



Geotechnical  
Water Resources  
Environmental and  
Ecological Services

# Cherry Creek Reservoir 2008 Annual Aquatic Biological Nutrient Monitoring Study and Cottonwood Creek Phosphorus Reduction Facilities Monitoring

Submitted to:

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## 1.0 Executive Summary

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The purpose of this report is to present the 2008 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.

### 1.1 Phosphorus Loading

The total inflow of gaged tributary streams and ungaged surface water flows was 16,084 ac-ft/yr and contributed 7,879 lbs of phosphorus to the Reservoir. Annual precipitation accounted for 792 ac-ft of water and contributed 250 lbs of phosphorus, while the normalized alluvial inflow was 1,965 ac-ft/yr, and contributed 1,015 lbs of phosphorus to the Reservoir.

Combined, the total external load to the Reservoir was 9,144 lbs in 2008, which was less than the phased Total Maximum Annual Load (TMAL) of 14,270 lbs/yr specified in Control Regulation No. 72. The 2008 flow-weighted total phosphorus concentration of 0.49 lbs/ac-ft (178 µg/L) was one of the lowest observed concentrations since 1992.

### 1.2 Total Phosphorus

Total phosphorus concentrations in the upper 3 m layer of the Reservoir ranged from 56 to 156 µg/L during the July to September sampling events, with a seasonal mean of 118 µg/L. The 2008 in-lake total phosphorus concentration was considerably greater than the phosphorus goal of 40 µg/L, which has been met only once since 1987. The long-term (1992 to 2008) seasonal mean total phosphorus concentration for the Reservoir is 84 µg/L.

### 1.3 Chlorophyll *a*

Chlorophyll *a* concentrations in the upper 3 m layer of the Reservoir ranged from 5.6 to 38 µg/L during the July to September sampling events, with a seasonal mean of 16.6 µg/L. Despite the operation of the destratification system, the seasonal mean chlorophyll *a* exceeded the standard of 15 µg/L. The long-term (1992 to 2008) seasonal mean chlorophyll *a* concentration for the Reservoir is 19.6 µg/L.

## **1.4 Temperature and Dissolved Oxygen**

The winter period for many front-range reservoirs is often a time of concern, because high algal activity, followed by mortality and microbial decomposition can create optimal conditions for reservoir anoxia during ice-covered periods. This phenomenon may potentially lead to a fish kill during the ice-covered period or even during spring turnover. Lake ice-cover during the winter December 2007 and January – February 2008 was insufficient to allow monitoring of dissolved oxygen. The dissolved oxygen profiles collected in early March, following the spring turnover period, was well oxygenated ( $>11$  mg/L) from the surface to the bottom of the Reservoir. Following spring turnover, the Reservoir was well mixed and oxygenated from March to early May 2008. From mid May through July, the Reservoir was periodically stratified, with brief periods of natural mixing that were induced by wind/storm events. By early June, 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.

The Reservoir was also evaluated for compliance with the dissolved oxygen criteria ( $>5$  mg/L) for Class I Warm Water lakes and reservoirs. As a conservative estimate, regardless of stratification, the mean dissolved oxygen concentration for the 0 to 6 m water layer was computed for each sampling event and revealed the Reservoir met the standard during all sample events in 2008.

## **1.5 Destratification System Effectiveness**

The 2008 summer season represents the first full seasonal operation of the destratification system with mixed results for the first year of observations. The continuous temperature monitoring shows that storm events greatly influence water temperatures, especially in the deeper layers because the cooler waters are more dense. These events give rise to conditions that are conducive for thermal stratification. The destratification system was effective in circulating the upper waters of the reservoir, but appears to be less effective at eroding the 6 to 7 m layer near the bottom of the reservoir. The increased reservoir circulation, via the destratification system, also resulted in slightly cooler surface water temperatures ( $1.5$  °C) despite a  $2.5$  °C increase in ambient air temperatures over the same period in 2007.

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.

From July to early August the Reservoir did contain a dominant assemblage of green algae (favorable algae), but was replaced by a cyanobacteria (undesirable algae) in late August

which was persistent through November. It is too soon in the destratification monitoring to evaluate changes in patterns of algal species composition or succession. However, the destratification system is designed to disrupt the useable habitat for cyanobacteria and limit their growth potential. It is also possible that the destratification system may effectively delay the onset algal growth.

## **1.6 Pollutant Reduction Facility Effectiveness**

The Cottonwood Creek Peoria Pond PRF underwent routine maintenance during the early part of 2008 and became operational in May, thus the data presented herein are for a partial year of operation. The Cottonwood Creek Peoria Pond PRF was effective in removing 127 pounds or 37 percent of the phosphorus load from Cottonwood Creek. Further downstream, the Cottonwood Creek Perimeter Pond was observed to be less effective at reducing the phosphorus load to the Reservoir. The poor performance of the PRF is due to the Cottonwood Creek Stream Reclamation project. During the construction phase, there was a noticeable increase in the sediment load of flow that was being diverted around the Site CT - 1 ISCO gage. This diversion of flow also resulted in only a partial year of data being collected for the Perimeter Pond PRF. The Perimeter Pond released approximately 102 pounds of phosphorus, which accounted for a 28 percent increase in phosphorus load in Cottonwood Creek when compared to measurements upstream of the PRF.

## 2.0 Introduction

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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 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 ( $\mu\text{g/L}$ ) and seasonal mean chlorophyll *a* goal of 15  $\mu\text{g/L}$ . 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 was changed to a seasonal July-to-September mean value of 15  $\mu\text{g/L}$  of chlorophyll *a* to be met 9 out of 10 years, with an underlying total phosphorus goal of 40  $\mu\text{g/L}$ , also as a July-to-September mean. In May 2001 at the CWQCC hearing, a new control regulation 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 total maximum daily load (TMDL) for 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 – 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). 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 the concentrations of selected nutrients, primarily nitrogen and phosphorus compounds, in Cherry Creek Reservoir, major tributary inflows, and the Reservoir outflow.
- Determine the pounds of phosphorus entering Cherry Creek Reservoir from streams and precipitation and leaving the Reservoir through its outlet.
- 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.
- Determine relationships between the nutrient levels and biological productivity in Cherry Creek Reservoir through correlation of the various measurements made during the study.
- Assess the effectiveness of pollutant reduction facilities (PRF) on Cottonwood Creek to reduce phosphorus loads into the Reservoir.

This report presents the 2008 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.

## 3.0 Study Area

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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 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.

### 3.1 Sampling Sites

Sampling in 2008 was 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). The sampling sites are summarized below:

#### 3.1.1 *Cherry Creek Reservoir*

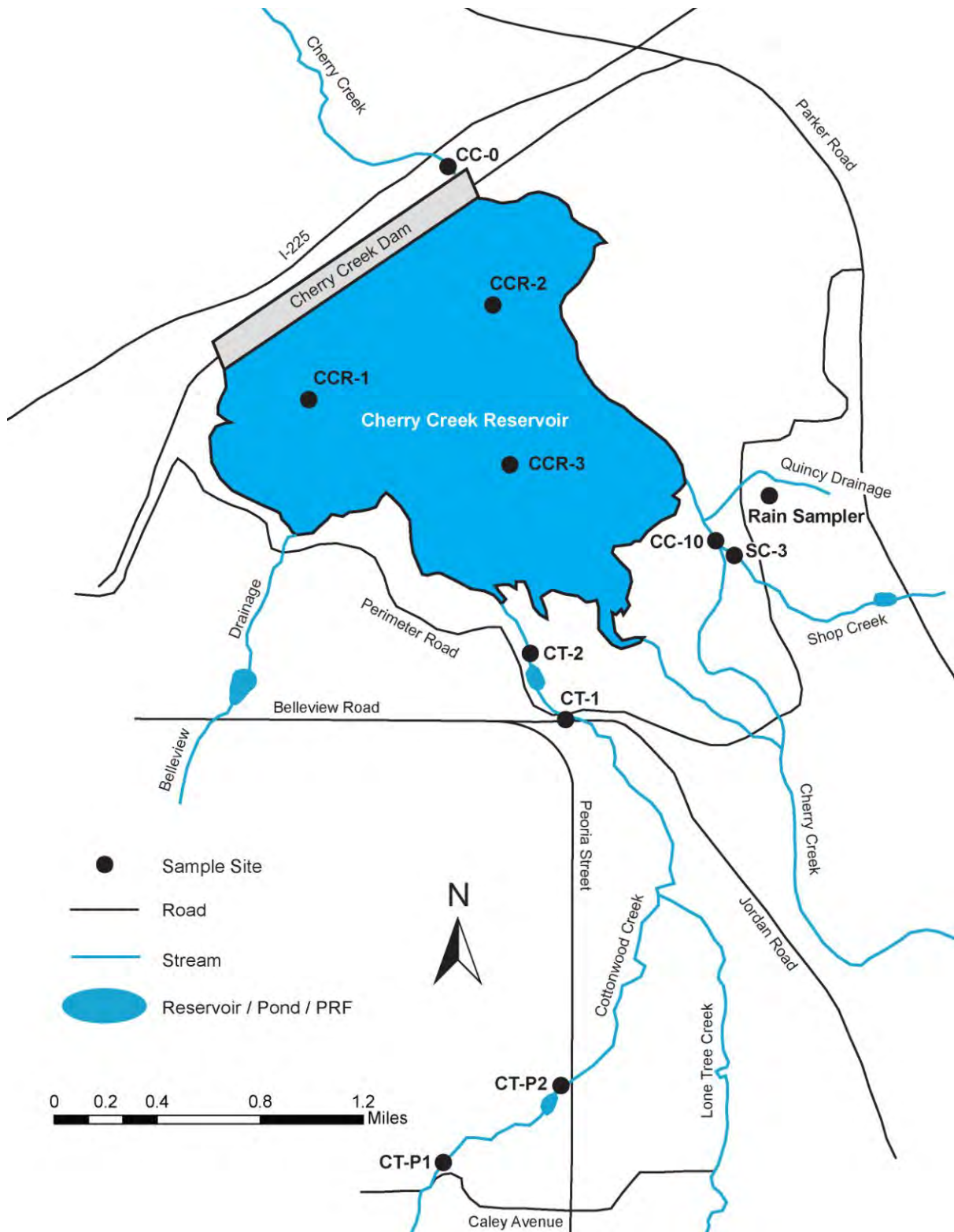
CCR-1 This site is also called the Dam site, and was established in 1987. CCR-1 corresponds to the northwest area within the lake (Knowlton and Jones 1993). Sampling was discontinued at this site in 1996 following determination that this site exhibited similar characteristics to the other two sites in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

#### 3.1.2 *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, 2008.**

### **3.1.3 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 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.

### **3.1.4 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 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.

## 4.0 Methods

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### 4.1 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 (CEC 2003b, Appendix A).

#### 4.1.1 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 14 reservoir sampling events were conducted in 2008. The December 2008 sampling event 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	2
May – Sept	Bi-Monthly	10	10
Oct – Dec	Monthly	3	2
	Total	17	14

##### 4.1.1.1 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).

##### 4.1.1.2 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. Data were collected using a Yellow Springs Instrument (YSI) meter, with Model #600 XL multi-probe sonde, that was calibrated prior to each sampling event to ensure accuracy of the measurements.

#### **4.1.1.3 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, 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.

#### **4.1.1.4 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 2 to 3 years in the past. The most recent fish population survey was conducted in 2004 by the CDOW (personal communication with Harry Vermillion, CDOW). Therefore, only the 2008 fish stocking data are presented herein.

### **4.1.2 Stream Sampling**

#### **4.1.2.1 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.

#### **4.1.2.2 Storm Sampling**

Storm events sampled at the inflow sites on Cherry Creek, Cottonwood Creek, and Shop Creek characterize non-base flow conditions during the 2008 sampling season (Table 2). A detailed outline of storm sampling protocols can be found in the Sampling and Analysis Plan (Appendix A).

**Table 2: Number of storm samples collected from tributary streams to Cherry Creek Reservoir, 2008. See Appendix C for sample dates.**

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

\* Storm samples not collected during construction of Cottonwood Creek Reclamation Phase II project.

### **4.1.3 Surface Hydrology**

Pressure transducers attached to ISCO Series 4200 or 6700 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.

## **4.2 Laboratory Procedures**

### **4.2.1 Nutrient Laboratory Analysis**

Physicochemical and biological analyses from the Reservoir and stream water quality samples were performed by the GEI analytical laboratory in Littleton, Colorado (Table 3). In past years randomly selected QA water samples were also sent to the University of Colorado, Center for Limnology, for nutrient analyses as a quality assurance check. Comparisons of inter-laboratory data were analyzed up until 2007, at which time the methodologies used by GEI were deemed to be appropriate; therefore, Quality Assurance/Quality Control aspects of nutrient analysis were conducted by GEI laboratories in 2008.

### **4.2.2 Biological Laboratory Analysis**

Biological analyses of the Reservoir phytoplankton samples were conducted by the University of Colorado Center of Limnology and GEI. The University of Colorado 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). 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, 2008.**

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 <i>a</i>	APHA 10200 H (modified)	1 µg/L

APHA = American Public Health Association, 1998.

### 4.3 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 2008 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.

## 5.0 Results and Discussion

### 5.1 Reservoir Water Quality

#### 5.1.1 2008 Transparency

The whole-reservoir mean Secchi depth varied from 0.57 m in early July to 1.61 m in late May (Figure 2). The seasonal (July to September) whole-reservoir mean Secchi depth was 0.80 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 1.89 m in early July to a maximum depth of 4.71 m in late May (Figure 2). The period from late May to early June represented a time when chlorophyll *a* levels were among the lowest observed and water clarity was at its best, with 1 percent light transmittance averaging 4.6 m. There was no

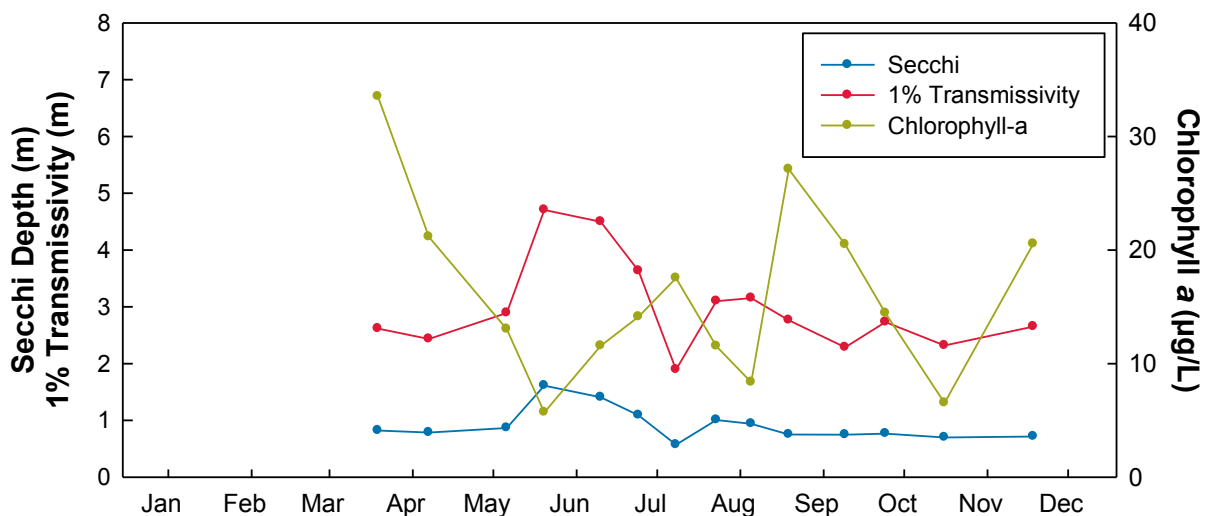
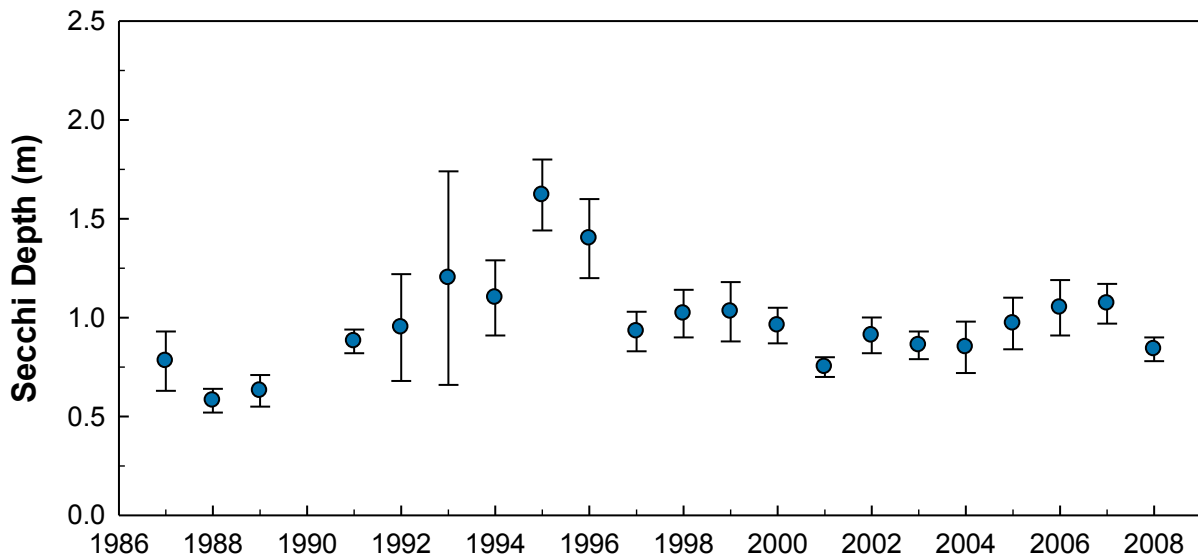


Figure 2: Annual patterns for mean whole-lake Secchi depth, 1% transmissivity, and chlorophyll *a* in Cherry Creek Reservoir, 2008.

#### 5.1.2 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 2008 seasonal whole-reservoir mean Secchi depth was less than the long-term mean value of 1.07 m since 1992.



**Figure 3: Whole-lake seasonal mean (July to September) Secchi depths (m) measured in Cherry Creek Reservoir, 1987 to 2008. Error bars represent a 95 percent confidence interval for each mean.**

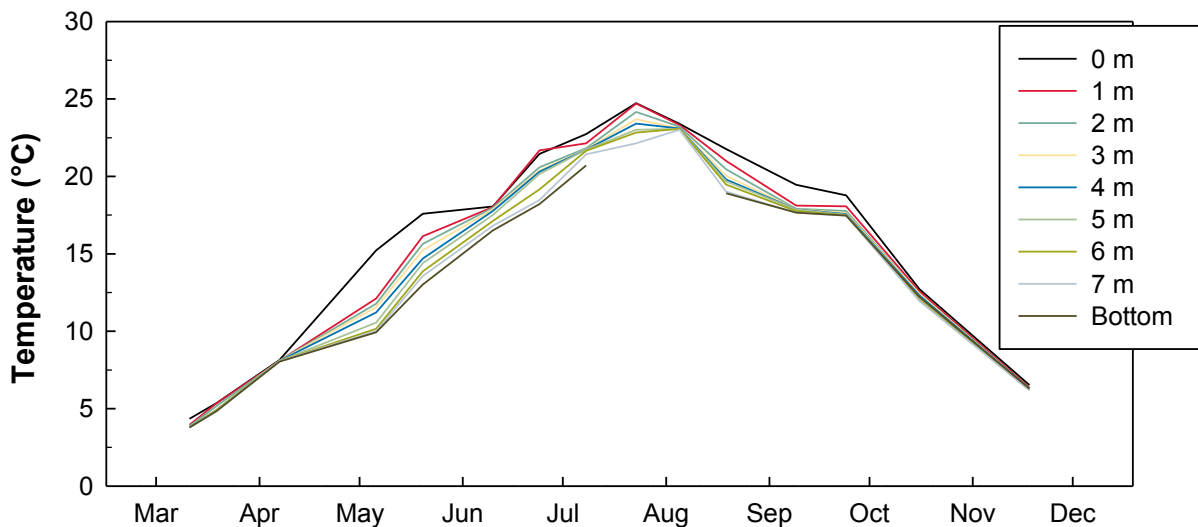
### 5.1.3 2008 Temperature and Dissolved Oxygen

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.

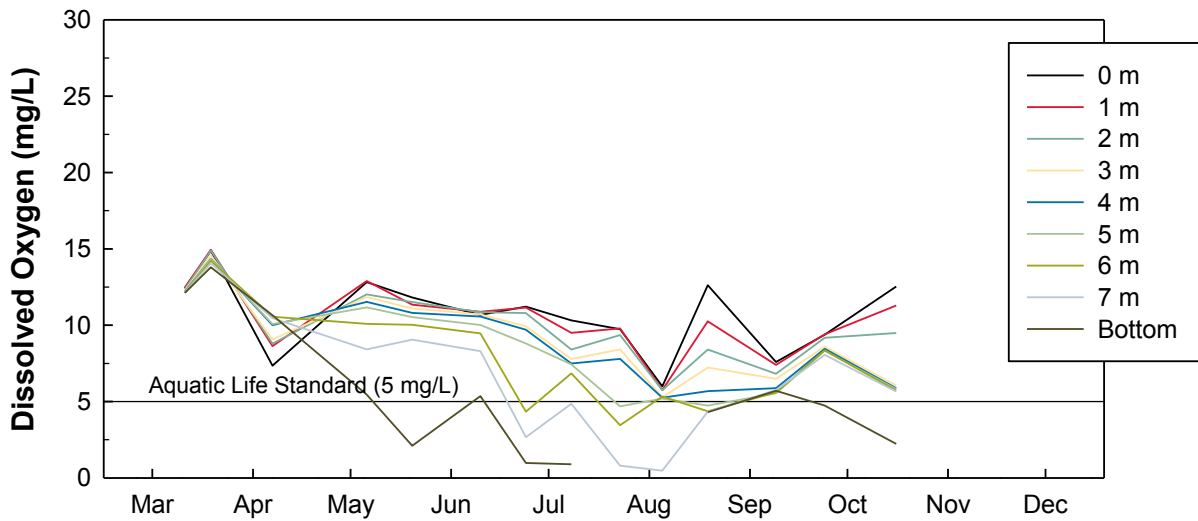
Measurement of routine water temperatures (i.e., YSI multimeter) in Cherry Creek Reservoir ranged from 3.5 °C at the bottom in early March to 25.5 °C at the surface in late July. Following the spring turnover in early March, the Reservoir was well mixed and oxygenated in March, April, and May. By June, 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 during most of the summer period. Periods of thermal stratification were observed in the Reservoir at all lake sites (5.1.3.1).

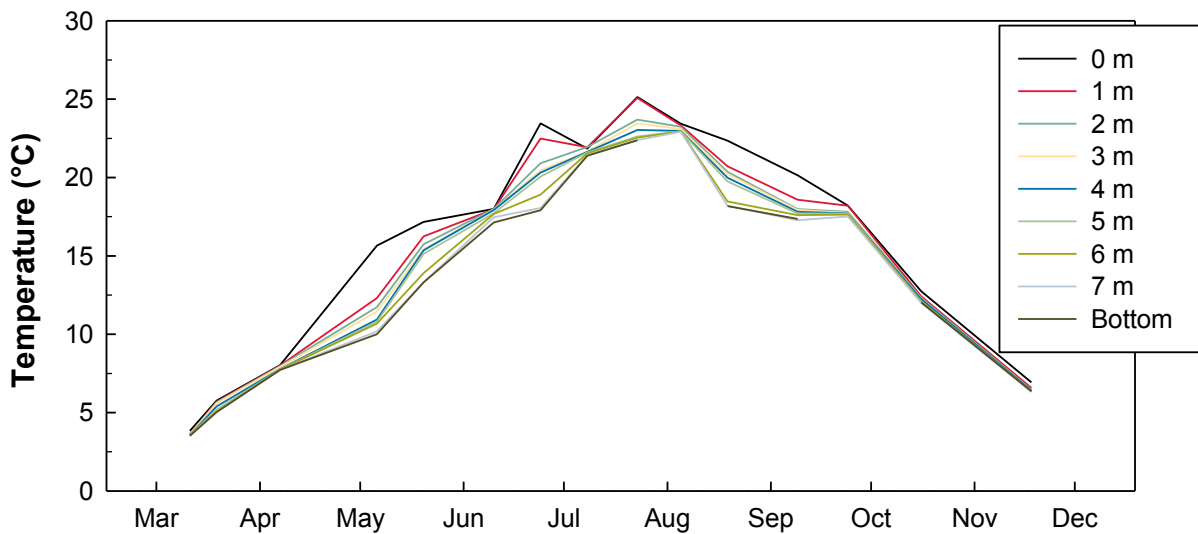
Water column dissolved oxygen profiles were also compared to the table value standard (5 mg/L) for Class 1 Warm Water lakes and reservoirs (Figure 5, Figure 7, and Figure 9). The Colorado Department of Public Health and Environment ([CDPHE] 2007) established this value as the year round warm water aquatic 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, and ranged from 5.66 mg/L in early August to 15.2 mg/L in late March (November data was excluded due to DO probe malfunction). The Reservoir met the Class 1 warm water criteria during all sample events.



