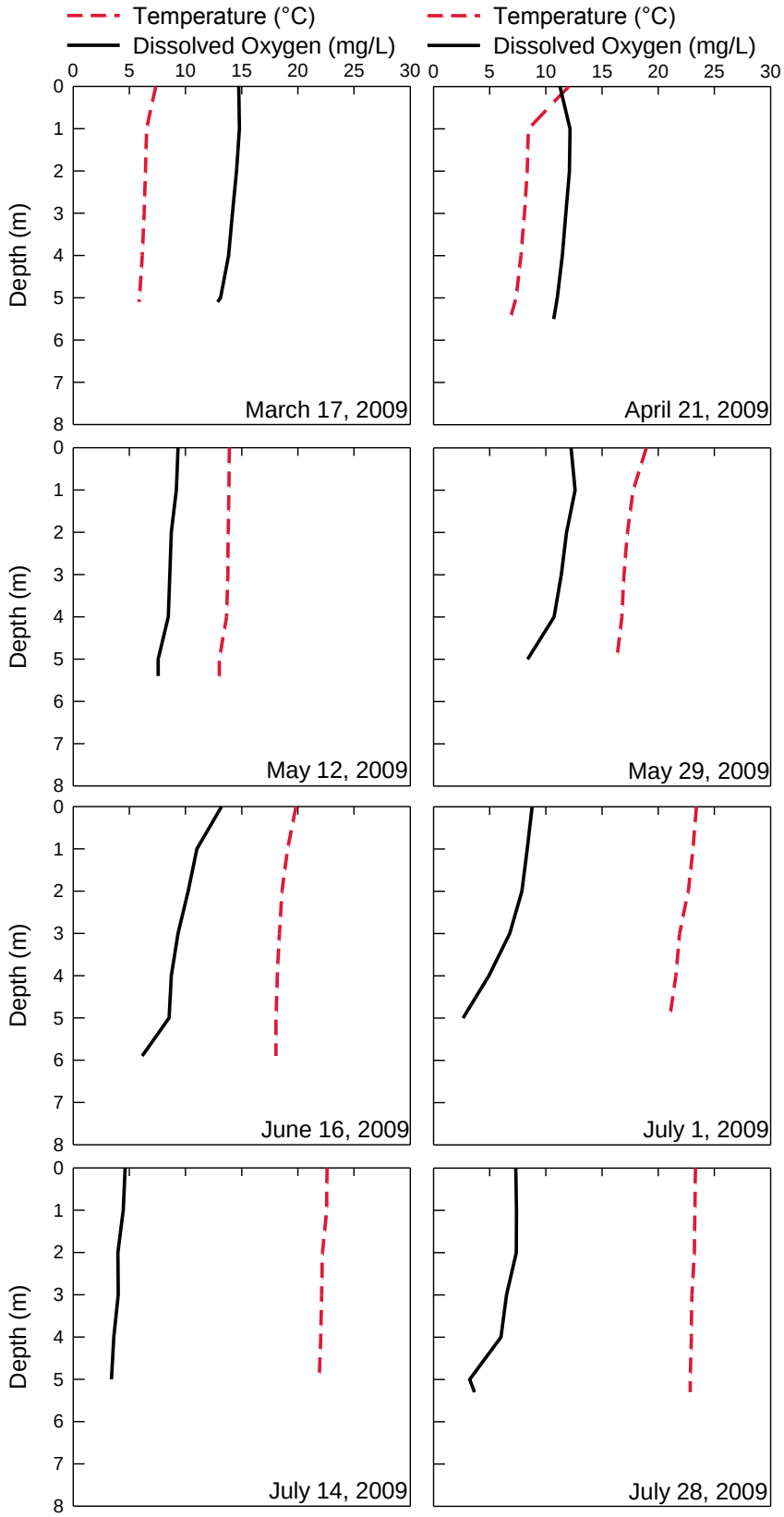
CCR-3 Small Tables

Sample Date	Depth	Temperature	Conductivity	Dissolved Oxygen	pH	ORP	1% Transmittance	Secchi Disk
2/17/2009	--	--	--		--	--	--	--
3/17/2009	0	7.35	667	14.73	7.92	109.6		
	1	6.55	652	14.79	7.91	105.5		
	2	6.44	650	14.54	7.90	104.2		
	3	6.32	649	14.18	7.89	102.9		
	4	6.16	646	13.84	7.87	101.5		
	5	5.92	642	13.12	7.86	100.0		
	5.1	5.87	641	12.84	7.87	99.2		
	--						3.23	0.74
4/21/2009	0	12.04	554	11.25	7.55	166.3		
	1	8.45	589	12.15	7.48	168.1		
	2	8.34	613	12.09	7.47	169.0		
	3	8.10	609	11.78	7.45	167.9		
	4	7.79	598	11.46	7.39	167.1		
	5	7.36	598	11.02	7.32	166.8		
	5.5	6.82	596	10.70	7.28	165.3		
	--						1.23	0.23
5/12/2009	0	13.91	736	9.33	8.07	197.4		
	1	13.87	735	9.18	8.09	195.0		
	2	13.81	734	8.74	8.06	196.2		
	3	13.77	734	8.60	8.11	192.2		
	4	13.66	732	8.46	8.11	191.6		
	5	13.03	723	7.56	8.04	192.2		
	5.4	13.01	723	7.56	8.04	191.3		
	--						4.75	1.95
5/29/2009	0	18.95	773	12.25	8.87	172.0		
	1	17.78	753	12.60	8.87	182.5		
	2	17.27	744	11.84	8.82	187.7		
	3	16.96	741	11.37	8.79	190.7		
	4	16.77	736	10.73	8.79	194.0		
	5	16.33	720	8.37	8.50	161.7		
	--						3.76	1.23
6/16/2009	0	19.84	765	13.20	8.77	58.7		
	1	19.08	750	11.01	8.75	67.6		
	2	18.59	743	10.23	8.73	69.2		
	3	18.37	741	9.34	8.67	73.2		
	4	18.17	737	8.73	8.63	72.2		
	5	18.06	737	8.54	8.47	69.0		
	5.9	18.05	737	6.14	8.43	67.4		
	--						2.90	1.08
7/1/2009	0	23.40	862	8.78	8.49	173.4		
	1	23.11	861	8.34	8.50	172.7		
	2	22.68	862	7.86	8.46	172.9		
	3	21.90	864	6.78	8.33	173.1		
	4	21.58	866	4.93	8.14	174.0		
	5	21.03	864	2.63	7.91	175.1		
	--						3.58	1.25

