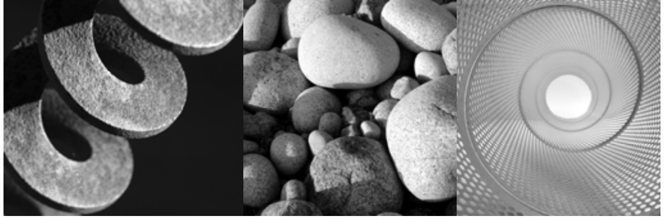


Geotechnical
Water Resources
Environmental and
Ecological Services

Cherry Creek Reservoir
2006 Annual Aquatic Biological Nutrient Monitoring Study and Cottonwood Creek Phosphorus Reduction Facilities Monitoring

Submitted to:
Cherry Creek Basin Water Quality Authority
Fiddler's Green Center, Building 1
6399 South Fiddler's Green Circle, Suite 102
Greenwood Village, CO 80111-4974

Submitted by:
GEI Consultants, Inc.
Chadwick Ecological Division
5575 S. Sycamore Street, Suite 101
Littleton, CO 80120

June 2007
Project 062470

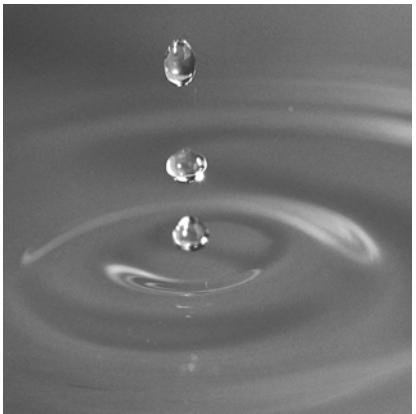


Table of Contents

List of Tables

List of Figures

List of Appendices

1.0 Introduction

An inter-governmental agreement was executed in 1985 by several local governmental entities within the Cherry Creek basin to form the Cherry Creek Basin Water Quality Authority (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. An in-lake phosphorus standard of 35 micrograms per liter (µg/L) was adopted to maintain a seasonal mean chlorophyll *a* goal of 15 µg/L. Subsequently, a phosphorus TMDL was prepared for Cherry Creek Reservoir (Reservoir) allocating loads among point sources, background, 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 µg/L of chlorophyll *a* to be met 9 out of 10 years, with an underlying total phosphorus goal of 40 µg/L, also as a July-to-September mean. 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 to 2001), and assisted with the transition of the program to Chadwick Ecological Consultants, Inc. (CEC) in 1994. Results of the aquatic biological and nutrient analyses have been summarized in annual monitoring reports (CEC, 1995 to 2006). In 2006, CEC merged with GEI Consultants, Inc. (GEI). GEI continues to perform the annual monitoring duties of Cherry Creek Reservoir. The present study was designed to continue the characterization of the potential 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 potential 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 2006 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 CCBWQA PRFs located on Cottonwood Creek, evaluates their effectiveness in reducing phosphorus loads to the Reservoir, and provides comparisons to historical data.

2.0 Study Area

Cherry Creek was impounded in 1950 by the U.S. Army Corps of Engineers (USACE) to protect the City of Denver from flash floods that may originate in the 995 square kilometers (385 square miles) drainage basin. The Reservoir has maintained a surface area of approximately 350 ha (approximately 852 acres) since 1959. The Reservoir and surrounding state park has also become an important recreational site, providing opportunities for activities that include fishing, boating, swimming, bicycling, bird watching, and hiking.

2.1 Sampling Sites

Sampling in 2006 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:

2.1.1 Cherry Creek Reservoir

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

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

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

2.1.2 Shop Creek

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

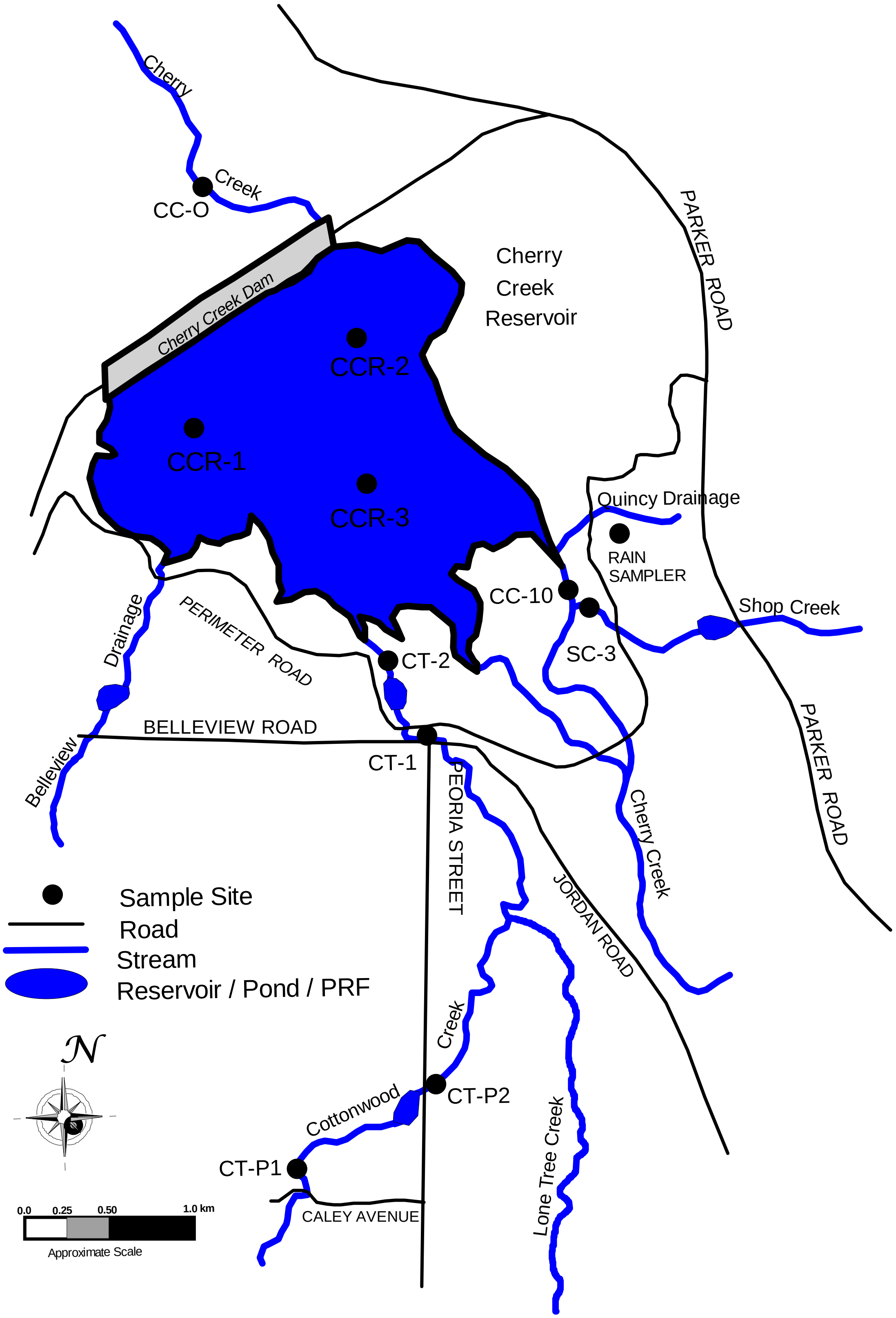


Figure 1: Sampling sites on Cherry Creek Reservoir and selected streams, 2006.

2.1.3 Cherry Creek

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

In 1995, this site was relocated farther downstream between the Perimeter Road and the Reservoir, approximately 800 meters 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 2006).

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. Site CC-O (i.e., CC-Outflow) monitors the water quality of Cherry Creek downstream of the Reservoir outlet.

2.1.4 Cottonwood Creek

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

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

CT-1 This site was established in 1987 where the Cherry Creek Park Perimeter Road crosses Cottonwood Creek. It was chosen to monitor the water quality of Cottonwood Creek before it enters the Reservoir. During the fall/winter of 1996, a

PRF, consisting of a water quality/detention pond and wetland system, was constructed downstream of this site. As a result of the back-flow from this pond inundating this site, this site was relocated approximately 250 m upstream near Belleview Avenue in 1997.

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.

3.0 Methods

3.1 Sampling Methodologies

Field sampling protocols and analytical methods used for monitoring the Reservoir and stream sites follow the Cherry Creek Reservoir Sampling and Analysis Plan (CEC, 2003b) (Appendix A).

3.1.1 Reservoir Sampling

The general sampling schedule included regular sampling trips to the Reservoir at varying frequencies over the annual sampling period, as outlined below, with increased sampling frequency during the summer growing season. A total of 14 reservoir sampling events were conducted in 2006, with events not being performed in January, February, and December 2006 due to unsafe ice conditions.

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

During each sampling episode on the Reservoir, three main tasks were conducted, including: 1) determining water clarity; 2) collecting depth profile measurements for temperature, dissolved oxygen, pH, and conductivity; and 3) collecting water samples for chemical and biological analyses.

3.1.1.1 Water Clarity

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

3.1.1.2 Profile Measurements

The second task involved collecting dissolved oxygen, temperature, conductivity, and pH measurements every meter from the surface to near the bottom of the Reservoir 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.

3.1.1.3 Water Sampling

Water samples for nutrient, phytoplankton, and chlorophyll *a* analyses were collected at the three Reservoir sites. Data collected from each site during a single sampling event (i.e., three replicate samples), are averaged to provide a whole-reservoir mean estimate for each parameter. Sample event means are then used to calculate annual or seasonal mean values for key parameters such as chlorophyll *a* and total phosphorus, 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 some of the laboratory methods in sample handling and preparation.

3.1.1.4 Fish Population Data

Historically, this monitoring study has also reviewed fish stocking and population data collected by the Colorado Division of Wildlife (CDOW). As part of their sampling schedule to reduce mortality to a walleye brood-stock population in Cherry Creek Reservoir, CDOW samples fish populations every 2 to 3 years. The most recent fish population survey was conducted in 2004 by the CDOW (personal communication with Harry Vermillion, CDOW). Therefore, only the 2006 fish stocking data are presented herein.

3.1.2 Stream Sampling

3.1.2.1 Base Flow Sampling

Base flow stream sampling was conducted on a monthly basis (11 events; July event excluded, see below) 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. However, in 2006 there was one exception to this basic premise. On July 5, base flow water quality samples were collected from the six inflow sites, which happened to occur between two major storm events, one on July 2 and the second on July 7. The flow during this period is categorized as storm event flows (i.e., >90th percentile flow), and is not representative of base flow conditions. Therefore, the water quality data collected on July 5 was categorized as storm event data and used in the calculation of the annual storm event median. For the purposes of estimating total phosphorus loads, the July base flow data was interpolated, using June and August base flow data.