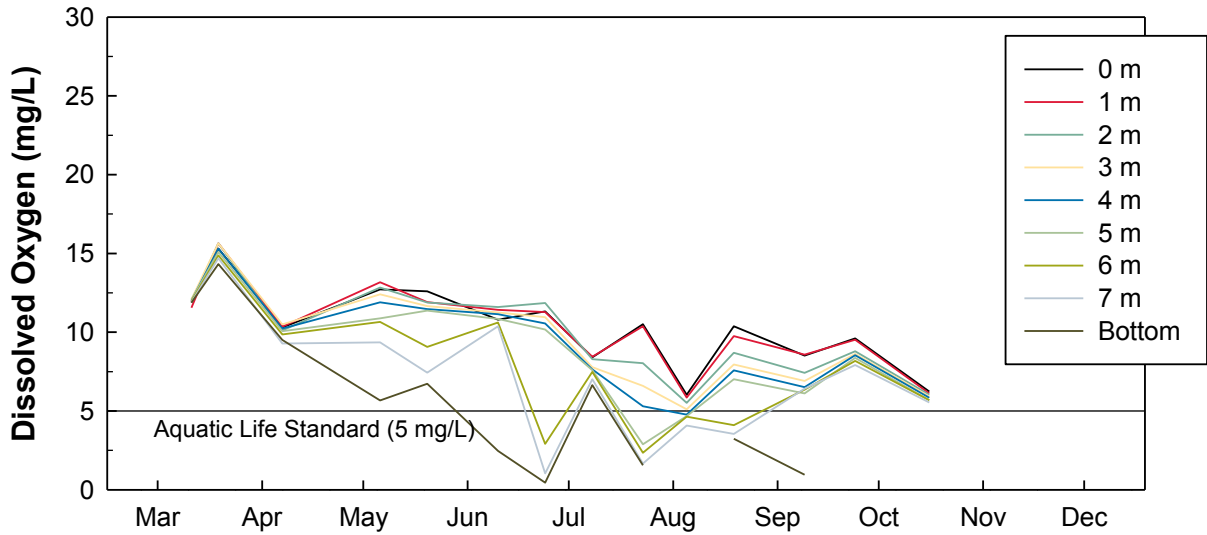
**Figure 4: Temperature (°C) recorded at depth during routine monitoring at Site CCR-1 in 2008.**



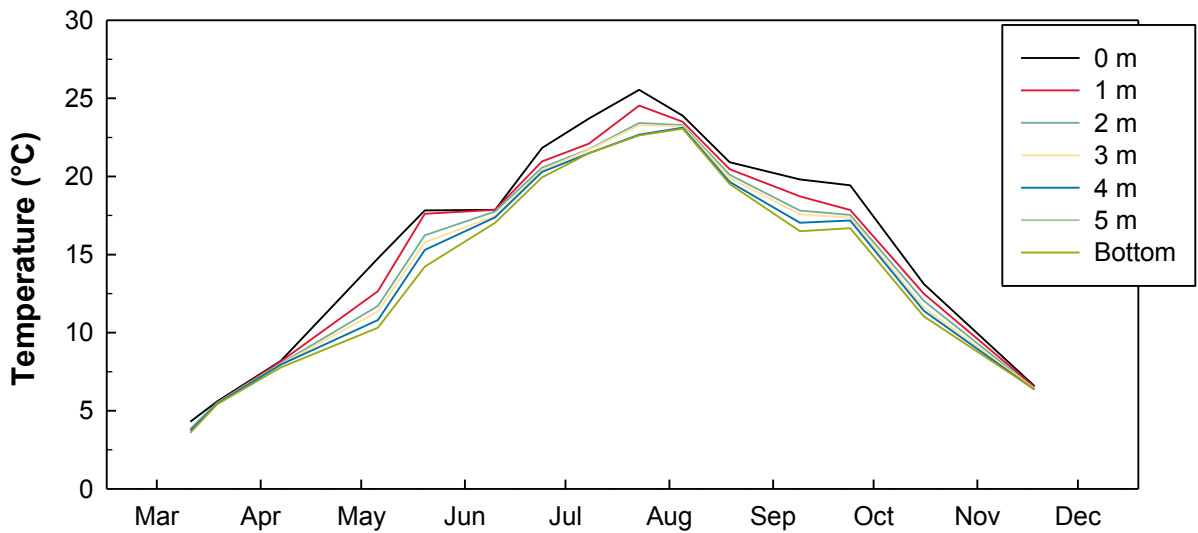
**Figure 5: Dissolved oxygen (mg/L) recorded at depth during routine monitoring at Site CCR-1 in 2008. The dissolved oxygen basic standards table value for Class 2 warm water lakes and reservoirs is provided for comparison (5 mg/L).**



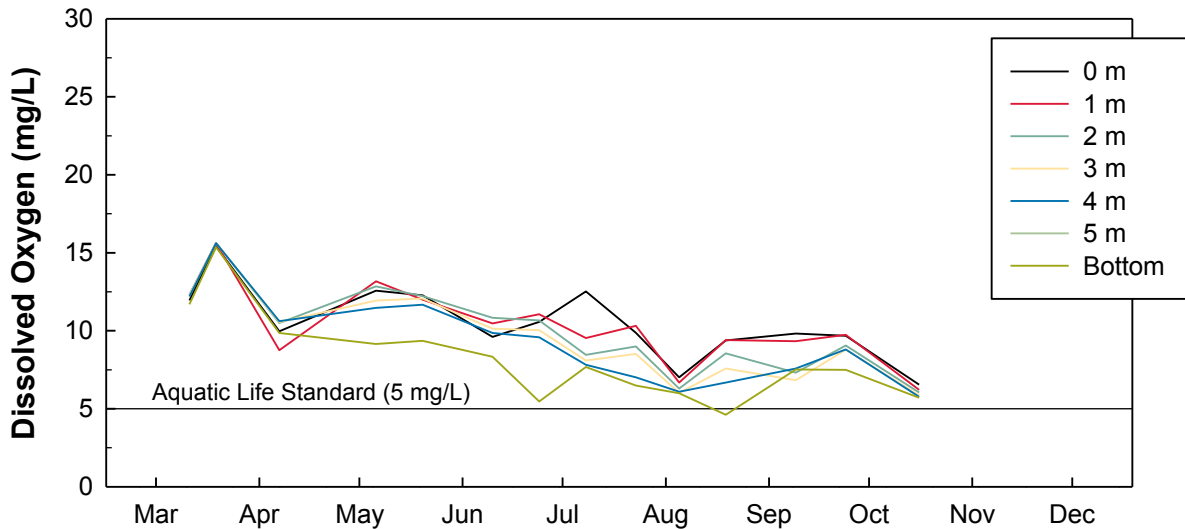
**Figure 6: Temperature (°C) recorded at depth during routine monitoring at Site CCR-2 in 2008.**



**Figure 7: Dissolved oxygen (mg/L) recorded at depth during routine monitoring at Site CCR-2 in 2008. The dissolved oxygen basic standards table value for Class 2 warm water lakes and reservoirs is provided for comparison (5 mg/L).**



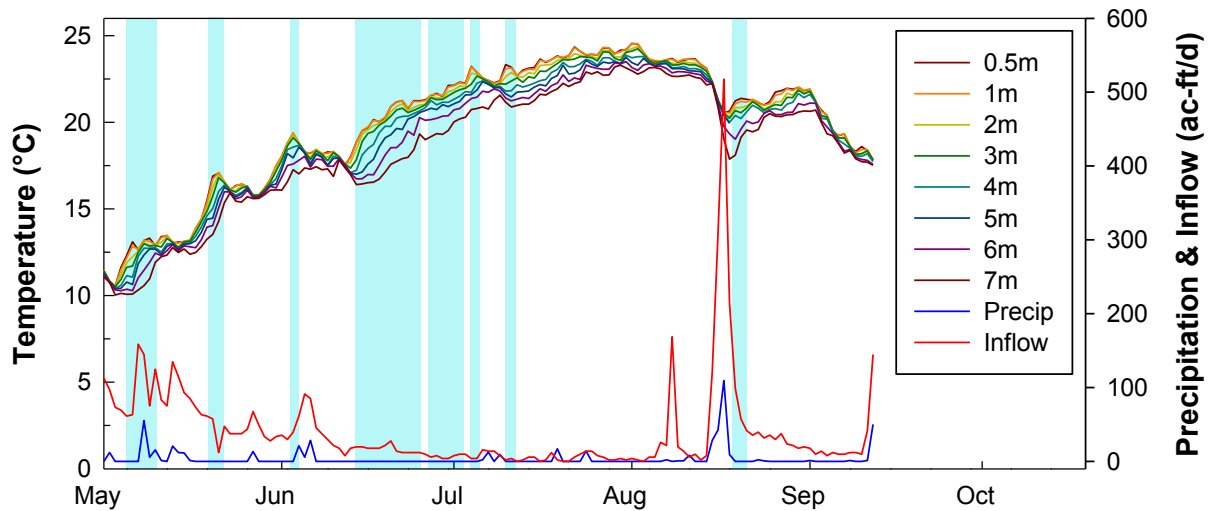
**Figure 8: Temperature (°C) recorded at depth during routine monitoring at Site CCR-3 in 2008.**



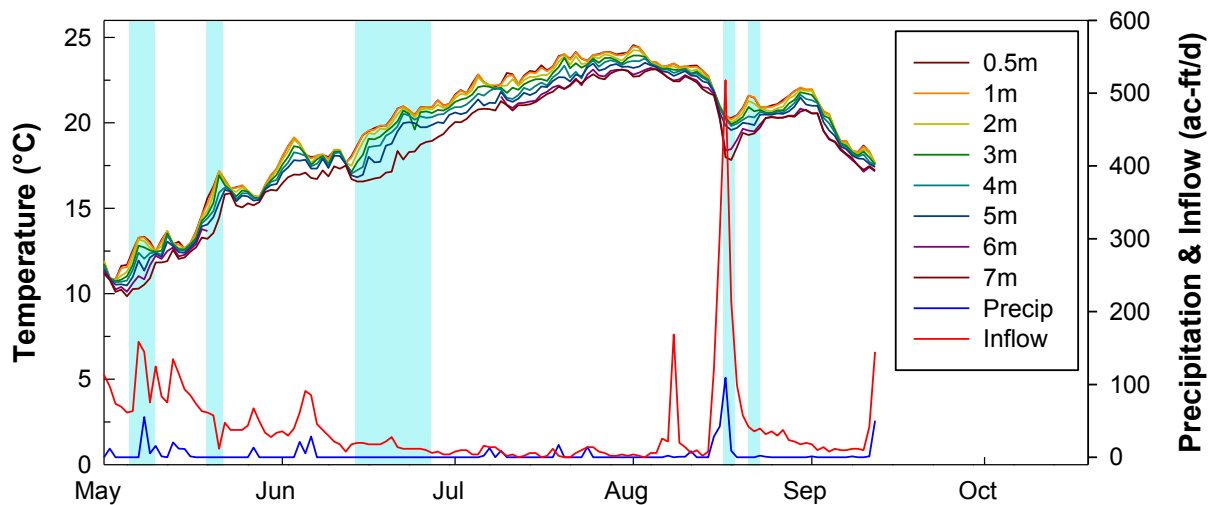
**Figure 9: Dissolved oxygen (mg/L) recorded at depth during routine monitoring at Site CCR-3 in 2008. The dissolved oxygen basic standards table value for Class 2 warm water lakes and reservoirs is provided for comparison (5 mg/L).**

#### 5.1.3.1 Continuous Temperature Monitoring

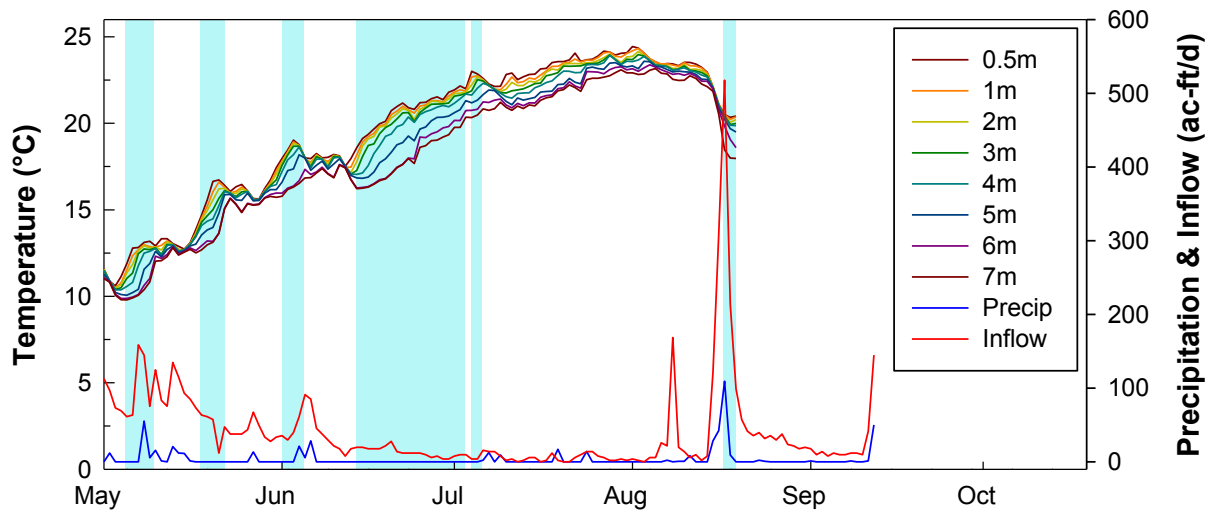
In March 2008, temperature loggers were deployed for monitoring the efficiency of the destratification system at mixing the water column. From March through April the temperature loggers revealed a very uniform water column temperature, and it was not until May 6<sup>th</sup> before the Reservoir started showing signs of variation in water temperature (Figure 4, Figure 6, and Figure 8). Using the  $> 2^{\circ}\text{C}$  difference criteria from the surface to bottom, Cherry Creek Reservoir was investigated for periods of stratification using the continuous temperature record at depths for all three Reservoir sites from May 1<sup>st</sup> to September 12<sup>th</sup> (Figure 10, Figure 11, and Figure 12). From May to mid-June the Reservoir showed brief periods of thermal stratification. From mid-June through the first week of July, the weather conditions appeared favorable for the development of thermally stratified conditions using the  $> 2^{\circ}\text{C}$  criteria (Figure 10 – Figure 12). In addition, the difference in temperature from the 5 m to 6 m layer and even the 6 m to 7 m layer was often  $> 1^{\circ}\text{C}$ , lending further support of stratified conditions. The storm events in early July appear to have briefly disrupted stratification and the input of storm water affected water temperatures. Similarly, in mid-August, storm events again disrupted water temperatures with cooler inflows entering the Reservoir along the bottom. The cooler waters briefly set up a thermally stratified period in mid-August. 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.



**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.**

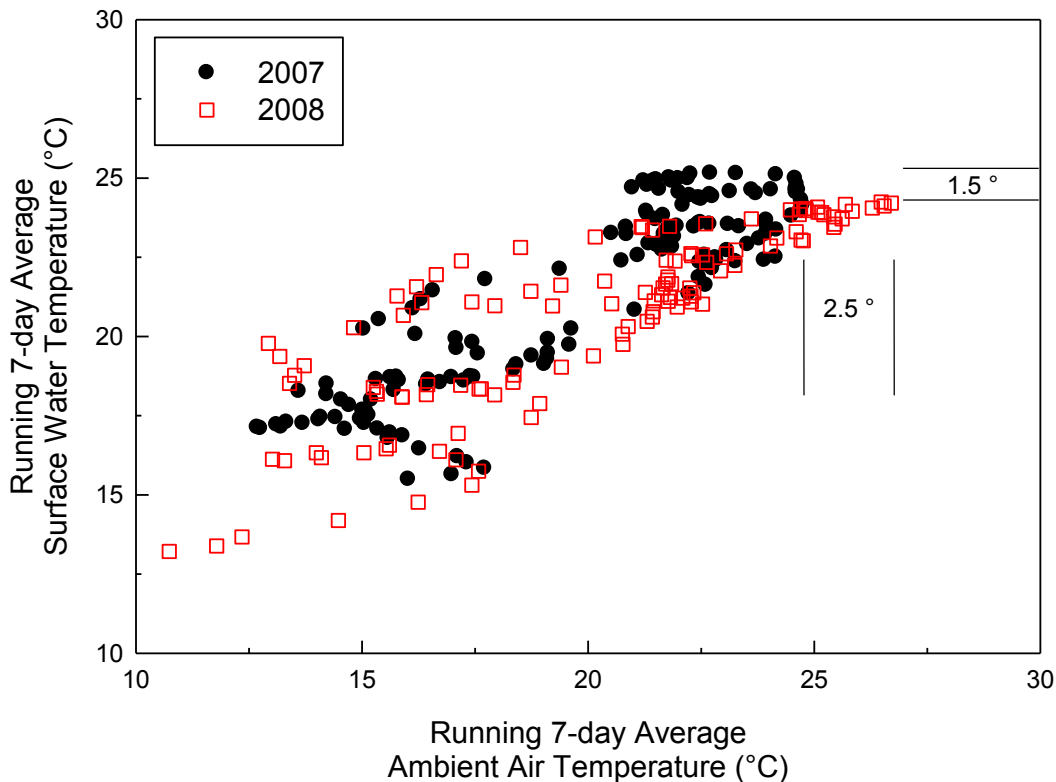


**Figure 11: Daily mean temperature recorded at depth for Site CCR-2 based on 15-minute interval data collected by temperature loggers, with USACE inflow and KAPA precipitation. Shaded areas denote periods of thermal stratification.**



**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.**

Despite the lack of evidence of complete water column mixing by the destratification system, there is evidence that the mixing of the upper water layers has resulted in slightly cooler reservoir temperatures. Ambient air temperatures collected at the KAPA weather station from May 15<sup>th</sup> to September 12<sup>th</sup>, for both 2007 and 2008, were compared to Reservoir water temperatures during the same time period (Figure 13). The maximum running 7-day average ambient air temperature was approximately 2.5 °C warmer during the 2008 season than during same period in 2007, yet the maximum surface water temperature of the Reservoir was approximately 1.5 °C cooler. This difference is likely due to the circulation pattern resulting from the destratification system, though storm water inflows may also affect this relationship as deeper waters are circulated.



**Figure 13: Running 7-day average surface water temperatures for the reservoir were evaluated against running 7-day ambient air temperature averages recorded at the KAPA weather gage. Differences between 2007 and 2008 were compared.**

#### **5.1.3.2 Dissolved Oxygen and Oxidation-Reduction Potential Transect**

In 2008, 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 Map Appendix F). 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 14).

During the first sample date on June 24<sup>th</sup>, the Reservoir was well oxygenated (6 – 11 mg/l DO) from the surface down to a depth of approximately 6 m. This pattern was consistent from Site D1 near the dam to Site D9, at which point the maximum Reservoir depth became shallower (4-5 m). From the 6 m layer to the bottom of the Reservoir (mean max profile depth = 7.2 m; n = 6), dissolved oxygen levels were less than 5 mg/L (warm water aquatic life standard), with dissolved oxygen levels at the water/sediment interface less than 1 mg/L (Figure 14).

The oxidation-reduction potential profiles on June 24<sup>th</sup> also indicate that conditions were favorable for a reducing environment at the water/sediment interface (Figure 15).

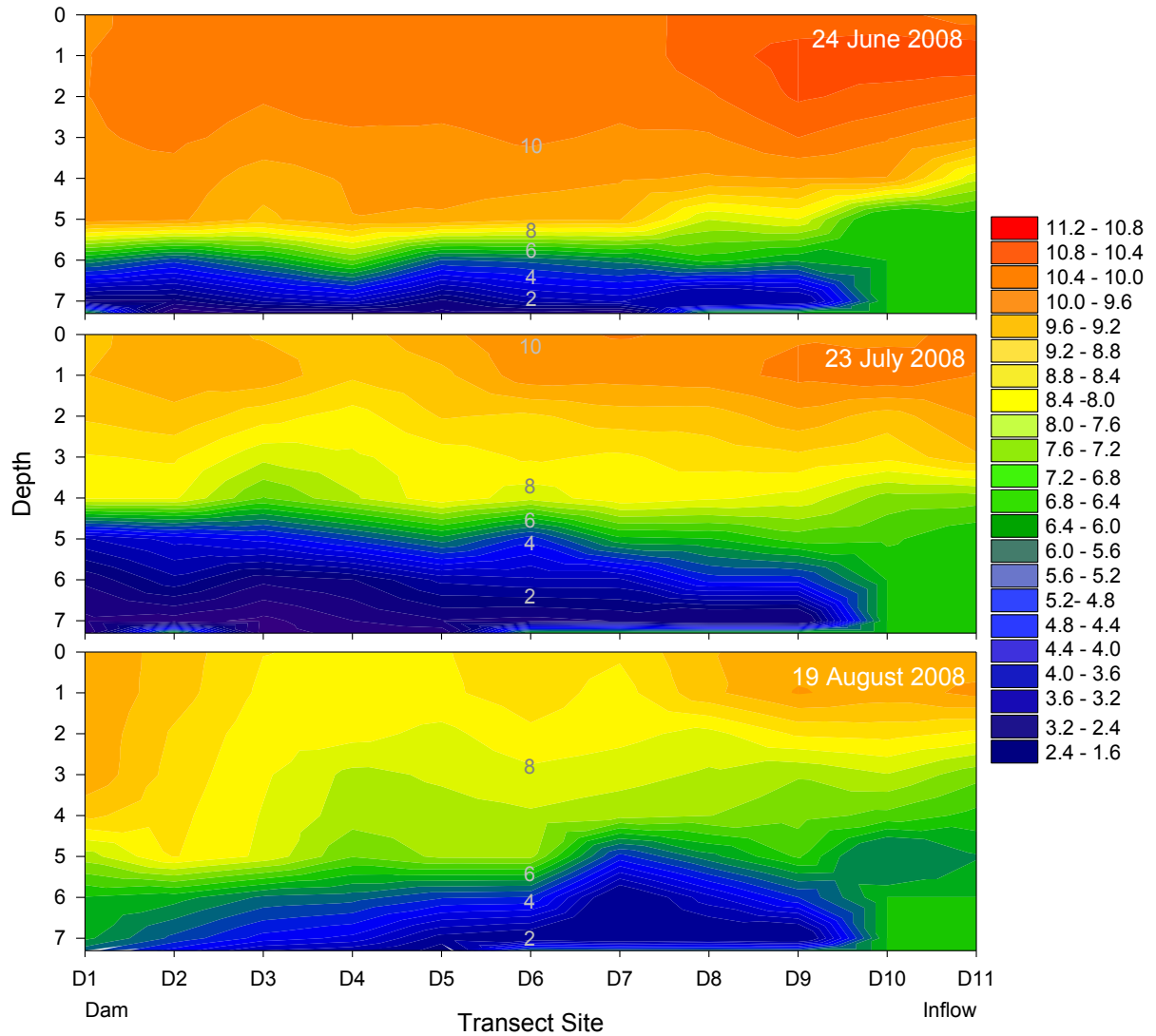
The water/sediment interface acts as a barrier to the free exchange of soluble phosphorus between water and sediment, and when conditions are favorable (e.g., anoxic – reducing environment) phosphorus is released (i.e., internal load) at rates as much as 1,000 times faster than during well oxygenated 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 23, the boundary layer defined by the 5 mg/L dissolved oxygen level migrated upward to approximately the 4.5 m water depth near the dam, and approximately the 5.5 m layer at Site D9 (Figure 14).

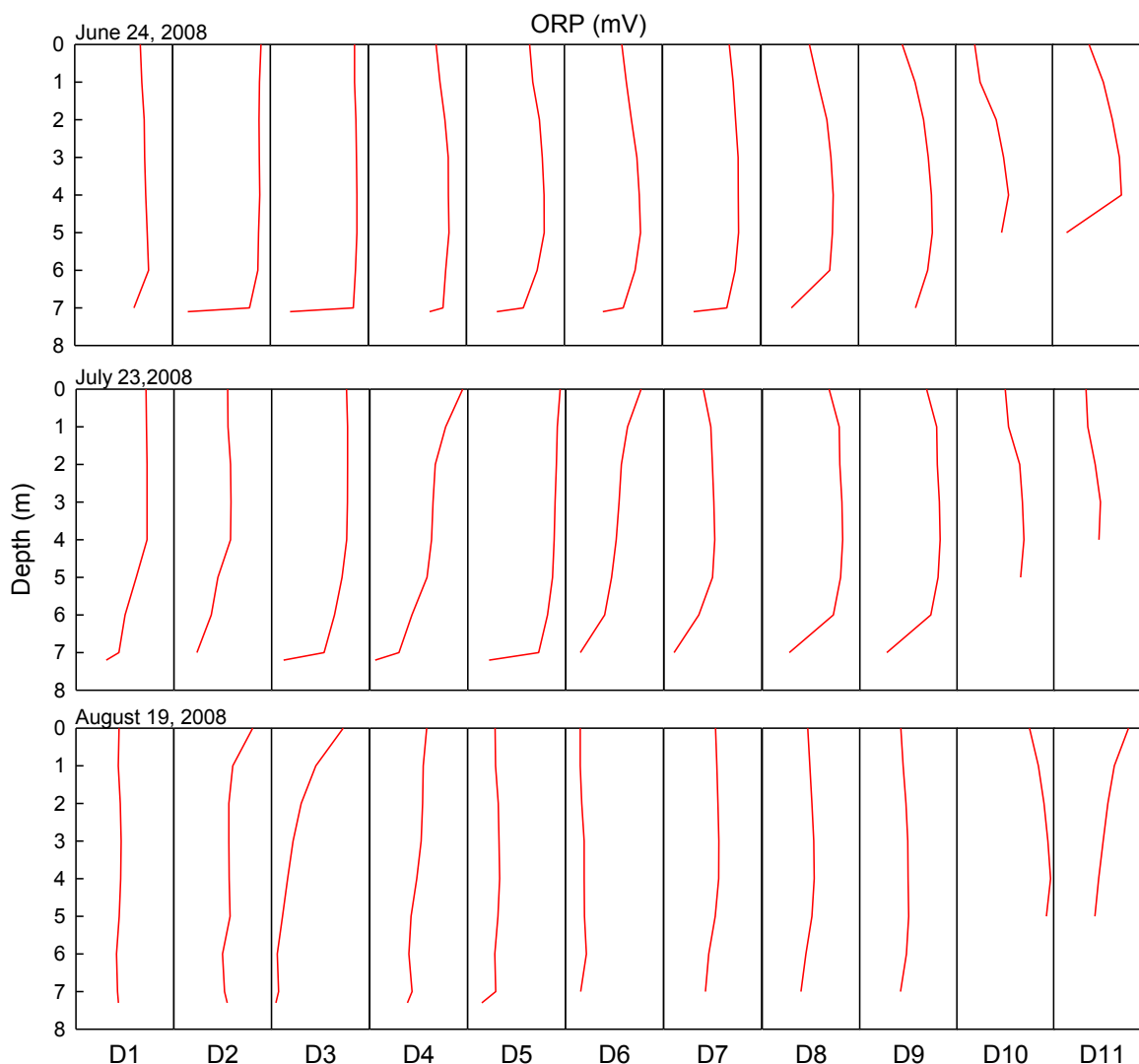
Below these depths, dissolved oxygen levels were considerably less, with levels less than 1 mg/L at the water/sediment interface. Similarly, the oxidation-reduction potentials at the water/sediment interface were favorable for a reducing environment (Figure 15).

On August 19<sup>th</sup>, the timing of the transect profiles followed a major storm event that occurred days earlier, and during that period, including the day of collection there was a moderate southerly wind blowing from the inlet towards the dam. The dissolved oxygen profiles collected during this event provide a snap-shot of the whole-reservoir mixing event that resulted from the storm event, and shows the movement of well oxygenated surface waters towards the dam. Ultimately, the dam forces the overlying water to the bottom of the Reservoir and degraded the stratified oxic conditions observed during the previous month (Figure 14).

The oxidation-reduction profiles also indicate that conditions were becoming less favorable for a reducing environment following the storm event (Figure 15).



**Figure 14: Dissolved oxygen conditions in Cherry Creek Reservoir for three dates based on transect profile data.**



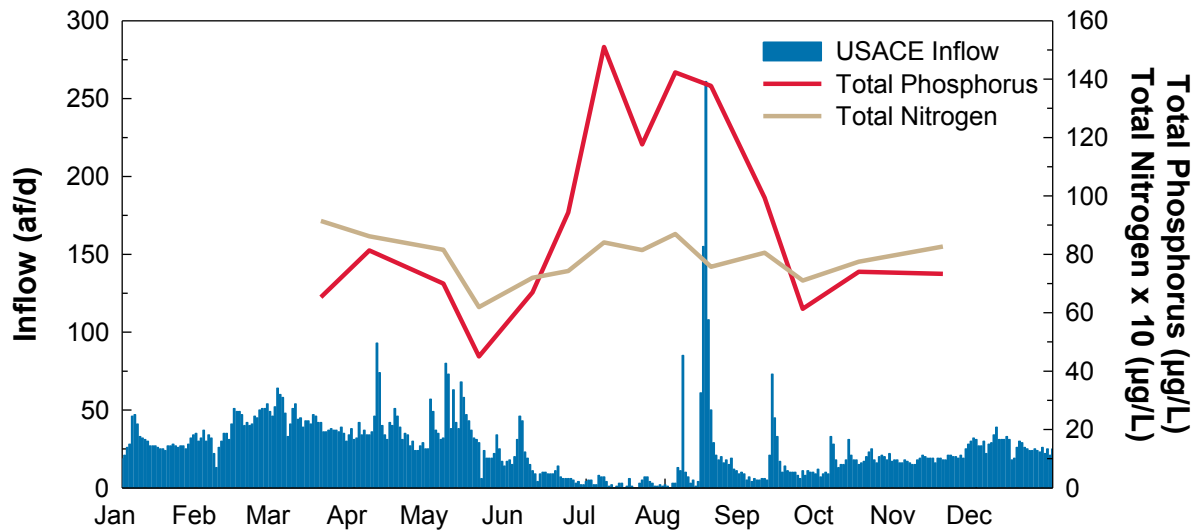
**Figure 15: Oxidation reduction potentials in Cherry Creek Reservoir for three dates based on transect profile data. The ORP (mV) scales for each profile within each sample event panel are all relative to each other, but are different with respect to the three sample events. Oxidation-reduction potentials (mV) are provided in Appendix B.**

#### **5.1.4 2008 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 2008, the photic zone mean concentration of total phosphorus ranged from 45 to 151  $\mu\text{g/L}$  with an overall annual mean of 91  $\mu\text{g/L}$ . The seasonal photic zone mean (July-to-September)

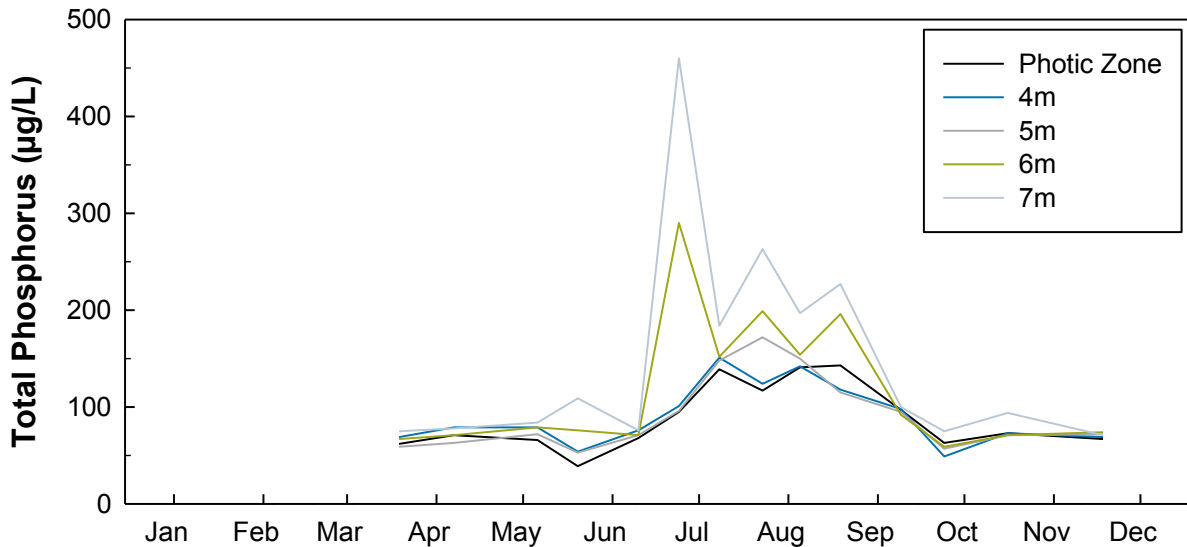
concentration ranged from 61 to 151  $\mu\text{g/L}$ , with a seasonal mean of 118  $\mu\text{g/L}$  (Figure 16). Monthly reservoir phosphorus concentrations did not correlate with monthly USACE inflow or phosphorus loads. The annual phosphorus pattern indicates internal loading substantially



**Figure 16: Annual pattern of photic zone total phosphorus, total nitrogen and USACE inflow in Cherry Creek Reservoir, 2008.**

Patterns in total phosphorus concentrations collected along depth profiles at Site CCR-2 showed a well-mixed Reservoir during the spring and fall (Figure 17). There were periods of nutrient release from bottom sediments from early June through August as evidenced by increasing total phosphorus concentrations in the deeper layers of the Reservoir (Figure 17).