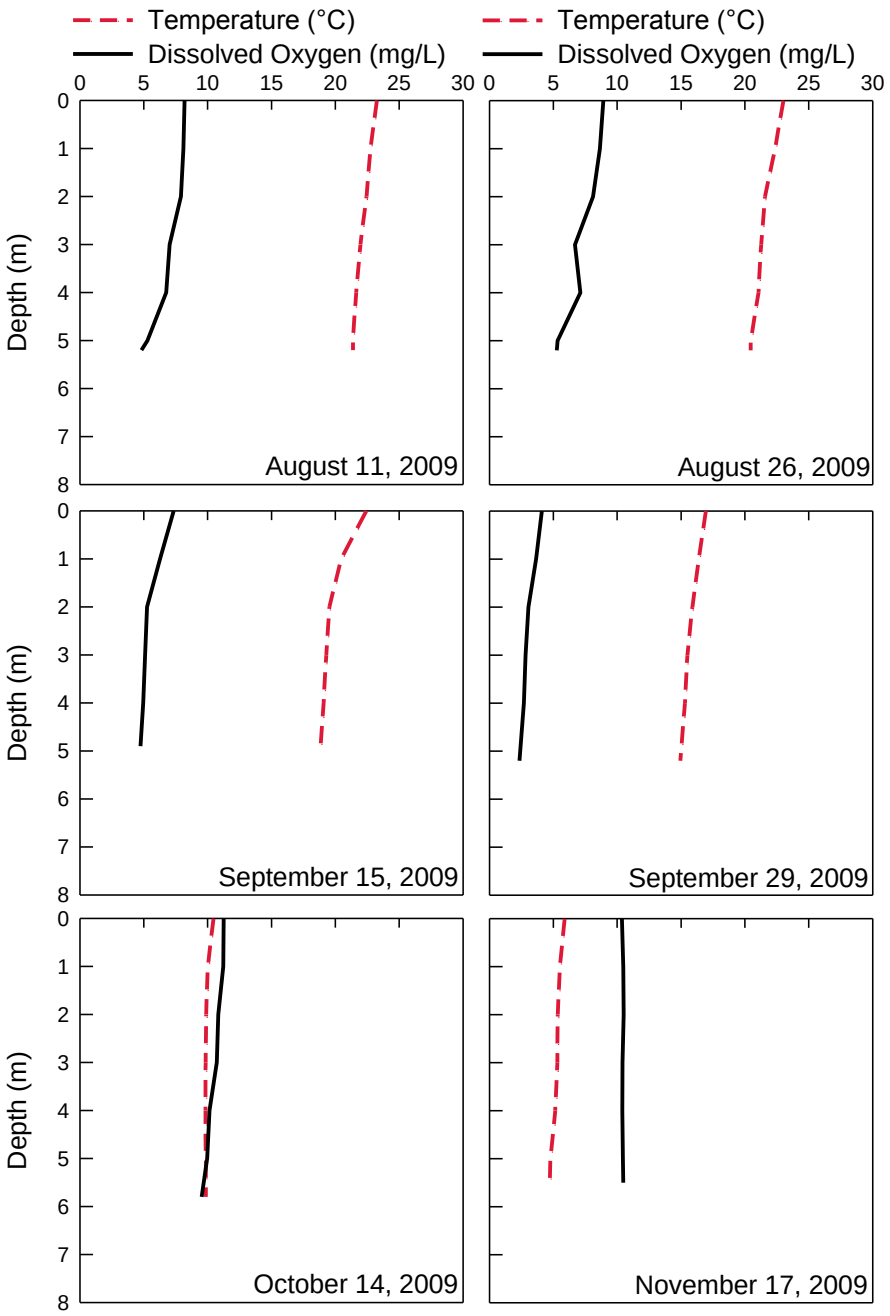
Sample Date	Depth	Temperature	Conductivity	Dissolved Oxygen	pH	ORP	1% Transmittance	Secchi Disk
7/14/2009	0	22.60	800	4.62	8.19	52.7		
7/14/2009	1	22.57	798	4.46	8.18	53.4		
	2	22.19	791	3.98	8.14	54.6		
	3	22.11	791	4.01	8.13	55.5		
	4	22.04	790	3.62	8.10	56.4		
	5	21.91	789	3.41	8.09	54.7		
	--						3.40	1.13
7/28/2009	0	23.31	841	7.33	9.09	-346.0		
	1	23.27	840	7.39	9.11	-342.0		
	2	23.22	841	7.37	9.10	-338.0		
	3	23.00	842	6.50	9.04	-335.0		
	4	22.95	842	6.00	8.99	-332.0		
	5	22.85	852	3.21	8.68	-326.0		
	5.3	22.85	852	3.65	8.68	-332.0		
	--						3.25	1.05
8/11/2009	0	23.26	819	8.20	8.57	73.7		
	1	22.76	804	8.11	8.58	73.1		
	2	22.45	800	7.91	8.55	74.2		
	3	21.96	794	7.02	8.48	75.3		
	4	21.64	792	6.75	8.43	76.5		
	5	21.38	791	5.28	8.31	75.8		
	5.2	21.38	790	4.82	8.26	70.7		
	--						3.74	1.25
8/26/2009	0	23.01	805	8.91	8.62	41.6		
	1	22.37	795	8.64	8.61	25.7		
	2	21.57	782	8.10	8.57	20.1		
	3	21.28	779	6.70	8.44	16.3		
	4	21.07	779	7.12	8.48	12.9		
	5	20.47	791	5.33	8.27	9.7		
	5.2	20.45	791	5.27	8.24	7.7		
	--						2.77	0.81
9/15/2009	0	22.43	918	7.34	8.53	377.0		
	1	20.47	916	6.27	8.57	378.0		
	2	19.54	917	5.26	8.36	385.0		
	3	19.29	917	5.10	8.32	387.0		
	4	19.08	917	4.95	8.29	388.0		
	4.9	18.85	925	4.75	8.24	372.0		
	--						3.00	0.98
9/29/2009	0	16.94	916	4.10	8.52	289.0		
	1	16.40	915	3.65	8.51	290.0		
	2	15.89	912	3.05	8.52	291.0		
	3	15.50	914	2.82	8.46	293.0		
	4	15.31	916	2.69	8.35	296.0		
	5.2	14.94	917	2.35	8.27	299.0		
	--						3.00	1.01

Sample Date	Depth	Temperature	Conductivity	Dissolved Oxygen	pH	ORP	1% Transmittance	Secchi Disk
10/14/2009	0	10.46	875	11.25	7.94	130.6		
	1	10.03	876	11.22	7.92	133.8		
	2	9.89	876	10.84	7.85	140.8		
	3	9.84	876	10.72	7.82	142.6		
	4	9.83	877	10.15	7.80	141.6		
	5	9.86	879	9.97	7.77	140.4		
	5.8	9.86	884	9.53	7.73	120.6		
	--						3.25	1.10
11/17/2009	0	5.89	903	10.37	8.45	384.0		
	1	5.53	906	10.47	8.45	384.0		
	2	5.35	910	10.50	8.45	385.0		
	3	5.31	914	10.42	8.43	385.0		
	4	5.15	916	10.40	8.42	386.0		
	5	4.78	922	10.44	8.43	386.0		
	5.5	4.73	923	10.48	8.43	386.0		
	--						3.13	1.13