3.1.2.2 Storm Sampling

Storm events sampled at the inflow sites on Cherry Creek, Cottonwood Creek, and Shop Creek characterize non-base flow conditions during the 2006 sampling season (Table 1). A detailed outline of storm sampling protocols can be found in the Sampling and Analysis Plan (Appendix A).

Table 1: Number of storm samples collected from tributary streams to Cherry Creek Reservoir, 2006. See Appendix C for sample dates.

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

3.1.3 Surface Hydrology

Pressure transducers attached to ISCO Series 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 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 using a Marsh McBirney Model 2000 flowmeter. For a complete description of streamflow determination, see Appendix D.

3.2 Laboratory Procedures

3.2.1 Nutrient Laboratory Analysis

Physicochemical and biological analyses on Reservoir and stream water quality samples were performed by the GEI analytical laboratory in Littleton, Colorado (Table 2). Randomly selected QA water samples were also sent to the University of Colorado, Center for Limnology, for nutrient analyses as a quality assurance check. Detailed methodologies and laboratory Quality Assurance/Quality Control (QA/QC) procedures are available from GEI, with the comparison of inter-laboratory data provided in Appendix F.

3.2.2 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.

3.3 Quality Assurance/Quality Control

To ensure data quality, a number of quality assurance checks were used. During each reservoir sampling event, a QA sample was randomly collected at one of the Reservoir sites, and analyzed by the University of Colorado, Center for Limnology. No QA samples were collected from the stream sites during any of the stream sampling events. These QA samples resulted in approximately 7 percent of the total samples collected during the year as having a duplicate sample, and provided a reasonable independent assessment of lake water nutrient analyses conducted by GEI.

Table 2: Parameter list, method number, and detection limits for chemical and biological analyses of water collected from Cherry Creek Reservoir and tributaries, 2006.

Parameter	Method	Detection Limit
Total Phosphorus	QC 10-115-01-1-U	2 µg/L
Total Dissolved Phosphorus	QC 10-115-01-1-U	2 µg/L
Soluble Reactive Phosphorus	QC 10-115-01-1-T	3 µg/L
Total Nitrogen	APHA 4500-N B (modified)	4 µg/L
Total Dissolved Nitrogen	APHA 4500-N B (modified)	4 µg/L
Ammonia	QC 10-107-06-3-D	3 µg/L
Nitrate and Nitrite	QC 10-107-04-1-B	5 µg/L
TSS	APHA 2540D	4 mg/L
TVSS	APHA 2540E	4 mg/L
Chlorophyll *a*	APHA 10200 H (modified)	1 µg/L

APHA = American Public Health Association, 1998.

In addition, field sampling quality control included the use of a field blank. This field blank contained laboratory grade deionized water in a sample container identical to those used in the field collections and was carried through the entire sampling episode. The cap of this container was removed at each Reservoir site and left open during the regular sampling effort at that site. Upon completion of sampling at that site, the cap was replaced. One field blank was used for every sampling trip. The field blanks and duplicate samples were analyzed for all the parameters, identical to a routine sample. Chain of custody procedures were observed during the field sampling and delivery of samples to GEI, and for samples shipped to the Center for Limnology, University of Colorado.

Detailed methods and results of QA/QC checks performed on the water quality data from the Reservoir for 2006, with comparison between labs, are located in Appendix F. This analysis showed that results from the analytical labs were similar. As such, all values reported herein are based on results obtained from the GEI analytical laboratory.

3.4 Calculation of Phosphorus Loading

During the past year, there has been extensive dialogue with the Colorado Water Quality Control Division (WQCD) regarding the calculation of phosphorus loads when placed in the context of long term modeling and the predictive use for control regulation usage. From these discussions, a methodology was agreed upon that would create some continuity among Colorado reservoirs with control regulations in place, and also create a long term database using consistent methodologies based on contemporary scientific understandings. While these methodological changes are expected to have minimal changes on the annual external phosphorus load to the Reservoir, comparative differences within a source may exist between 2006 data and the long term data. Notably, in the past when methodologies have changed (i.e., 2002-alluvial flow changed to residual flow estimate), these changes have been carried throughout the historical database such that the long term annual values are compared using consistent methodologies. Given the timing of these recent changes, the long term data present herein do not reflect the current methodology used to calculate loads. The long term data are being evaluated and updated values will be provided in the near future. Detailed discussion of the streamflow measurements and derivation of loads can be found in Appendix D.

3.5 Calculation 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 2006 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.

Linear regression analyses was also used to evaluate QA/QC relationships between labs, and comparisons of biological and physical parameters for each site were conducted using SPSS 2006 or NCSS 2000 statistical software (Hintze, 2001). Basic descriptive statistics were used to evaluate the distributional characteristics of the data, and to determine whether a variable required transformation to meet the basic assumptions of normality. Logarithmic transformations were used to increase the symmetry of the data about the mean, approximating a normal distribution. If the transformation did not improve normality, the untransformed data were used in subsequent analyses.

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

4.0 Results and Discussion

4.1 Reservoir Water Quality

4.1.1 2006 Transparency

The whole-reservoir mean Secchi depth varied from 0.71 m in April to 1.98 m in early June (Figure 2). The seasonal (July to September) whole-reservoir mean Secchi depth was 1.05 (Figure 3) and is similar to the long term mean value of 1.06 m. The depth at which 1 percent of photosynthetically active radiation (PAR) penetrated (i.e., photic zone depth) ranged from 2.17 m in early May to a maximum depth of 4.71 m in late July (Figure 2). The period from late May through June, and again in September, represented a time when Reservoir water clarity was at its best, with 1 percent light transmittance averaging 4.1 m. There was a significant negative relationship between 1 percent PAR transmittance and chlorophyll *a* concentration ($p < 0.05$), though chlorophyll *a* concentrations only accounted for 33 percent of the variation observed in water clarity.

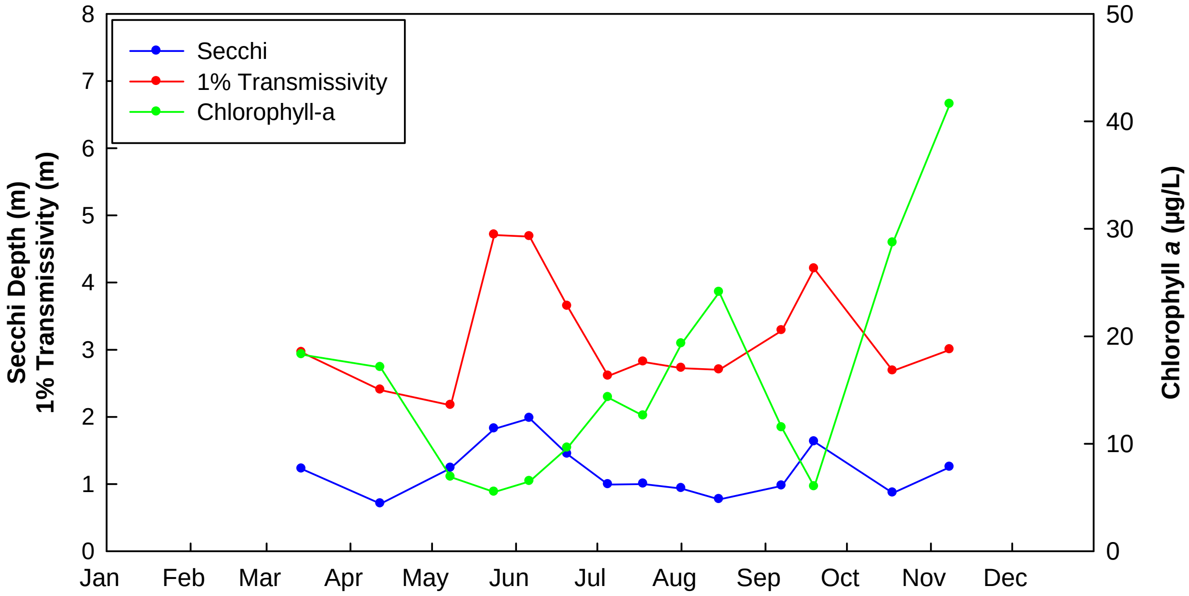


Figure 2: Whole-lake patterns for Secchi depth, 1% transmissivity, and chlorophyll *a* in Cherry Creek Reservoir, 2006.

4.1.2 Long Term Secchi Transparency Trends in Cherry Creek Reservoir

In general, seasonal mean (July-to-September) Secchi depths increased from 1987 to 1996, then decreased in 1997 and have been relative stable since (Figure 3). There is not, however, a statistically significant long term upward or downward trend for seasonal mean Secchi depths over the period of record.

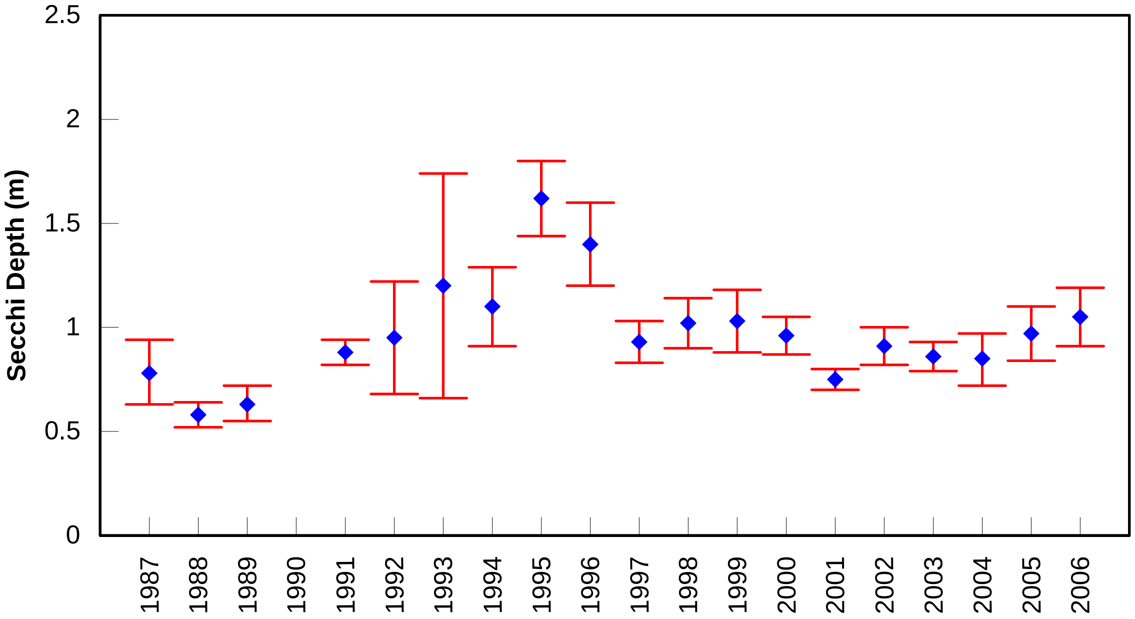


Figure 3: **Whole-lake seasonal mean (July to September) Secchi depths (m) measured in Cherry Creek Reservoir, 1987 to 2006. Error bars represent a 95% confidence interval for each mean.**

4.1.3 2006 Dissolved Oxygen and Temperature

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 a recent mixing event (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 the rate of temperature change is less than 1 °C/m. Using the above criteria, Cherry Creek Reservoir was evaluated for periods of potential stratification and low dissolved oxygen levels (Figures 4 through 9).