Photic zone total nitrogen concentrations ranged from 619 to 914  $\mu\text{g/L}$ , with an annual average of 791  $\mu\text{g/L}$ . During the July-to-September period, the photic zone mean total nitrogen concentration ranged from 710 to 869  $\mu\text{g/L}$ , with a mean concentration of 800  $\mu\text{g/L}$ . There was no correlation between monthly reservoir total nitrogen concentrations and monthly USACE inflow.

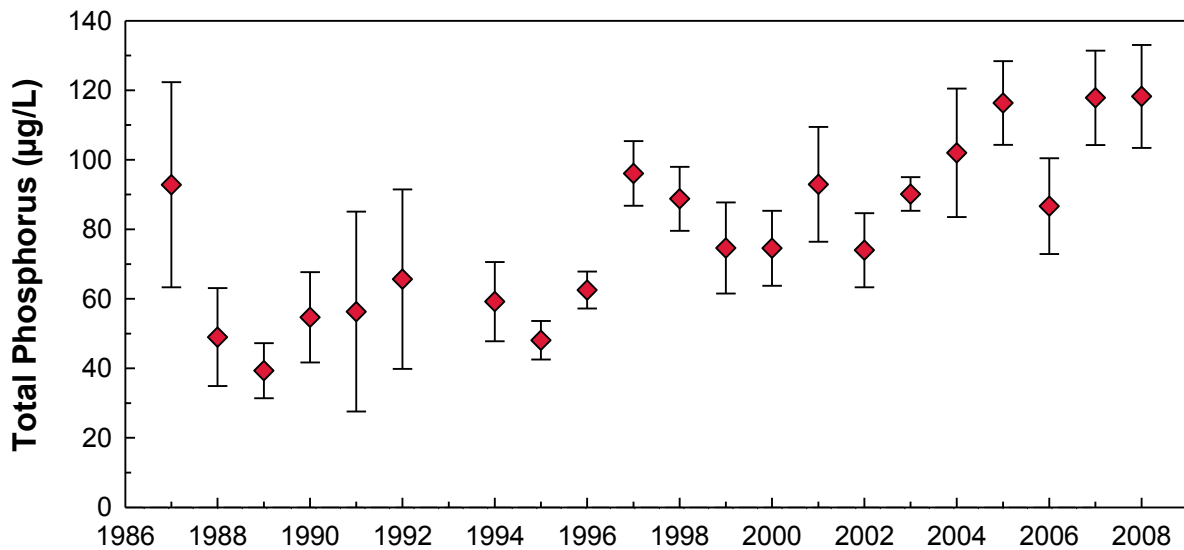


**Figure 17: Total phosphorus concentrations recorded for the photic zone and at depth during routine monitoring in 2008.**

### **5.1.5 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 2008 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 2008.

Routine monitoring data collected since 1987 indicates a general increasing pattern in summer mean concentrations of total phosphorus (Figure 18). In 2008, the July to September mean concentration of total phosphorus was 118 µg/L. This is the highest observed value since monitoring began in 1987 and is considerably greater than the long-term median value of 81 µg/L (Table 4). Regression analyses performed on 1987 to 2008 seasonal mean TP data indicates a significant ( $p < 0.01$ ) increasing trend. With the exception of the seasonal mean value observed in 1989 (39 µg/L), seasonal mean concentrations have consistently exceeded the goal of 40 µg/L over the past 20 years of monitoring.



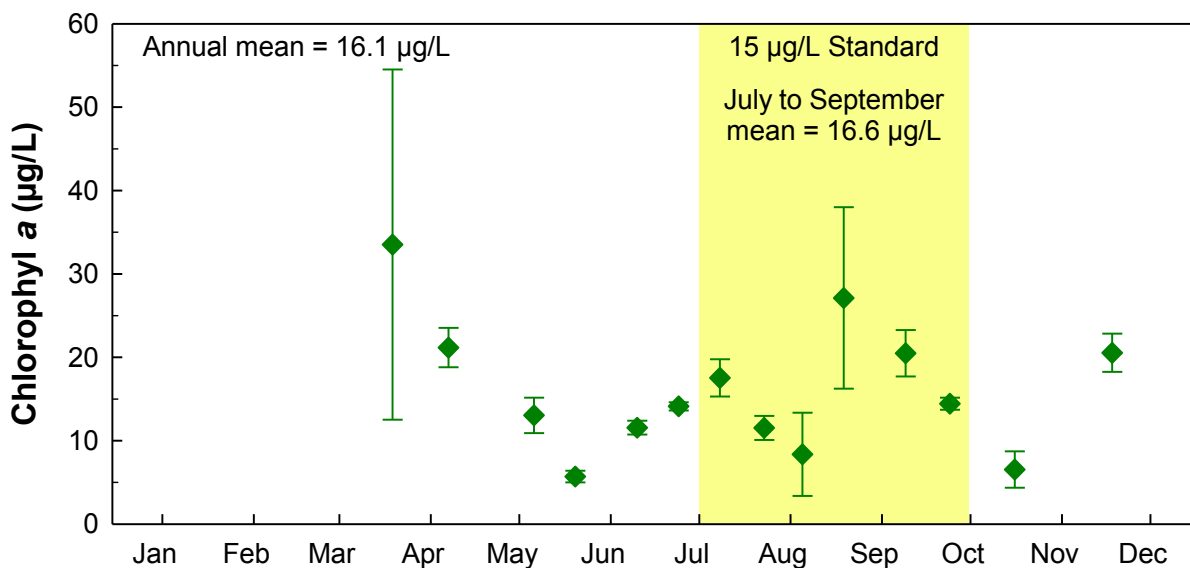
**Figure 18: Seasonal mean (July to September) total phosphorus concentrations (µg/L) measured in Cherry Creek Reservoir, 1987 to 2008. Error bars represent a 95 percent confidence interval for each mean.**

**Table 4: Comparison of annual mean (monitoring period) and July to September mean phosphorus, nitrogen, and chlorophyll a levels in Cherry Creek Reservoir, 1987 to 2008.**

Year	Total Nitrogen (µg/L)		Total Phosphorus (µg/L)		Mean Chlorophyll a (µg/L)	
	Annual	Jul-Sep	Annual	Jul-Sep	Annual	Jul-Sep
1987	1,580	741	86	93	11.1	8.3
1988	902	1,053	52	49	21.8	31.8
1989	803	828	45	39	8.5	5.6
1990	600	--	58	55	2.3	8.6
1991	1,067	1,237	86	56	9.7	9.8
1992	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	22.2
1998	850	880	82	89	21.7	26.6
1999	715	753	80	81	20.7	28.9
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
<b>Mean</b>	<b>897</b>	<b>920</b>	<b>73</b>	<b>79</b>	<b>16.1</b>	<b>18.1</b>
<b>Median</b>	<b>874</b>	<b>914</b>	<b>81</b>	<b>81</b>	<b>16.1</b>	<b>17.3</b>

### 5.1.6 2008 Chlorophyll *a* Levels

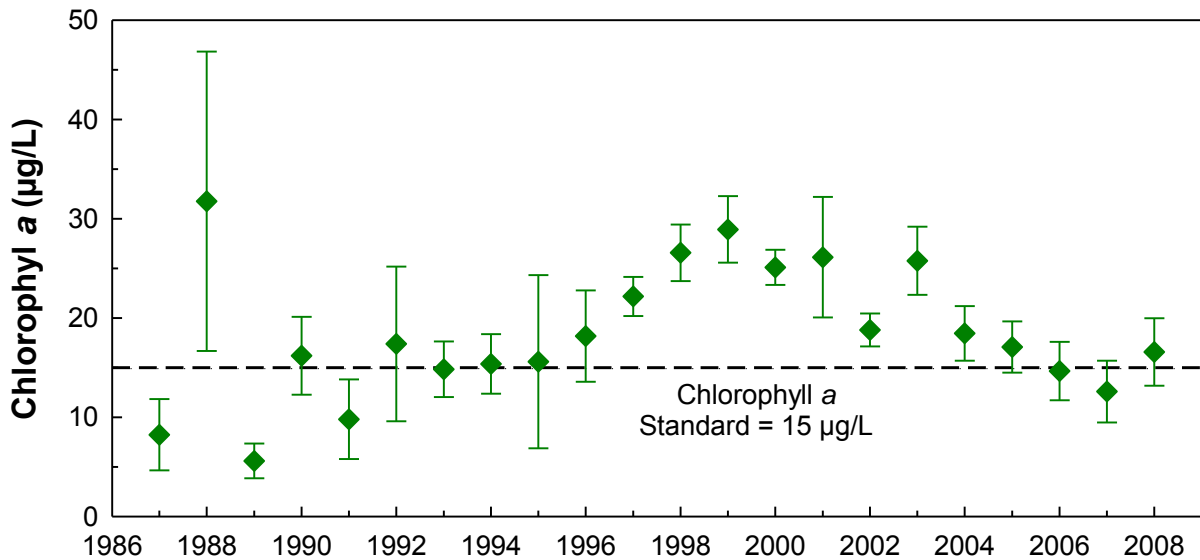
The annual pattern of photic zone chlorophyll *a* concentrations revealed relatively high concentrations (34 µg/L) of chlorophyll *a* following ice-off and spring turnover (March). From early April through early November, chlorophyll *a* concentrations ranged from 5.7 to 27 µg/L (Figure 19). The 2008 annual mean chlorophyll *a* concentration was 16.1 µg/L, while the July to September mean chlorophyll *a* concentration was 16.6 µg/L, which



**Figure 19: Concentration of chlorophyll *a* (µg/L) in Cherry Creek Reservoir, 2008. Error bars represent 95 percent confidence interval around each mean. Highlighted area denotes the seasonal period for the chlorophyll *a* standard.**

### 5.1.7 Long-term Chlorophyll *a* Trends in Cherry Creek Reservoir

The seasonal mean chlorophyll *a* concentration has met the standard of 15 µg/L only six of the past 22 years (Figure 20). Since 1987, there is no significant trend in the seasonal mean chlorophyll *a* concentration (Figure 20). However, since 1999 there has been a steady decline in the seasonal mean chlorophyll *a* concentration, reaching a low level last year.



**Figure 20: Seasonal mean (July to September) chlorophyll *a* concentrations measured in Cherry Creek Reservoir, 1987 to 2008. Error bars represent 95 percent confidence interval around each mean.**

## 5.2 Reservoir Biology

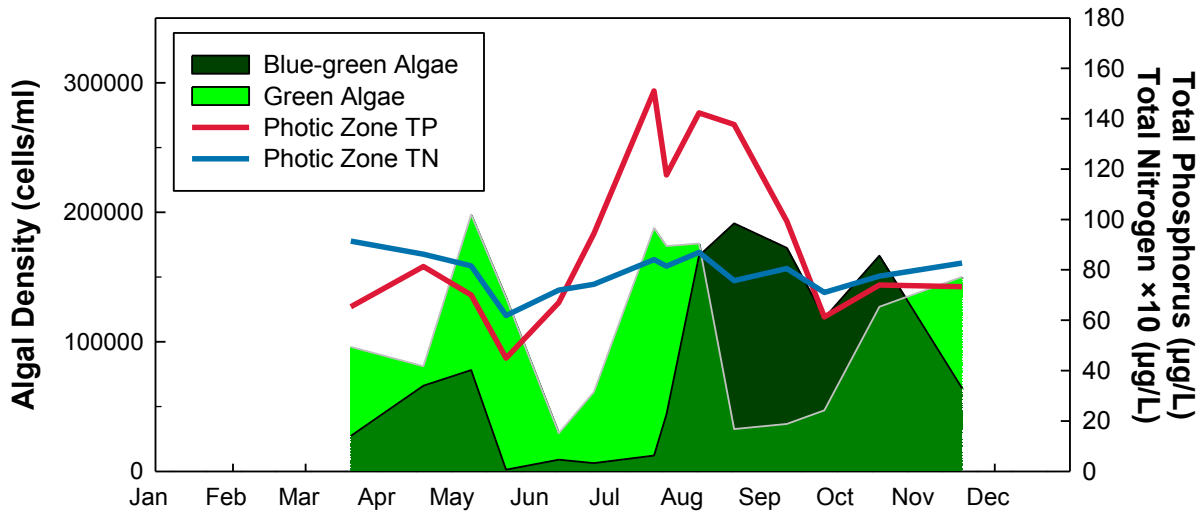
### 5.2.1 2008 *Phytoplankton*

Phytoplankton density in the photic zone ranged from 42,644 cells/mL on June 10<sup>th</sup> to 344,293 cells/mL on August 5<sup>th</sup> (Table 5). The number of algal taxa present in the Reservoir ranged from 29 on May 20<sup>th</sup> to 65 on October 16<sup>th</sup>. Annually, the assemblage was dominated in terms of density by green algae, with blue-green algae being the second most abundant taxonomic group (Figure 21).

**Table 5: Density (cells/mL) of phytoplankton and total number of taxa collected from all three sites on Cherry Creek Reservoir 2008.**

<b>Taxa</b>	<b>19 Mar</b>	<b>17 Apr</b>	<b>5 Jun</b>	<b>20 May</b>	<b>10 Jun</b>	<b>24 Jun</b>	<b>8 Jul</b>
Diatoms							
Centrics	20	26	5,060	148	160	1,520	471
Pennates	11	2	1,770	320	3,260	5,200	2,240
Green Algae	96,120	81,120	198,360	133,983	29,508	61,239	187,768
Blue-Green Algae	27,320	66,116	78,152	1,290	9,055	6,348	12,310
Golden-Brown Algae	2,500	125	0	0	0	0	2,500
Yellow-Green Algae	0	8	0	0	0	0	0
Euglenoids	0	0	0	0	1	0	5
Dinoflagellates	560	20	0	0	0	4	8
Cryptomonads	4,800	4,000	2,260	1,995	660	291	10,619
Haptomonads	29,360	9,760	0	0	0	0	0
Microflagellates	1,800	1,520	40	0	0	0	120
<b>Total Density</b>	<b>162,491</b>	<b>162,697</b>	<b>285,642</b>	<b>137,736</b>	<b>42,644</b>	<b>74,602</b>	<b>216,041</b>
<b>Total Taxa</b>	<b>36</b>	<b>39</b>	<b>44</b>	<b>29</b>	<b>30</b>	<b>35</b>	<b>53</b>
<b>Taxa</b>	<b>23 Jul</b>	<b>5 Aug</b>	<b>19 Aug</b>	<b>9 Sep</b>	<b>24 Sep</b>	<b>16 Oct</b>	<b>18 Nov</b>
Diatoms							
Centrics	485	160	1,155	644	1,173	1,516	1,989
Pennates	160	33	34	51	52	3	18
Green Algae	173,984	175,897	32,725	36,631	47,161	126,982	150,101
Blue-Green Algae	44,066	166,519	191,460	172,543	118,320	166,558	64,140
Golden-Brown Algae	0	0	20	1,000	0	0	125
Yellow-Green Algae	0	0	0	5	0	0	0
Euglenoids	1	212	5	26	1	8	0
Dinoflagellates	83	26	2	1		18	
Cryptomonads	433	1,395	2,770	1,418	1,689	2,136	1,496
Haptomonads	0	0	0	0	0	0	1,280
Microflagellates	266	51	4,160	2,480	800	880	800
<b>Total Density</b>	<b>219,478</b>	<b>344,293</b>	<b>232,331</b>	<b>214,799</b>	<b>169,196</b>	<b>298,101</b>	<b>219,949</b>
<b>Total Taxa</b>	<b>44</b>	<b>51</b>	<b>47</b>	<b>55</b>	<b>49</b>	<b>65</b>	<b>47</b>

Regression analysis revealed no significant correlation between green algal or blue-green algal density with monthly total or soluble reactive phosphorus concentrations during 2008. 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 between both green algal and blue-green algal density and photic zone total phosphorus concentrations. Both taxonomic groups showed similar responses to the increase in phosphorus concentrations. There is also evidence that the blue-green community began to competitively exclude the green algal community in August and September. The 2008 annual pattern in blue-green algal density is very similar to ones observed in the past (prior to destratification system), though the proliferation of green algae during mid-summer is less characteristic.



**Figure 21: Annual pattern of blue-green and green algal densities and photic zone total phosphorus and total nitrogen concentrations in Cherry Creek Reservoir, 2008.**

### 5.2.2 Long-Term Phytoplankton

In 2008, the phytoplankton assemblage was dominated, in terms of density, by green algae (55 percent) and blue-green algae (41 percent), and distantly followed by cryptomonads (1 percent; Table 5). Historically, the blue-green algae have been the most abundant algae, especially during the late summer season. Both the diatom and haptomonad algae comprised approximately one percent of the algal assemblage, but were greater than their respective long-term median values (Appendix E).

### 5.2.3 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 three hybrids have been stocked in Cherry Creek Reservoir from 1985 to 2008 (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 2008, two fish taxa were stocked (Appendix E): approximately fifteen thousand catchable rainbow trout, and approximately four million walleye fry.

## 5.3 Stream Water Quality

### 5.3.1 2008 Phosphorus Concentrations in Streams

The median annual total phosphorus concentration for base flow conditions ranged from 40 µg/L at CT-P2 to 188 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 53 µg/L at Site CT-1 to 211 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 56 µg/L at Site CT-1 to 271 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, 2008.**

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)
<b>Cherry Creek</b>						
CC-10	211	11	188	20	271	39
CC-O	123	27	79	15	--	--
<b>Cottonwood Creek</b>						
CT-1	53	20	53	25	56	40
CT-2	62	30	63	34	79	48
CT-P1	141	30	50	11	140	88
CT-P2	76	22	40	22	123	51
<b>Shop Creek</b>						
SC-3	92	16	45	11	175	20

### 5.3.2 Long-Term Trends in Phosphorus Concentrations in Cherry Creek Reservoir Tributaries

Long-term patterns (1995-2008) in total phosphorus and soluble reactive phosphorus concentrations were evaluated for the three main tributary sites (CC-10, SC-3, and CT-2) to Cherry Creek Reservoir, for both base flow and storm flow conditions. The long-term median annual base flow total phosphorus concentration for Cherry Creek (CC-10) and Shop Creek (SC-3) are 210 µg/L and 102 µg/L, respectively (Table 7), with storm flow concentrations being approximately 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 78 percent and 70 percent, respectively, of the total phosphorus concentrations, while soluble reactive phosphorus fractions in Cottonwood Creek (CT-2) have been approximately 18 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 2008.**

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
<b>Median</b>	<b>210</b>	<b>164</b>	<b>102</b>	<b>71</b>	<b>81</b>	<b>14</b>

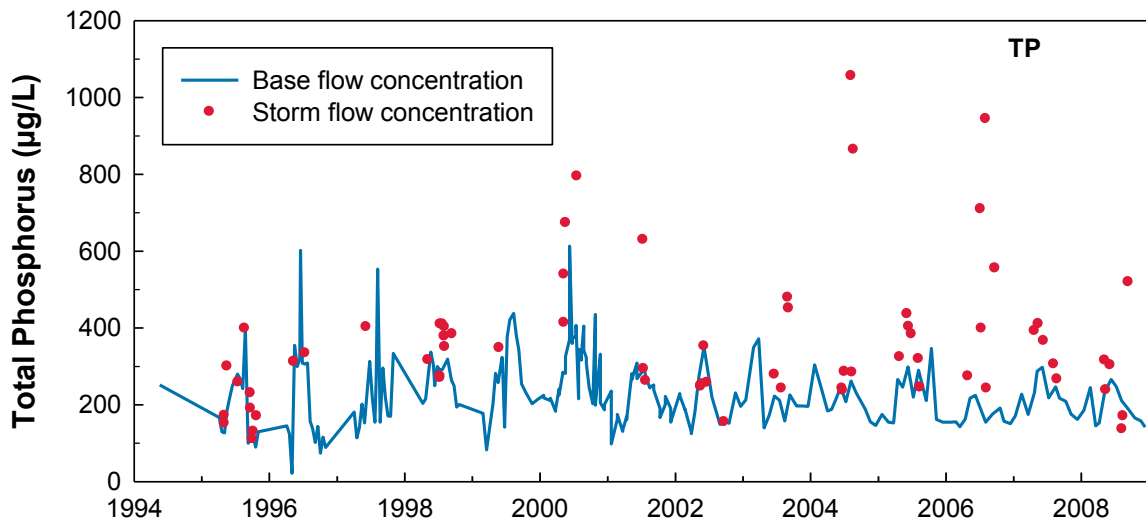
\* Results for total phosphorus and soluble reactive phosphorus are obtained independently and are within the 10 percent analytical error rate for all data used to calculate the median annual value.

**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 2008.**

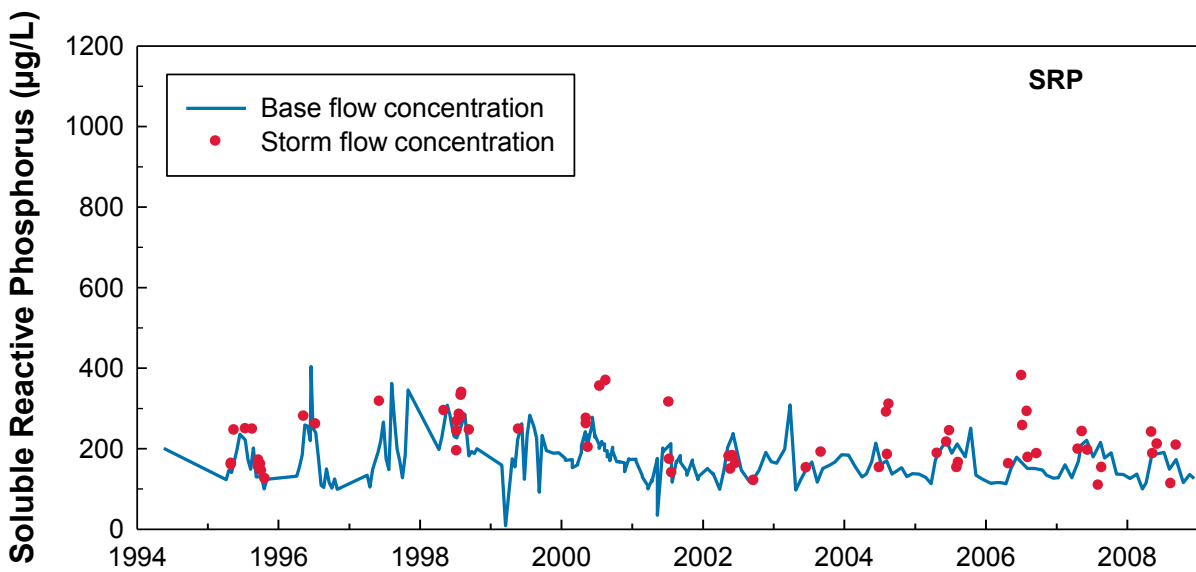
Year	CC-10		SC-3		CT-2	
	TP (µg/L)	SRP (µg/L)	TP (µg/L)	SRP (µg/L)	TP (µg/L)	SRP (µg/L)
1995	181	161	122	95	--	--
1996	323	270	132	85	336	160
1997	402	316	175	74	391	221
1998	378	277	155	124	314	108
1999	348	247	141	112	118	58
2000	673	274	407	166	277	93
2001	293	172	227	84	209	33
2002	251	171	207	110	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
<b>Median</b>	<b>351</b>	<b>214</b>	<b>175</b>	<b>106</b>	<b>209</b>	<b>35</b>

Base flow total phosphorus and soluble reactive phosphorus concentrations revealed no trends over time at Site CC-10 (Figure 22 and Figure 23). At Site SC-3, base flow phosphorus concentrations for both total and SRP fractions, have exhibited a significant ( $p < 0.05$ ) increasing trend over time (Figure 24 and Figure 25). However, the increased variability in data since 1999 may have resulted in the significant trend. This may be an indication of potentially reduced effectiveness of the Shop Creek wetlands over time.

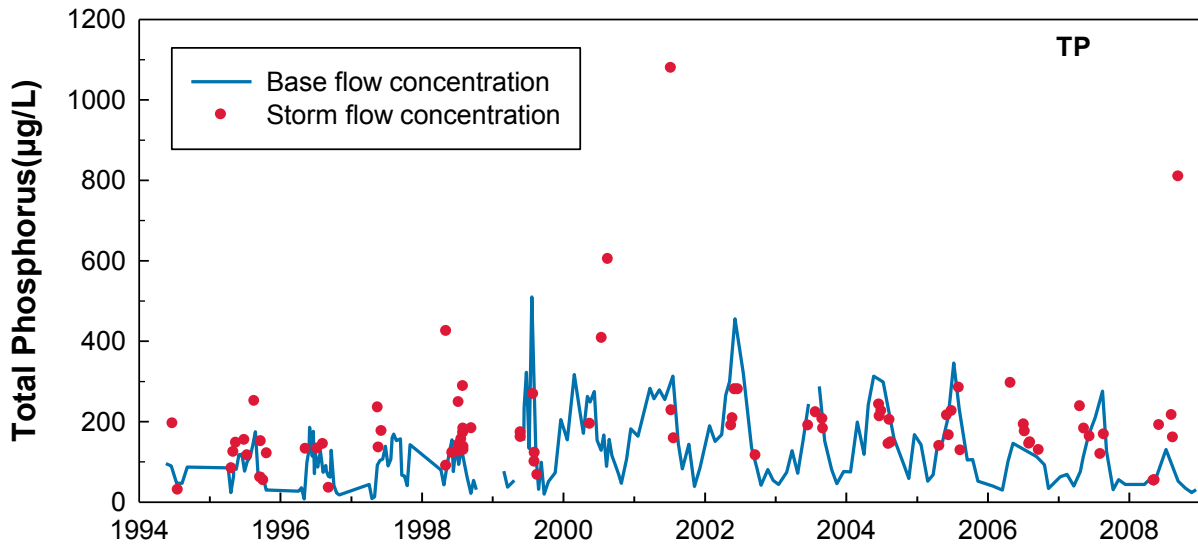
Both the total phosphorus and soluble reactive phosphorus concentrations reveal a significant ( $p < 0.05$ ) decreasing trend at Site CT-2 (Figure 26 and Figure 27) during base flow conditions. The observed decreasing trend and greatly reduced variability in soluble reactive phosphorus concentrations at Site CT-2 from 1995 to 2008 is the result of the effectiveness of the PRFs near the Perimeter Road and Peoria Street, along with habitat restoration on Cottonwood Creek. There appears to be a seasonal pattern in phosphorus concentration at all sites, which is not specifically addressed in the trend analysis.



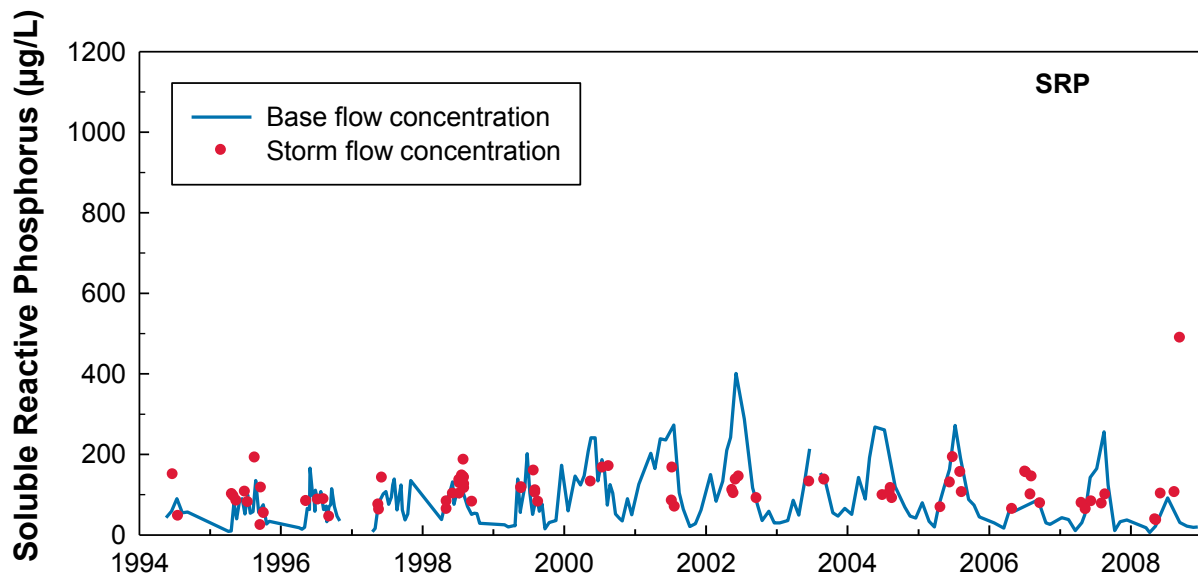
**Figure 22: Base flow and storm flow total phosphorus concentrations measured in Site CC-10, 1994 to 2008.**



**Figure 23: Base flow and storm flow soluble reactive phosphorus concentrations measured in Site CC-10, 1994 to 2008.**



**Figure 24: Base flow and storm flow total phosphorus concentrations measured in Site SC-3, 1994 to 2008.**



**Figure 25: Base flow and storm flow soluble reactive phosphorus concentrations measured in Site SC-3, 1994 to 2008.**

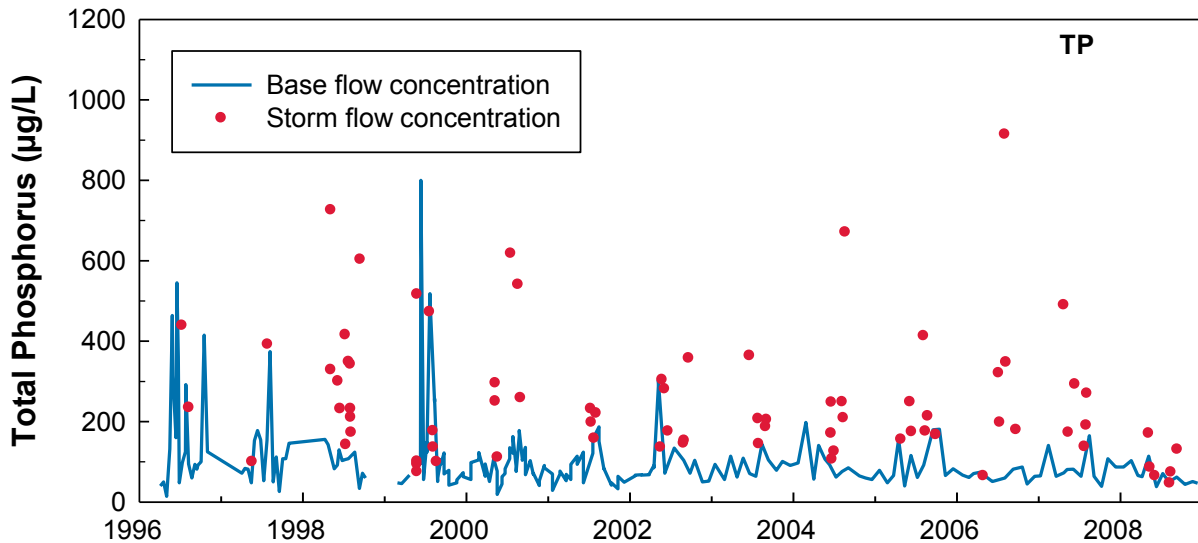


Figure 26: Base flow and storm flow total phosphorus concentrations measured in Site CT-2, 1996 to 2008.