CCR-3


Temperature (°C)
Dissolved Oxygen (mg/L)
Depth (m)
March 17, 2009
April 21, 2009
May 12, 2009
May 29, 2009
June 16, 2009
July 1, 2009
July 14, 2009
July 28, 2009

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
August 11, 2009
August 26, 2009
September 15, 2009
September 29, 2009
October 14, 2009
November 17, 2009

Cherry Creek Transect ORP Data

Collection Date	Depth	Transect ORP (mV)											
		D1	D2	D3	D3.5	D4	D5	D6	D7	D8	D9	D10	D11
7/1/2009	0	244.7	195.7	177.5	161.7	149.7	137.5	151.8	160.9	156.9	165.8	173.4	219.0
	1	245.2	197.4	178.2	162.9	151.0	139.3	152.9	161.4	157.3	166.3	172.7	220.6
	2	245.8	199.2	179.2	162.8	152.1	140.7	153.5	162.2	159.3	166.8	172.9	222.1
	3	247.1	200.6	180.5	164.9	153.2	142.6	154.5	162.9	161.9	167.8	173.1	224.7
	4	247.7	202.2	181.4	165.8	154.2	144.2	155.6	163.8	163.1	168.5	174.0	220.8
	5	248.5	206.6	182.1	167.6	156.7	147.6	157.3	165.9	164.9	169.7	175.1	
	6	249.2	209.8	185.0	170.3	159.4	149.1	158.9	167.1	166.5	170.9		
	7	166.6	209.0	175.5	168.4	148.7	134.4	159.7	134.9	167.3	172.8		
	Bottom	68.3	55.6	75.2	68.9	66.7							

Collection Date	Depth	Transect ORP (mV)											
		D1	D2	D3	D3.5	D4	D5	D6	D7	D8	D9	D10	D11
7/28/2009	0	-183.0	-226.0	-243.0	-242.0	-282.0	-278.0	-287.0	-349.0	-357.0	-363.0	-346.0	-325.0
	1	-186.0	-227.0	-242.0	-242.0	-280.0	-277.0	-285.0	-346.0	-353.0	-358.0	-342.0	-324.0
	2	-189.0	-227.0	-242.0	-242.0	-278.0	-274.0	-283.0	-337.0	-350.0	-352.0	-338.0	-321.0
	3	-192.0	-227.0	-242.0	-242.0	-277.0	-268.0	-281.0	-335.0	-346.0	-351.0	-335.0	-320.0
	4	-196.0	-227.0	-241.0	-242.0	-275.0	-265.0	-280.0	-333.0	-342.0	-349.0	-332.0	-316.0
	5	-199.0	-226.0	-241.0	-242.0	-273.0	-263.0	-280.0	-333.0	-341.0	-347.0	-326.0	-322.0
	6	-202.0	-227.0	-240.0	-242.0	-270.0	-261.0	-279.0	-331.0	-337.0	-343.0	-332.0	
	7	-205.0	-228.0	-240.0	-230.0	-257.0	-247.0	-266.0	-327.0	-335.0	-341.0		
	Bottom		-248.0	-247.0	-330.0	-289.0	-378.0	-542.0	-558.0	-576.0			

Collection Date	Depth	Transect ORP (mV)											
		D1	D2	D3	D3.5	D4	D5	D6	D7	D8	D9	D10	D11
8/26/2009	0	103.6	138.3	36.4	18.3	29.9	2.3	-11.6	20.2	-0.2	35.8	41.6	11.7
	1	105.5	108.2	21.0	-5.7	-11.2	2.8	-10.6	12.6	0.1	28.3	25.7	2.9
	2	107.3	91.0	9.4	-15.0	-20.3	5.5	-9.3	9.1	0.0	22.5	20.1	1.9
	3	106.8	79.4	-0.4	-20.8	-25.7	5.8	-9.8	5.7	0.4	19.3	16.3	0.6
	4	105.4	72.5	-6.3	-23.7	-25.9	5.0	-10.6	3.6	-0.6	17.0	12.9	0.8
	5	103.5	64.3	-11.7	-26.5	-27.2	3.9	-13.1	2.1	-0.7	16.1	9.7	
	6	99.8	56.0	-14.8	-29.7	-32.7	-1.5	-14.3	-0.1	-0.1	14.3	7.7	
	7	96.5	51.4	-27.3	-51.1	-50.7	-17.8	-25.2	-11.3	-7.2	9.3		
	Bottom	85.4	-96.2	-131.2	-63.5	-172.4	-142.8	-38.3	-123.7	-10.4	-47.1		

Cherry Creek Transect DO Data

Collection Date	Depth	Dissolved Oxygen (mg/L)											
		D1	D2	D3	D3.5	D4	D5	D6	D7	D8	D9	D10	D11
7/1/2009	0	8.82	8.05	7.40	7.66	7.77	8.23	8.20	8.16	8.47	8.01	8.78	8.52
	1	8.89	8.03	7.45	7.23	7.65	7.99	8.02	8.13	8.11	8.11	8.34	8.53
	2	8.50	7.70	7.62	7.28	7.23	7.83	7.81	7.77	7.73	7.63	7.86	8.18
	3	8.34	7.50	7.59	7.14	7.05	7.15	7.27	7.19	7.08	6.99	6.78	7.53
	4	8.20	7.37	7.36	6.84	6.90	6.90	6.94	6.29	5.47	6.21	4.93	5.47
	5	7.57	7.20	6.68	5.79	5.39	4.83	5.32	5.13	4.94	4.93	2.63	
	6	5.85	3.49	3.31	3.14	3.01	3.63	3.98	3.45	3.45	3.42		
	7	1.72	0.91	0.69	0.51	0.43	0.59	0.33	0.36	0.89	0.75		
	Bottom	1.70	0.83	0.57	0.42	0.36							