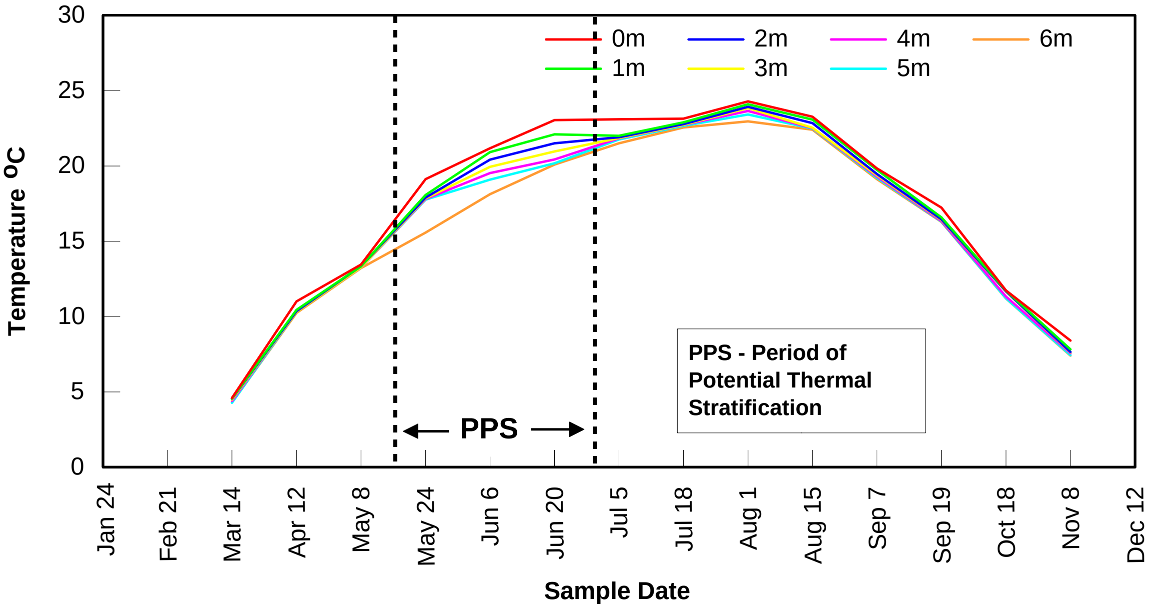


Figure 4: Temperature (°C) recorded at depth during routine monitoring at Site CCR-1 in 2006.

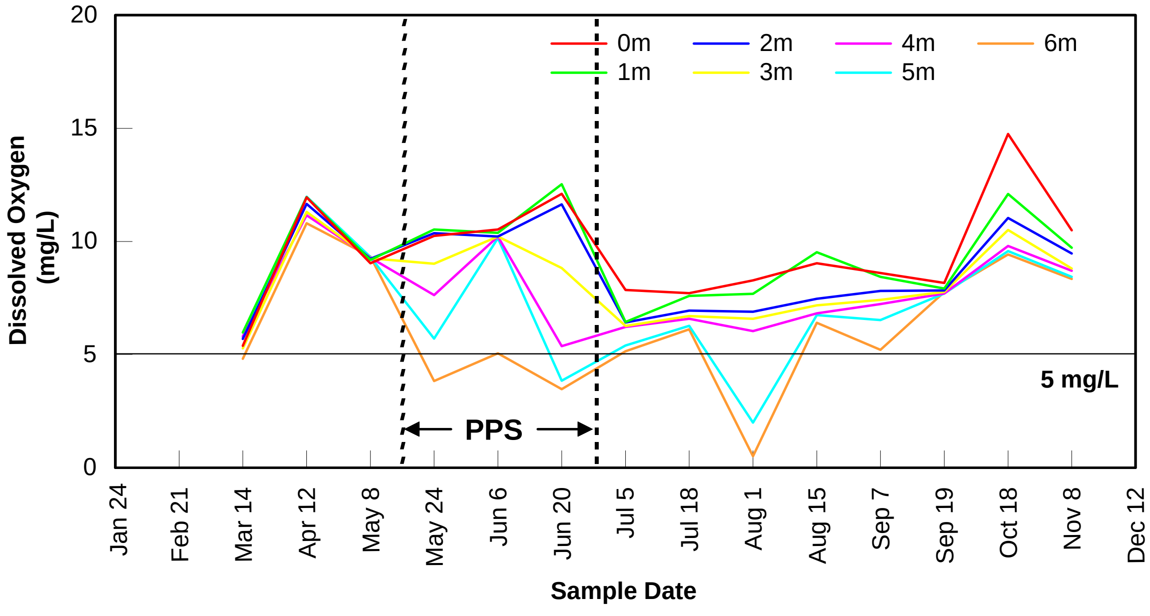


Figure 5: Dissolved oxygen (mg/L) recorded at depth during routine monitoring at Site CCR-1 in 2006. The dissolved oxygen basic standards table value for Class 2 warm water lakes and reservoirs is provided for comparison (5 mg/L).

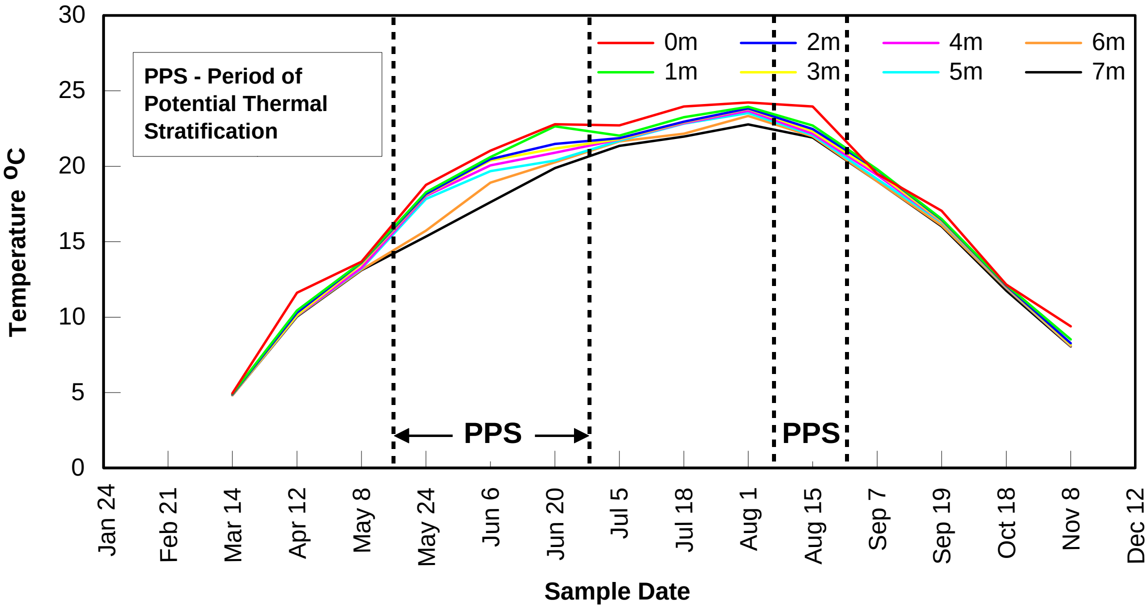


Figure 6: Temperature (°C) recorded at depth during routine monitoring at Site CCR-2 in 2006.

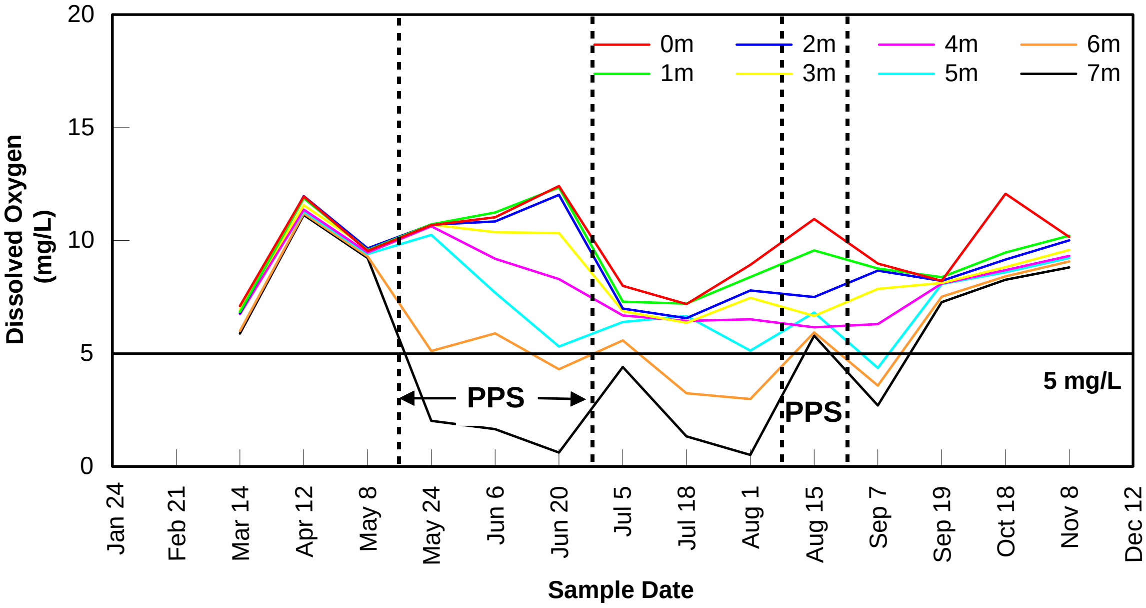


Figure 7: Dissolved oxygen (mg/L) recorded at depth during routine monitoring at Site CCR-2 in 2006. The dissolved oxygen basic standards table value for Class 2 warm water lakes and reservoirs is provided for comparison (5 mg/L).