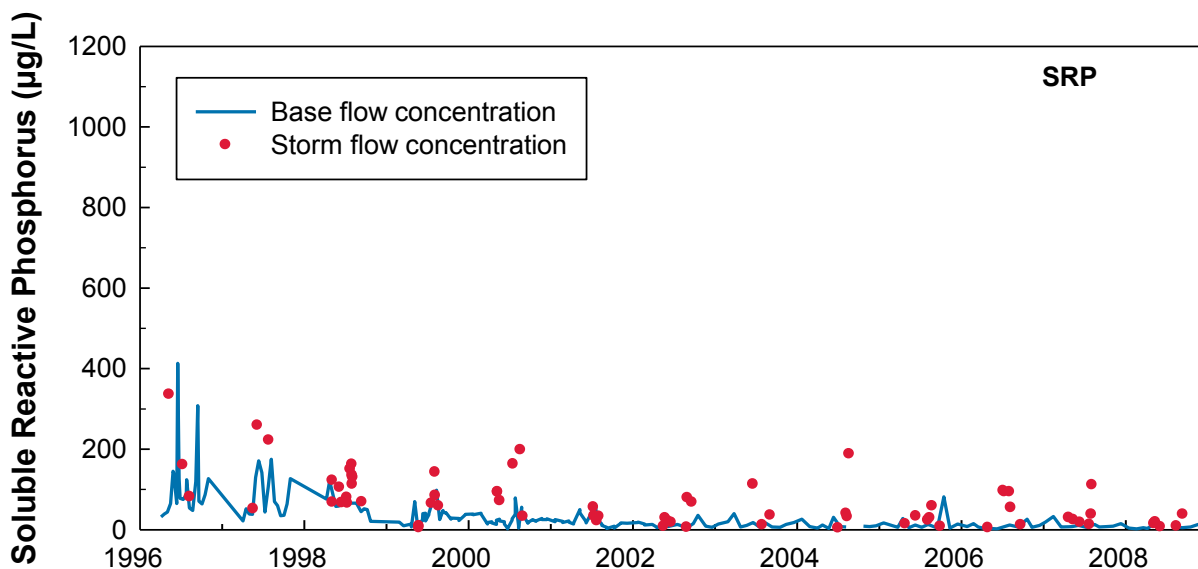
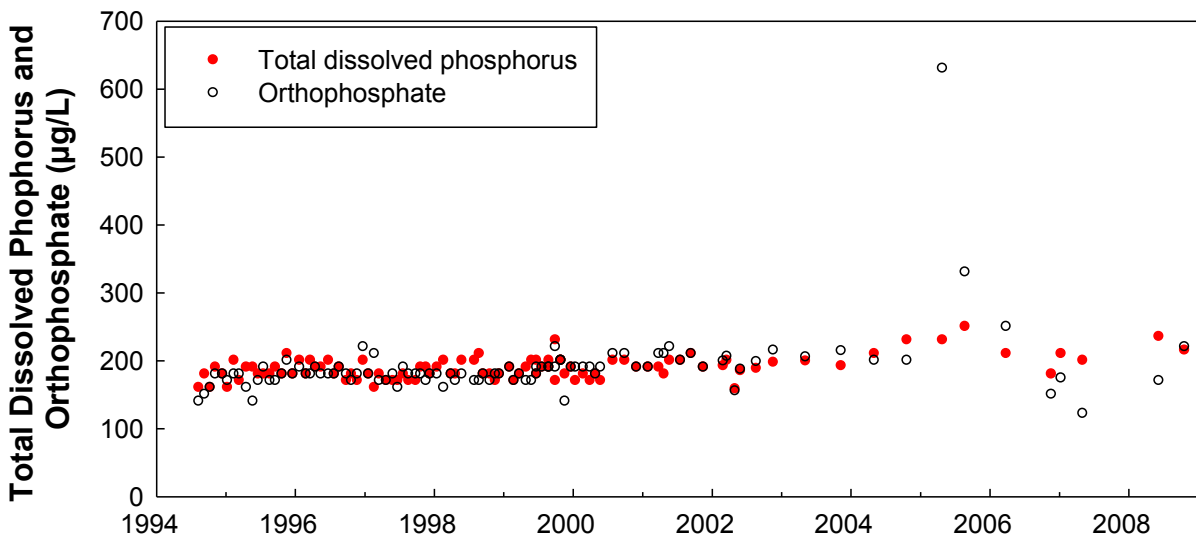


Figure 27: Base flow and storm flow soluble reactive phosphorus concentrations measured in Site CT-2, 1996 to 2008.

### 5.3.3 Long-Term Trends in Phosphorus Concentrations in Cherry Creek Reservoir Alluvium

Alluvial phosphorus data were obtained from JCHA for Site MW-9, and are used to estimate the alluvial phosphorus load component, as summarized in Appendix D (JCHA 2001 through 2008). 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



**Figure 28: Total dissolved phosphorus and soluble reactive phosphorus concentrations measured at Site MW-9 (1994 to 2008).**

## 5.4 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. (2005) 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 concentrated on phosphorus loading. In 2006, changes were made to the phosphorus loading methodology in response to comments from WQCD, with all historical loads being recalculated using the revised load methodology (Appendix D). 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.

#### **5.4.1 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 90<sup>th</sup> percentile of all flows measured during the respective year and for that site were categorized as storm flows. The greatest proportion (77 percent) of the total phosphorus load to the Reservoir was from Cherry Creek mainstem flows (7,043 lbs). Because Cherry Creek is monitored downstream of Shop Creek, the 78 lbs (<1 percent) contributed by Shop Creek has been subtracted from the total load calculated for Site CC-10. Cottonwood Creek accounted for 8 percent of the phosphorus load, or 758 lbs. In 2008, the total phosphorus load to Cherry Creek Reservoir from tributary streams was 7,879 lbs (Table 9).

#### **5.4.2 Phosphorus Export from Reservoir Outflow**

The total outflow from Cherry Creek Reservoir as measured by the USACE was 17,129 ac-ft in 2008 (Appendix D). Monthly total phosphorus data collected from Site CC-O near the dam outlet was used to estimate the phosphorus export (4,828 lbs/yr) leaving the Reservoir in 2008 (Table 9).

**Table 9: Normalized phosphorus loads and export (lbs/year) for Cherry Creek Reservoir, 1992 to 2008.**

Year	Shop Creek	Cherry Creek	Cottonwood Creek	Stream & Ungaged Residual Load	Cherry Creek Alluvium	Direct Precipitation	External Load	Cherry Creek Outflow	Net External Load	Flow-weighted TP (µg/L)
1992	105	3,142	408	3,925	1,010	429	5,364	1,443	3,921	214
1993	69	1,524	179	1,773	1,027	314	3,114	928	2,186	196
1994	100	2,437	164	2,700	857	227	3,785	1,055	2,730	199
1995	73	2,251	1,402	4,160	1,015	561	5,736	1,434	4,302	179
1996	95	2,467	599	3,161	916	349	4,425	1,323	3,102	213
1997	145	3,110	884	4,139	1,033	487	5,659	1,599	4,060	200
1998	162	9,963	1,633	11,840	1,033	449	13,322	4,010	9,311	234
1999	–	11,788	1,314	16,167	1,033	471	17,672	6,759	10,913	235
2000	–	10,714	1,644	12,357	1,033	398	13,788	4,426	9,362	272
2001	–	5,642	1,820	7,707	1,033	359	9,099	4,697	4,402	194
2002	–	1,815	505	2,320	916	288	3,525	1,843	1,681	173
2003	–	6,337	974	7,934	1,033	423	9,390	4,673	4,717	231
2004	–	5,710	1,753	7,486	1,033	454	8,974	3,421	5,553	192
2005	–	7,843	1,502	9,345	1,033	346	10,725	3,644	7,080	213
2006	–	3,813	1,272	5,084	1,033	375	6,492	3,287	3,206	187
2007	–	16,142	2,133	18,408	1,033	331	19,772	8,042	11,730	246
2008	–	7,121	758	7,879	1,015	250	9,144	4,828	4,316	178
<b>Median</b>	<b>100</b>	<b>5,642</b>	<b>1,272</b>	<b>7,486</b>	<b>1,033</b>	<b>375</b>	<b>8,974</b>	<b>3,421</b>	<b>4,316</b>	<b>200</b>

### 5.4.3 Phosphorus Load from Precipitation

In 2008, a total of 11.2 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 792 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 2008 annual total phosphorus load of 250 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 2008 is 376 lbs (Table 10).

**Table 10: Phosphorus loading into Cherry Creek Reservoir from precipitation, 1992 to 2008.**

<b>Year</b>	<b>Precipitation (inches/yr)</b>	<b>Total Phosphorus Load (lbs/yr)</b>
1992	18.5	414
1993	15.6	349
1994	11.0	245
1995	25.1	561
1996	14.6	328
1997	21.7	487
1998	20.0	449
1999	21.0	471
2000	17.8	398
2001	16.0	359
2002	12.9	288
2003	18.9	423
2004	20.3	454
2005	15.5	346
2006	16.7	376
2007	14.8	331
2008	11.2	250
<b>Median</b>	<b>16.7</b>	<b>376</b>

#### **5.4.4 Phosphorus Load from Alluvium**

In 2008, the alluvial inflow quantity was set as a constant 1,965 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 1,015 lbs in 2008 (Table 9).

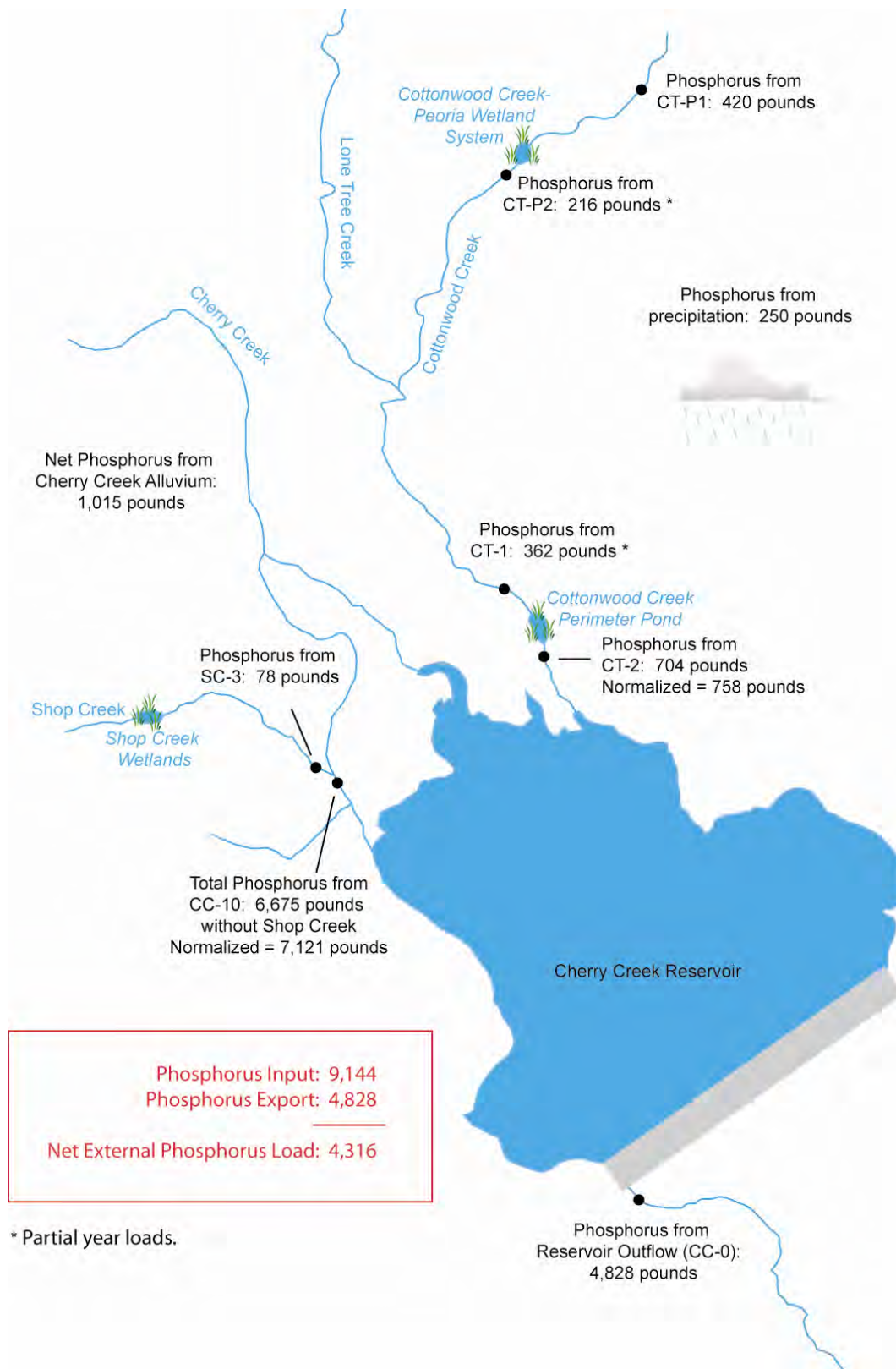
#### **5.4.5 Mass Balance/Net Loading of Phosphorus to the Reservoir**

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., Bellevue 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 2008, the USACE calculated inflow was 18,841 ac-ft/yr, while the GEI calculated stream inflow was 14,998 ac-ft/yr (Appendix D). To compare these two inflow values, the USACE inflow was adjusted for precipitation (792 ac-ft/yr) and alluvial inflows (1,965 ac-ft/yr), which resulted in an adjusted USACE inflow of 16,049 ac-ft/yr. The difference between the adjusted USACE inflow and the GEI stream inflow was 1,052 ac-ft of water. This water volume difference was reapportioned between Cherry Creek (84 percent) and Cottonwood Creek (16 percent). Flow-weighted total phosphorus concentrations for Cherry Creek and Cottonwood Creek were used to calculate the combined reapportioned load of 500 lbs.

Following the water balance normalization process, flow from the two tributary streams accounted for a total phosphorus load of 7,879 lbs to the Reservoir in 2008 (Figure 29). The alluvial inflow contributed 1,015 lbs of phosphorus, with precipitation events contributing 250 lbs to the Reservoir. The total external load of phosphorus to the Reservoir in 2008 was 9,144 lbs (Figure 29), which met the TMAL of 14,270 lbs/yr.

The Reservoir outflow phosphorus load was estimated to be 4,828 lbs. Consistent with the TMAL, these values do not include any estimates of internal phosphorus loads. The flow-weighted total phosphorus concentration for all external sources of inflow to the Reservoir is 178 µg/L and the flow-weighted export concentration for the Reservoir is 104 µg/L. The difference of 74 µg/L was retained by the Reservoir. The net external phosphorus load to the Reservoir was 4,316 lbs in 2008.



**Figure 29: Mass balance diagram of phosphorus loading in Cherry Creek Reservoir, 2008.**

## 5.5 Effectiveness of Pollutant Reduction Facilities

### 5.5.1 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 loading of phosphorus upstream and downstream of the facility. Notably, the loads 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 17 January to 8 May 2008, stream flows were diverted around the Cottonwood Creek Peoria Pond and the pond was drained for maintenance purposes (sediment removal). As a result, stream flows, total phosphorus loads, and the efficiency of the PRF could not be evaluated during this period. The data presented herein is based on a partial year of operation for the PRF.

Despite the maintenance and an expected increase in sediment transport downstream of the PRF following the disturbance of the sediment, the mean total phosphorus concentration downstream of the PRF was considerably less than the upstream concentration (Table 11). Total suspended solids data also showed a slight decrease downstream of the PRF (Table 11). The water budget for the Peoria Pond also showed a slight decrease in flow (~160 ac-ft/yr), and when combined with the change in phosphorus content, revealed a 37 percent decrease downstream of the PRF. This reduction in load equates to a one percent decrease in the external load at the Reservoir. The flow-weighted total phosphorus concentration upstream and downstream of the PRF was 116 µg/L and 86 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 2008.**

Parameter	Year	Sampling Sites		Difference	Percent Change Downstream
		CT-P1	CT-P2		
Mean Total Phosphorus Concentration (µg/L) (base flow and storm flow samples combined)	2002	138	152	14	10
	2003	101	92	-9	-9
	2004	142	123	-19	-13
	2005	92	101	9	10
	2006	132	133	1	1
	2007	179	125	-54	-30
	2008*	101	77	-24	-24
	<b>Mean</b>	<b>126</b>	<b>115</b>	<b>-11</b>	<b>-9</b>
Mean Total Suspended Solids (mg/L)	2002	66	79	13	20
	2003	31	34	3	10
	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
	<b>Mean</b>	<b>55</b>	<b>49</b>	<b>-6</b>	<b>-11</b>

Parameter	Year	Sampling Sites		Difference	Percent Change Downstream
		CT-P1	CT-P2		
Total Phosphorus Load (pounds)	2002	142	89	-53	-37
	2003	628	620	-8	-1
	2004	839	897	58	7
	2005	621	633	12	2
	2006	705	533	-172	-24
	2007	1106	732	-374	-34
	2008*	343	216	-127	-37
	Mean	626	531	-95	-15

\* Eight months of operation.

### 5.5.2 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). Monitoring of the Cottonwood Creek Perimeter Pond was also affected by the Cottonwood Creek Reclamation Phase II project from 26 March to 3 July 2008. During this period, stream flow was diverted around the Site CT-1 ISCO stream level gage; therefore, inflow and total phosphorus load to the Perimeter Pond could not be determined. The data presented herein is based on a partial year of operation for the PRF.

In 2008, the mean concentration of total phosphorus slightly increased from 65 to 67 µg/L after passing through the PRF, representing a 3 percent increase in phosphorus concentration (Table 12). The mean concentration of TSS also increased, from 30 mg/L upstream to 34 mg/L downstream of the PRF. The total phosphorus load also increased downstream of the pond by 25 percent, although the flow-weighted concentrations were very similar, 73 µg/L upstream of the PRF and 74 µg/L downstream of the PRF.

The decreased efficiency of the Perimeter Pond is largely due to the reclamation of the Cottonwood Creek stream channel upstream of the PRF. The noted increase in the total phosphorus load downstream of the PRF is likely due to the uncertainty associated with determining flow at the new location of Site CT-1. The geomorphology of the new stream channel is very effective at spreading out the stream flow and dispersing the hydraulic energy across a wide portion of the stream channel. While this is a very effective stream management design, the stream channel morphology is not very conducive to accurately determine stream flow. In 2009, additional stream discharge measurements will be performed to increase the accuracy of stream flow.

### 5.5.3 Shop Creek and Quincy Drainage Pond

Historical sampling of the PRFs on Shop Creek and Quincy Drainage indicate efficient phosphorus removal in these streams. Shop Creek was monitored for 10 years from 1990 to 2000 at sites upstream and downstream of PRF stations (detention pond and wetlands). The Shop Creek PRF had an average annual phosphorus load reduction of 173 lbs, with an average of 63 percent reduction in load. Quincy Drainage was even more efficient with 99 percent reduction in loads over the period of 1996 to 1999. The average phosphorus load reduction was 138 lbs. GEI has not monitored the Shop Creek and Quincy Drainage PRFs for effectiveness since 2000. Based on past data, loads from these two drainages averaged less than 1 percent of total external load to the Reservoir.

**Table 12: Historical total phosphorus and total suspended solids concentrations and total phosphorus loads upstream and downstream of the Cottonwood Creek Perimeter Pond (1997-2008).**

Parameter	Year	Sampling Sites		Difference	Percent Change Downstream
		CT-1	CT-2		
Average Total Phosphorus Concentration (µg/L) (baseflow and storm samples combined)	1997	200	133	-67	-34
	1998	289	210	-79	-27
	1999	158	157	-1	-1
	2000	187	149	-38	-20
	2001	165	114	-51	-31
	2002	146	143	-3	-2
	2003	144	129	-15	-10
	2004	212	151	-61	-29
	2005	180	142	-38	-21
	2006	170	161	-9	-5
	2007	213	148	-65	-31
	2008*	65	67	2	3
	<b>Mean</b>	<b>177</b>	<b>142</b>	<b>-35</b>	<b>-20</b>
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	34	4	13
	<b>Mean</b>	<b>138</b>	<b>73</b>	<b>-65</b>	<b>-47</b>

Parameter	Year	Sampling Sites		Difference	Percent Change Downstream
		CT-1	CT-2		
Loading of Total Phosphorus (pounds)	1997	2,359	614	-1745	-74
	1998	1,556	1,070	-486	-31
	1999	1,140	984	-156	-14
	2000	1,617	1,057	-560	-35
	2001	1,181	1,212	31	3
	2002	636	801	165	26
	2003	1,356	864	-492	-36
	2004	2,023	1,433	-590	-29
	2005	1,575	1,725	150	10
	2006	1,924	1,220	-704	-37
	2007	2,244	1,854	-390	-17
	2008*	362	454	92	25
	<b>Mean</b>	<b>1,498</b>	<b>1,107</b>	<b>-390</b>	<b>-26</b>

\* Nine months of operation.

## 6.0 Summary and Conclusions

### 6.1 Transparency

The period from late May to early June represented a time when chlorophyll *a* levels were among the lowest observed and water clarity was at its best, with 1 percent light transmittance averaging 4.6 m. The whole-reservoir mean Secchi depth was 0.80 m during the July-to-September period. This value represents one of the shallowest mean values since 1998, and is considerably less than the long-term mean value (Table 13).

**Table 13: Water quality and total phosphorus loads for Cherry Creek Reservoir, (1992 to 2008).**  
Shaded cell indicates value meets the respective standard, goal, or phased-TMAL value.

Year	Jul-Sep Secchi Depth (m)	Jul-Sep Total Phosphorus (µg/L)	Jul-Sep Total Nitrogen (µg/L)	Jul-Sep Chlorophyll <i>a</i> (µg/L)	USACE Inflow (ac-ft)	External Phosphorus Load (lbs/yr)	Flow- weighted Total Phosphorus (µg/L)
1992	0.96	66	970	17.4	9,210	5,364	214
1993	1.72	62	826	14.8	5,851	3,114	196
1994	1.08	59	1,144	15.4	6,998	3,785	199
1995	1.64	48	913	15.6	11,788	5,736	179
1996	1.43	62	944	18.2	7,654	4,425	213
1997	1.01	96	1,120	22.0	10,391	5,659	200
1998	1.08	89	880	26.5	20,902	13,322	234
1999	1.03	81	753	28.6	27,604	17,672	235
2000	0.96	81	802	25.1	18,611	13,788	272
2001	0.75	87	741	26.1	17,246	9,099	194
2002	0.91	74	858	18.8	7,511	3,525	173
2003	0.86	90	1,121	25.8	14,953	9,390	231
2004	0.85	102	977	18.4	17,203	8,974	192
2005	0.97	116	990	17.1	18,534	10,725	213
2006	1.05	87	914	14.7	12,799	6,492	187
2007	1.12	118	716	12.6	29,586	19,772	246
2008	0.80	118	800	16.6	18,841	9,144	178
<b>Mean</b>	<b>1.07</b>	<b>84</b>	<b>910</b>	<b>19.6</b>	<b>15,040</b>	<b>8,823</b>	<b>209</b>
<b>Median</b>	<b>1.01</b>	<b>87</b>	<b>913</b>	<b>18.2</b>	<b>14,953</b>	<b>8,974</b>	<b>200</b>

## **6.2 Temperature and Dissolved Oxygen**

The Reservoir was well mixed and oxygenated from March through April 2008. From early May through mid-July the Reservoir showed signs of periodic thermal stratification, which was supported by evidence of an oxycline throughout the Reservoir. During this period, dissolved oxygen concentrations were often less than 5 mg/L at depths greater than 5 m. Microbial mediated anoxia may create favorable conditions for nutrient loading via the sediments. Soluble reactive phosphorus concentrations observed at depth also provide evidence of internal nutrient loading during this low oxygen period. Dissolved oxygen data were also evaluated with the basic table value standard for Class 1 Warm Water lakes and reservoirs, and revealed that the Reservoir was in compliance with the standard on all sample dates.

## **6.3 Total Phosphorus**

Total phosphorus concentrations during the July to September period ranged from 56 to 156 µg/L, with a seasonal mean of 118 µg/L (Table 13). Since 1987, the goal of 40 µg/L total phosphorus has only been met once in 1989.

## **6.4 Chlorophyll *a***

Chlorophyll *a* concentrations ranged from 4.7 µg/L in October to 46.5 µg/L in March, with the annual mean chlorophyll *a* concentration being 16.1 µg/L. The seasonal (July-to-September) mean chlorophyll *a* concentration was 16.6 µg/L (Table 13), which exceeded the chlorophyll *a* standard of 15 µg/L.

## **6.5 Phosphorus Loading**

The total inflow of gaged tributary streams and ungaged surface water flows was 18,841 ac-ft/yr and contributed 7,879 lbs of phosphorus to the Reservoir. Annual precipitation accounted for 792 ac-ft of water and contributed 250 lbs of phosphorus, while the alluvial inflow was assumed to be a constant 1,965 ac-ft/yr, and contributed 1,015 lbs of phosphorus to the Reservoir.

Combined, the total external load to the Reservoir was 9,144 lbs in 2008, which met the phased Total Maximum Annual Load (TMAL) of 14,270 lbs/yr specified in Control Regulation No. 72. When the 2008 external load is placed in the context of total inflow, the flow-weighted total phosphorus concentration was 178 µg/L.

## **6.6 Destratification System Effectiveness**

The 2008 summer season represents the first full seasonal operation of the destratification system with mixed results for the first year of observations. The continuous temperature

monitoring shows that storm events greatly influence water temperatures, especially in the deeper layers because the cooler waters are more dense. These events give rise to conditions that are conducive for thermal stratification. The destratification system was effective in circulating the upper waters of the reservoir, but appears to be less effective at eroding the 6 to 7 m layer near the bottom of the reservoir. The increased reservoir circulation, via the destratification system, also resulted in slightly cooler surface water temperatures (1.5 °C) despite a 2.5 °C increase in ambient air temperatures over the same period in 2007.

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.

From July to early August the Reservoir did contain a dominant assemblage of green algae (favorable algae), but was replaced by a cyanobacteria (undesirable algae) in late August which was persistent through November. It is too soon in the destratification monitoring to evaluate changes in patterns of algal species composition or succession. However, the destratification system is designed to disrupt the useable habitat for cyanobacteria and limit their growth potential. It is also possible that the destratification system may effectively delay the onset algal growth.

## **6.7 Pollutant Reduction Facility Effectiveness**

The efficiency of both the Cottonwood Creek Peoria Pond PRF and Perimeter Pond PRF at removing phosphorus was greatly affected by either maintenance or stream restoration projects in 2008. As a result, the effectiveness of each PRF is based on approximately eight months of data rather than the full year. The Cottonwood Creek Peroria Pond PRF was effective in removing approximately 127 pounds or 37 percent of the phosphorus load from Cottonwood Creek at the pond. This load reduction is primarily the result of the PRF's efficiency in reducing outflow phosphorus concentrations as well as reducing the water load through the system.

The Cottonwood Creek Perimeter Pond was not effective in reducing the total phosphorus load, and in fact, showed a net increase of 92 pounds of total phosphorus load to Cottonwood Creek or a 25 percent increase in total phosphorus downstream of the Perimeter Pond for the 2008 sampling period. When combined, the Perimeter Pond and Peoria Pond PRF's only accounted for a 0.3 percent reduction in the total external phosphorus load to the Reservoir, which is largely a result of the PRF maintenance and stream reclamation projects that occurred on Cottonwood Creek in 2008.