Collection Date	Depth	Dissolved Oxygen (mg/L)											
		D1	D2	D3	D3.5	D4	D5	D6	D7	D8	D9	D10	D11
7/28/2009	0	5.58	6.11	5.62	5.54	5.70	6.11	6.16	6.34	6.80	7.36	7.33	7.55
	1	5.51	6.12	5.63	5.56	5.74	5.99	6.16	6.34	6.75	7.19	7.39	7.65
	2	5.50	5.86	5.55	5.52	5.79	5.73	6.02	6.25	6.73	5.92	7.37	6.70
	3	5.46	5.83	5.48	5.42	5.79	5.61	5.82	6.16	6.47	6.10	6.50	6.36
	4	5.43	5.61	5.32	5.47	5.79	5.62	5.81	5.83	5.70	6.13	6.00	5.98
	5	5.40	5.40	5.21	5.46	5.65	5.49	5.82	5.79	5.59	6.53	3.21	5.92
	6	5.44	5.18	5.06	5.33	4.99	5.22	5.76	5.57	3.99	5.58	3.65	
	7	5.28	4.95	4.49	2.20	2.65	1.60	1.48	2.54	2.02	1.72		
	Bottom	4.81	4.73	4.40	0.79	0.70	0.86	0.66	0.84	1.12			

Collection Date	Depth	Dissolved Oxygen (mg/L)											
		D1	D2	D3	D3.5	D4	D5	D6	D7	D8	D9	D10	D11
8/26/2009	0	7.04	7.29	7.53	7.24	7.80	7.89	7.89	7.57	8.87	9.18	8.91	9.16
	1	7.31	6.87	7.46	7.46	6.82	8.21	7.68	7.30	8.37	9.20	8.64	9.31
	2	6.80	6.43	7.19	6.56	7.19	7.59	7.16	6.85	7.84	7.13	8.10	9.11
	3	6.10	6.32	6.24	6.29	6.15	6.39	6.32	6.25	6.60	6.33	6.70	8.33
	4	5.97	5.98	5.99	6.10	5.88	5.89	5.87	5.69	6.04	6.49	7.12	7.84
	5	5.83	5.80	5.87	5.94	5.65	5.51	5.38	6.50	6.61	6.78	5.33	
	6	4.82	3.82	5.69	5.72	4.07	3.32	5.61	5.58	6.31	6.47	5.27	
	7	2.94	0.45	0.88	1.25	0.62	0.33	0.54	0.78	5.21	5.54		
	Bottom	1.30	0.06	0.09	0.65	0.19	0.08	0.40	0.57	5.19	4.98		

Appendix C

2009 Stream Water Quality and Precipitation Data

GEI Water Chemistry Data									
Analytical Detection Limits	2	2	2	2	2	2	3	4	4
Site/Sample Date	Total Phosphorus (µg/L)	Total Dissolved Phosphorus (µg/L)	Orthophosphate (µg/L)	Total Nitrogen (µg/L)	Total Dissolved Nitrogen (µg/L)	Nitrate+ Nitrite (µg/L)	Ammonia (µg/L)	Total Suspended Solids (mg/L)	Total Volatile Suspended Solids (mg/L)
CC-10									
1/21/2009	185	130	131	2091	1614	946	64	31	4
2/17/2009	141	104	96	1262	1189	908	25	21	4
3/17/2009	145	104	110	1219	1162	788	31	13	
4/16/2009	196	132	119	946	867	463	28	58	8
5/12/2009	58	47	39	349	309	13	5	64	9
6/30/2009	348	246	230	1354	1202	792	40	50	6
7/14/2009	485	240	225	1528	1037	619	47	168	19
8/11/2009	294	176	188	1230	940	569		54	7
9/29/2009	245	186	186	1339	1226	977	14	21	
10/14/2009	190	158	163	1262	1276	973	13	13	4
11/17/2009	155	133	140	1266	1336	1010	25	36	4
12/16/2009	188	152	147	1520	1398	1137	69	12	
CC-10 Storm									
4/17/2009	289	137	139	1413	1186	685	59	211	14
4/28/2009	264	161	147	1158	956	499	65	83	8
5/26/2009	489	162	165	1750	952	511	30	171	18
6/1/2009	391	208	218	1239	1151	645	61	133	14
6/26/2009	526	245	219	1490	854	271		153	17
7/21/2009	848	227	211	1693	1071	635	35	896	108
7/30/2009	310	227	192	1385	1198	861	29	55	10
8/18/2009	365	156	167	2119	1300	900	36	147	18
CC-Out @ I225									
1/21/2009	83	33	19	1032	761	93	65	11	4
2/17/2009	62	16	6	987	597	4	24	14	6
3/17/2009	75	6	5	852	440		10	14	6
4/16/2009	91	8	5	747	416			31	10
4/21/2009	82	18	11	1065	600	10	32	12	5
4/22/2009	83	17	13	754	457	5	9	12	5
5/12/2009	82	54	50	753	601	50	101	11	4
5/29/2009	77	12	5	776	502		26	20	7
6/30/2009	350	236	223	1226	873	19	391	32	8
7/14/2009	200	121	106	1091	755	23	194	24	6
8/11/2009	83	84	77	1043	657	11	122	40	9
9/29/2009	101	29	29	804	582	75	104	23	5
10/14/2009	58	18	7	668	450	3	16	13	6
11/17/2009	67	19	7	789	387		34	21	5
12/16/2009	81	20	14	924	533	74	23	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)	Orthophosphate (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									
1/21/2009	102	29	29	2761	2600	2241	27	26	4
2/17/2009	75	22	25	2639	2389	2014	23	47	9
3/17/2009	79	17	14	2202	1897	1526	17	45	7
4/16/2009	78	35	30	1860	1704	1269	49	29	7
5/12/2009	36	9	11	736	606	228	10	13	5
6/30/2009	39	25	17	645	557	56	26	21	5
7/14/2009	46	20	7	1139	996	468	31	22	7
8/11/2009	66	10	6	1154	884	347	31	21	5
9/29/2009	47	13	13	1552	1385	966	15	13	
10/14/2009	53	16	7	2190	2039	1671	19	21	
11/17/2009	79	21	15	1400	1125	786	48	57	8
12/16/2009	95	23	22	1995	1690	1134	209	51	7
CT-1 Storm									
4/17/2009	47	27	25	1071	956	1051	79	38	8
4/28/2009	82	44	35	978	868	362	44	20	5
5/26/2009	218	75	74	1231	889	400	80	58	8
6/1/2009	74	17	11	1197	912	359	76	38	9
6/26/2009	117	42	31	1271	881	353		25	7
7/21/2009	176	71	58	1455	1049	502	74	86	23
7/30/2009	97	46	35	1425	1117	620	64	26	7
8/18/2009	101	6	6	1921	1120	613	51	41	9
9/21/2009	57	17	16	1408	1266	834		20	
CT-2									
1/21/2009	52	13	11	3288	2957	2560	20	57	7
2/17/2009	63	12		3207	2829	2385	17	45	10
3/17/2009	62	9	3	2844	2643	1978	24	36	6
4/16/2009	48	10	3	2352	2089	1488	46	37	7
5/12/2009	38	11	3	888	724	154	14	24	6
6/30/2009	56	16	9	828	687	31	52	10	
7/14/2009	42	18	7	1062	933	414	24	18	6
8/11/2009	13	11	5	1002	718	215	19	19	6
9/29/2009	71	6	3	1739	1440	977	15	34	7
10/14/2009	65	12	5	2155	1978	1550	23	30	5
11/17/2009	41	15	10	1283	1177	752	76	27	6
12/16/2009	64	15	10	2057	1792	1208	195	31	5
CT-2 Storm									
4/17/2009	64	21	15	2190	2022	1380	81	36	8
4/28/2009	85	47	36	988	824	388	42	20	5
5/26/2009	178	54	57	1205	855	375	108	56	8
6/1/2009	62	16	9	1170	959	330	118	31	9
6/26/2009	131	39	33	1391	1018	430		32	8
7/21/2009	168	66	41	1534	1097	493	81	50	9
7/30/2009	78	32	25	1454	1142	638	65	23	7
8/18/2009	77	10	8	1745	1143	602	22	29	9
9/21/2009	72	7	5	1282	1203	686		32	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)	Orthophosphate (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									
1/21/2009	8	5	6	1103	1109	701	23	4	
2/17/2009	21	8	6	971	899	507	52	10	
3/17/2009	29	9	7	802	706	294	55	10	
5/12/2009	38	18	11	933	831	372	41	13	4
6/30/2009	87	40	28	1015	851	279	76	26	6
7/14/2009	113	32	20	1150	830	293	34	28	8
8/11/2009	104	30	20	1256	649	268	10	17	7
9/29/2009	79	48	42	1009	838	491	39	11	
10/14/2009	35	11	6	990	879	500	14	14	5
11/17/2009	29	20	14	1048	994	672	50	14	5
12/16/2009	13	5	7	1252	1157	904	45	4	
CT-P1 Storm									
4/17/2009	185	18	15	1509	1061	364	183	124	18
5/26/2009	259	74	72	1278	565	236	63	55	8
6/1/2009	115	37	30	1368	1048	496	125	36	8
6/26/2009	419	55	54	2062	1276	564		183	31
7/21/2009	402	163	147	1660	876	366	70	252	27
7/30/2009	178	91	72	1315	924	381	110	31	9
8/18/2009	159	34	30	1722	921	451	69	50	15
9/21/2009	152	36	29	1264	892	364		30	8
CT-P2									
1/21/2009	16	7	6	1315	1282	939	23	7	
2/17/2009	47	6	5	1204	1055	694	30	36	7
3/17/2009	19	6	5	1086	879	496	32	11	
4/16/2009	27	6	5	891	743	302	27	17	5
5/12/2009	37	15	9	1176	1035	702	27	11	
6/30/2009	75	39	31	1274	1149	626	66	19	5
7/14/2009	99	20	18	1182	855	399	13	21	5
8/11/2009	75	15	8	1366	958	639	14	15	6
9/29/2009	66	30	28	1350	1180	834	31	13	
10/14/2009	53	12	7	1343	1268	857	39	40	9
11/17/2009	31	19	13	1095	1039	774	33	23	5
12/16/2009	50	6	8	1685	1485	1256	45	37	7
CT-P2 Storm									
4/17/2009	122	39	33	1422	1184	490	155	41	7
4/28/2009	106	52	47	1017	828	388	75	23	5
5/26/2009	217	102	100	1203	843	357	68	36	6
6/1/2009	88	31	23	1325	1033	487	94	18	5
6/26/2009	213	98	82	1385	932	361		38	11
7/21/2009	309	141	124	1452	864	395	80	106	25
7/30/2009	133	81	59	1256	963	461	88	21	8
8/18/2009	67	44	41	1739	1025	496	81	25	13
9/21/2009	115	56	49	1160	946	402		27	7