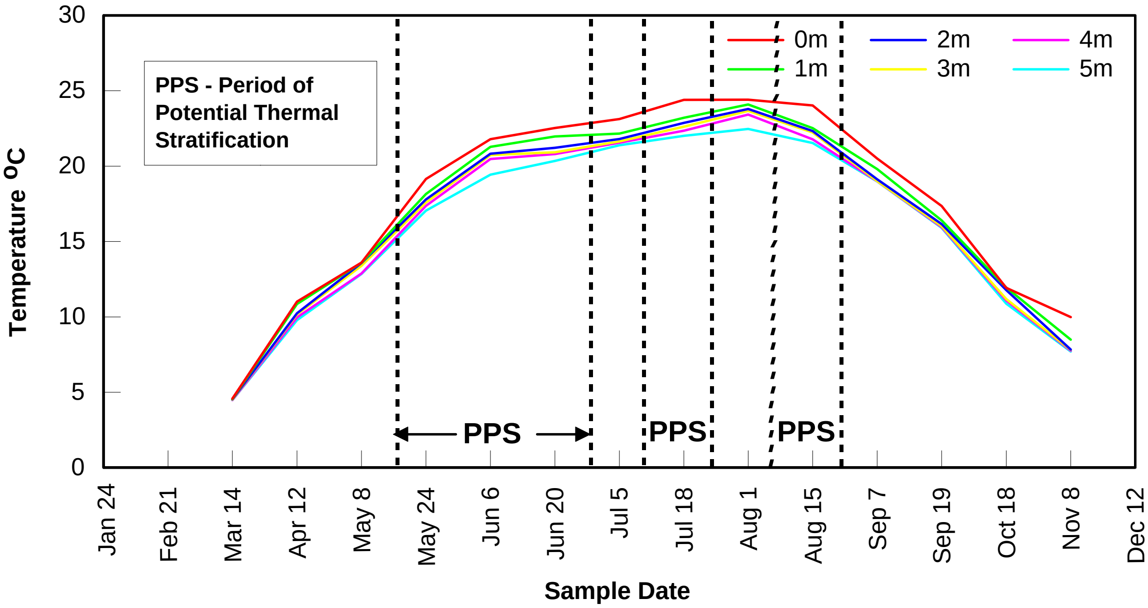


Figure 8: Temperature (°C) recorded at depth during routine monitoring at Site CCR-3 in 2006.

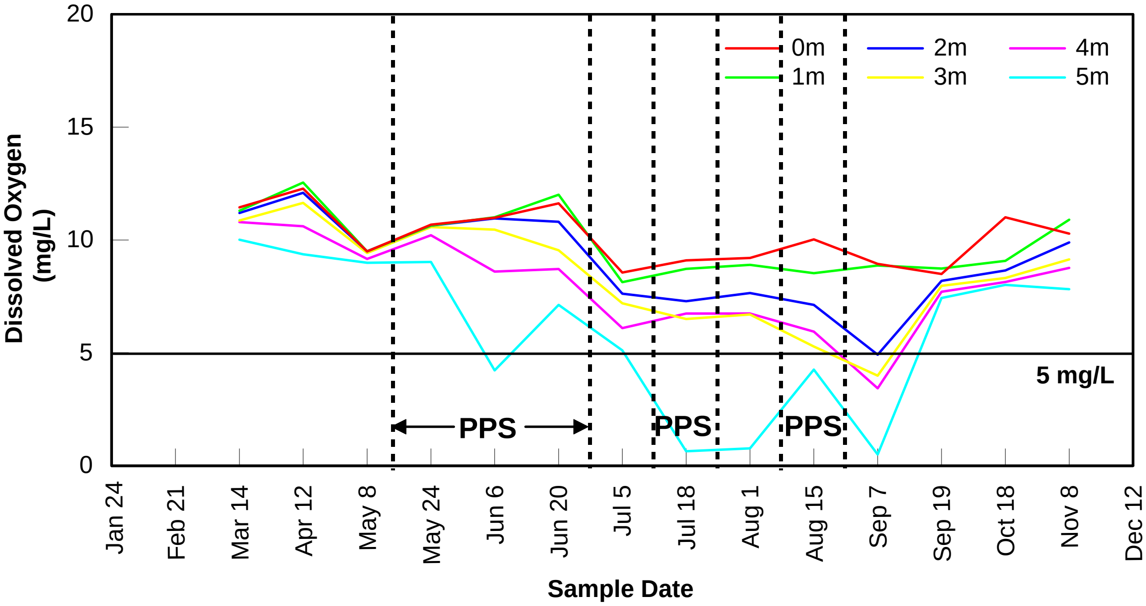


Figure 9: Dissolved oxygen (mg/L) recorded at depth during routine monitoring at Site CCR-3 in 2006. The dissolved oxygen basic standards table value for Class 2 warm water lakes and reservoirs is provided for comparison (5 mg/L).

Water temperatures in Cherry Creek Reservoir ranged from 4.3 °C in mid-March to 24.4 °C in early August. Periods of thermal stratification were observed in the Reservoir at all lake sites (Figures 4, 6, and 8). From late May through June and in Mid-August, the Reservoir was thermally stratified. In mid-July, only a portion of the Reservoir appeared stratified. Thermal stratification was evident at Site CCR-1 on May 24, June 6, and June 20. At Site CCR-2, stratification was evident on May 24, June 6, June 20, and August 15. Stratification was also evident at Site CCR-3 on May 24, June 6, June 20, and July 18, and August 15.

The Reservoir was well mixed and oxygenated during the first three sampling events of 2006, and by May the Reservoir began showing signs of thermal stratification, which was supported by evidence of a well developed oxycline throughout the Reservoir. During this period, dissolved oxygen concentrations were often less than 5 milligrams per liter (mg/L) at depths greater than 4 m. While these conditions in the deep layers of the Reservoir may pose relatively little affect on the biological community, microbial mediated anoxia may create favorable conditions for nutrient loading via the sediments.

Water column dissolved oxygen profiles were also compared to the basic standards table value for Class 2 Warm Water lakes and reservoirs (5 mg/L). 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. While Cherry Creek Reservoir is designated as a Class 1 Warm Water reservoir, the Class 2 standard is a conservative classification for the Reservoir. 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 2EC 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 entire water column, including the bottom 1 m layer, was computed for each sampling event, and ranged from 6.0 mg/L in early August to 11.5 mg/L in mid-April. The whole-reservoir mean dissolved oxygen content met the Class 2 warm water criteria for lakes and reservoirs for each sample event.

4.1.4 2006 Nutrients

Monitoring at Cherry Creek Reservoir has focused on the concentrations of phosphorus and nitrogen, because these inorganic nutrients are necessary for life in aquatic systems. Often, these nutrients are the limiting factor in the growth of algae (Cole, 1979; Goldman and Horne, 1983; 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 2006, the photic zone mean concentration of total phosphorus ranged from 44 to 144 µg/L with an overall annual mean of 81 µg/L. The seasonal photic zone mean (July-to-September) concentration ranged from 44 to 129 µg/L, with a seasonal mean of 87 µg/L (Figure 10). The annual pattern in Reservoir phosphorus concentration corresponds well to the USACE inflow pattern, and when evaluated on a monthly basis, Reservoir total phosphorus concentrations are significantly ($p < 0.05$) related to monthly inflow total phosphorus load ($R^2 = 0.80$).

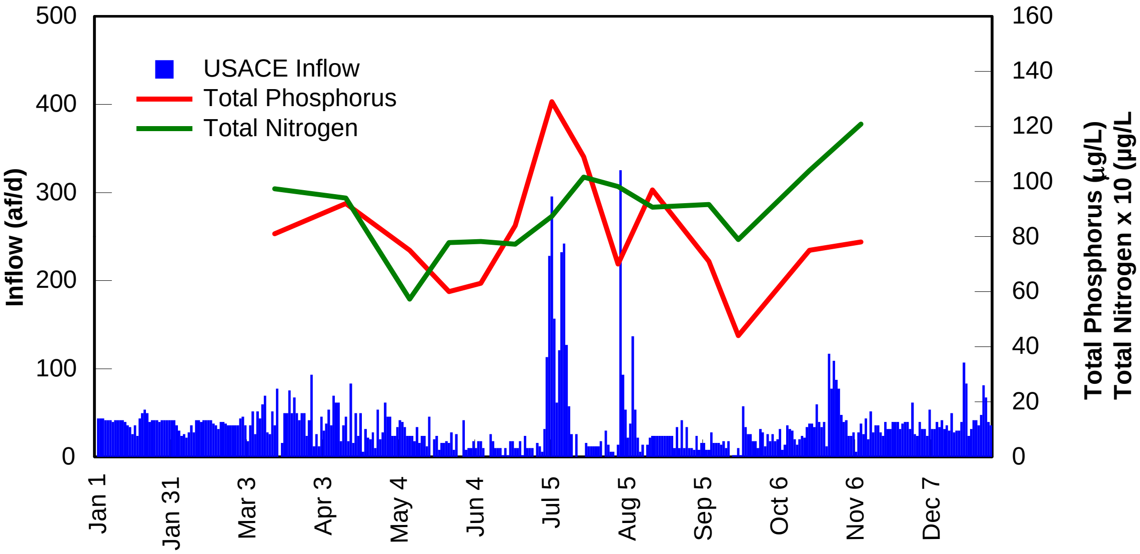


Figure 10: Annual pattern of photic zone total phosphorus, total nitrogen and USACE inflow in Cherry Creek Reservoir, 2006.

Patterns in total phosphorus concentrations collected along depth profiles showed a well-mixed Reservoir during the spring and fall (Figure 11). There were periods of nutrient release from bottom sediments from May through July as evidenced by increasing TP concentrations in the deeper layers of the Reservoir (Figure 11).

The photic zone mean concentration of total nitrogen ranged from 573 to 1,209 µg/L, with an annual mean of 897 µg/L in 2006. During the July-to-September period, the photic zone mean total nitrogen concentration ranged from 789 to 1,016 µg/L, with a mean concentration of 914 µg/L. The annual pattern of Reservoir total nitrogen concentrations did not correlate with the USACE inflow pattern, and when evaluated on a monthly basis, Reservoir total nitrogen concentrations are not significantly related to monthly inflow.

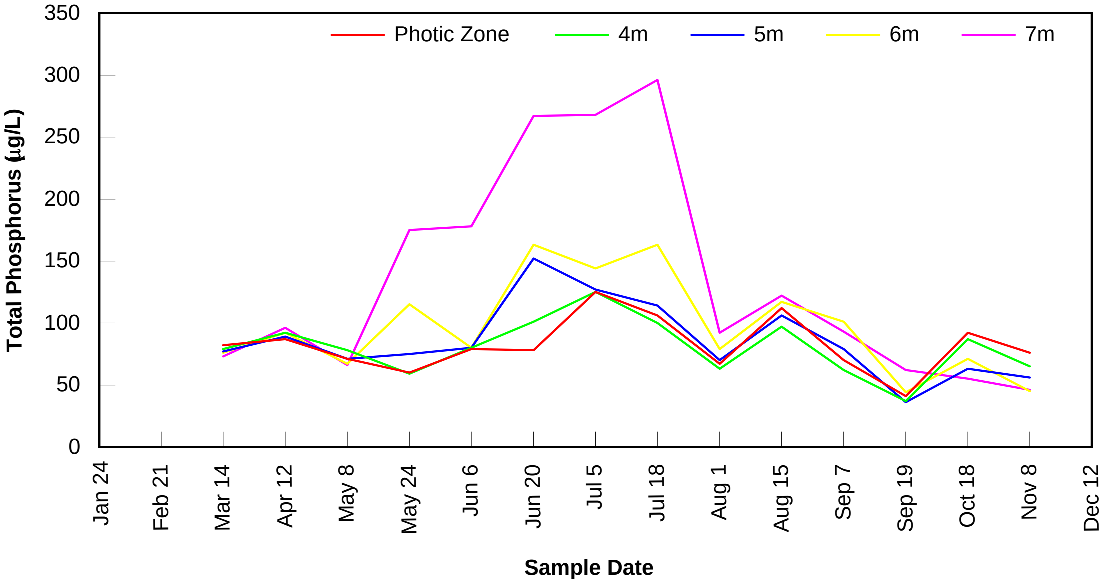


Figure 11: Total phosphorus concentrations recorded for the photic zone composite and at depth during routine monitoring in 2006.