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# Appendix A

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## Cherry Creek Reservoir Sampling and Analysis Plan



Geotechnical  
Water Resources  
Environmental and  
Ecological Services

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

Submitted to:

**Cherry Creek Basin Water Quality Authority  
R.S. Wells LLC**

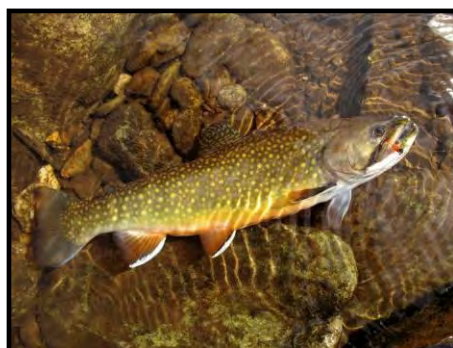
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April 2008  
Project 062450



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# 1.0 Introduction

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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**

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### **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).

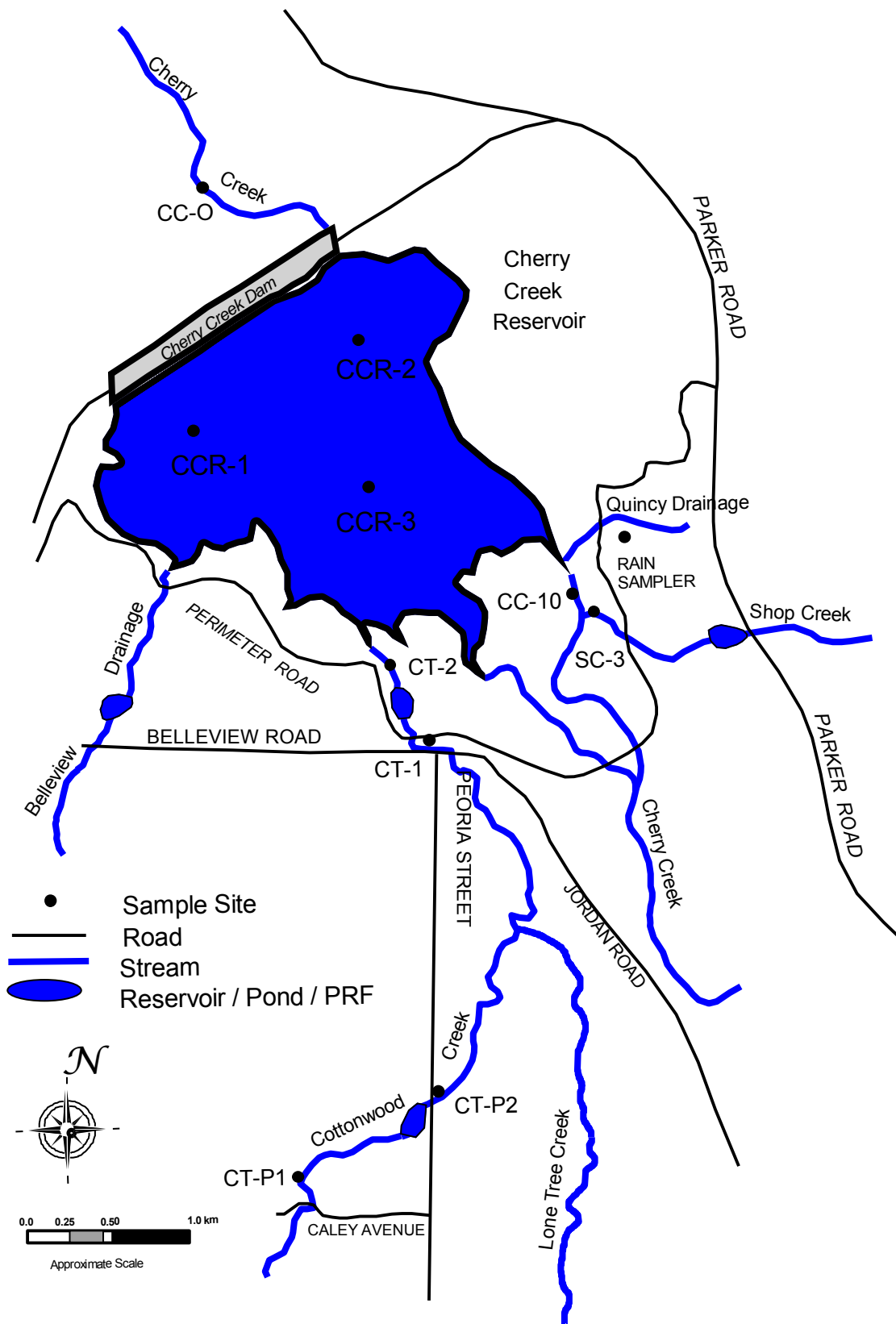
#### **4.1.1 Cherry Creek Reservoir**

- 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 <sub>3</sub> +NO <sub>2</sub>	4500-NO31	48 hrs	2 µg/L
Ammonium Ion Nitrogen	NH <sub>4</sub>	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 <i>a</i>	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.**

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

#### **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.**

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

#### **4.5.3 Storm Flow Sampling**

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

#### **4.5.4 Precipitation Sampling**

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

## **4.6 Field Methodologies**

### **4.6.1 Reservoir Sampling**

#### **4.6.1.1 Transparency**

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

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

#### **4.6.1.2 Depth Profile Measurements**

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

#### **4.6.1.3 Continuous Temperature Monitoring**

The effectiveness of the destratification system at mixing the entire water column would be evaluated by deploying Onset HOBOTM 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.**

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

#### **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 ( $\text{ft}^3/\text{sec}$ ) 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 <i>a</i>	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  $\pm 20$  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  $\geq$  total dissolved phosphorus  $\geq$  orthophosphate and that the concentration of total nitrogen  $\geq$  total dissolved nitrogen  $\geq$  nitrate/nitrite and ammonia. If parameters are not in agreement samples are reanalyzed.

## **6.0 Data Verification, Reduction, and Reporting**

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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

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- American Public Health Association. 2005. *Standard Methods for Examination of Water and Wastewater*, 20<sup>th</sup> 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**

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### **2008 Reservoir Water Quality Data**

CCR-1 C&A Water Chemistry Data									
Analytical Detection Limits		2	2	2	2	2	2	3	
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 <i>a</i> (mg/m <sup>3</sup> )
19-Mar-08	CCR-1 Photic	66	12	8	897	386		10	12.25
7-Apr-08	CCR-1 Photic	81	17	7	889	450	12	12	23.15
6-May-08	CCR-1 Photic	75	17	7	903	519		13	15.2
20-May-08	CCR-1 Photic	43	21	28	666	356	2	28	6.05
10-Jun-08	CCR-1 Photic	59	43	34	689	514	2	18	11.65
24-Jun-08	CCR-1 Photic	97	57	43	651	548	2	7	14
8-Jul-08	CCR-1 Photic	156	77	62	934	560		32	19
23-Jul-08	CCR-1 Photic	120	66	53	841	500	2	9	11.8
5-Aug-08	CCR-1 Photic	139	87	75	901	628	3	67	6.05
19-Aug-08	CCR-1 Photic	145	56	39	804	470		6	38
9-Sep-08	CCR-1 Photic	100	28	24	871	524		16	17.85
24-Sep-08	CCR-1 Photic	56	18	11	736	521		38	14.75
16-Oct-08	CCR-1 Photic	76	19	16	809	517		8	6.35
18-Nov-08	CCR-1 Photic	78	20	12	915	533	2	15	22.25

CCR-2 C&A Water Chemistry Data									
Analytical Detection Limits		2	2	2	2	2	2	3	
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 <sup>3</sup> )
19-Mar-08	CCR-2 Photic	62	17	9	905	378		6	46.45
19-Mar-08	CCR-2 4m	69	11	8	895	391		6	
19-Mar-08	CCR-2 5m	59	13	10	895	376		6	
19-Mar-08	CCR-2 6m	67	12	9	804	387		7	
19-Mar-08	CCR-2 7m	75	14	10	954	367		5	
7-Apr-08	CCR-2 Photic	71	15	8	816	427		12	21.35
7-Apr-08	CCR-2 4m	79	16	8	852	459		9	
7-Apr-08	CCR-2 5m	63	17	6	792	453		9	
7-Apr-08	CCR-2 6m	71	13	7	860	453		9	
7-Apr-08	CCR-2 7m	78	17	8	828	439		10	
6-May-08	CCR-2 Photic	66	16	11	762	432		7	12.1
6-May-08	CCR-2 4m	79	19	8	743	426		7	
6-May-08	CCR-2 5m	72	16	11	801	427		6	
6-May-08	CCR-2 6m	79	21	12	765	419		5	
6-May-08	CCR-2 7m	84	25	17	773	450		8	
20-May-08	CCR-2 Photic	39	22	16	631	316	2	14	5
20-May-08	CCR-2 4m	54	22	16	530	273		7	
20-May-08	CCR-2 5m	53	21	17	544	275		9	
20-May-08	CCR-2 6m	76	38	35	607	324	8	65	
20-May-08	CCR-2 7m	109	58	57	730	351	13	131	
10-Jun-08	CCR-2 Photic	68	39	33	776	488	2	33	10.8
10-Jun-08	CCR-2 4m	76	41	33	662	442	2	12	
10-Jun-08	CCR-2 5m	71	39	34	724	466	2	12	
10-Jun-08	CCR-2 6m	71	41	36	713	439	2	23	
10-Jun-08	CCR-2 7m	76	43	39	736	434	2	27	
24-Jun-08	CCR-2 Photic	95	53	40	696	445	2	10	13.75
24-Jun-08	CCR-2 4m	101	55	38	665	439		3	
24-Jun-08	CCR-2 5m	96	53	37	559	419		3	
24-Jun-08	CCR-2 6m	290	242	197	1001	716	5	344	
24-Jun-08	CCR-2 7m	460	355	298	1298	862		511	
8-Jul-08	CCR-2 Photic	139	77	64	734	554		22	15.3
8-Jul-08	CCR-2 4m	151	72	65	708	486		28	
8-Jul-08	CCR-2 5m	148	75	64	741	426		18	
8-Jul-08	CCR-2 6m	152	73	62	698	431		15	
8-Jul-08	CCR-2 7m	184	72	60	777	437		32	

CCR-2 C&A Water Chemistry Data									
Analytical Detection Limits		2	2	2	2	2	2	3	
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 <sup>3</sup> )
23-Jul-08	CCR-2 Photic	117	71	55	781	473	2	7	12.65
23-Jul-08	CCR-2 4m	124	80	71	723	514	3	35	
23-Jul-08	CCR-2 5m	172	110	96	879	561	3	110	
23-Jul-08	CCR-2 6m	199	134	114	890	648	3	151	
23-Jul-08	CCR-2 7m	263	130	127	1135	697	4	192	
5-Aug-08	CCR-2 Photic	141	90	76	826	619	2	72	5.6
5-Aug-08	CCR-2 4m	142	95	82	803	560	2	103	
5-Aug-08	CCR-2 5m	150	94	82	605	511	2	97	
5-Aug-08	CCR-2 6m	154	97	87	684	516		116	
5-Aug-08	CCR-2 7m	197	108	96	680	552	2	152	
19-Aug-08	CCR-2 Photic	143	55	38	768	451		7	23.6
19-Aug-08	CCR-2 4m	118	56	42	678	414		5	
19-Aug-08	CCR-2 5m	115	60	46	687	433		5	
19-Aug-08	CCR-2 6m	196	121	101	896	589	72	86	
19-Aug-08	CCR-2 7m	227	137	116	943	689	80	153	
9-Sep-08	CCR-2 Photic	97	31	23	760	439		8	20.9
9-Sep-08	CCR-2 4m	98	34	29	836	475		19	
9-Sep-08	CCR-2 5m	95	35	30	790	453	2	23	
9-Sep-08	CCR-2 6m	92	33	27	787	423	2	16	
9-Sep-08	CCR-2 7m	100	29	26	762	462		10	
24-Sep-08	CCR-2 Photic	63	20	12	735	504		19	13.7
24-Sep-08	CCR-2 4m	49	17	12	596	447		16	
24-Sep-08	CCR-2 5m	57	18	15	626	464		20	
24-Sep-08	CCR-2 6m	59	21	14	646	460		40	
24-Sep-08	CCR-2 7m	75	20	16	639	463	2	15	
16-Oct-08	CCR-2 Photic	73	13	13	771	462		8	8.55
16-Oct-08	CCR-2 4m	73	19	14	772	399		4	
16-Oct-08	CCR-2 5m	71	23	13	681	405		6	
16-Oct-08	CCR-2 6m	71	12	13	749	420		6	
16-Oct-08	CCR-2 7m	94	18	15	746	414		7	
18-Nov-08	CCR-2 Photic	67	20	9	787	444		9	18.3
18-Nov-08	CCR-2 4m	69	19	8	666	371		12	
18-Nov-08	CCR-2 5m	72	20	8	646	411		6	
18-Nov-08	CCR-2 6m	74	13	8	667	387		7	
18-Nov-08	CCR-2 7m	71	18	8	675	390		7	

CCR-3 C&A Water Chemistry Data									
Analytical Detection Limits		2	2	2	2	2	2	3	
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 <i>a</i> (mg/m <sup>3</sup> )
3/19/2008	CCR-3 Photic	68	18	8	941	382		5	41.85
4/7/2008	CCR-3 Photic	92	13	7	881	422		7	19
5/6/2008	CCR-3 Photic	69	14	6	783	432		6	11.8
5/20/2008	CCR-3 Photic	53	21	16	560	305		9	6.05
6/10/2008	CCR-3 Photic	74	43	34	695	499	2	32	12.25
6/24/2008	CCR-3 Photic	91	47	35	882	547	2	13	14.6
7/8/2008	CCR-3 Photic	158	69	57	854	460		13	18.3
7/23/2008	CCR-3 Photic	116	60	50	821	510	2	10	10.15
8/5/2008	CCR-3 Photic	147	74	63	881	571	3	18	13.45
8/19/2008	CCR-3 Photic	125	56	41	700	462		7	19.75
9/9/2008	CCR-3 Photic	101	25	20	786	439		5	22.7
9/24/2008	CCR-3 Photic	65	17	12	660	495		16	14.85
10/16/2008	CCR-3 Photic	73	15	15	745	466		10	4.7
11/18/2008	CCR-3 Photic	75	10	8	778	412		9	21.05

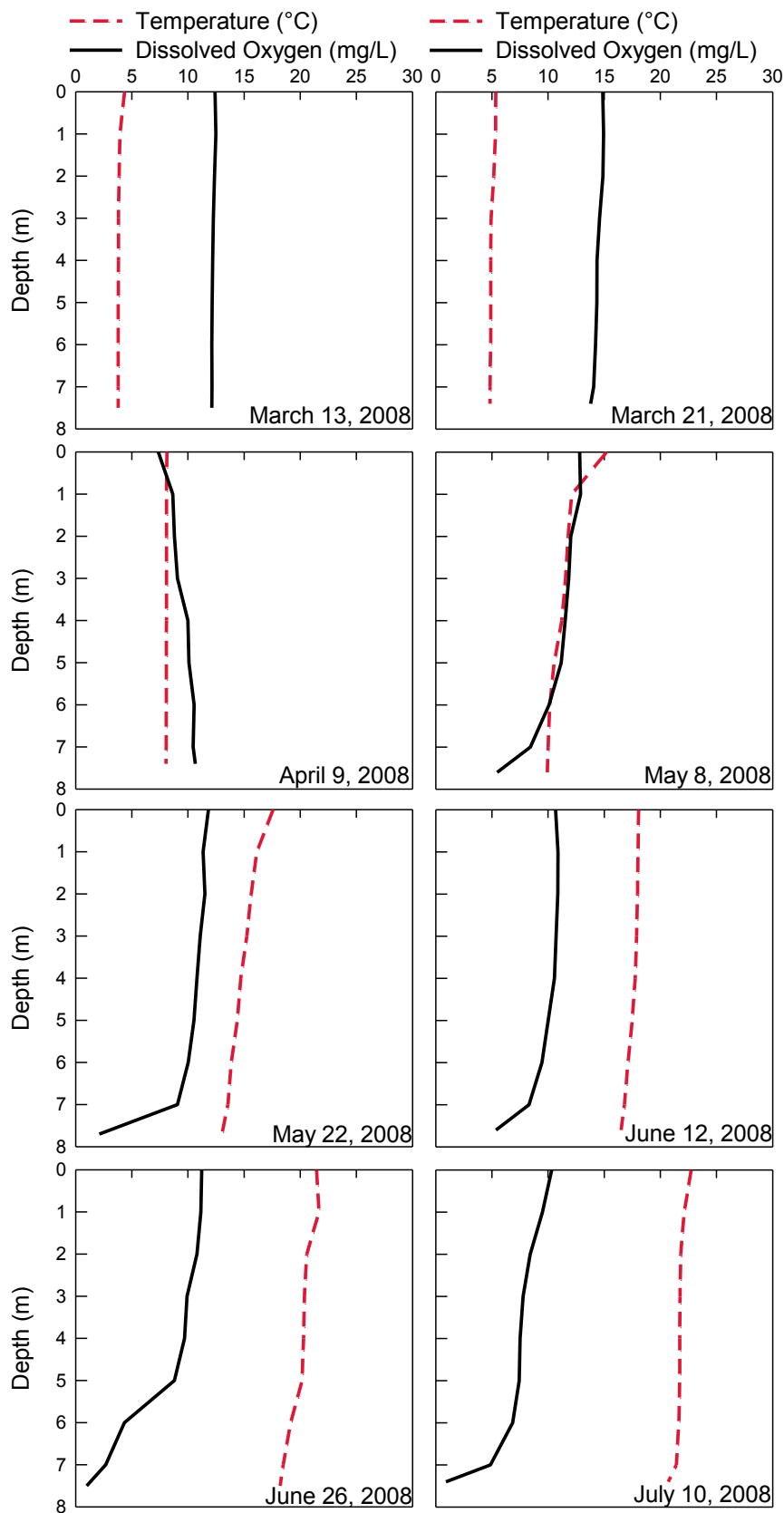
Site CCR-1 Small Tables

COLLECT DATE	DEPTH	Temperature	Conductivity	Dissolved Oxygen	pH	ORP	1% transmittance	secchi disk
3/11/2008	0	4.35	564	12.41	8.51	54.2		
	1	3.95	557	12.48	8.48	49.3		
	2	3.88	557	12.37	8.47	49.5		
	3	3.82	555	12.26	8.47	44.7		
	4	3.81	556	12.2	8.47	43.9		
	5	3.8	556	12.16	8.47	43.5		
	6	3.79	556	12.13	8.47	42.7		
	7	3.79	556	12.14	8.47	42		
	7.5	3.79	555	12.12	8.48	41.1		
3/19/2008	0	5.35	578	14.87	8.07	188.4		
	1	5.33	578	14.95	8.19	168.4		
	2	5.16	576	14.88	8.3	150.2		
	3	4.92	573	14.59	8.31	142		
	4	4.89	573	14.36	8.36	132.1		
	5	4.9	573	14.35	8.38	117.4		
	6	4.89	574	14.22	8.4	113.3		
	7	4.83	573	14.06	8.4	109.5		
	7.4	4.83	574	13.79	8.39	106.3		
	--						2.85	0.875
4/7/2008	0	8.14	678	7.35	8.78	151.8		
	1	8.09	678	8.64	8.66	147.1		
	2	8.09	676	8.79	8.64	146.1		
	3	8.09	677	9.07	8.59	144		
	4	8.09	677	10	8.59	142		
	5	8.08	677	10.08	8.57	141		
	6	8.07	677	10.55	8.56	138		
	7	8.06	678	10.46	8.58	137		
	7.4	8.04	676	10.65	8.55	136.1		
	--						2.4	0.79
5/6/2008	0	15.22	808	12.82	8.17	43.1		
	1	12.11	748	12.89	8.15	44.2		
	2	11.78	742	12.02	8.12	44.7		
	3	11.55	736	11.84	8.11	44.3		
	4	11.22	731	11.53	8.1	45		
	5	10.55	722	11.17	8.1	46.5		
	6	10.16	715	10.09	8.05	49.1		
	7	10.01	712	8.42	8	50.4		
	7.6	9.93	711	5.46	7.91	51.2		
	--						2.9	0.9
5/20/2008	0	17.59	860	11.82	8.25	27.8		
	1	16.14	827	11.35	8.18	28.2		
	2	15.64	817	11.51	8.18	28.7		
	3	15.24	809	11.09	8.19	28.7		
	4	14.7	799	10.81	8.15	29.7		
	5	14.4	795	10.53	8.14	30.9		
	6	13.87	784	10.03	8.12	31.6		
	7	13.57	780	9.06	8.07	32.7		
	7.7	13.02	773	2.11	8.01	29.7		
	--						5	1.6

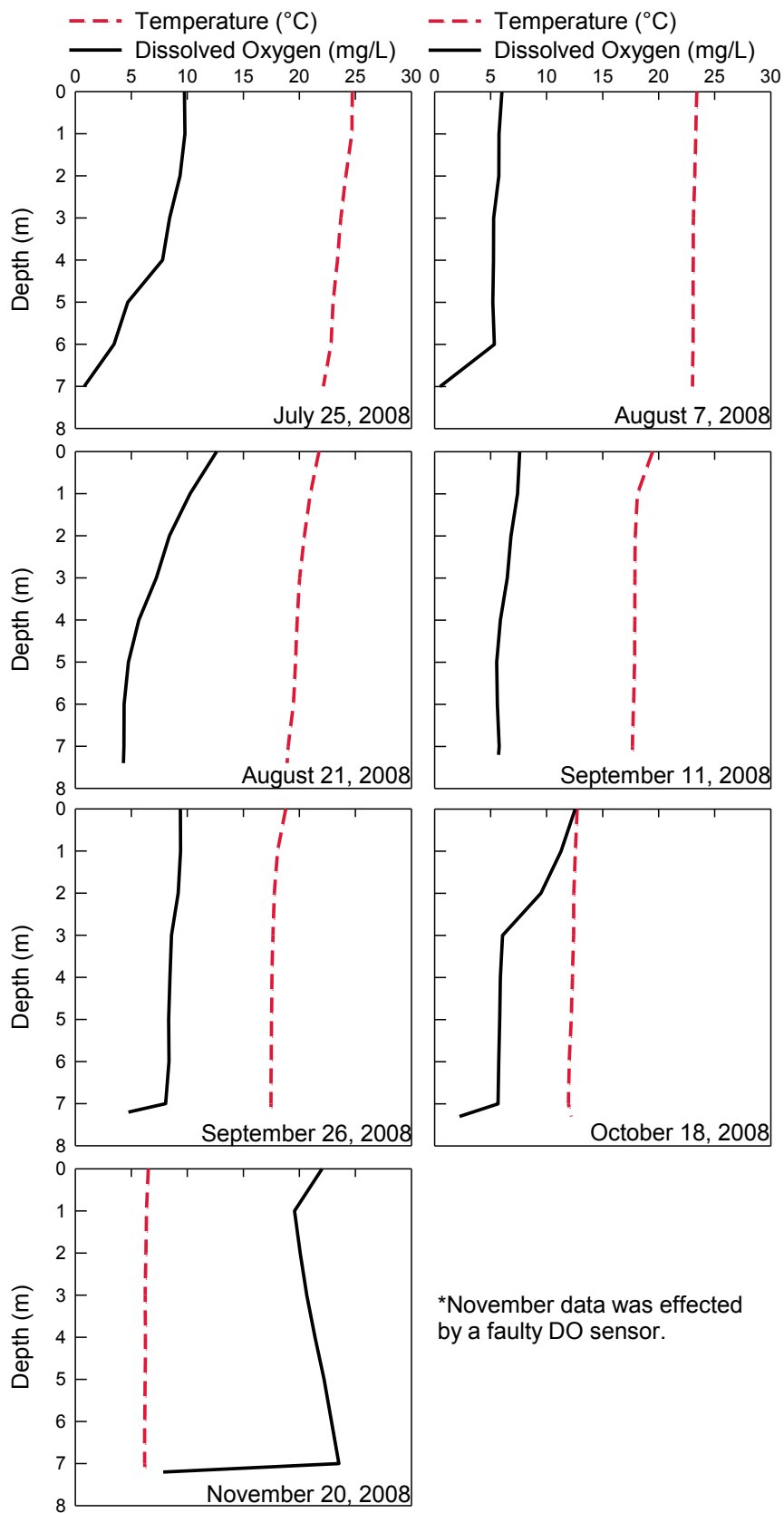
COLLECT DATE	DEPTH	Temperature	Conductivity	Dissolved Oxygen	pH	ORP	1% transmittance	secchi disk
6/10/2008	0	18.06	853	10.67	8.42	-8		
	1	18.02	851	10.88	8.29	-7.3		
	2	17.97	850	10.86	8.18	-4.5		
	3	17.88	848	10.71	8.14	-3		
	4	17.77	846	10.57	8.09	-2.3		
	5	17.5	841	10.01	8.07	-2		
	6	17.12	835	9.46	8.03	-1.7		
	7	16.81	829	8.3	7.99	-1.3		
	7.6	16.51	826	5.36	7.94	-19.6		
	--						4.72	1.46
6/24/2008	0	21.45	923	11.22	8.58	-45.1		
	1	21.68	924	11.15	8.47	-37.4		
	2	20.59	902	10.8	8.44	-33.9		
	3	20.38	897	9.92	8.37	-28.9		
	4	20.3	895	9.7	8.34	-26.2		
	5	20.16	893	8.8	8.32	-24		
	6	19.16	890	4.34	8.17	-25.6		
	7	18.48	863	2.67	8.01	-30.6		
	7.5	18.21	854	0.98	8	-48.3		
	--						3.8	1.25
7/8/2008	0	22.74	969	10.32	8.27	-25.3		
	1	22.13	958	9.5	8.18	-23		
	2	21.82	952	8.41	8.12	-21.2		
	3	21.75	952	7.78	8.05	-21.6		
	4	21.73	949	7.5	8.05	-21.3		
	5	21.73	951	7.43	8.01	-22.8		
	6	21.65	950	6.85	7.99	-24		
	7	21.43	946	4.86	7.93	-27.2		
	7.4	20.71	935	0.9	7.83	-84.9		
	--						1.75	0.5
7/23/2008	0	24.73	1020	9.74	8.45	33.2		
	1	24.7	1020	9.79	8.5	10.9		
	2	24.16	1008	9.35	8.51	8.4		
	3	23.7	1002	8.42	8.48	7.4		
	4	23.41	997	7.79	8.46	7.1		
	5	23.01	991	4.69	8.35	4.9		
	6	22.83	987	3.45	8.26	1.1		
	7	22.14	975	0.8	8.17	-21.7		
	--						3.05	0.98
8/5/2008	0	23.4	1005	6	8.22	-22.3		
	1	23.32	1003	5.75	8.11	-26.8		
	2	23.22	1001	5.74	8.07	-27.5		
	3	23.1	999	5.27	8.04	-28.4		
	4	23.09	999	5.25	8.01	-28.1		
	5	23.07	999	5.19	8.01	-27.4		
	6	23.07	998	5.33	8.01	-27		
	7	23.01	997	0.48	7.99	-67.2		
	--						3.32	0.89

COLLECT DATE	DEPT H	Temperature	Conductivity	Dissolved Oxygen	pH	ORP	1% transmittance	secchi disk
8/19/2008	0	21.76	930	12.62	8.62	25.1		
	1	20.99	915	10.25	8.57	31.3		
	2	20.45	907	8.41	8.53	32.6		
	3	20.03	902	7.23	8.48	31.9		
	4	19.8	901	5.68	8.42	31		
	5	19.67	896	4.74	8.36	29.6		
	6	19.47	874	4.36	8.33	27.7		
	7	19.01	848	4.34	8.34	25.8		
	7.4	18.91	841	4.3	8.32	25.7		
	--						2.5	0.7
9/9/2008	0	19.46	911	7.59	8.07	-15.3		
	1	18.11	883	7.4	8.02	-11.7		
	2	17.91	879	6.82	7.96	-9		
	3	17.89	878	6.49	7.93	-8.1		
	4	17.87	878	5.87	7.89	-8.1		
	5	17.86	881	5.54	7.87	-8.7		
	6	17.76	881	5.6	7.87	-9.8		
	7	17.66	883	5.76	7.85	-14.2		
	7.2	17.66	883	5.71	7.87	-20		
	--						2.24	0.76
9/24/2008	0	18.78	897	9.38	7.85	58.5		
	1	18.07	879	9.4	7.88	51.5		
	2	17.77	873	9.18	7.9	47		
	3	17.64	871	8.59	7.89	45.5		
	4	17.56	870	8.45	7.88	44.7		
	5	17.52	869	8.33	7.88	44.1		
	6	17.49	867	8.36	7.88	42.9		
	7	17.46	867	8.06	7.86	40.2		
	7.2	17.46	869	4.74	7.79	-27.9		
	--						2.61	0.8
10/16/2008	0	12.72	784	12.54	8.6	-9.9		
	1	12.57	780	11.29	8.53	-10.6		
	2	12.43	778	9.49	8.49	-11.8		
	3	12.41	777	6.06	8.41	-12.4		
	4	12.31	776	5.87	8.37	-11.5		
	5	12.2	774	5.81	8.33	-12		
	6	12.02	770	5.72	8.32	-11.5		
	7	11.95	770	5.66	8.32	-11.1		
	7.3	12.21	776	2.23	8.17	-14.8		
	--						2.33	0.73
11/18/2008	0	6.52	680	22.03	7.73	81.5		
	1	6.36	678	19.57	8.15	62.8		
	2	6.3	677	20.08	8.27	49.9		
	3	6.25	676	20.66	8.3	43.6		
	4	6.27	676	21.39	8.33	39.1		
	5	6.25	676	22.2	8.33	37.9		
	6	6.2	675	22.86	8.32	34.6		
	7	6.19	676	23.52	8.31	34.4		
	7.2	6.29	669	7.85	8.29	-26.1		
	--						2.58	0.72