GEI Water Chemistry Data									
Analytical Detection Limits	2	2	2	2	2	2	3	4	4
Site/Sample Date	Total Phosphorus (µg/L)	Total Dissolved Phosphorus (µg/L)	Orthophosphate (µg/L)	Total Nitrogen (µg/L)	Total Dissolved Nitrogen (µg/L)	Nitrate+ Nitrite (µg/L)	Ammonia (µg/L)	Total Suspended Solids (mg/L)	Total Volatile Suspended Solids (mg/L)
SC-3									
1/21/2009	29	26	24	2149	2113	2010	12	6	
2/17/2009	31	25	16	2411	2348	2169	12	23	
3/17/2009	83	9	6	733	441	127	7	82	10
4/16/2009	36	14	12	372	281	19	8	15	5
5/12/2009	274	182	187	1311	1123	1139	31	7	
6/30/2009	175	158	143	484	435	64	59	9	
7/14/2009	171	155	143	400	347	56	16	18	7
8/11/2009	331	208	180	1595	1251	627	71	58	9
9/29/2009	79	35	53	357	238	36	4	9	
10/14/2009	47	31	27	751	673	475	11	15	6
11/17/2009	44	32	27	1242	958	801	24	5	
12/16/2009	46	34	30	2588	2488	2417	49		
SC-3 Storm									
4/17/2009	64	43	38	1604	1524	1065	56	12	
4/28/2009	58	37	32	779	719	500	14	22	4
5/26/2009	104	67	61	926	788	472	18	14	
6/1/2009	106	89	92	411	339	36	43	17	6
6/26/2009	701	193	181	1586	630	220		260	34
7/21/2009	120	87	73	881	786	470	20	24	7
7/30/2009	160	146	133	547	478	144	31	7	
8/18/2009	116	89	87	1653	1251	849	36	19	6
Rain Gauge									
4/17/2009	37	25	25	1635	1616	396	1076		
5/26/2009	130	49	51	2581	1693	627	1888		
6/26/2009	341	125	108	2689	1335	367			
7/21/2009	398	371	209	2844	1858	286	1351		
7/30/2009	154	72	62	2229	1642	591	988		
8/18/2009	263	164	147	2726	1621	542	999		

Appendix D

2009 Streamflow, Rainfall, Phosphorus Loading Calculations and Final Inflow and Load Data Normalized to the U.S. Army Corps of Engineers Inflow Data

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 2009 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 2008 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. In 2009, a new drop structure was installed at Site CT-P1 which affected flows during March and April 2009. During construction, a coffer dam was placed on the channel with the flows being pumped around the project site. The ISCO sampler at Site CT-P1 was upstream of the coffer dam which caused a pooling of water at the transducer and affected water level and flow measurements during this time. Therefore, two separate rating curves were developed for Site CT-P1, the pre-construction rating curve utilized the historical dataset, and the post-construction curve utilized data collected after May 2009. 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 2009, Site CC-10 contained water level data gaps during both the first part and last part of the year. In January and February 2009, 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 only data from January 1, 2009 to March 30, 2009, to estimate periods of missing levels for CC-10 in late January and early February. Site CC-10 did reveal a strong relationship with CT-P2 level data in October and November 2009, which was used to estimate missing water level data in late November and December.