4.1.5 Long Term Phosphorus Trends in Cherry Creek Reservoir

In any long term database, consistency in data analysis (i.e., analytical chemistry) is paramount, especially when evaluating long term trends. Differences in methodologies or analytical laboratories may bias the data, which hinders the evaluation of potential trends. This is particularly evident in the total phosphorus and chlorophyll *a* database for Cherry Creek Reservoir. This database represents a variety of data produced by different analytical laboratories, and while the same standard method may have been utilized, subtle differences are apparent in the database. Over the monitoring period, analytical method detection limits varied and the precision of the analyses have increased with time. During the late 1990s, a transition from Metro Wastewater analytical services to GEI occurred, with the period from 1999 to 2006 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.

Routine monitoring data collected since 1987 indicates a general increasing pattern in summer mean concentrations of total phosphorus (Figure 12). In 2006, the July to September mean concentration of total phosphorus was 87 µg/L. This value is greater than the long term median value of 78 µg/L (Table 3). Regression analyses performed on 1987 to 2006 seasonal mean TP data indicates a significant ($p < 0.01$) increasing trend, though the relationship is likely a result of the shift in the data that occurred in 1997. 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.

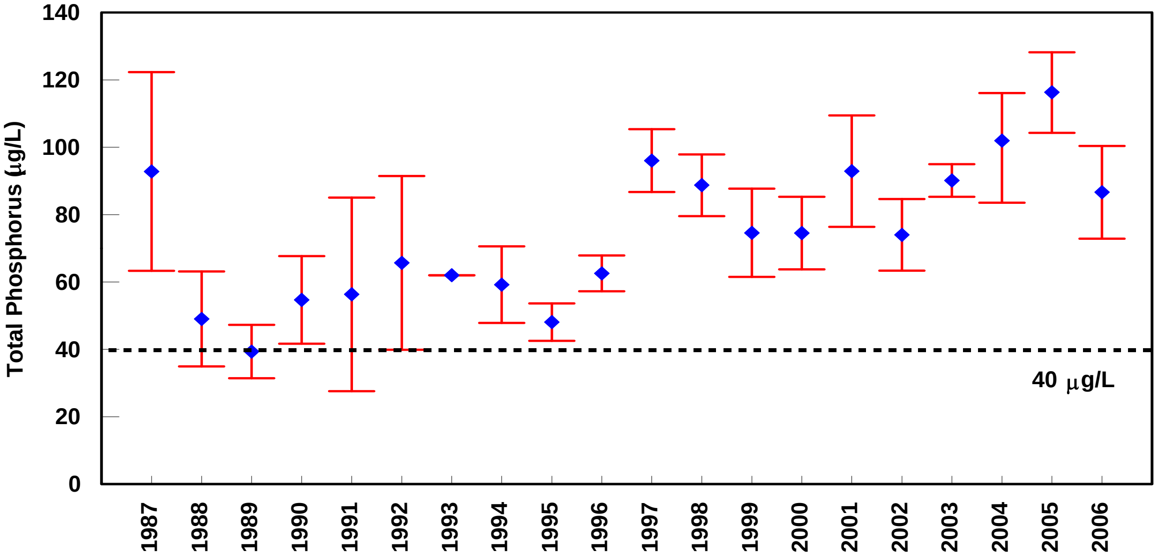


Figure 12: Seasonal mean (July to September) total phosphorus concentrations (µg/L) measured in Cherry Creek Reservoir, 1987 to 2006. Error bars represent a 95% confidence interval for each mean.

Table 3: Comparison of annual mean (monitoring period) and July to September mean phosphorus, nitrogen, and chlorophyll *a* levels in Cherry Creek Reservoir, 1987 to 2006.

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	12.1	17.0
1993	790	826	50	62	12.5	14.4
1994	1,134	1,144	56	59	4.7	6.2
1995	910	913	48	48	13.9	15.6
1996	889	944	54	62	16.9	20.5
1997	976	1,120	75	96	16.1	22.3
1998	850	880	82	89	20.4	26.5
1999	715	753	80	81	20.8	28.9
2000	784	802	81	81	22.0	25.2
2001	740	741	81	87	26.7	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
Mean	**905**	**937**	**70**	**75**	**15.7**	**18.1**
Median	**893**	**914**	**78**	**78**	**16.1**	**17.8**

4.1.6 2006 Chlorophyll a Levels

The annual pattern of photic zone chlorophyll *a* concentrations revealed relatively low concentrations (5 - 7 µg/L) of chlorophyll *a* in late May, June, and late September, with levels greater than 20 µg/L occurring in late August, late October, and early November (Figure 13). The 2006 annual mean chlorophyll *a* concentration was 15.9 µg/L, and represents the lowest annual value since 1995 (Table 3). The July to September mean chlorophyll *a* concentration in 2006 was 14.7 µg/L, and is the first time since 1994 that the seasonal chlorophyll *a* levels met the Reservoir standard.

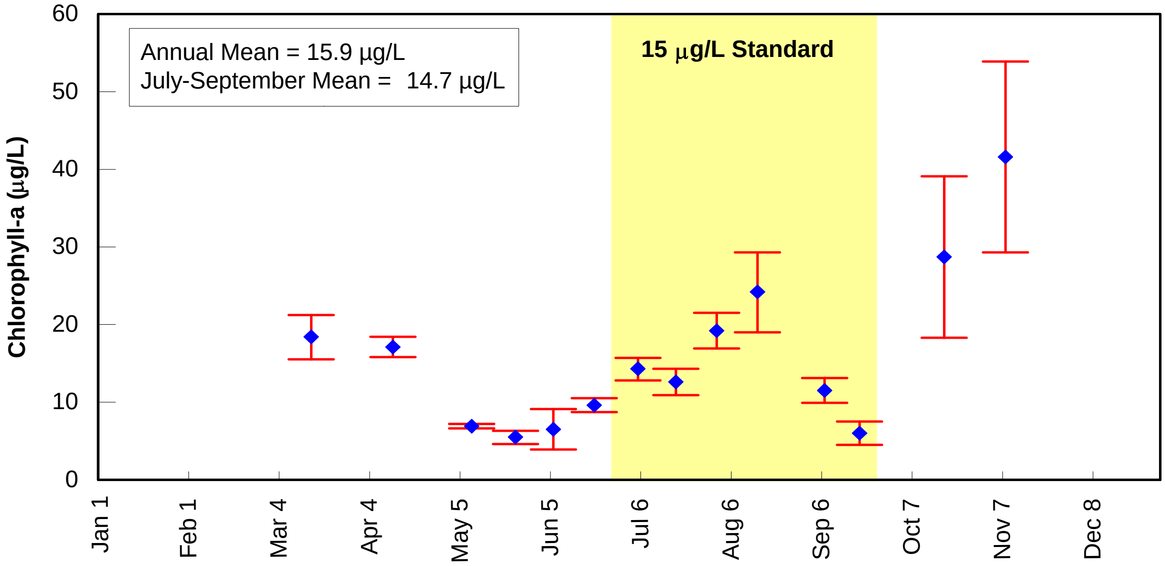


Figure 13: Concentration of chlorophyll *a* (µg/L) in Cherry Creek Reservoir, 2006. Error bars represent 95% confidence interval around each mean. Highlighted area denotes the seasonal period for the chlorophyll *a* standard.

4.1.7 Long term Chlorophyll a Trends in Cherry Creek Reservoir

The seasonal mean chlorophyll *a* concentration has met the standard of 15 µg/L only five out of the past 20 years (Figure 14), and not since 1994. Since 1987, there is no significant trend in the seasonal mean chlorophyll *a* concentration (Figure 14). However, since 1999 there has been a steady decline in the seasonal mean chlorophyll *a* concentration, with the Reservoir meeting the standard in 2006 for the first time in 12 years.

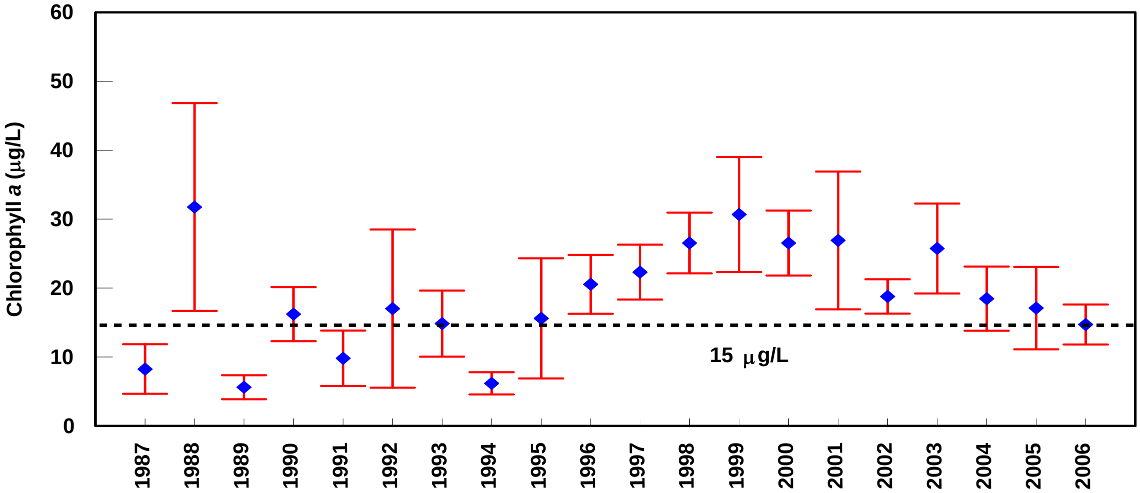


Figure 14: Seasonal mean (July to September) chlorophyll *a* concentrations measured in Cherry Creek Reservoir, 1987 to 2006. Error bars represent 95% confidence interval around each mean.

4.2 Reservoir Biology

4.2.1 2006 Phytoplankton

Phytoplankton density in the photic zone ranged from 8,889 cells/mL on September 19 to 601,915 cells/ml on April 12 (Table 4). The number of algal taxa present in the Reservoir ranged from 24 on May 24 to 49 on July 18. Annually, the assemblage was dominated in terms of density by green algae, with blue-green algae being the second most abundant taxonomic group (Figure 15).