CCR-1



CCR-1



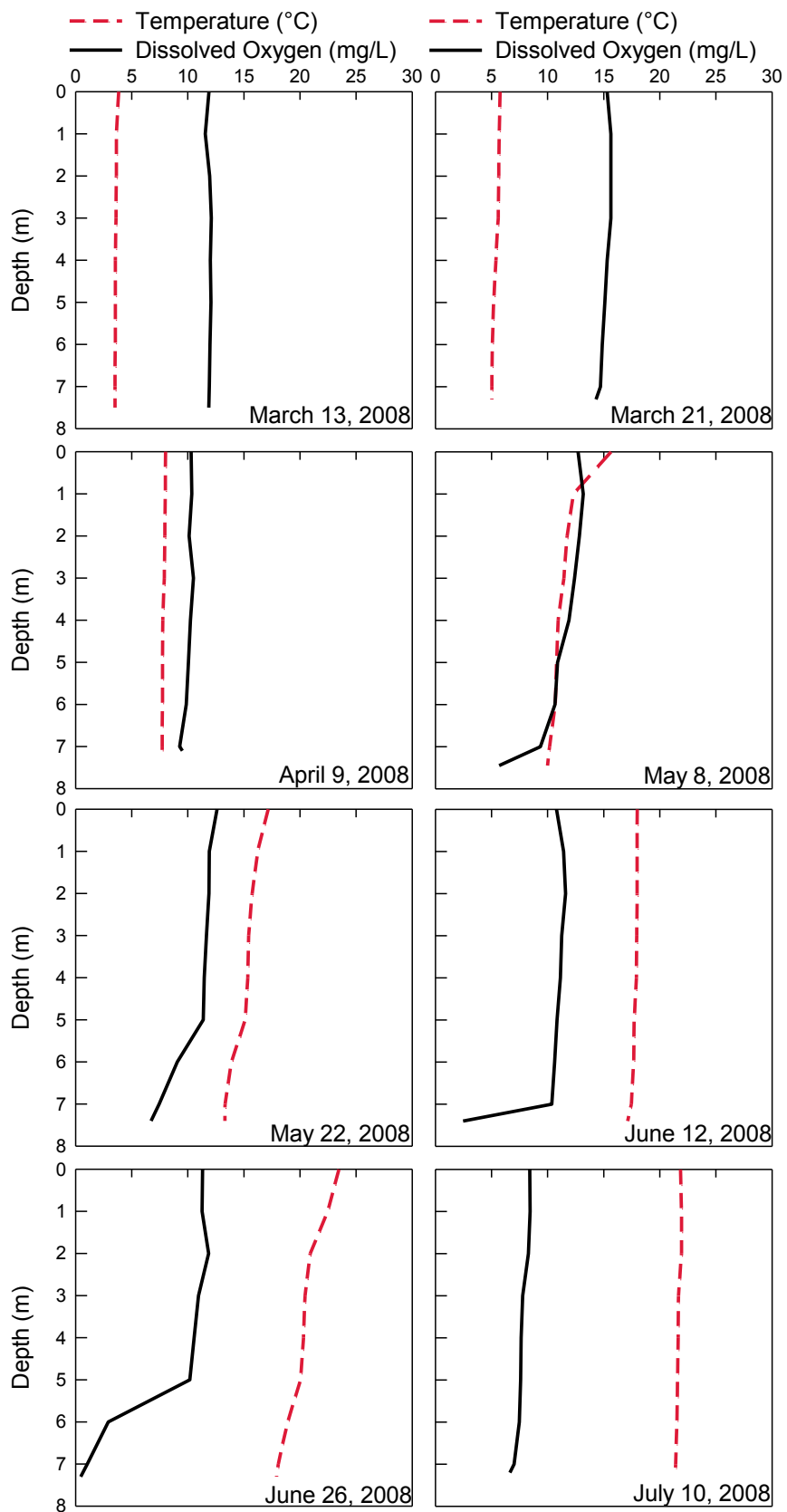
## CCR-2 Small Tables

COLLECT DATE	DEPTH	Temperature	Conductivity	Dissolved Oxygen	pH	ORP	1% transmittance	secchi disk
3/11/2008	0	3.84	556	11.89	8.66	71.1		
	1	3.63	552	11.55	8.49	75.2		
	2	3.63	553	11.95	8.44	74.9		
	3	3.6	542	12.09	8.42	72.6		
	4	3.55	550	12.01	8.43	70.6		
	5	3.56	551	12.07	8.42	70		
	6	3.55	549	11.97	8.43	67.9		
	7	3.52	551	11.91	8.43	67.2		
	7.5	3.52	555	11.87	8.43	66.6		
3/19/2008	0	5.77	585	15.31	8.66	75.6		
	1	5.69	584	15.64	8.54	77.6		
	2	5.65	582	15.64	8.58	77.2		
	3	5.6	582	15.64	8.49	77.2		
	4	5.39	576	15.31	8.48	76.6		
	5	5.19	575	15.09	8.48	76		
	6	5.07	574	14.87	8.48	75		
	7	5.03	574	14.7	8.48	74		
	7.3	5.03	575	14.32	8.47	64		
	--						2.75	0.85
4/7/2008	0	8.02	699	10.3	8.69	141.5		
	1	8	676	10.35	8.66	137.5		
	2	7.96	696	10.11	8.68	134.6		
	3	7.91	673	10.5	8.66	134.6		
	4	7.77	673	10.23	8.65	133.6		
	5	7.75	671	10.06	8.63	133.4		
	6	7.75	671	9.86	8.65	132.3		
	7	7.72	671	9.28	8.64	132.6		
	7.1	7.72	671	9.51	8.64	132.6		
	--						2.3	0.77
5/6/2008	0	15.65	815	12.71	8.31	37.1		
	1	12.31	750	13.17	8.33	37.6		
	2	11.73	741	12.83	8.26	40.9		
	3	11.45	737	12.4	8.21	44.1		
	4	10.94	726	11.9	8.16	46.5		
	5	10.8	722	10.88	8.1	48		
	6	10.68	719	10.65	8.08	48.5		
	7	10.18	715	9.35	8.06	50.4		
	7.45	10	712	5.67	7.89	-13		
	--						2.8	0.85
5/20/2008	0	17.17	848	12.6	8.11	45		
	1	16.24	828	11.91	8.11	44		
	2	15.74	820	11.89	8.12	43.5		
	3	15.42	812	11.66	8.11	41.7		
	4	15.35	811	11.47	8.12	40.4		
	5	15.13	806	11.37	8.12	40.1		
	6	13.9	785	9.07	8.08	42.9		
	7	13.32	775	7.44	8.02	43.7		
	7.4	13.31	775	6.73	8	31.6		
	--						4.82	1.7

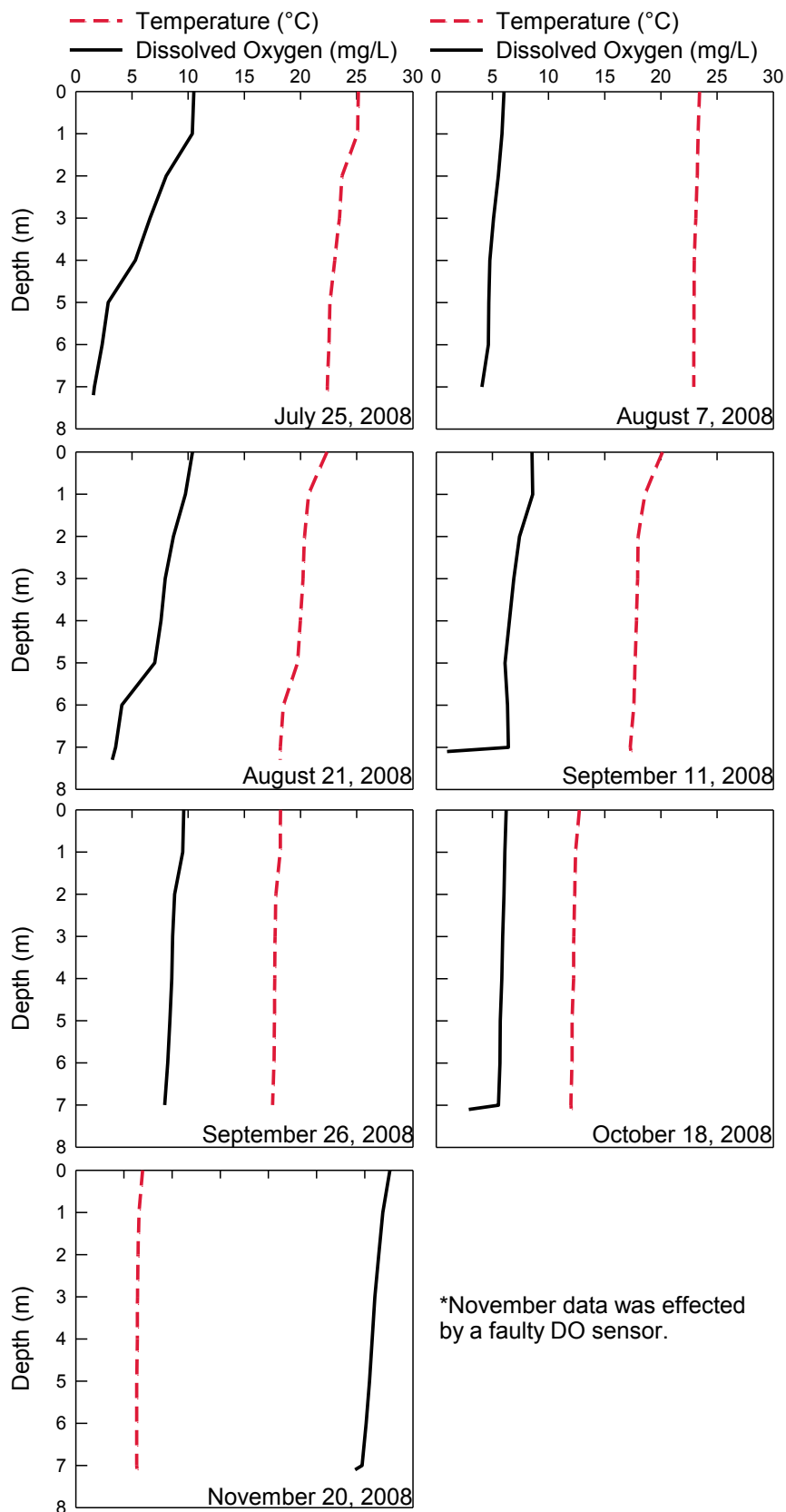
COLLECT DATE	DEPTH	Temperature	Conductivity	Dissolved Oxygen	pH	ORP	1% transmittance	secchi disk
6/10/2008	0	17.99	848	10.79	8.1	54.2		
	1	17.97	847	11.42	8.16	42.8		
	2	17.99	848	11.6	8.17	36.2		
	3	17.95	847	11.25	8.17	30.2		
	4	17.92	847	11.14	8.17	27.5		
	5	17.72	843	10.84	8.17	24.5		
	6	17.67	842	10.62	8.17	23		
	7	17.46	839	10.37	8.15	21.3		
	7.4	17.13	832	2.47	7.89	-131		
	--						4.77	1.41
6/24/2008	0	23.46	987	11.32	8.76	-77.8		
	1	22.48	959	11.27	8.6	-60.9		
	2	20.91	917	11.85	8.56	-50.3		
	3	20.45	906	10.95	8.48	-42.4		
	4	20.31	899	10.56	8.41	-33.6		
	5	20.06	899	10.17	8.37	-32.2		
	6	18.91	881	2.91	8.15	-44.3		
	7	18.06	864	1.04	8.03	-57.8		
	7.3	17.91	873	0.45	7.99	-120		
	--						3.68	1.04
7/8/2008	0	21.85	951	8.41	8.18	-0.6		
	1	21.93	952	8.44	8.17	-5.3		
	2	21.94	953	8.29	8.17	-8.1		
	3	21.66	949	7.78	8.16	-9.4		
	4	21.63	947	7.64	8.14	-10.3		
	5	21.59	946	7.59	8.14	-10.8		
	6	21.53	946	7.48	8.13	-11.1		
	7	21.41	946	7.01	8.12	-15.6		
	7.2	21.39	944	6.64	8.11	-19.9		
	--						2.18	0.72
7/23/2008	0	25.14	1027	10.51	8.55	5.8		
	1	25.08	1028	10.37	8.57	2.4		
	2	23.69	1002	8.04	8.49	5.6		
	3	23.46	999	6.6	8.42	5.7		
	4	23.04	991	5.3	8.34	4.5		
	5	22.62	984	2.89	8.23	-4.2		
	6	22.54	983	2.35	8.18	-10.3		
	7	22.39	981	1.66	8.13	-21.2		
	7.2	22.38	981	1.56	8.12			
	7.4					-30.8		
	--						2.92	1.02
8/5/2008	0	23.43	1009	6.03	8.1	-35		
	1	23.32	1007	5.85	8.09	-37.6		
	2	23.24	1005	5.52	8.07	-37.9		
	3	23.1	1002	5.11	8.06	-38.5		
	4	22.97	1000	4.77	8.04	-39.7		
	5	22.95	998	4.68	8.04	-41.1		
	6	22.94	997	4.64	8.04	-41.4		
	7	22.92	999	4.07	8.02	-52.5		
	--						3.39	0.95

COLLECT DATE	DEPTH	Temperature	Conductivity	Dissolved Oxygen	pH	ORP	1% transmittance	secchi disk
8/19/2008	0	22.35	942	10.38	8.59	6.5		
	1	20.72	912	9.75	8.58	8.3		
	2	20.36	910	8.69	8.53	11.8		
	3	20.23	908	7.95	8.5	14.2		
	4	19.99	902	7.58	8.49	16.3		
	5	19.75	894	7.02	8.46	18		
	6	18.48	792	4.1	8.35	21.2		
	7	18.2	788	3.55	8.27	22.2		
	7.3	18.18	796	3.24	8.22	22.8		
	--						2.87	0.76
9/9/2008	0	20.14	923	8.52	8.13	11.1		
	1	18.58	890	8.58	8.14	7.1		
	2	17.98	880	7.42	8.07	8		
	3	17.93	879	6.91	8.03	7.8		
	4	17.82	877	6.51	8.01	8		
	5	17.71	876	6.12	7.98	8.1		
	6	17.6	873	6.35	7.96	6.6		
	7	17.27	867	6.42	7.97	-6		
	7.1	17.36	866	0.96	7.86	-93		
	--						2.3	0.7
9/24/2008	0	18.21	883	9.61	7.98	14.5		
	1	18.2	883	9.52	7.98	14.4		
	2	17.81	876	8.79	7.96	15.9		
	3	17.74	874	8.62	7.95	17.2		
	4	17.71	874	8.54	7.92	17.3		
	5	17.69	873	8.37	7.94	17.7		
	6	17.64	872	8.18	7.94	18		
	7	17.51	869	7.91	7.92	18.1		
	--						2.73	0.74
10/16/2008	0	12.74	784	6.23	8.25	-15.3		
	1	12.41	778	6.11	8.23	-13.2		
	2	12.33	776	6.03	8.23	-13.1		
	3	12.25	775	5.92	8.23	-13.6		
	4	12.23	774	5.84	8.23	-13.6		
	5	12.1	773	5.7	8.22	-11.8		
	6	12.09	771	5.68	8.21	-9.4		
	7	11.99	769	5.54	8.19	-8.3		
	7.1	12.03	771	2.9	8.19			
	--						2.21	0.65
11/18/2008	0	6.93	689	32.61	8.32	39.4		
	1	6.57	683	31.87	8.33	35.3		
	2	6.46	682	31.45	8.31	34.2		
	3	6.42	680	31.06	8.32	33.4		
	4	6.4	681	30.78	8.31	34.1		
	5	6.34	680	30.49	8.32	33.6		
	6	6.33	680	30.15	8.31	32.5		
	7	6.33	679	29.72	8.31	-31.6		
	7.1	6.37	673	29.01	8.27	-55.9		
	--						2.65	0.75

CCR-2



# CCR-2



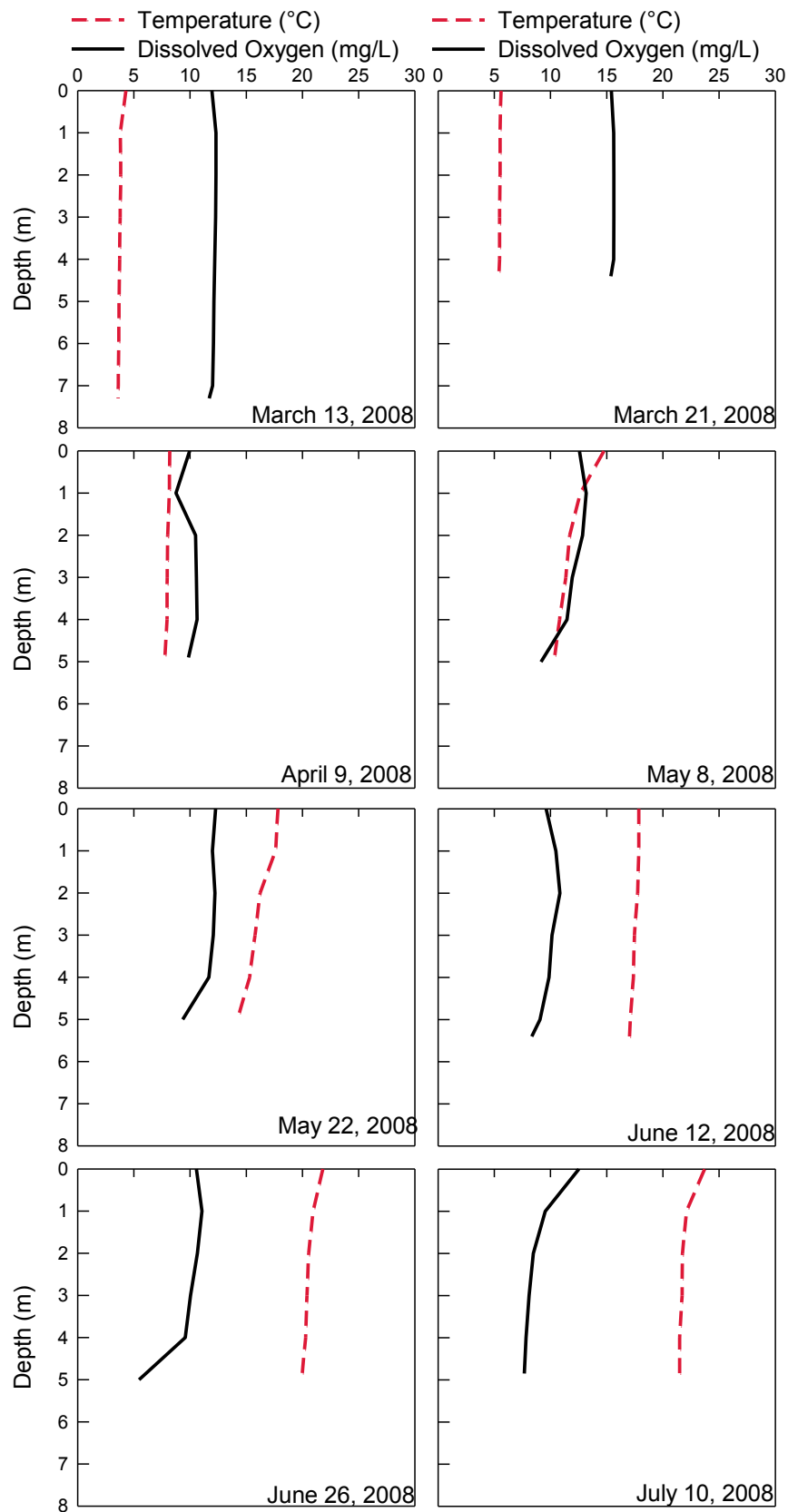
### CCR-3 Small Tables

COLLECT DATE	DEPTH	Temperature	Conductivity	Dissolved Oxygen	pH	ORP	1% transmittance	secchi disk
3/11/2008	0	4.3	563	11.95	8.55	73.1		
	1	3.8	564	12.3	8.49	74.4		
	2	3.85	556	12.31	8.49	73.8		
	3	3.78	552	12.28	8.47	73.4		
	4	3.74	554	12.2	8.46	73.3		
	5	3.7	554	12.13	8.46	73.1		
	6	3.66	552	12.08	8.45	72.6		
	7	3.62	554	12	8.45	71.6		
	7.3	3.6	553	11.7	8.45	63		
3/19/2008	0	5.6	583	15.41	8.64	77.8		
	1	5.51	582	15.62	8.55	79.6		
	2	5.51	582	15.63	8.55	79.1		
	3	5.47	582	15.63	8.52	78.4		
	4	5.47	582	15.62	8.51	78.5		
	4.4	5.42	580	15.36	8.52	77.5		
	--						2.25	0.74
4/7/2008	0	8.19	677	9.97	8.81	138		
	1	8.16	677	8.75	8.76	136.2		
	2	8.02	676	10.49	8.71	132.8		
	3	7.97	674	10.56	8.71	131.5		
	4	7.95	673	10.62	8.7	131.3		
	4.9	7.77	671	9.86	8.68	131.2		
	--						2.6	0.8
5/6/2008	0	14.75	800	12.57	8.22	33		
	1	12.65	756	13.17	8.25	33.6		
	2	11.71	738	12.85	8.2	37.3		
	3	11.36	734	11.93	8.18	39		
	4	10.81	722	11.47	8.13	41.1		
	5	10.31	723	9.15	8.07	40.6		
	--						2.97	0.85
5/20/2008	0	17.83	863	12.27	8.33	17.4		
	1	17.61	858	11.99	8.22	20.9		
	2	16.23	829	12.22	8.2	25.9		
	3	15.78	819	12.07	8.21	28.1		
	4	15.3	813	11.67	8.2	30.2		
	5	14.23	794	9.35	8.15	32		
	--						4.3	1.53
6/10/2008	0	17.86	846	9.61	8.16	-11.5		
	1	17.86	846	10.47	8.14	-9.9		
	2	17.75	844	10.83	8.14	-8.5		
	3	17.46	840	10.13	8.12	-6.9		
	4	17.38	838	9.86	8.1	-6.2		
	5	17.1	835	9.06	8.07	-5.1		
	5.4	17.03	834	8.33	8.03	-12.6		
	--						4	1.35

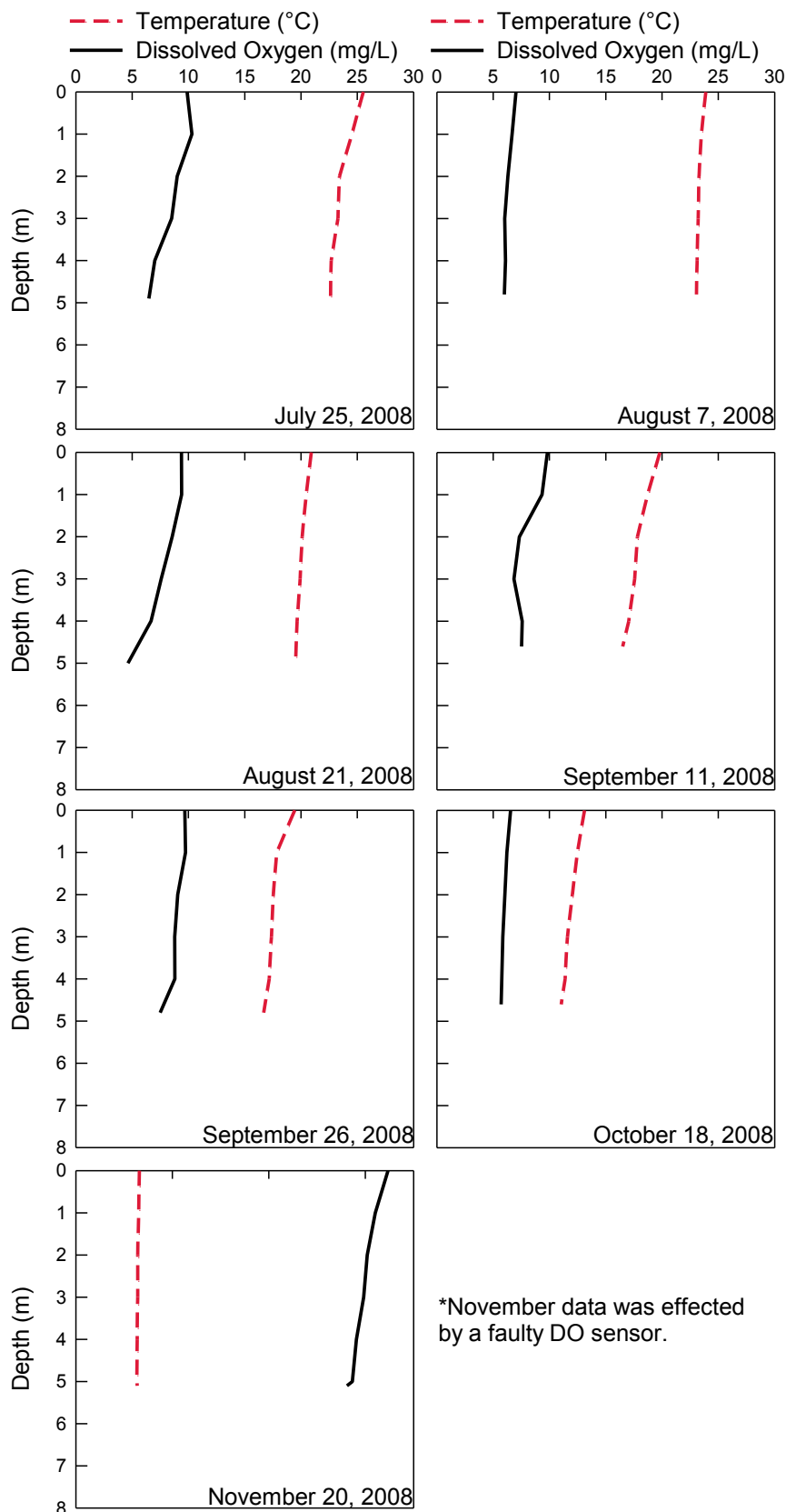
COLLECT DATE	DEPTH	Temperature	Conductivity	Dissolved Oxygen	pH	ORP	1% transmittance	secchi disk
6/24/2008	0	21.82	919	10.57	8.4	-16.1		
	1	20.96	899	11.06	8.43	-15		
	2	20.56	891	10.66	8.41	-11.7		
	3	20.41	889	10.04	8.38	-10.2		
	4	20.29	887	9.58	8.37	-9.2		
	5	19.94	883	5.47	8.2	-10.6		
	--						3.42	0.98
7/8/2008	0	23.71	987	12.52	8.42	47.9		
	1	22.1	956	9.53	9.56	39.6		
	2	21.74	951	8.46	8.23	38.4		
	3	21.71	950	8.09	8.21	35.2		
	4	21.49	946	7.82	8.2	33.1		
	4.85	21.49	941	7.67	8.2	32		
	--						1.75	0.49
7/23/2008	0	25.54	1038	9.87	8.53	-40.6		
	1	24.53	1013	10.31	8.56	-37.8		
	2	23.42	994	9	8.46	-28.7		
	3	23.28	991	8.51	8.44	-26.5		
	4	22.68	985	7.01	8.38	-25.3		
	4.9	22.63	984	6.49	8.35	-28		
	--						3.33	1.02
8/5/2008	0	23.89	1015	7.02	8.19	-30		
	1	23.5	1007	6.68	8.19	-31.4		
	2	23.29	1005	6.3	8.16	-29.8		
	3	23.21	1003	6.02	8.15	-29.7		
	4	23.12	1001	6.09	8.18	-28.3		
	4.8	23.06	1001	5.99	8.18	-29.5		
	--						2.75	0.98
8/19/2008	0	20.91	918	9.38	8.47	-10.3		
	1	20.46	909	9.4	8.45	-6.7		
	2	20.11	902	8.55	8.42	-4.4		
	3	19.92	899	7.58	8.4	-2.8		
	4	19.65	894	6.68	8.35	-1.7		
	5	19.52	891	4.62	8.28	-3.4		
	--						2.92	0.79
9/9/2008	0	19.81	919	9.82	8.18	42.7		
	1	18.73	894	9.33	8.17	35.2		
	2	17.81	877	7.32	8.02	37.4		
	3	17.57	873	6.84	7.97	36.7		
	4	17.04	865	7.58	8	33.5		
	4.6	16.5	856	7.52	8	32.8		
	--						2.32	0.78
9/24/2008	0	19.44	907	9.68	8.07	32		
	1	17.85	876	9.74	8.09	26.1		
	2	17.54	870	9.05	8.05	25.5		
	3	17.37	867	8.78	8.04	24.1		
	4	17.18	864	8.8	8.03	23		
	4.8	16.69	858	7.49	7.95	23.8		
	--						2.85	0.76