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 2008.

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
SC-3	2005	25-Apr-05	0.79	0.836	2.64
SC-3	2005	19-May-05	0.22	0.165	0.08
SC-3	2005	26-May-05	0.20	0.231	0.06
SC-3	2005	01-Jun-05	0.28	0.280	0.27
SC-3	2005	16-Aug-05	0.25	0.413	0.54
SC-3	2005	13-Oct-05	0.29	0.361	0.51
SC-3	2006	20-Apr-06	0.02	0.150	0.03
SC-3	2006	13-Jun-06	0.06	--	0.13
SC-3	2007	13-Mar-07	0.06	0.145	0.24

Site	Year	Date	Staff Gage Level (ft)	Transducer Level (ft)	Discharge (cfs)
SC-3	2007	10-May-07	0.32	0.255	0.18
SC-3	2007	26-Jul-07	0.11	0.120	0.004
SC-3	2007	9-Aug-07	0.32	0.337	0.22
SC-3	2008	15-Aug-08	0.90	--	7.24
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
CT-P1	2002	27-Jun-02	0.45	0.430	0.80
CT-P1	2002	11-Jul-02	0.60	0.580	2.43
CT-P1	2002	04-Sep-02	0.36	0.359	0.43
CT-P1	2003	04-Feb-03	0.50	0.502	1.35
CT-P1	2003	18-Jun-03	1.10	1.072	12.04
CT-P1	2003	30-Jul-03	0.72	0.726	3.18
CT-P1	2003	20-Nov-03	0.53	0.530	0.70
CT-P1	2004	09-Jan-04	0.49	0.483	0.42
CT-P1	2004	24-Feb-04	0.54	0.552	0.87
CT-P1	2004	27-May-04	0.51	0.508	0.71
CT-P1	2004	22-Jun-04	0.89	0.890	5.08
CT-P1	2004	23-Jun-04	0.69	0.677	1.99
CT-P1	2004	24-Aug-04	0.59	0.595	1.44
CT-P1	2005	01-Apr-05	0.66	0.655	1.88
CT-P1	2005	14-Apr-05	1.16	1.188	13.36
CT-P1	2005	25-Apr-05	1.39	1.369	15.62
CT-P1	2005	19-May-05	0.56	0.549	1.06
CT-P1	2005	26-May-05	0.55	0.575	0.77
CT-P1	2005	01-Jun-05	0.73	0.739	2.74
CT-P1	2005	16-Aug-05	0.96	1.120	7.40
CT-P1	2005	13-Oct-05	0.94	0.934	7.73
CT-P1	2006	20-Apr-06	0.55	0.540	0.64
CT-P1	2006	13-Jun-06	0.51	0.515	0.47
CT-P1	2006	12-Jul-06	0.66	0.631	1.57
CT-P1	2006	08-Aug-06	0.83	0.844	4.97
CT-P1	2006	27-Dec-06	0.76	--	2.16
CT-P1	2007	13-Mar-07	0.68	0.668	1.51
CT-P1	2007	26-Apr-07	0.99	0.956	7.33
CT-P1	2007	26-Jul-07	0.82	0.832	2.97
CT-P1	2007	9-Aug-07	0.70	0.718	1.73
CT-P1	2007	13-Nov-07	0.59	0.597	0.24
CT-P1	2008	26-Jun-08	0.53	0.525	0.19
CT-P1	2008	15-Aug-08	3.10	3.100	28.03
CT-P1	2009	22-Jan-09	0.56	0.557	0.44
CT-P1	2009	24-Mar-09	0.58	0.582	0.66
CT-P1 post-const.	2009	26-May-09	2.29	2.286	21.80
CT-P1 post-const.	2009	23-Jun-09	1.42	1.401	1.27

Site	Year	Date	Staff Gage Level (ft)	Transducer Level (ft)	Discharge (cfs)
CT-P1 post-const.	2009	12-Aug-09	1.38	1.375	0.82
CT-P1 post-const.	2009	18-Aug-09	2.00	1.916	12.43
CT-P1 post-const.	2009	20-Nov-09	1.64	1.634	1.79
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

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+0.4552)/0.8467)	0.77
	> 1.0	Q = EXP((H+9.3697)/2.7502)-37.9369	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 pre-const	<0.5	Q = EXP((H-0.6098)/0.1747)	0.80
	0.5 – 1.5	Q = EXP(H/0.4248)-2.834	0.92
	>1.5	Q = (H-0.4623)/0.0776	
CT-P1 post-const	<2.2	Q = EXP((H-1.4159)/0.2644)	0.98
	>2.2	Q = (H-1.4322)/0.0410	0.79
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((-0.0717+SQRT((0.0717^2)-(4*0.0359*(0.4895-CT-1 Level))))/(2*0.0359))	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 = 1.9889*(Parker Level) - 6.3624	0.71	11%
CC-10, Nov to Dec	CC-10 Level = 0.3283*(CT-P2 Level) + 1.6209	0.58	11%
SC-3, Mar	SC-3 Level = 0.2783*(CT-P2 Level) - 0.0529	0.78	6%
SC-3, Dec	Interpolated ice conditions	0.15	5%
CT-P1, Jan to Feb	CT-P1 Level = 0.2691(CT-P2 Level) + 0.4392	0.55	13%
CT-P1, May to Dec	CT-P1 Level = 0.2028*(CT-P2 Level) +1.4018	0.64	18%
CT-P2, Feb	CT-P2 Level = (CT-1 Level - 0.5142)/0.1456	0.92	1%
CT-1, Jan to Mar	CT-1 Level = 0.1456*(CT-P2 Level) + 0.5142	0.92	8%
CT-1, May to Nov	CT-1 Level = 0.1083*(CT-P2 Level) + 0.5783	0.86	15%
CT-2	CT-2 Level = 0.3234*(CT-P2 Level) + 0.4334	0.83	18%

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 ac-ft, then the first 1,000 ac-ft is redistributed proportionally to the stream sites, with the remainder being placed in an Ungaged Flow category. This category represents unmonitored flow that may be attributed to wetland seepage, stream bank storage, or ungaged surface flows during the respective month. Once the redistributed inflows are apportioned to the stream sites,

monthly loads are computed using their respective flow-weighted phosphorus concentrations and identified as "Normalized" to the USACE inflow. The alluvial load is based on the long-term median phosphorus concentration for 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.

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 2008.

Site	90th Percentile (cfs)
CC-10	39.93
SC-3	0.95
CT-1	10.01
CT-2	15.38
CTP-1	5.95
CTP-2	6.48

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,

µg/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 2009.