Regression analysis revealed no significant correlation between phytoplankton density and total or soluble reactive phosphorus concentrations during 2006. Additionally, no significant relationship was observed between phytoplankton density and chlorophyll *a*. Chlorophyll *a* concentrations did not correlate well with Reservoir total phosphorus concentrations, but did reveal a significant correlation ($p < 0.001$, $R^2 = 0.67$) with Reservoir total nitrogen concentrations. These relationships suggest that algal biomass (chlorophyll *a*) was limited by nitrogen during 2006, and support conclusions made by Lewis *et al.* 2004. Lewis et al. observed that algal biomass was often limited by nitrogen given the surplus of phosphorus in the system. During their study, May to October 2003, photic zone phosphorus concentrations would need to be reduced to approximately 30 µg/L, to induce phosphorus limitation in the algal assemblage.

4.2.2 Long Term Phytoplankton

In 2006, the phytoplankton assemblage was dominated by green and blue-green algae, 65 percent and 32 percent, respectively (Table 4). The dominance of green algae over blue-green algae is only the fourth occurrence since 1984, but has been the general trend for the last 3 years. Historically, the blue-green algae have dominated the phytoplankton assemblage in terms of density. The proportion of the phytoplankton assemblage comprised by diatoms, golden-brown algae, and dinoflagellates was greater than their respective long term median values (Appendix E). Additionally, the cryptomonad density in 2006 was greater than their long term mean density, while euglenoids were less than their long term mean density.

Table 4: Density (cells/mL) of phytoplankton and total number of taxa collected from all three sites on Cherry Creek Reservoir, 2006.

Taxa	Mar 14	Apr 12	May 08	May 24	Jun 06	Jun 20	Jul 05
Diatoms							
Centrics	280	7,700	0	8	42	820	2,450
Pennates	220	1,700	2,203	1,250	240	3,750	920
Green Algae	81,530	560,830	37,289	54,198	77,427	32,389	144,270
Blue-Green Algae	58,400	25,630	3,526	0	8,798	45,980	32,000
Golden-Brown Algae	0	0	5	2	0	20	380
Yellow-Green Algae	0	5	0	0	0	0	0
Euglenoids	20	0	0	0	0	2	35
Dinoflagellates	110	35	0	0	3	17	15
Cryptomonads	5,300	5,040	1,534	840	1,955	643	3,654
Haptomonads	960	800	0	0	0	0	0
Microflagellates	90	175	0	0	0	0	60
Total Density	**146,910**	**601,915**	**44,557**	**56,298**	**88,465**	**83,621**	**183,784**
Total Taxa	**35**	**41**	**34**	**24**	**28**	**33**	**41**
Taxa	**Jul 18**	**Aug 01**	**Aug 15**	**Sep 07**	**Sep 19**	**Oct 18**	**Nov 08**
Diatoms							
Centrics	1,400	5,855	NA	16	340	1,972	738
Pennates	5	30	NA	1	20	27	49
Green Algae	184,620	88,260	NA	43,720	7,328	30,316	16,071
Blue-Green Algae	18,825	272,732	NA	188,045	220	2,000	9,540
Golden-Brown Algae	0	0	NA	0	0	10	125
Yellow-Green Algae	0	0	NA	0	0	0	0
Euglenoids	55	980	NA	454	1	2	0
Dinoflagellates	25	70	NA	30	0	5	20
Cryptomonads	1,610	1,700	NA	4,600	955	6,240	6,440
Haptomonads	320	0	NA	0	0	0	0
Microflagellates	1,040	500	NA	800	25	80	0
Total Density	**207,900**	**370,127**		**237,666**	**8,889**	**40,652**	**32,983**
Total Taxa	**49**	**43**		**46**	**31**	**38**	**31**

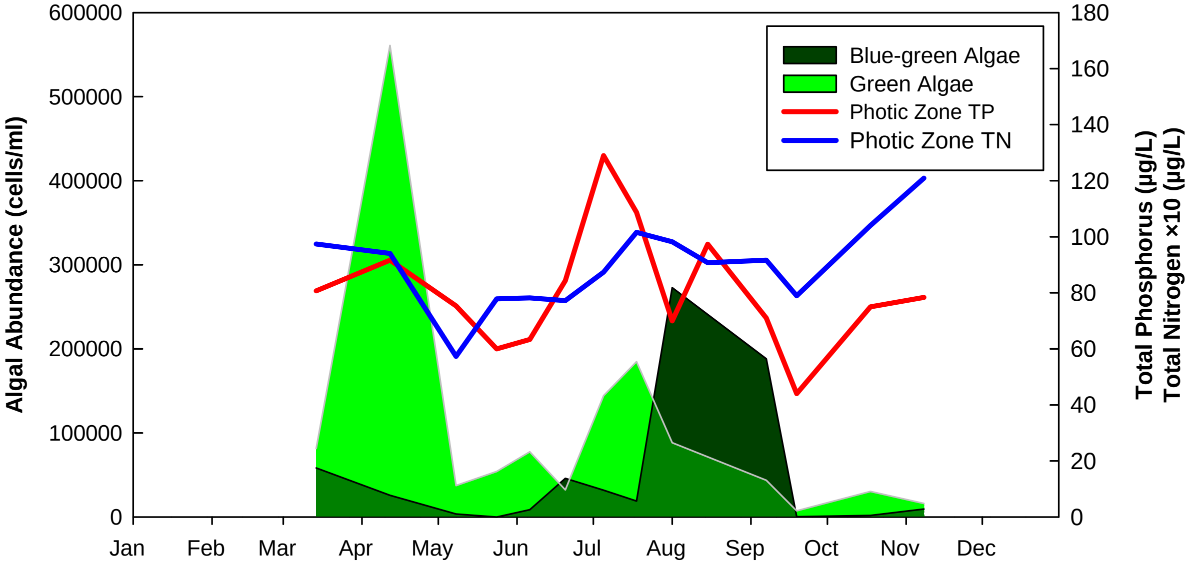


Figure 15: Annual pattern of blue-green and green algal densities and photic zone total phosphorus and total nitrogen concentrations in Cherry Creek Reservoir, 2006.

4.2.3 Fish Populations

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

Stocking data from the Colorado Division of Wildlife (CDOW) shows that 11 species and three hybrids have been stocked in Cherry Creek Reservoir from 1985 to 2006 (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 2006, eight fish taxa were stocked (Appendix E): rainbow trout, Snake River cutthroat trout, rainbow × cutthroat hybrid, walleye, wiper, channel catfish, black crappie, and largemouth bass.

4.3 Stream Water Quality

4.3.1 2006 Phosphorus Concentrations in Streams

The median annual total phosphorus concentration for base flow conditions ranged from 52 µg/L at CT-P2 to 157 µg/L at CC-10 (Table 5). 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 71 µg/L at Site CT-2 to 166 µg/L at Site CC-10. At all stream sites, the storm flow TP concentration was greater than concentrations during base flow conditions. The annual median storm flow concentration ranged from 161 µg/L at Site SC-3 to 477 µg/L at Site CC-10.

Table 5: 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, 2006.

Stream, Site	Base Flow				Storm Flow	
	Summer		Annual		Annual	
	TP (µg/L)	TSS (mg/L)	TP (µg/L)	TSS (mg/L)	TP (µg/L)	TSS (mg/L)
Cherry Creek						
CC-10	166	10	157	18	477	122
CC-O	190	19	83	17	--	--
Cottonwood Creek						
CT-1	55	19	73	29	326	167
CT-2	71	39	64	38	259	83
CT-P1	96	21	64	13	227	61
CT-P2	80	31	52	19	218	57
Shop Creek						
SC-3	113	5	93	7	161	10

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

Long term patterns (1995-2006) 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 219 µg/L and 105 µg/L, respectively (Table 6), with storm flow concentrations being approximately 1.5 fold greater (Table 7). In Cottonwood Creek (CT-2), the long term median annual base flow total phosphorus concentration is 84 µg/L; however, the long term median storm flow concentration is approximately 2.5 fold 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 27 percent of total phosphorus concentrations.

Table 6: 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 2006.

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
Median	**219**	**171**	**105**	**74**	**84**	**23**

* 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 7: 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 2006.

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
Median	**319**	**209**	**165**	**106**	**220**	**65**

Base flow total phosphorus and soluble reactive phosphorus concentrations revealed no trends over time at Site CC-10 (Figures 16 and 17). 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 (Figures 18 and 19). 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 (Figures 20 and 21) during base flow conditions. The observed decreasing trend and greatly reduced variability in soluble reactive phosphorus concentrations at Site CT-2 from 1995 to 2006 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.

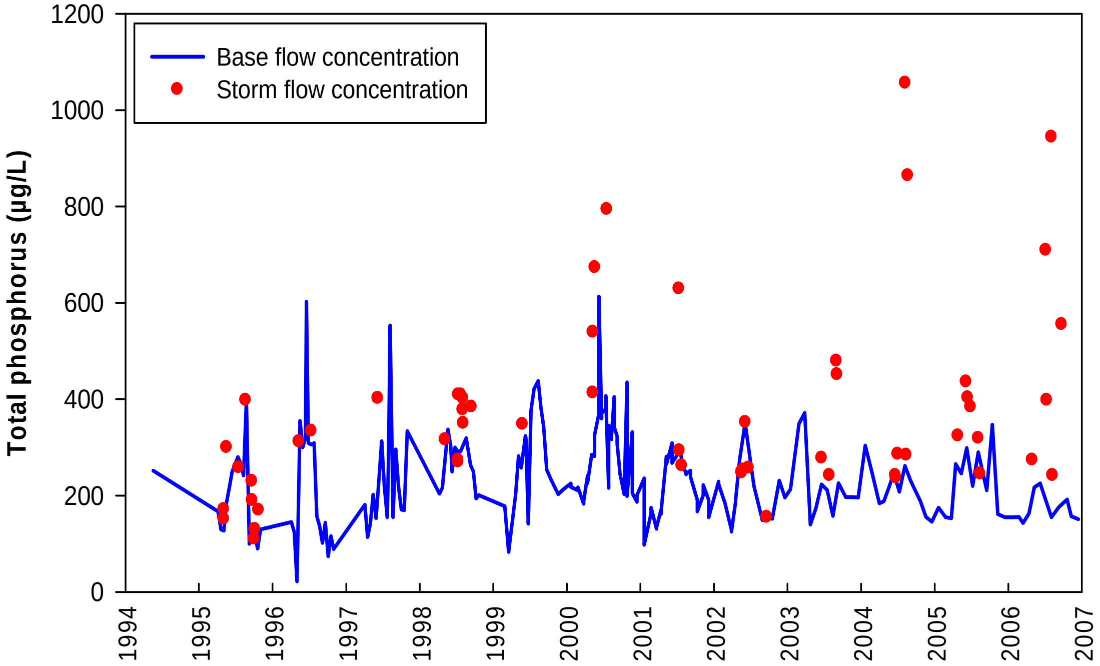


Figure 16: Base flow and storm flow total phosphorus concentrations measured in Site CC-10, 1994 to 2006.