COLLECT DATE	DEPTH	Temperature	Conductivity	Dissolved Oxygen	pH	ORP	1% transmittance	secchi disk
10/16/2008	0	13.11	791	6.55	8.23	-7.5		
	1	12.49	779	6.21	8.22	-5.5		
	2	12.03	770	6.04	8.22	-3.9		
	3	11.6	763	5.86	8.22	-2.6		
	4	11.39	760	5.77	8.23	-0.3		
	4.6	11.04	756	5.71	8.22	0.8		
	--						2.42	0.72
11/18/2008	0	6.58	415	32.35	8.34	85.7		
	1	6.52	409	31.04	8.28	78		
	2	6.41	411	30.19	8.26	74.1		
	3	6.41	398	29.82	8.26	68		
	4	6.36	404	29.08	8.28	65		
	5	6.33	416	28.65	8.28	63.1		
	5.1	6.38	441	28.1	8.28	-58.9		
	--						2.72	0.68

CCR-3



CCR-3



## Cherry Creek Transect ORP Data

Collection Date	Depth	Transect ORP (mV)										
		D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11
6/24/2008	0	-6.6	-3.9	-8.4	-15.5	-14.2	-16.5	-12.7	-20.2	-22.1	-16.1	-25
	1	-6.3	-4.5	-8.4	-13.5	-12.9	-14.7	-11.1	-16.8	-16.9	-15	-19.2
	2	-5.8	-4.7	-7.5	-11	-10.2	-12.6	-10.1	-13.1	-13.4	-11.7	-15.5
	3	-5.7	-4.6	-7.2	-9.3	-9	-10.4	-9.1	-11.4	-11.5	-10.2	-12.6
	4	-5.5	-4.4	-6.9	-9.2	-8.3	-9.4	-9	-10.5	-10.2	-9.2	-11.8
	5	-5.2	-4.9	-6.9	-8.9	-8.2	-8.9	-8.9	-10.8	-9.8	-10.6	-34.2
	6	-4.9	-5.2	-7.8	-10.6	-11.1	-11.1	-10.3	-11.9	-11.7		
	7	-7.9	-8.6	-9.1	-12	-16.8	-16	-13.7	-27.6	-16.7		
	Bottom		-33.8	-47.9	-18.8	-27.6	-24.3	-27.3				

Collection Date	Depth	Transect ORP (mV)										
		D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11
7/23/2008	0	-42.7	-45.2	-46.9	42.3	36	65.6	-9.6	-14.5	-31.7	-40.6	-33.5
	1	-42.2	-44.9	-44.9	16.3	28.7	44.7	-1.9	-13.2	-21.5	-37.8	-32.6
	2	-41.3	-42.2	-44.7	0.3	26.4	35.3	-0.4	-9.4	-20.8	-28.7	-28.8
	3	-41.2	-41.7	-45.2	-3.1	23	31.9	1.2	-7.1	-18.7	-26.5	-26.1
	4	-41.2	-42.3	-46.5	-5.4	20.4	27.4	2	-6.4	-18	-25.3	-26.9
	5	-57.9	-55.1	-56.3	-12.5	16.2	20.3	-0.3	-10.4	-20.1	-28	
	6	-74.9	-62	-71.6	-35.5	3.6	9.6	-14.3	-14.7	-27.4		
	7	-84.3	-76.6	-92.7	-55.4	-18.9	-27.6	-39.4	-112.6	-72.4		
	Bottom	-103.7		-175.5	-91.8	-145.7						

Collection Date	Depth	Transect ORP (mV)										
		D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11
8/19/2008	0	-22.4	-7.8	98.6	23.3	11.2	6	2.4	-2.8	-6.4	-10.3	101.2
	1	-22.7	-15.9	76.2	21.9	11.4	6	3.5	-1.1	-4.5	-6.7	89.7
	2	-21.9	-17.5	64.3	21.6	12.5	6.6	4.4	0.7	-2.2	-4.4	84.4
	3	-21.5	-17.5	57.7	21	12.8	7.6	5.1	2.1	-0.7	-2.8	80.5
	4	-21.7	-17.4	53.2	19.2	13.1	7.6	5	2.5	-0.4	-1.7	76.8
	5	-22.3	-17	49.1	16.9	12.4	7.7	2.1	0.7	0.1	-3.4	73.8
	6	-23.4	-20.1	44.7	16	11.1	8.5	-3.1	-4.2	-1.8		
	7	-23	-19.3	45.9	17.3	11.5	6.2	-5.8	-8.3	-6.6		
	Bottom	-22.6	-18.2	43.6	15.4	5.8						

## Cherry Creek Transect DO Data

Collection Date	Depth	Transect DO (mg/L)										
		D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11
6/24/2008	0	9.82	10.39	10.11	10.38	10.27	10.29	10.15	10.62	10.57	10.57	10.14
	1	9.98	10.28	10.03	10.37	10.31	10.34	10.14	10.64	10.96	11.06	11.2
	2	9.99	10.19	10.03	10.26	10.15	10.25	10.11	10.35	10.86	10.66	10.36
	3	9.95	10.08	9.86	9.91	9.92	10.06	9.94	9.95	10.4	10.04	9.65
	4	9.88	9.87	9.38	9.66	9.79	9.79	9.65	9.55	9.6	9.58	7.7
	5	9.84	9.7	9.1	9.59	9.54	9.28	9.21	7.61	7.98	5.47	7.59
	6	5.48	4.55	5.57	6.81	4.75	4.94	5.35	6.17	5.65		
	7	1.49	1.45	2.45	2.94	1.47	2.55	2.85	1.22	1.97		
	Bottom		0.33	0.9	0.86	1.06	0.96	0.63				

Collection Date	Depth	Transect DO (mg/L)										
		D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11
7/23/2008	0	9.08	9.46	9.15	9.02	9.5	9.89	10.03	9.93	9.96	9.87	10.15
	1	9.19	9.41	9.47	8.87	9.09	9.85	9.77	9.85	10.11	10.31	9.99
	2	8.86	9.09	8.56	8.22	8.83	8.73	9.01	8.99	9.47	9	9.63
	3	8.36	8.46	7.71	7.94	8.19	8.46	8.33	8.59	8.71	8.51	9.14
	4	8.05	8.06	6.77	7.53	8.3	7.74	8.29	8.06	7.87	7.01	6.97
	5	2.75	3.35	3.73	4.52	5.42	4.15	5.88	5.96	6.57	6.49	
	6	1.28	2.28	1.3	1.57	2.51	2.69	2.7	4.16	4.19		
	7	0.7	0.58	0.27	0.79	1.16	1.04	1.22	0.59	0.53		
	Bottom	0.47		0.23	0.53	0.49						

Collection Date	Depth	Transect DO (mg/L)										
		D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11
8/19/2008	0	9.5	9.03	8.41	8.34	8.37	8.63	8.47	9.17	9.4	9.38	9.31
	1	9.52	8.99	8.31	8.3	8.32	8.62	8.22	9.1	9.64	9.4	9.71
	2	9.53	8.74	8.16	8.14	7.87	8.32	8.13	7.86	8.47	8.55	8.3
	3	9.53	8.64	8.06	7.49	7.66	7.89	7.75	7.54	7.23	7.58	6.94
	4	8.89	8.52	7.97	7.39	7.45	7.54	7.37	7.21	6.96	6.68	6.27
	5	7.4	8.43	7.91	6.83	7.29	7.31	4.23	5.45	6.47	4.62	5.56
	6	5.97	5.78	5.12	4.98	4.45	4.37	1.61	3.07	4.39		
	7	5.71	4.69	3.84	3.48	2.19	1.87	1.45	1.66	1.34		
	Bottom	4.74	3.55	2.45	2.21	1.63						

## **Appendix C**

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### **2008 Stream Water Quality and Precipitation Data**

CC-10 C&A Water Chemistry Data										
Analytical Detection Limits		2	2	2	2	2	2	3	4	4
Sample Date	Sample Name/ Location	Total Phosphorous µg/L	Total Dissolved Phosphorous µg/L	Ortho-phosphate µg/L	Total Nitrogen µg/L	Total Dissolved Nitrogen µg/L	Nitrate+ Nitrite µg/L	Ammonia µg/L	TSS mg/L	TVSS mg/L
1/15/2008	CC-10	186	137	126	1831	1639	1332	55	20.6	
2/19/2008	CC-10	245	149	137	1768	1599	1078	189	45.8	5
3/19/2008	CC-10	145	101	100	1346	1128	692	50	19.4	
4/7/2008	CC-10	153	124	115	1521	1444	1077	80	17.4	
5/6/2008	CC-10	234	193	185	1177	1061	631	42	28.4	5.4
6/10/2008	CC-10	266	192	188	975	880	533	45	24.7	4.8
7/8/2008	CC-10	247	198	191	814	721	432	79	11.4	
8/5/2008	CC-10	211	148	149	717	688	284	48	23.3	6
9/9/2008	CC-10	190	166	173	878	766	467	31	4	
10/16/2008	CC-10	166	119	116	871	772	469	34	11.8	
11/18/2008	CC-10	158	122	136	920	797	513	24	36.4	5.6
12/11/2008	CC-10	142	118	126	1408	1390	730	45	14.6	
5/7/2008	CC-10 storm	315	246	240	1347	1373	715	131	62	9
5/13/2008	CC-10 storm	238	191	186	1382	1188	698	48	41.8	7.4
6/5/2008	CC-10 storm	303	224	210	1384	1140	580	80	36.5	7
8/9/2008	CC-10 storm	136			875				31.2	7.2
8/15/2008	CC-10 storm	170	137	112	1123	996	590	96	21.6	5.8
9/12/2008	CC-10 storm	519	213	207	2272	1350	817	113	139.3	19

CC-O at I-225 C&A Water Chemistry Data										
Analytical Detection Limits		2	2	2	2	2	2	3	4	4
Sample Date	Sample Name/ Location	Total Phosphorous µg/L	Total Dissolved Phosphorous µg/L	Ortho-phosphate µg/L	Total Nitrogen µg/L	Total Dissolved Nitrogen µg/L	Nitrate+ Nitrite µg/L	Ammonia µg/L	TSS mg/L	TVSS mg/L
1/15/2008	CC-Out at I225	59	27	15	929	711	134	98	6.8	
2/19/2008	CC-Out at I225	82	11	9	980	694	154	72	7	
3/19/2008	CC-Out at I225	68	18	8	1085	541		10	8.6	5
4/7/2008	CC-Out at I225	80	14	5	840	435		8	8.4	
5/6/2008	CC-Out at I225	233	34	25	914	508	3	13	19	7.8
6/10/2008	CC-Out at I225	101	59	54	722	577	6	66	14.7	5.7
8/5/2008	CC-Out at I225	170	90	84	754	570	18	114	25	5.3
9/24/2008	CC-Out at I225	75	18	16	808	520	3	31	29	7.6
10/16/2008	CC-Out at I225	79	17	14	759	423		16	24.7	6.5
11/18/2008	CC-Out at I225	75	17	9	671	418	2	7	24.4	5.8
12/11/2008	CC-Out at I225	61	8	6	741	506		13	9.8	4.8

CT-1 C&A Water Chemistry Data										
Analytical Detection Limits		2	2	2	2	2	2	3	4	4
Sample Date	Sample Name/ Location	Total Phosphorous µg/L	Total Dissolved Phosphorous µg/L	Ortho-phosphate µg/L	Total Nitrogen µg/L	Total Dissolved Nitrogen µg/L	Nitrate+ Nitrite µg/L	Ammonia µg/L	TSS mg/L	TVSS mg/L
1/15/2008	CT-1	88	10	4	5377	4860	3828	496	43	6.8
2/19/2008	CT-1	99	8	2	3832	3963	2682	774	32.6	5.8
3/19/2008	CT-1	56	11	9	3853	3889	3403	198	6.6	
4/7/2008	CT-1	52	10	5	3796	3944	3315	374	29.8	4.4
6/10/2008	CT-1	44	19	14	1155	1032	462	20	27.5	9
7/8/2008	CT-1	71	28	20	814	735	260	22	20.4	5
8/5/2008	CT-1	53	22	17	704	611	122	15	19.8	4.7
9/9/2008	CT-1	47	7	7	2393	2039	1620	6	13.1	4
10/16/2008	CT-1	42	12	9	2629	2408	2281	25	13	4
11/18/2008	CT-1	43	20	18	2904	2761	2195	52	31.4	5
12/11/2008	CT-1	53	12	6	3277	2967	1720	75	25.4	5
8/9/2008	CT-1 storm	56			893				31.4	7.4
8/15/2008	CT-1 storm	56	10	4	1134	925	368	15	40	7
9/12/2008	CT-1 storm	146	44	39	1635	1203	704	245	87.5	20.5

CT-2 C&A Water Chemistry Data										
Analytical Detection Limits		2	2	2	2	2	2	3	4	4
Sample Date	Sample Name/ Location	Total Phosphorous µg/L	Total Dissolved Phosphorous µg/L	Ortho-phosphate µg/L	Total Nitrogen µg/L	Total Dissolved Nitrogen µg/L	Nitrate+Nitrite µg/L	Ammonia µg/L	TSS mg/L	TVSS mg/L
1/15/2008	CT-2	87	8	4	5346	4922	3774	460	28.4	5
2/19/2008	CT-2	103	6	2	4314	3833	2619	827	35.4	6
3/19/2008	CT-2	66	8	5	3528	3179	2619	164	42	6.6
4/7/2008	CT-2	63	10	3	4850	4505	3816	433	32.8	6.2
5/6/2008	CT-2	114	20	14	2491	2285	1650	77	158	15.6
6/10/2008	CT-2	38	10	2	1039	844	208	107	40.2	7
7/8/2008	CT-2	71	9		925	615	44	28	29.5	7.9
8/5/2008	CT-2	50	12	7	428	337	10	13	27.7	6.2
9/9/2008	CT-2	62	45	5	2139	1762	1362	14	37.2	6.7
10/16/2008	CT-2	44	7	7	2382	2406	1920	38	29	6.3
11/18/2008	CT-2	51	12	13	2568	2288	1948	30	44.6	8.8
12/11/2008	CT-2	47	44	6	3137	2817	1618	64	18.2	4.2
5/7/2008	CT-2 storm	170	18	14	1590	1504	1043	102	231.3	24
5/13/2008	CT-2 storm	85	20	18	1488	1358	794	81	90.2	14.6
6/5/2008	CT-2 storm	64	16	6	1261	851	212	87	52	14
8/9/2008	CT-2 storm	46			831				31	8.6
8/15/2008	CT-2 storm	73	13	8	986	776	212	19	39.2	8
9/12/2008	CT-2 storm	130	26	37	1644	1200	650	196	43.5	14

CT-P1 C&A Water Chemistry Data										
Analytical Detection Limits		2	2	2	2	2	2	3	4	4
Sample Date	Sample Name/ Location	Total Phosphorous µg/L	Total Dissolved Phosphorous µg/L	Ortho-phosphate µg/L	Total Nitrogen µg/L	Total Dissolved Nitrogen µg/L	Nitrate+ Nitrite µg/L	Ammonia µg/L	TSS mg/L	TVSS mg/L
1/15/2008	CT-P1	40	25	18	2478	2152	842	356	9	
2/19/2008	CT-P1	29	11	4	1316	1230	771	26	6.2	
3/19/2008	CT-P1	28	5	5	905	634	282	27	8	
4/7/2008	CT-P1	42	8	4	738	585	133	31	12.8	
5/6/2008	CT-P1	155	22	15	838	718	208	50	8.6	
6/10/2008	CT-P1	88	21	14	997	843	332	77	21.5	8
7/8/2008	CT-P1	162	40	25	1368	907	242	72	43.1	11.3
8/5/2008	CT-P1	141	44	24	1143	969	350	76	30	7
9/9/2008	CT-P1	115	9	6	1271	606	121	8	27.8	11.4
10/16/2008	CT-P1	38	10	8	937	801	446	32	8	
11/18/2008	CT-P1	19	5	7	1095	981	487	69	9.6	
12/11/2008	CT-P1	58	4	2	1566	1226	575	29	26.6	7.4
5/7/2008	CT-P1 storm	142	35	29	1427	1489	626	365	94	18
5/13/2008	CT-P1 storm	57	36	28	1201	1228	569	214	31.8	10
6/5/2008	CT-P1 storm	116	17	8	1456	887	293	167	103	23
8/9/2008	CT-P1 storm	137			1500				33.4	14.2
8/15/2008	CT-P1 storm	293	78	62	1611	1069	462	139	110.6	19
9/12/2008	CT-P1 storm	154	84	85	1321	992	453	347	82.5	21.5

CT-P2 C&A Water Chemistry Data										
Analytical Detection Limits		2	2	2	2	2	2	3	4	4
Sample Date	Sample Name/ Location	Total Phosphorous µg/L	Total Dissolved Phosphorous µg/L	Ortho-phosphate µg/L	Total Nitrogen µg/L	Total Dissolved Nitrogen µg/L	Nitrate+ Nitrite µg/L	Ammonia µg/L	TSS mg/L	TVSS mg/L
1/15/2008	CT-P2	29	12	9	2391	1400	1211	214	17.6	
2/19/2008	CT-P2	33	12	8	1519	1397	931	32	6.6	
3/19/2008	CT-P2	47	15	11	1198	932	581	21	10.6	
4/7/2008	CT-P2	60	11	6	1220	1057	388	203	166.8	12.6
5/6/2008	CT-P2	40	28	22	1497	1408	450	88	9.4	
6/10/2008	CT-P2	40	20	15	1338	1205	676	111	23	7
7/8/2008	CT-P2	65	27	17	1256	1069	504	67	24.6	9.5
8/5/2008	CT-P2	83	29	19	1244	1122	631	37	19.8	5
9/9/2008	CT-P2	76	12	7	1384	897	450	14	22.4	8.2
10/16/2008	CT-P2	34	10	9	1418	1250	871	52	24	6.3
11/18/2008	CT-P2	38	4	9	1400	1270	813	55	27.2	5.2
12/11/2008	CT-P2	32	8	7	1382	1262	483	42	20.6	7
5/7/2008	CT-P2 storm	109	44	41	1252	1270	506	240	61	12.5
5/13/2008	CT-P2 storm	53	35	31	1116	1065	522	148	18.4	6.6
6/5/2008	CT-P2 storm	135	59	44	1415	1125	446	154	55	17
8/9/2008	CT-P2 storm	144			1571				26	9
8/15/2008	CT-P2 storm	122	58	44	1295	983	317	120	26	8
9/12/2008	CT-P2 storm	238	69	65	1901	1348	737	315	76.5	21.5

SC-3 C&A Water Chemistry Data										
Analytical Detection Limits		2	2	2	2	2	2	3	4	4
Sample Date	Sample Name/ Location	Total Phosphorous µg/L	Total Dissolved Phosphorous µg/L	Ortho-phosphate µg/L	Total Nitrogen µg/L	Total Dissolved Nitrogen µg/L	Nitrate+Nitrite µg/L	Ammonia µg/L	TSS mg/L	TVSS mg/L
3/19/2008	SC-3	44	19	18	1503	1243	1021	20	17.4	
4/7/2008	SC-3	53	9	6	522	375	125	9	60	5.6
5/6/2008	SC-3	45	27	22	386	359	45	11	9	
7/8/2008	SC-3	131	109	92	616	535	42	15	25.5	6.9
9/9/2008	SC-3	52	38	31	287	273	10	5	7.2	
10/16/2008	SC-3	35	22	22	288	270	62	5		
11/18/2008	SC-3	24	19	19	585	546	368	7	11	
12/11/2008	SC-3	31	18	20	2346	2218	1298	72	9.2	4
5/7/2008	SC-3 storm	52	37	37	574	546	138	19	21	6
5/13/2008	SC-3 storm	53	40	35	1332	1245	909	4	11.2	5.2
6/5/2008	SC-3 storm	190	109	101	854	654	168	33	46.5	8
8/9/2008	SC-3 storm	215			2408				18.6	4.6
8/15/2008	SC-3 storm	159	125	105	1243	1107	628	107	14	4.4
9/12/2008	SC-3 storm	808	541	488	5188	3964	3199	90	111	28.5

Rain Gauge C&A Water Chemistry Data								
Analytical Detection Limits		2	2	2	2	2	2	3
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
5/7/2008	Rain Gauge storm	76	26	23	1350	1189	442	565
5/13/2008	Rain Gauge storm	26	8	8	1143	1098	378	630
8/15/2008	Rain Gauge storm	43	6	6	649	565	240	250
9/12/2008	Rain Gauge storm	24	10	5	360	218	89	136

## **Appendix D**

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**2008 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 4220 and 6700 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 ( $\text{ft}^3/\text{sec}$ ) 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 2008 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. A rating curve was also developed for Site CT-P2, but was only used for quality control to evaluate the multi-level weir equation for the Peoria Pond outlet structure. A multi-level weir equation was also used to estimate flows through the Perimeter Pond outlet structure. 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 2008, 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 March 1, 2008 to June 30, 2008, to estimate periods of missing levels for CC-10 from March through June. Similarly, data from September 1, 2008 to October 24, 2008 was used to estimate missing levels for CC-10 from late October through December 2008.

**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
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
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
CT-P1	2002	27-Jun-02	0.45	0.430	0.80
CT-P1	2002	11-Jul-02	0.60	0.580	2.43

Site	Year	Date	Staff Gage Level (ft)	Transducer Level (ft)	Discharge (cfs)
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-P2	2004	09-Jan-04	0.32	0.327	0.79
CT-P2	2004	27-May-04	0.33	0.332	0.67
CT-P2	2004	22-Jun-04	3.25	3.257	12.00
CT-P2	2004	23-Jun-04	1.07	1.051	2.75
CT-P2	2005	01-Apr-05	1.04	1.038	2.81
CT-P2	2005	14-Apr-05	3.84	3.858	11.86
CT-P2	2005	25-Apr-05	4.13	4.153	19.02
CT-P2	2005	19-May-05	0.43	0.428	1.44
CT-P2	2005	26-May-05	0.42	0.438	1.12
CT-P2	2005	01-Jun-05	1.44	1.377	4.56
CT-P2	2005	16-Aug-05	3.40	3.417	13.90
CT-P2	2005	13-Oct-05	3.10	3.172	11.56
CT-P2	2006	20-Apr-06	0.38	0.380	1.45
CT-P2	2006	13-Jun-06	0.29	0.293	0.85

Site	Year	Date	Staff Gage Level (ft)	Transducer Level (ft)	Discharge (cfs)
CT-P2	2006	12-Jul-06	1.22	1.260	2.79
CT-P2	2006	08-Aug-06	2.24	2.204	8.18
CT-P2	2007	13-Mar-07	2.30	2.308	5.24
CT-1 (old site)	2007	26-Apr-07	2.98	2.935	18.56
CT-1 (old site)	2007	26-Jul-07	2.54	2.545	9.81
CT-1 (old site)	2007	9-Aug-07	2.24	2.248	4.76
CT-1 (old site)	2007	13-Nov-07	2.16	2.175	0.84
CT-1 (new site)	2008	26-Jun-08	0.39	--	0.45
CT-1 (new site)	2008	3-Jul-08	0.46	0.458	0.35
CT-1 (new site)	2008	15-Aug-08	0.75	--	11.29
CT-1 (new site)	2008	11-Dec-08	0.63	0.650	2.98

**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 <sup>2</sup>
CC-10	< 1.0	$Q = \text{EXP}((H+0.4483)/0.8725)$	0.82
	> 1.0	$Q = \text{EXP}((H+7.4774)/2.4024)-28.5645$	0.92
SC-3	< 0.5	$Q = \text{EXP}((H-0.4766)/0.1135)$	0.66
	> 0.5	$Q = (H-0.3446)/0.2969-0.4310$	0.87
CT-P1	<1.5	$Q = \text{EXP}((H+0.3172)/0.5314)-4.2269$	0.93
	>1.5	$Q = (H-0.4623)/0.0776$	0.91
CT-P2	< 0.60	$Q = (3.3)^*(1)^*(H)^{(1.5)}$	
	0.61 - 1.09	$Q = (0.60)^*(0.50)^*((2*32.2*(H_{\text{adj}}))^{(0.5)})$	
	1.10 - 1.99	$Q = (0.60)^*(0.50)^*((2*32.2*(H_{\text{adj}}))^{(0.5)})+((3.33)^*(1)^*(H-1.0)^{(1.5)})$	
	2.00 - 2.59	$Q = (0.60)^*(0.50)^*((2*32.2*(H_{\text{adj}}))^{(0.5)})+((0.60)^*(0.50)^*((2*32.2*(H_{\text{adj}}-1.0))^{(0.5)})+((3.33)^*(1)^*(H-2.0)^{(1.5)})$	
	2.60 - 2.99	$Q = (0.60)^*(0.50)^*((2*32.2*(H_{\text{adj}}))^{(0.5)})+((0.60)^*(0.50)^*((2*32.2*(H_{\text{adj}}-1.0))^{(0.5)})+((0.60)^*(0.50)^*((H_{\text{adj}}-2.0)^{(0.5)})$	
	3.00 - 3.59	$Q = (0.60)^*(0.50)^*((2*32.2*(H_{\text{adj}}))^{(0.5)})+((0.60)^*(0.50)^*((2*32.2*(H_{\text{adj}}-1.0))^{(0.5)})+((0.60)^*(0.50)^*((H_{\text{adj}}-2.0)^{(0.5)})+((3.3)^*(1)^*(H-3.0)^{(1.5)})$	
	3.60 - 3.99	$Q = (0.60)^*(0.50)^*((2*32.2*(H_{\text{adj}}))^{(0.5)})+((0.60)^*(0.50)^*((2*32.2*(H_{\text{adj}}-1.0))^{(0.5)})+((0.60)^*(0.50)^*((H_{\text{adj}}-2.0)^{(0.5)})+((0.60)^*(0.50)^*((2*32.2*(H_{\text{adj}}-3.0))^{(0.5)})$	
	4.00 - 4.49	$Q = (0.60)^*(0.50)^*((2*32.2*(H_{\text{adj}}))^{(0.5)})+((0.60)^*(0.50)^*((2*32.2*(H_{\text{adj}}-1.0))^{(0.5)})+((0.60)^*(0.50)^*((H_{\text{adj}}-2.0)^{(0.5)})+((0.60)^*(0.50)^*((2*32.2*(H_{\text{adj}}-3.0))^{(0.5)})+((3.3)(1)(H-4.0))^{(1.5)}$	
	4.50 - 5.19	$Q = (0.60)^*(0.50)^*((2*32.2*(H_{\text{adj}}))^{(0.5)})+((0.60)^*(0.50)^*((2*32.2*(H_{\text{adj}}-1.0))^{(0.5)})+((0.60)^*(0.50)^*((H_{\text{adj}}-2.0)^{(0.5)})+((0.60)^*(0.50)^*((2*32.2*(H_{\text{adj}}-3.0))^{(0.5)})+((0.60)(0.50)(2*32.2*H_{\text{adj}}-4.0))^{(0.5)}$	
	5.20 - 6.80	$Q = (0.60)^*(0.50)^*((2*32.2*(H_{\text{adj}}))^{(0.5)})+((0.60)^*(0.50)^*((2*32.2*(H_{\text{adj}}-1.0))^{(0.5)})+((0.60)^*(0.50)^*((H_{\text{adj}}-2.0)^{(0.5)})+((0.60)^*(0.50)^*((2*32.2*(H_{\text{adj}}-3.0))^{(0.5)})+((0.60)(0.50)(2*32.2*H_{\text{adj}}-4.0))^{(0.5)})+((3.3)(1)(H-5.2))^{(1.5)}$	
CT-1 (old site)		$Q = (H-2.0637)/0.0485$	0.98
CT-1 (new site)		$Q = \text{EXP}((H-0.5173)/0.0960)$	0.94
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<sub>adj</sub> = 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 <sup>2</sup>	Percent of Annual Data Estimated
CC-10, Mar & Apr	CC-10 Level = 2.8751*(Parker Level) - 9.6527	0.88	7%
CC-10, Oct – Dec	CC-10 Level = 5.2729*(Parker Level) - 18.69	0.51	19%
SC-3, Jan – Mar	Interpolated ice conditions		16%
SC-3, Jul – Sep	SC-3 Level = 0.1764*Ln(CC-10 Level) + 0.2695	0.15	14%
CT-P1, Jan – Feb	CT-P1 Level = 1.5004*Ln(CT-1 Level) - 0.6089	0.87	6%
CT-P1, Aug – Sep	CT-P1 Level = 7.8614*(CT-1 Level)^3- 13.071*(CT-1 Level)^2+7.5543*(CT-1 Level)-0.9134	0.95	8%
CT-P1, Dec	CT-P1 Level = 0.207*(CT-P2)+0.4856	0.94	5%
CT-P2, Jul	CT-P2 Level = 2.142*(CT-P1 Level) - 0.7789	0.82	7%
CT-P2, Oct	CT-P2 Level = 2.2113*(CT-P1 Level) - 0.8062	0.42	6%
CT-1, Mar	CT-1 Level = 7.8353(CTP1 Level^2) - 8.9459(CTP1 Level) + 4.7459	0.72	2%
CT-1, Oct – Dec	CT-1 Level = 0.8452+0.3594*Ln(CT-2 Level - 0.1734)	0.90	23%
CT-2	CT-2 Level = 0.2955*(CT-P2 Level)+0.4845	0.79	12%

## 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, Jan – May	41.78
CC-10, May – Dec	20.48
SC-3	0.55
CT-1, Jan – Mar	5.34
CT-1, Jul – Dec	4.21
CT-2	4.22
CTP-1	2.91
CTP-2	2.28