Month	CC-O	CC-10	SC-3	CT-P1	CT-P2	CT-1	CT-2
January	83	185	29	8	16	102	52
February	62	141	31	21	47	75	63
March	75	145	83	29	19	79	62
April	85	196	36	34	27	78	48
May	80	58	274	38	37	36	38
June	350	348	175	87	75	39	56
July	200	485	171	113	99	46	42
August	83	294	331	104	75	66	13
September	101	245	79	79	66	47	71
October	58	190	47	35	53	53	65
November	67	155	44	29	31	79	41
December	81	188	46	13	50	95	64
Annual storm flow median	--	435	179	234	152	108	102

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 2009 export load (Equation 1).

Precipitation

Precipitation data collected at Denver/Centennial Airport (KAPA) was used to estimate phosphorus loading due to precipitation in 2009 (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.

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 ft. At depths greater than 2 ft 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 2009 alluvial component was defined as a constant source of water to the reservoir that accounted for 2,000 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

Redistributed Inflows

In 2009, 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 ac-ft will be redistributed among the two streams, and the remainder will be placed into an "Ungaged Inflow" category. The reasoning behind this category is if the redistributed inflow is truly this great, then the current inflow monitoring regime should be reevaluated to address such occurrences. In April 2009, extensive storm flow events resulted in 92 ac-ft of water being categorized as Ungaged Inflow.

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	970	599	559	24	56	58	149	187	20	170	585	196
February	1,470	1,430	518	6	47	45	131	173	18	153	973	325
March	1,662	1,579	544	6	106	91	183	190	81	170	1,046	365
April	4,750	3,396	2,398	89	340	428	594	850	246	164	3,136	1,112
May	2,771	2,908	1,763	23	165	209	327	403	158	170	1,989	454
June	5,242	4,675	3,416	115	231	291	433	565	228	164	4,162	688
July	3,499	2,971	2,473	55	315	330	474	734	228	170	2,392	710
August	1,260	1,210	1,031	22	157	120	232	302	87	170	776	227
September	1,567	1,299	706	15	302	160	281	381	162	164	806	435
October	2,231	2,124	1,085	28	194	196	388	443	232	170	1,299	531
November	2,537	2,024	1,747	22	164	209	411	407	23	164	1,906	444
December	1,777	1,909	1,337	25	106	105	284	219	40	170	1,347	221
Annual Total	**29,736**	**26,124**	**17,577**	**430**	**2,183**	**2,242**	**3,887**	**4,854**	**1,522**	**2,000**	**20,416**	**5,706**
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	--	135	281	8	1	3	41	26	6	88	294	28
February	--	241	199	0	3	6	27	30	6	79	373	56
March	--	322	215	2	30	10	39	32	26	88	413	62
April	--	788	2,419	41	161	147	160	205	77	85	3,164	268
May	--	629	604	13	48	43	50	69	50	88	681	78
June	--	4,450	3,816	56	103	96	87	133	72	85	4,650	162
July	--	1,616	3,083	27	159	118	101	168	72	88	2,981	163
August	--	273	824	18	63	31	44	22	28	88	620	17
September	--	357	512	3	128	40	48	84	51	85	584	95
October	--	335	633	9	65	57	75	100	73	88	757	119
November	--	369	899	5	29	29	96	75	7	85	981	82
December	--	421	684	3	4	14	73	38	13	88	689	38
Annual Total	**--**	**9,935**	**14,168**	**185**	**794**	**594**	**841**	**982**	**480**	**1,033**	**16,187**	**1,167**

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	780	746	34	75%	25%	26	9	0	14	13	1	0
February	1,298	691	607	75%	25%	455	152	0	200	174	26	0
March	1,411	734	677	74%	26%	502	175	0	228	198	30	0
April	4,340	3,248	1,092	74%	26%	738	262	92	808	745	63	70
May	2,443	2,166	278	81%	19%	226	52	0	86	77	9	0
June	4,850	3,981	869	86%	14%	746	123	0	862	833	29	0
July	3,101	3,207	-105	77%	23%	-81	-24	0	-107	-101	-6	0
August	1,002	1,333	-330	77%	23%	-256	-75	0	-210	-204	-6	0
September	1,241	1,088	153	65%	35%	99	54	0	84	72	12	0
October	1,829	1,528	302	71%	29%	214	87	0	145	125	20	0
November	2,350	2,154	196	81%	19%	159	37	0	89	82	7	0
December	1,568	1,556	11	86%	14%	10	2	0	5	5	0	0
Annual Total	**26,214**	**22,430**	**3,784**	**--**	**--**	**2,839**	**853**	**92**	**2,204**	**2,019**	**185**	**70**

Appendix E

2009 Biological Data

Table E-1: Quantity and size of fish stocked in Cherry Creek Reservoir, 1985 to 2009.

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

Year	Species	Size (inches)	Number
	Walleye	0.2	2,400,000
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

Table E-2: 2009 Cherry Creek Reservoir Phytoplankton

	2009													
	17-Feb	17-Mar	21-Apr	12-May	29-May	16-Jun	1-Jul	14-Jul	28-Jul	11-Aug	26-Aug	15-Sep	29-Sep	14-Oct
Bacillariophyta														
Order Centrales														
Cyclotella meneghiniana							36		33					18
Cyclotella stelligera		1684	193	7		550			1227	766	447			
Cymbella affinis				7										
Cymbella tumida				7										
Stephanodiscus astraea minutula		60	11							192	140	303	44	74
Stephanodiscus hantzschii	88		43							109		37		18
Stephanodiscus niagarae					570	37								
Synedra radians										82				
Order Pennate														
Achnanthes minutissima			11											
Asterionella formosa		120	64	29	52	110	182							
Fragilaria construens												9		37
Fragilaria construens venter						18								
Fragilaria crotonensis					778	238	36					28	87	
Fragilaria pinnata							36					9		
Melosira ambigua													66	111
Melosira distans alpigena												9		
Melosira granulata			11								28			18
Navicula gregaria			11											
Navicula sp.							36							
Nitzschia acicularis	354	2045	21		17						140	9		
Nitzschia fruticosa			11											
Nitzschia microcephala									33					
Nitzschia palea									33					
Nitzschia paleacea						18								
Nitzschia sp.												9		
Chlorophyta														
Ankistrodesmus falcatus	177	180	75		52	55	36	148	199	192	84	9		37
Chlamydomonas sp.	1857	722	408	29	17	73	400	74	730	328	195	46	175	129
Coelastrum microporum										55	28			
Crucigenia crucifera												9		
Crucigenia quadrata		60	21	7			109		166	137	56	9	219	185
Crucigenia tetrapedia						18					28			
Dictyosphaerium ehrenbergianum										27				
Gloeocystis ampla											28			
Oocystis lacustris				44		18		19	33	137	84		44	
Oocystis pusilla			21	7	35	37	182	93	166	55	56	9	153	37
Pediastrum boryanum											28			
Pediastrum duplex					17			19	99					
Pediastrum tetras											28			
Scenedesmus abundans												18		18
Scenedesmus acuminatus			21							55		18		
Scenedesmus quadricauda	177	60	32		86	37	73	37		274	84	28	66	92
Selenastrum minutum		60	43		17				33	137				
Sphaerocystis schroeteri					17	55								
Tetraedron minimum					17						28	55		37
Tetrastrum staurogeniaforme			11				36							
Chrysophyta														
Chrysococcus rufescens													22	74
Dinobryon sertularia						92								
Kephyrion littorale												18	22	
Kephyrion sp.														18
Cyanobacteria														
Anabaena circinalis						37								
Anabaena flos-aquae						92				27	56	9		
Aphanizomenon flos-aquae								111						
Euglenophycota														
Trachelomonas acanthostoma												18		
Trachelomonas hispida												18		
Trachelomonas scabra												28		18
Pyrrophycophyta														
Glenodinium sp.	531	421	21	29			73	19	66	27	670		87	37
Gymnodinium sp.											28			
Peridinium cinctum							36	19	66		28			
Unidentified flagellate	1415	661		15	17	92			33		84		22	
Cryptophyta														
Cryptomonas erosa	707	60	75	407	86	92	145	93	199	246	279	257	1180	684
Rhodomonas minuta	5571	481	32	218	86	330	7456	2318	298	55	251	9	328	333
Total Density (cells/mL)	10877	6615	1138	806	1866	1998	8875	2949	3416	2901	2875	972	2513	1978
Total Taxa	10	14	21	13	16	20	16	12	17	19	24	25	15	20