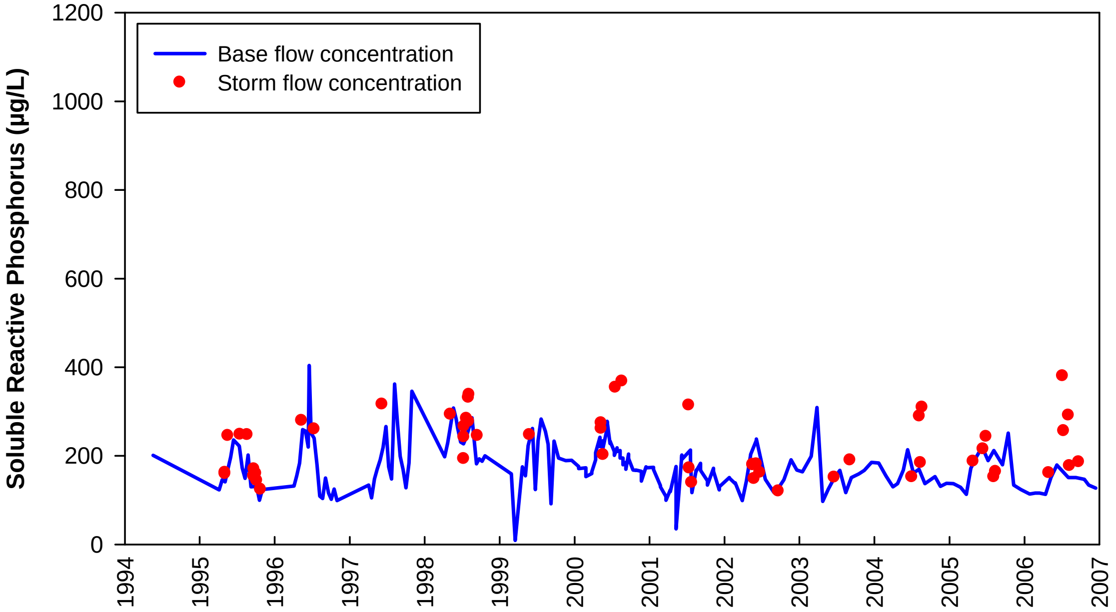


Figure 17: Base flow and storm flow soluble reactive phosphorus concentrations measured in Site CC-10, 1994 to 2006.

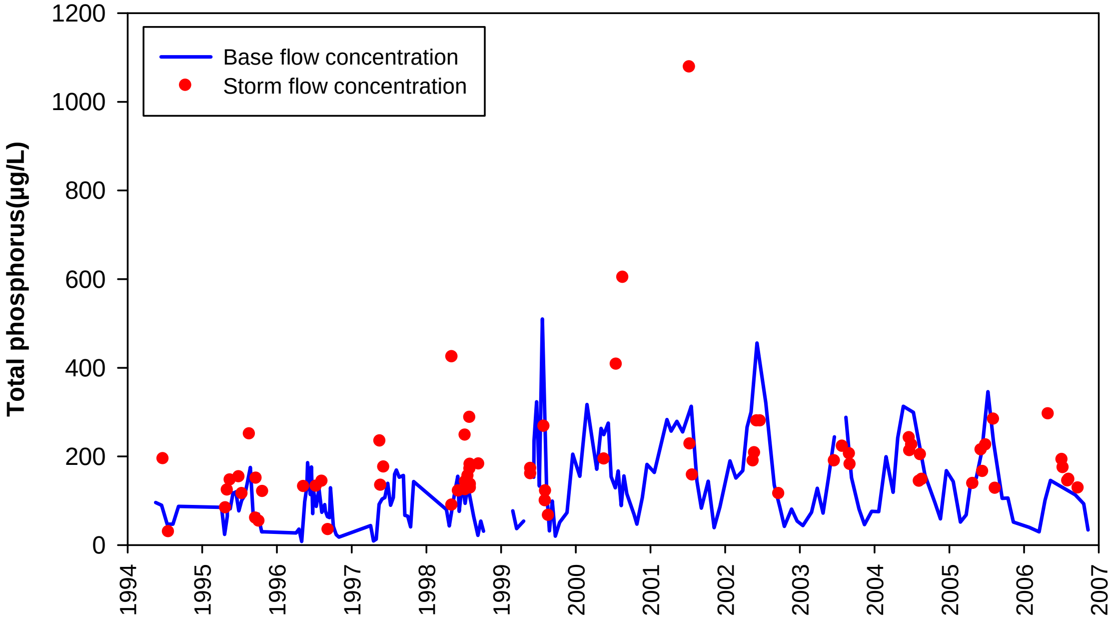


Figure 18: Base flow and storm flow total phosphorus concentrations measured in Site SC-3, 1994 to 2006.

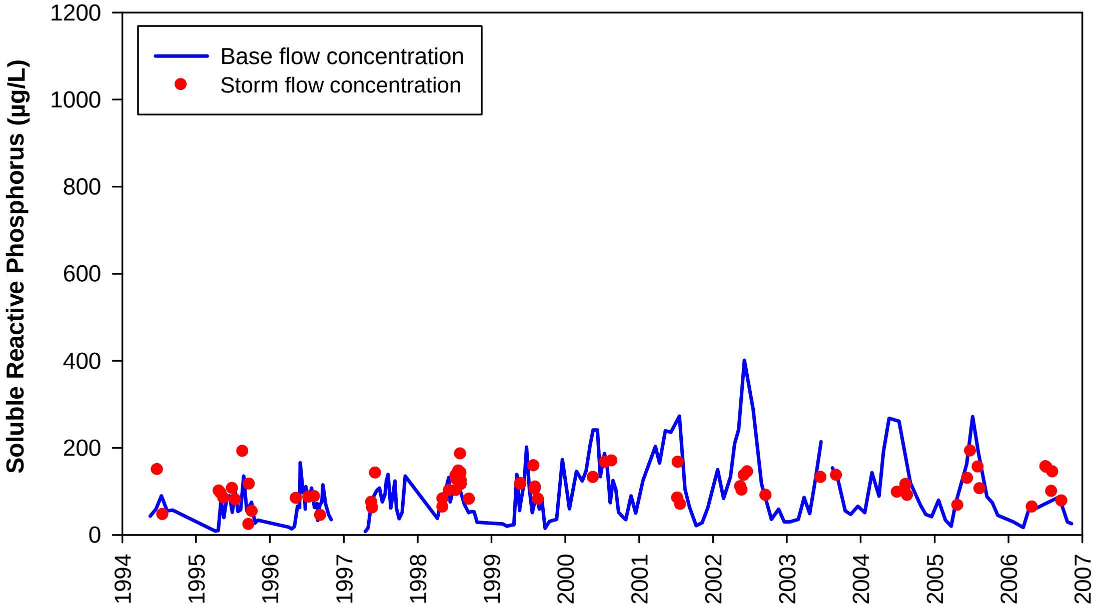


Figure 19: Base flow and storm flow soluble reactive phosphorus concentrations measured in Site SC-3, 1994 to 2006.

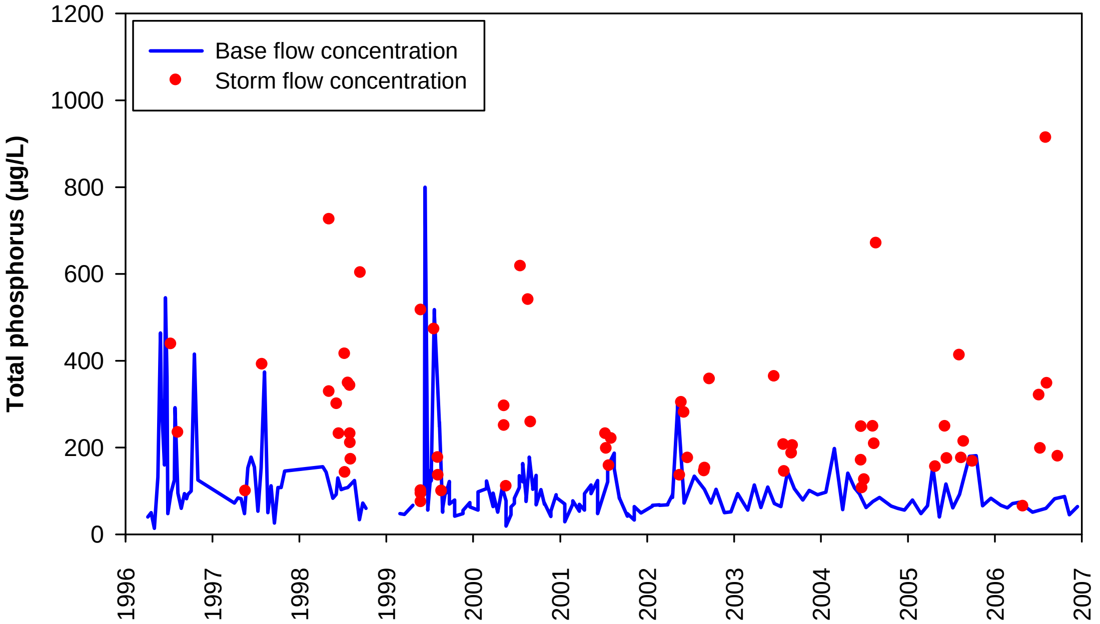


Figure 20: Base flow and storm flow total phosphorus concentrations measured in Site CT-2, 1996 to 2006.

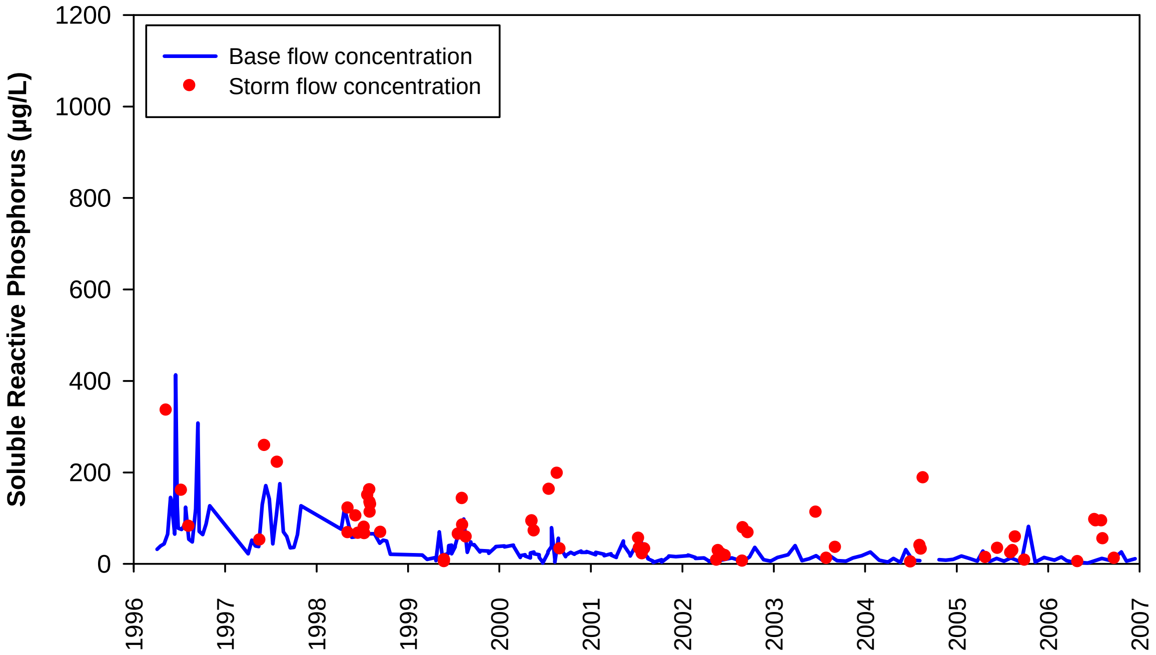


Figure 21: Base flow and storm flow soluble reactive phosphorus concentrations measured in Site CT-2, 1996 to 2006.