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:

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

where:

$L_{\text{day}}$  = pounds per day phosphorus loading,

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

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

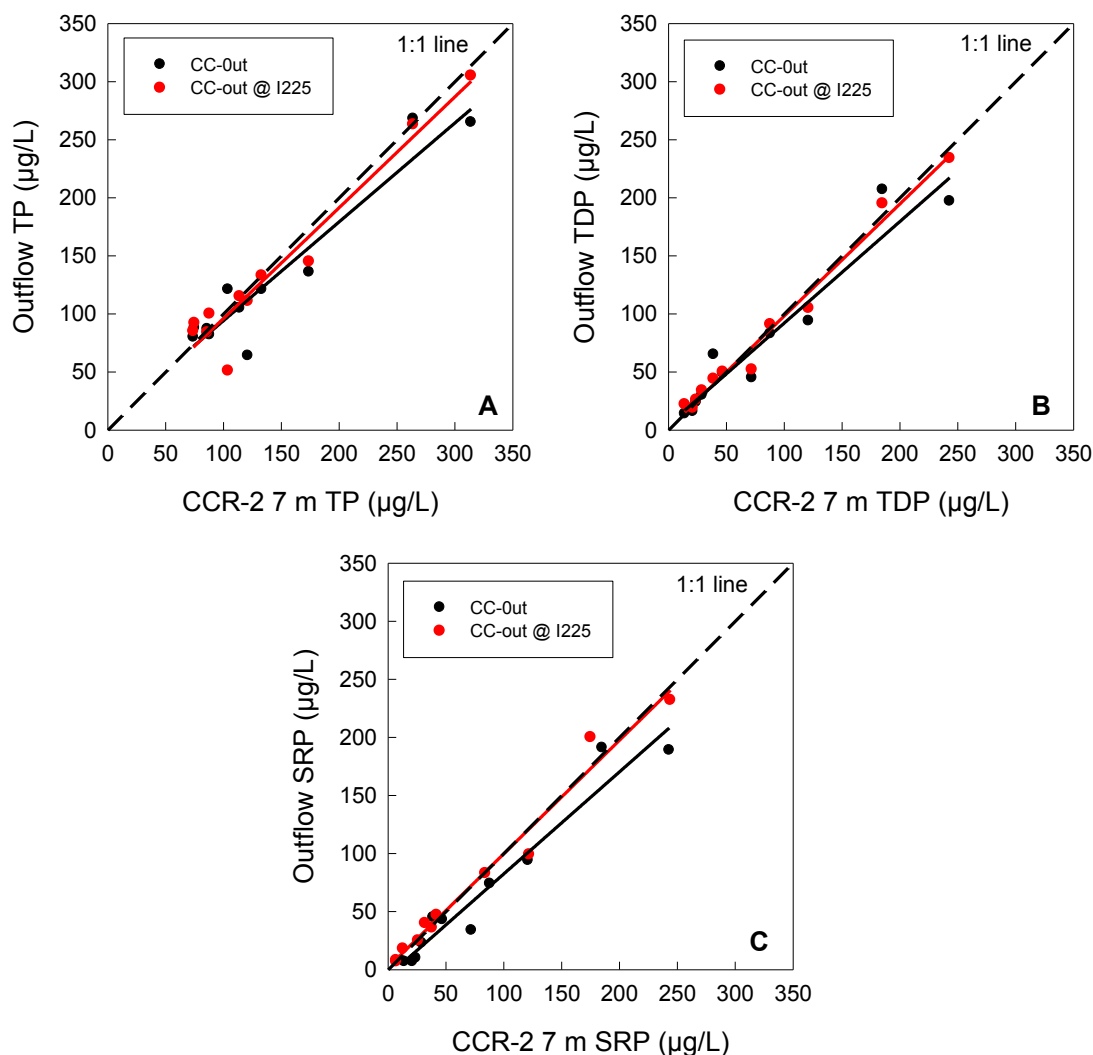
**Table D-5: Monthly base flow TP concentrations (µg/L) and median annual storm flow TP concentration (µg/L) applied to respective flows in 2008.**

Month	CC-O	CC-10	SC-3	CT-P1	CT-P2	CT-1	CT-2
January	59	186	44	40	29	88	87
February	82	245	44	29	33	99	103
March	68	145	44	28	47	56	66
April	80	153	53	42	60	52	63
May	233	234	45	155	40	48	114
June	101	266	88	88	40	44	38
July	184	247	131	162	65	71	71
August	170	211	92	141	83	53	50
September	75	190	52	115	76	47	62
October	79	166	35	38	34	42	44
November	75	158	24	19	38	43	51
December	61	142	31	58	32	53	47
Annual storm flow median	--	280	246	150	134	86	95

## 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. In 2006, concerns were raised about the appropriateness of using water quality data collected at the CC-O site which may not accurately represent conditions with the reservoir. Following many discussions between the Authority's consultants and WQCD, it was agreed upon that water quality data collected downstream of the reservoir would be more appropriate to use when estimating the export load, given the geological underpinnings and the potential for seepage at the base of the dam, as well as the uncertainties associated with the relative differences in depth between the outflow structure (~13 m) and the bottom waters sampled at CCR-2 (~7 m).

In 2007, GEI monitored water quality of the outflow at two locations on Cherry Creek, Site CC-O and a site located approximately 75 m downstream of the concrete outflow structure at the base of the dam (CC-O @ I-225). The 2007 outflow phosphorus concentrations were compared to the 2007 in-lake CCR-2 7 m phosphorus concentrations to evaluate which data would be more appropriate to use when determining the export load (Figure D-1). While ANOVA of log transformed data revealed no statistical differences between the three sources of data, the water quality data collected from Site CC-O @ I-225 consistently revealed greater correlation with the in-lake concentration. Furthermore, the slopes of the regressions for CC-O @ I-225 were always closer to the 1:1 line than for slopes of the regressions for data collected at CC-O. Therefore, the monthly total phosphorus concentration collected from Site CC-O @ I-225 was applied to the USACE outflow to estimate the 2008 export load (Equation 1).



**Figure D-1: Relationship between 2007 outflow phosphorus concentrations (Panel A-TP, Panel B-TDP, Panel C-SRP) and in-lake phosphorus concentrations with best-fit linear regression lines and the 1:1 line for reference.**

## Precipitation

Precipitation data collected at Denver/Centennial Airport (KAPA) was used to estimate phosphorus loading due to precipitation in 2008 (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 (1987-2005) and Equation 2.

## EQUATION 2:

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

where:

$L_{\text{precip}}$  = pounds of phosphorus from precipitation,

PR = rainfall precipitation in inches,

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

$\mu\text{g/L}$  = 116  $\mu\text{g/L}$ , long-term median TP concentration.

## Alluvium

The alluvial water component remains one of the unmonitored sources of inflow to the reservoir; however there is agreement among the Authority's consultants and WQCD that the annual flow is relatively constant given the boundaries of the alluvium in relation to the reservoir. The majority of the alluvial water monitored at MW-9 flows 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 2008 alluvial component was defined as a constant source of water to the reservoir that accounts for 2,000 ac-ft/yr, with no seasonal fluctuations, but was adjusted to 1,965 ac-ft/yr during the stream flow normalization process. The long-term (1994-2005) median total dissolved phosphorus concentration for MW-9 (190  $\mu\text{g/L}$ ) was used to estimate the alluvial load component (Equation 3).

## EQUATION 3:

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

where:

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

$\mu\text{g/L}$  = 190  $\mu\text{g/L}$ , long-term median TDP concentration

$Q_{\text{alluvium}}$  = alluvial inflow in Ac-ft

## Redistributed Inflows

In 2008, 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:

$$\text{Redistributed Inflow} = (\text{USACE Inflow} - \text{Precipitation} - \text{Alluvial Inflow}) - \text{GEI Stream Inflow}$$

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 potentially new category is if the redistributed inflow is truly this great, then the current inflow monitoring regime should be reevaluated to address such occurrences.

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

Month	Unadjusted Flow (ac-ft/mo)										Normalized Flow (ac-ft/mo)	
	USACE Inflow	USACE Outflow	CC-10	SC-3	CT-P1	CT-P2	CT-1	CT-2	Precip	Alluvium	CC-10	CT-2
January	1,801	1,585	1,548	69	75	45	197	203	21	169	1,424	186
February	2,279	1,861	1,856	66	79	0	209	205	35	158	1,878	208
March	2,630	2,943	2,244	27	96	0	154	216	16	169	2,230	214
April	2,235	2,104	1,431	21	157	0	0	309	62	164	1,652	357
May	2,253	2,277	1,131	24	209	151	0	397	149	169	1,432	502
June	758	547	401	22	99	84	0	331	55	164	295	244
July	190	153	171	2	63	54	31	151	56	135	0	0
August	1,946	1,452	721	26	291	212	360	465	205	169	955	616
September	787	708	185	9	138	157	324	423	77	164	166	380
October	1,125	1,148	255	4	110	82	219	241	49	169	466	440
November	1,178	930	619	7	76	64	153	196	9	164	763	242
December	1,658	1,420	1,085	22	89	78	171	210	58	169	1,199	232
<b>Annual Total</b>	<b>18,841</b>	<b>17,129</b>	<b>11,648</b>	<b>299</b>	<b>1,482</b>	<b>927</b>	<b>1,818</b>	<b>3,348</b>	<b>792</b>	<b>1,965</b>	<b>12,461</b>	<b>3,623</b>
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	--	254	783	8	10	7	47	48	7	88	720	44
February	--	415	1,270	8	6	0	56	57	11	82	1285	58
March	--	544	1,153	3	12	0	28	40	5	88	1145	40
April	--	458	630	9	42	0	0	66	20	85	727	76
May	--	1,443	804	9	86	44	0	110	47	88	1018	140
June	--	150	293	10	31	17	0	62	17	85	216	46
July	--	76	115	1	27	10	6	29	18	70	0	0
August	--	671	510	16	117	69	79	103	65	88	676	137
September	--	144	96	4	49	46	66	95	24	85	86	85
October	--	247	115	0	21	8	34	37	15	88	210	68
November	--	190	280	0	4	7	20	27	3	85	345	34
December	--	236	627	8	14	8	26	28	18	88	693	31
<b>Annual Total</b>	<b>--</b>	<b>4,828</b>	<b>6,675</b>	<b>76</b>	<b>420</b>	<b>216</b>	<b>362</b>	<b>704</b>	<b>250</b>	<b>1,015</b>	<b>7,121</b>	<b>758</b>

**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)	Redistri- buted Load (lbs/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)	CC-10 Redistri- buted Load (lbs/mo)	CT-2 Redistri- buted Load (lbs/mo)	Ungaged Residual Load (lbs/mo)
January	1610	1750	-140	-67	88%	12%	-124	-16	0	-63	-4	0
February	2086	2061	25	16	90%	10%	22	3	0	15	1	0
March	2444	2460	-16	-7	91%	9%	-14	-2	0	-7	0	0
April	2009	1741	268	107	82%	18%	221	47	0	97	10	0
May	1935	1528	407	243	74%	26%	301	106	0	214	29	0
June	538	732	-193	-93	55%	45%	-106	-87	0	-77	-16	0
July	-35	322	-357	-144	53%	47%	-171	-151	0	-115	-29	0
August	1572	1187	385	198	61%	39%	234	151	0	165	33	0
September	546	609	-63	-20	30%	70%	-19	-44	0	-10	-10	0
October	907	497	410	126	51%	49%	211	199	0	95	31	0
November	1006	816	190	71	76%	24%	144	46	0	65	6	0
December	1431	1295	136	69	84%	16%	114	22	0	66	3	0
<b>Annual Total</b>	<b>16,049</b>	<b>14,998</b>	<b>1,052</b>	<b>499</b>	<b>--</b>	<b>--</b>	<b>813</b>	<b>274</b>	<b>0</b>	<b>445</b>	<b>54</b>	<b>0</b>

# Appendix E

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## Biological Data

**Table E-1: Quantity and size of fish stocked in Cherry Creek Reservoir, 1985 to 2008.**

<b>Year</b>	<b>Species</b>	<b>Size (inches)</b>	<b>Number</b>
1985	Black crappie	5	7,234
	Channel catfish	2-8	116,784
	Rainbow trout	8-12	75,753
	Walleye	0.3	2,346,000
	Yellow perch	2	90,160
1986	Bluegill	1	111,968
	Channel catfish	4	25,594
	Cutthroat trout	6	52,228
	Rainbow trout	2-18	414,136
	Tiger musky	5-6	4,723
	Walleye	0.3	1,734,000
	Wiper	0.2	80,000
1987	Bluegill	0.2	70,000
	Channel catfish	4	25,600
	Largemouth bass	5	10,000
	Rainbow trout	2-26	129,715
	Tiger musky	7	4,000
	Walleye	0.2	1,760,000
1988	Channel catfish	3	16,000
	Largemouth bass	5	10,000
	Rainbow trout	9-10	293,931
	Tiger musky	8	4,500
	Walleye	0.2	1,760,000
1989	Channel catfish	2-4	10,316
	Largemouth bass	6	8,993
	Rainbow trout	8-22	79,919
	Walleye	0.2	1,352,000
	Wiper	0.2	99,000
1990	Channel catfish	3-4	25,599
	Rainbow trout	9-15	74,986
	Tiger musky	8	2,001
	Walleye	0.2	1,400,000
	Wiper	1	8,996
1991	Channel catfish	3	13,500
	Rainbow trout	9-10	79,571
	Tiger musky	5-8	6,500
	Walleye	0.2	1,300,000
	Wiper	1	9,000
1992	Blue catfish	3	9,000
	Channel catfish	4	13,500
	Rainbow trout	9-10	101,656
	Tiger musky	7	4,940
	Walleye	0.2	2,600,000
	Wiper	10	15,520

Year	Species	Size (inches)	Number
1993	Channel catfish	4	13,500
	Rainbow trout	9-10	92,601
	Tiger musky	9	4,500
	Walleye	0.2	2,600,000
	Wiper	1	9,003
1994	Blue catfish	3	21,000
	Channel catfish	4	23,625
	Cutthroat trout	9	9,089
	Flathead catfish	1	148
	Tiger musky	8	900
	Walleye	0.2	2,600,000
	Wiper	1-4	26,177
	Rainbow trout	9-18	62,615
1995	Channel catfish	4	18,900
	Rainbow trout	9-20	139,242
	Tiger musky	8	4,500
	Walleye	0.2	2,600,000
	Wiper	1	4,500
1996	Channel catfish	3	8,100
	Cutthroat trout	9-10	85,802
	Tiger musky	7	3,500
	Rainbow trout	4-22	163,007
	Walleye	0.2	3,202,940
	Wiper	1	8,938
1997	Channel catfish	3	13,500
	Cutthroat trout	3-9	22,907
	Rainbow trout	10-24	74,525
	Tiger musky	6	4,500
	Walleye	0.2	2,600,000
	Wiper	1	9,000
1998	Channel catfish	4	7,425
	Rainbow trout	10-12	59,560
	Tiger musky	7	4,000
	Walleye	1.5	40,000
	Wiper	1.3	9,000
1999	Channel catfish	3.5	13,500
	Rainbow trout	10-19	32,729
	Tiger musky	7	3,000
	Walleye	0.2	2,400,000
	Wiper	1.3	9,000
2000	Channel catfish	4.1	13,500
	Northern pike	B	46
	Rainbow trout	4.5-20.3	180,166
	Rainbow/Cutthroat trout hybrid	B	5,600
	Tiger musky	8	4,086

Year	Species	Size (inches)	Number
	Walleye	0.23	2,400,000
2001	Channel catfish	3.5	13,500
	Rainbow trout	10-19	23,065
	Tiger musky	7	4,000
	Walleye	0.2	2,400,000
2002	Rainbow trout	10	13,900
	Tiger musky	7	4,000
	Walleye	0.2	2,519,660
2003	Rainbow trout	10-11	30,111
	Walleye	0.25	4,136,709
	Channel catfish	2-2.5	33,669
2004	Rainbow trout	10-11	43,553
	Walleye	0.25	2,874,100
	Channel catfish	2.5	13,500
2005	Rainbow trout	10.4	43,248
	Walleye	0.25	2,579,939
	Wiper	0.18	200,000
	Channel catfish	2.2	13,500
2006	Rainbow trout	10.8	47,150
	Snake River cutthroat	16.1	204
	Rainbow x cutthroat hybrid	10.6	7,895
	Walleye	0.24	2,788,825
	Wiper	2.1	5,000
	Channel catfish	2.8	13,500
	Black crappie	2.5	300
	Largemouth bass	2.1	195
2007	Rainbow trout	12	4,800
	Rainbow trout	10	37,709
	Walleye	1	7,998
	Walleye	0.25	4,300,000
	Wiper	1.5	4,600
	Channel Catfish	3	9,360
2008	TASMANIAN RAINBOW TROUT	9.9	2,741
	WALLEYE	0.2	3,992,572
	BEL-AIRE RAINBOW TROUT	10.4	5,352
	RAINBOW x CUTTHROAT HYBRID	9.7	4,001
	BEL-AIRE RAINBOW TROUT	9.9	3,495

Table E-2: 2008 Cherry Creek Reservoir Phytoplankton

	2008													
	19-Mar	17-Apr	6-May	20-May	10-Jun	24-Jun	8-Jul	23-Jul	5-Aug	19-Aug	9-Sep	24-Sep	16-Oct	18-Nov
<b>BACILLARIOPHYTA</b>														
Order Centrales														
<i>Aulacoseira granulata</i> var. <i>angustissima</i>	20	8	100	20	95	720	40	5		15		40	75	65
<i>Aulacoseira granulata</i> var. <i>granulata</i>		16				400	10			20				
<i>Cyclostephanos tholiformis</i>											3			3
<i>Cyclotella ocellata</i>							40		120	40	160			
<i>Discostella glomerata</i>							40	40		1040		880	240	
<i>Puncticulata bodanica</i>												13		
<i>Stephanodiscus agassizensis</i>											1			1
<i>Stephanodiscus niagarae</i>				3	65	400	60							
<i>Stephanodiscus parvus</i>			4960	120			280	440	40	40	480	240	1200	1920
<i>Stephanodiscus</i> sp.		2		5			1						1	
Order Pennate														
<i>Asterionella formosa</i>	10		10	320	3080	80								
<i>Fragilaria crotonensis</i>					180	5120	2240	160	33	25	10	25		
<i>Navicula lanceolata</i>	1													
<i>Nitzschia draveillensis</i>			1760							5			3	13
<i>Nitzschia gracilis</i>		2								3	3			5
<i>Nitzschia paleacea</i>											38	25		
<i>Nitzschia reversa</i>										1		2		
<b>CHLOROPHYTA</b>														
<i>Ankistrodesmus falcatus</i>	160	20						3						5
<i>Ankyra judayi</i>					400	40	80		5					
<i>Chlamydomonas globosa</i>	160	400				40					40		20	
<i>Chlamydomonas snowiae</i>										10				
<i>Chlamydomonas</i> sp.													500	
<i>Chlorella minutissima</i>	4000	3000	2000	2000	1500	3250	2000	1500	4000	2500	1000	500	52000	82000
<i>Chlorella</i> sp.											750			
<i>Chlorogonium</i> sp.		40							10	20	20			
<i>Choricystis</i> sp.	32500	64000	176625	110000	21250	33000	162000	150500	74000	10000	10000	23000		
<i>Closterium aciculare</i>											1			
<i>Closterium acutum</i> var. <i>variabile</i>						1	3	35	2		40	1	2	13
<i>Coelastrum microporum</i>				12	130			160		160	1280	1600	640	
<i>Coelastrum</i> sp.												960	80	
<i>Cosmarium</i> sp.			5	1	1	1								
<i>Crucigenia quadrata</i>	80					640							960	100
<i>Crucigenia tetrapedia</i>	2000		640	800	200	8800	1200	480	1840	640	1280	4480	1040	6040
<i>Crucigeniella apiculata</i>				2720	3600			160	160			640	160	
<i>Dictyosphaerium pulchellum</i>						1120								

Table E-2: 2008 Cherry Creek Reservoir Phytoplankton

	2008													
	19-Mar	17-Apr	6-May	20-May	10-Jun	24-Jun	8-Jul	23-Jul	5-Aug	19-Aug	9-Sep	24-Sep	16-Oct	18-Nov
<i>Diplochlois lunata</i>		1000	2400						80	40	2480	5120	3200	
<i>Elakatothrix viridis</i>	120					20								2
<i>Eudorina elegans</i>							40	155						
<i>Kirchneriella irregularis</i>				40										
<i>Kirchneriella lunaris</i>			160											
<i>Kirchneriella obesa</i>			240										480	480
<i>Lagerheimia genevensis</i>			480											
<i>Micractinium pusillum</i>			20							120				
<i>Monoraphidium contortum</i>	20	240	65					120	120	120	320	400	160	320
<i>Monoraphidium convolutum</i>													4000	400
<i>Monoraphidium griffithii</i>													40	80
<i>Monoraphidium irregulare</i>	560	320	80											
<i>Monoraphidium minutum</i>		80	880	40			40				160		80	80
<i>Monoraphidium mirabile</i>														5
<i>Monoraphidium</i> sp.			15											
<i>Mougeotia</i> sp.														
<i>Nephrocytium agardhianum</i>			160				20							
<i>Oocystis apiculata</i>						40	80	20	80			40		
<i>Oocystis borgei</i>			90			3280	1280	880	440		80	1920	640	320
<i>Oocystis lacustris</i>			10	50	35	400	240	33	80		80	240		
<i>Oocystis parva</i>	320			200			480	40	120		960	320	320	
<i>Oocystis pusilla</i>											160			
<i>Pandorina smithii</i>							240	30				12		
<i>Pediastrum boryanum</i>													20	
<i>Pediastrum duplex</i> var. <i>duplex</i>	120		40	54	1210	198	770	215	28	135	12	12	44	8
<i>Pediastrum duplex</i> var. <i>gracillimum</i>						30		185		155		32	12	
<i>Pediastrum simplex</i>													22	
<i>Pediastrum tetras</i>							20	20	8	20	8	8	20	
<i>Pseudodictyosphaerium</i> sp.	56000	11000	13280	17750	1040	10000	15000	16500	90000	1000	8000	6080	50000	55000
<i>Pseudodidymocystis planctonica</i>											160		320	160
<i>Pteromonas aculeata</i>								20						
<i>Quadrigula</i> sp.									160				20	
<i>Raphidocelis microscopica</i>		500					3500	2500	3500	17500	7000	500	6000	3000
<i>Scenedesmus acuminatus</i>			40				160		320	20	640	160	640	640
<i>Scenedesmus arcuatus</i> var. <i>gracilis</i>												8		
<i>Scenedesmus armatus</i>									320				4	
<i>Scenedesmus bicaudatus</i>		160												
<i>Scenedesmus communis</i>	40	160	40				160	160			320		1040	320
<i>Scenedesmus ellipticus</i>				36	140	38	95	25	20	22		8	30	8

Table E-2: 2008 Cherry Creek Reservoir Phytoplankton

[illegible]

Table E-2: 2008 Cherry Creek Reservoir Phytoplankton

	2008													
	19-Mar	17-Apr	6-May	20-May	10-Jun	24-Jun	8-Jul	23-Jul	5-Aug	19-Aug	9-Sep	24-Sep	16-Oct	18-Nov
<i>Euglena deses</i>							1		1					
<i>Euglena ehrenbergii</i>							2		3					
<i>Euglena oxyuris</i>							2		3		5			
<i>Euglena polymorpha</i>									15		10			
<i>Euglena</i> sp. 1									10					
<i>Euglena</i> sp. 2					1								1	
<i>Euglena viridis</i>									30	5	8	1	3	
<i>Phacus pleuronectes</i>													1	
<i>Phacus pyrum</i>								1						
<i>Trachelomonas volvocina</i>									150		3			
DINOPHYTA														
<i>Ceratium hirundinella</i>						4	5	12	6	2	1			
<i>Peridiniopsis polonicum</i>							3	65						
<i>Woloszynskia coronata</i>	560	20						6	20				18	
CRYPTOPHYTA														
<i>Chroomonas coerulea</i>	1280	80	60	20	10		40	20	20	800	30	240	1120	240
<i>Chroomonas nordstedtii</i>		20	30	10	15		160	240	40	20	30	80	160	20
<i>Chroomonas</i> sp.										20				
<i>Cryptomonas (Campylomonas reflexa) curvata</i>		860	10	50	15		3						5	
<i>Cryptomonas (rostratiformis) curvata</i>					30	4	3			10	13	13	70	3
<i>Cryptomonas erosa</i>	80	80	110	25	30	7	13	13	90	280	185	150	100	28
<i>Cryptomonas (Campylomonas) marsonii</i>	640	320	45	10	10							3		
<i>Cryptomonas ovata</i>			5		30				5	40		3	1	5
<i>Hemiselmis virescens</i>											40			
<i>Komma caudata</i>	2720	2560	1600	1880	520	280	10400	160	1240	1600	1120	1200	640	1200
<i>Plagioselmis</i> sp.	80	80	400										40	
HAPTOPHYTA														
<i>Chrysochromulina</i> sp.	29360	9760												1280
PRASINOPHYTA														
<i>Mesostigma viride</i>							40	1	1	1200	2000	400	480	320
<i>Nephroselmis olivacea</i>	640	480	40										80	
<i>Pedinomonas</i> sp.	160													
<i>Scourfieldia complanata</i>	960	640												
<i>Tetraselmis cordiformis</i>	40	400					80	265	50	2960	480	400	320	480
Total Density (cells/mL)	162491	162697	285642	137736	42644	74602	216041	219478	344293	232331	214799	169196	298101	219949
Total Taxa	36	39	44	29	30	35	53	44	51	47	55	49	65	47

Table E-3: Reservoir mean phytoplankton density (cells/mL) and number of taxa in Cherry Creek Reservoir, 1984 to 2008.

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

Table E-3: Reservoir mean phytoplankton density (cells/mL) and number of taxa in Cherry Creek Reservoir, 1984 to 2008.

Metric	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
<b>Blue-Green Algae</b>											
Density	16,599	19,716	44,951	15,263	164,290	148,691	941	54,114	165,677	79,154	665,696
Taxa	9	10	11	8	19	12	3	21	27	19	19
<b>Green Algae</b>											
Density	738	2,461	1,809	898	43,881	33,217	1,973	55,190	56,236	189,777	1,358,248
Taxa	11	18	18	18	71	56	27	70	75	66	63
<b>Diatoms</b>											
Density	2,354	1,109	628	838	12,019	5,256	978	2,026	1,720	3,610	32,036
Taxa	13	8	18	16	34	22	24	22	26	24	21
<b>Golden-Brown Algae</b>											
Density	249	227	56	--	391	1,346	34	44	57	335	542
Taxa	4	2	2	--	14	13	3	5	5	4	5
<b>Euglenoids</b>											
Density	409	838	698	1,252	126	91	22	308	24	39	1,549
Taxa	3	3	3	1	6	4	3	9	11	8	10
<b>Dinoflagellates</b>											
Density	21	--	18	45	80	157	193	20	57	60	330
Taxa	4	--	2	2	8	6	5	3	5	6	5
<b>Cryptomonads</b>											
Density	1,104	1,487	1,393	559	2,472	2,851	355	3,282	3,158	3,293	40,511
Taxa	1	1	1	1	4	6	4	8	8	9	12
<b>Miscellaneous</b>											
Density	--	--	--	--	1,923	5,714	15	1,294	164	2,014	4,855
Taxa	--	--	--	--	1	1	1	3	6	6	6
<b>Total Density</b>	21,474	25,838	49,553	18,855	225,182	197,323	4,511	116,278	227,093	278,282	2,103,767
<b>Total Taxa</b>	45	39	55	46	157	120	70	141	164	142	141

Table E-3: Reservoir mean phytoplankton density (cells/mL) and number of taxa in Cherry Creek Reservoir, 1984 to 2008.

<b>Metric</b>	<b>2007</b>	<b>2008</b>	<b>Long-term Median</b>
<b>Blue-Green Algae</b>			
Density	1,266,765	1,124,197	<b>78,335</b>
Taxa	21	19	<b>13</b>
<b>Green Algae</b>			
Density	563,344	1,531,579	<b>18,933</b>
Taxa	63	67	<b>47</b>
<b>Diatoms</b>			
Density	60,127	27,681	<b>2,982</b>
Taxa	21	17	<b>20</b>
<b>Golden-Brown Algae</b>			
Density	2,380	6,270	<b>193</b>
Taxa	3	3	<b>4</b>
<b>Euglenoids</b>			
Density	1,303	259	<b>241</b>
Taxa	10	11	<b>4</b>
<b>Dinoflagellates</b>			
Density	595	722	<b>45</b>
Taxa	5	3	<b>3</b>
<b>Cryptomonads</b>			
Density	61,037	35,962	<b>1,440</b>
Taxa	9	11	<b>4</b>
<b>Miscellaneous</b>			
Density	73,435	53,330	<b>2,014</b>
Taxa	7	8	<b>6</b>
<b>Total Density</b>	<b>2,028,986</b>	<b>2,780,000</b>	<b>126,581</b>
<b>Total Taxa</b>	<b>139</b>	<b>139</b>	<b>91</b>

# Appendix F

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## Water Quality Transect Map

# Cherry Creek Reservoir

## Aeration Equipment Location (October 2008), Sediment Oxidation Reduction Potential, and 2008 Monitoring Program