Table E-3: Reservoir mean phytoplankton density (cells/mL) and number of taxa in Cherry Creek Reservoir, 1984 to 2009.

Metric	1984	1985	1986	1987	1988	1989	1991	1992
Blue-Green Algae								
Density	71,780	66,496	99,316	168,259	155,180	273,175	307,691	77,516
Taxa	7	7	6	18	24	24	14	16
Green Algae								
Density	5,864	11,760	25,595	11,985	19,177	55,415	18,688	41,899
Taxa	11	10	13	58	76	66	46	48
Diatoms								
Density	1,776	3,863	5,428	10,677	12,880	9,311	4,160	1,243
Taxa	6	4	7	34	30	31	21	11
Golden-Brown Algae								
Density	--	7	125	469	56	505	821	93
Taxa	--	1	1	6	4	7	5	4
Euglenoids								
Density	514	135	208	251	276	108	89	23
Taxa	2	1	1	9	9	6	3	5
Dinoflagellates								
Density	--	13	19	19	83	28	23	54
Taxa	--	1	1	2	4	3	2	2
Cryptomonads								
Density	1,513	718	1,113	1,090	2,689	1,689	628	529
Taxa	2	3	3	6	4	5	2	3
Miscellaneous								
Density	--	--	--	--	--	--	--	--
Taxa	--	--	--	--	--	--	--	--
Total Density	81,447	82,992	131,804	192,750	190,341	340,231	329,773	121,357
Total Taxa	28	27	32	133	151	142	93	89

	1993	1994	1995	1996	1997	1998	1999	2000
Blue-Green Algae								
Density	15,708	10,015	18,194	16,599	19,716	44,951	15,263	164,290
Taxa	7	3	7	9	10	11	8	19
Green Algae								
Density	1,198	314	355	738	2,461	1,809	898	43,881
Taxa	16	2	11	11	18	18	18	71
Diatoms								
Density	946	194	2,189	2,354	1,109	628	838	12,019
Taxa	15	2	15	13	8	18	16	34
Golden-Brown Algae								
Density	158	3	63	249	227	56	--	391
Taxa	1	1	2	4	2	2	--	14
Euglenoids								
Density	231	196	304	409	838	698	1,252	126
Taxa	2	1	2	3	3	3	1	6
Dinoflagellates								
Density	--	31	5	21	--	18	45	80
Taxa	--	1	2	4	--	2	2	8
Cryptomonads								
Density	332	450	919	1,104	1,487	1,393	559	2,472
Taxa	1	1	1	1	1	1	1	4
Miscellaneous								
Density	--	--	--	--	--	--	--	1,923
Taxa	--	--	--	--	--	--	--	1
Total Density	18,573	11,203	22,029	21,474	25,838	49,553	18,855	225,182
Total Taxa	42	11	40	45	39	55	46	157

Table E-3: Reservoir mean phytoplankton density (cells/mL) and number of taxa in Cherry Creek Reservoir, 1984 to 2009.

Metric	2001	2002	2003	2004	2005	2006	2007	2008
Blue-Green Algae								
Density	148,691	941	54,114	165,677	79,154	665,696	1,266,765	1,124,197
Taxa	12	3	21	27	19	19	21	19
Green Algae								
Density	33,217	1,973	55,190	56,236	189,777	1,358,248	563,344	1,531,579
Taxa	56	27	70	75	66	63	63	67
Diatoms								
Density	5,256	978	2,026	1,720	3,610	32,036	60,127	27,681
Taxa	22	24	22	26	24	21	21	17
Golden-Brown Algae								
Density	1,346	34	44	57	335	542	2,380	6,270
Taxa	13	3	5	5	4	5	3	3
Euglenoids								
Density	91	22	308	24	39	1,549	1,303	259
Taxa	4	3	9	11	8	10	10	11
Dinoflagellates								
Density	157	193	20	57	60	330	595	722
Taxa	6	5	3	5	6	5	5	3
Cryptomonads								
Density	2,851	355	3,282	3,158	3,293	40,511	61,037	35,962
Taxa	6	4	8	8	9	12	9	11
Miscellaneous								
Density	5,714	15	1,294	164	2,014	4,855	73,435	53,330
Taxa	1	1	3	6	6	6	7	8
Total Density	197,323	4,511	116,278	227,093	278,282	2,103,767	2,028,986	2,780,000
Total Taxa	120	70	141	164	142	141	139	139

	2009	**Long-term Median**
Blue-Green Algae		
Density	332	**77,516**
Taxa	3	**12**
Green Algae		
Density	10733	**18,688**
Taxa	20	**46**
Diatoms		
Density	11609	**3,610**
Taxa	25	**21**
Golden-Brown Algae		
Density	246	**227**
Taxa	4	**4**
Euglenoids		
Density	83	**231**
Taxa	3	**3**
Dinoflagellates		
Density	4497	**50**
Taxa	4	**3**
Cryptomonads		
Density	22277	**1,487**
Taxa	2	**3**
Miscellaneous		
Density	--	**2,014**
Taxa	--	**6**
Total Density	49777	**121,357**
Total Taxa	61	**89**