4.3.3 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. Given the ability of alluvium to filter out particulates, total dissolved phosphorus was used as a surrogate to total phosphorus. Alluvial total dissolved phosphorus concentrations show a slight, but significant ($p < 0.05$), increasing trend over time (1994 – 2006) at Site MW-9 (Figure 22).

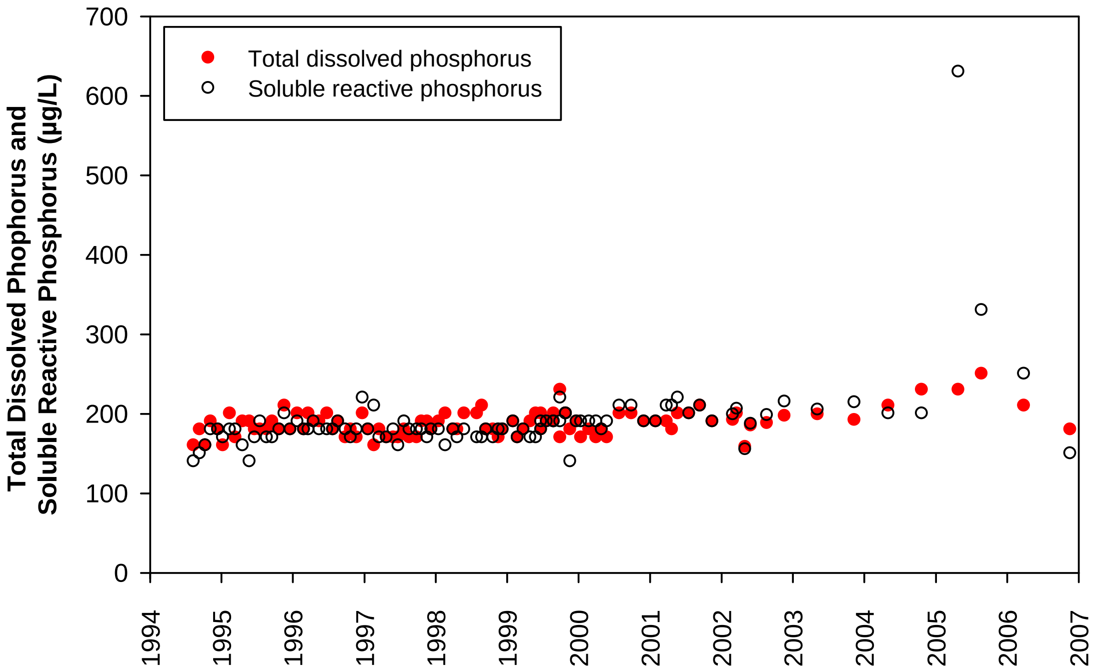


Figure 22: Total dissolved phosphorus and soluble reactive phosphorus concentrations measured at Site MW-9 (1994 to 2006).

4.4 Reservoir Phosphorus Loads and Export

Nutrients that limit or enhance algal growth in Cherry Creek Reservoir have many sources, both within the Reservoir (internal loading) or from outside the Reservoir (external loading). The direct release of nutrients from sediment, fish and plankton excrement, and the decay of organic matter are all internal sources of nutrients in a reservoir (Goldman and Horne 1983). However, the release of phosphorus from sediment during anoxic water conditions is the most substantial component of internal loading, and has been previously estimated to be 4,000 pounds per year in Cherry Creek Reservoir (Nürnberg and LaZerte, 2000; and LaZerte and Nürnberg, 2000). Recent 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 (Appendix D) in response to comments from CDPHE, which are expected to have minimal changes on the annual total phosphorus load to the Reservoir when compared to past methodologies. 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.

4.4.1 Phosphorus Load from Tributary Streams

Monthly base flow phosphorus concentrations, along with the annual storm flow median concentration were applied to their respective flow to estimate loads for each stream site. Stream flows that were greater than the 90th percentile of all flows measured for that site were categorized as storm flows. The greatest proportion (57 percent) of the total phosphorus load to the Reservoir was from Cherry Creek mainstem flows (3,691 lbs). Because Cherry Creek is monitored downstream of Shop Creek, the 76 lbs contributed by Shop Creek has been subtracted from the total load calculated for Site CC-10. Cottonwood Creek accounted for 20 percent of the phosphorus load, or 1,325 lbs. In 2006, the total phosphorus load to Cherry Creek Reservoir from tributary streams was 5,092 lbs (Table 8).

4.4.2 Phosphorus Export from Reservoir Outflow

The total outflow from Cherry Creek Reservoir as measured by the USACE was 11,292 acre-feet per year (ac-ft/yr) (Appendix D). Monthly total phosphorus data collected from Site CC-O was used to estimate the phosphorus export (3,278 lbs/yr) leaving the Reservoir in 2006 (Table 8).

Table 8: Estimated phosphorus loading and export (lbs/year) for Cherry Creek Reservoir, 1992 to 2006.

Year	Shop Creek	Cherry Creek	Cottonwood Creek	Stream Load Subtotal	Cherry Creek Alluvium	Direct Precipitation*	External Load	Cherry Creek Outflow	Net External Load	Flow-weighted TP (lbs/ac-ft)
1992	131	2,894	1,081	4,106	874	414	5,394	1,314	4,080	0.78
1993	83	1,727	177	1,987	1,387	349	3,723	711	3,012	0.70
1994	135	2,142	321	2,598	967	245	3,810	993	2,817	0.58
1995	115	2,795	2,184	5,094	1,676	561	7,331	2,049	5,282	0.68
1996	107	2,347	553	3,007	968	328	4,303	992	3,311	0.62
1997	117	2,041	646	2,804	1,937	487	5,228	1,628	3,600	0.56
1998	127	7,666	1,143	8,936	3,787	449	13,172	4,207	8,965	0.65
1999	96	8,745	1,822	10,663	5,912	471	17,046	9,650	7,396	0.63
2000	82	8,306	1,087	9,475	2,341	398	12,214	4,790	7,424	0.68
2001	103	3,412	1,292	4,807	4,444	359	9,610	4,842	4,768	0.57
2002	79	1,105	789	1,973	1,006	288	3,267	1,501	1,766	0.57
2003	103	4,637	1,130	5,870	2,307	423	8,600	4,978	3,622	0.51
2004	210	7,379	2,592	10,181	2,181	454	12,816	4,812	8,004	0.73
2005	127	6,636	1,697	8,460	1,123	346	9,929	3,669	6,260	0.54
2006	76	3,692	1,325	5,093	1,034	376	6,502	3,278	3,224	0.51
Median	**107**	**3,412**	**1,130**	**5,093**	**1,676**	**398**	**7,331**	**3,278**	**4,080**	**0.62**

Precipitation loads have been recalculated using the 1995 to 2005 median TP concentration
Note: Pre-2006 loads are in the process of being recalculated using a consistent methodology for all years

4.4.3 Phosphorus Load from Precipitation

In 2006, at total of 16.7 inches of precipitation was recorded at the KAPA meteorological station located at Centennial Airport. When scaled to the areal extent of the Reservoir (852 acres), precipitation accounted for a total of 1,189 acre-feet of inflow to the Reservoir. The mean concentration of total phosphorus collected from rainfall samples in 2006 was 55 µg/L, which is considerably less than the long term (1995 to 2005) median value of 116 µg/L used in the recalculation of the long term precipitation phosphorus loads.

The period from 1995 to 2005 represents a more consistent portion of the data in sample collection, analytical methods, and data variability. Therefore, the median value since 1995 was used for the recalculation process (Appendix D), and to calculate the 2006 annual total phosphorus load of 376 lbs/yr. The long-term median total phosphorus load from precipitation events collected from 1987 to 2006 is 387 lbs (Table 9).

Table 9: Phosphorus loading into Cherry Creek Reservoir from precipitation, 1987 to 2006. Data from 1987 to 1991 are based on water years, while data for 1992 to present are based on calendar years. Load is based on the long term (1995 to 2005) median total phosphorus concentration of 116 µg/L for sampled precipitation events.

Year	Precipitation (inches/yr)	Total Phosphorus Load (lbs/yr)
1987	18.1	405
1988	23.3	522
1989	13.0	292
1990	15.2	341
1991	16.5	370
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
Median	**17.2**	**387**

4.4.4 Phosphorus Load from Alluvium

In 2006, the alluvial inflow quantity was set as a constant 2000 ac-ft/yr with the rationale being summarized in Appendix D, per recommendations from CDPHE. 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 1,034 lbs in 2006 (Table 8).

4.4.5 Mass Balance/Net Loading of Phosphorus to the Reservoir

The USACE calculates daily inflow to Cherry Creek Reservoir as a function of change in storage (i.e., reservoir volume) based on: 1) changes in reservoir level; 2) measured outflow; 3) precipitation; and 4) evapotranspiration. This method for calculating reservoir volume accounts for groundwater inflow via alluvium, but does not directly quantify the flow. GEI monitors surface water inflow to the Reservoir using gaged stations on the three main surface inflows, Cherry Creek, Cottonwood Creek, and Shop Creek. Given the differences in the two methods for determining inflow, combined with the potential for unmonitored multiple

Cherry Creek channels in the wetlands adjacent to the Reservoir, unmonitored surface flow (i.e., Belleview and Quincy drainages), and the potential for the USACE calculations to underestimate dam leakage (Lewis and Saunders 2002), an exact match between USACE and GEI calculated inflows is not expected.

In 2006, the USACE calculated inflow was 12,799 ac-ft/yr, while the GEI calculated stream inflow was 8,821 ac-ft/yr (Appendix D). To compare these two inflow values, the USACE inflow was adjusted for precipitation (1,189 ac-ft/yr) and alluvial inflows (2,000 ac-ft/yr), which resulted in an adjusted USACE inflow of 9,610 ac-ft/yr. The difference between the adjusted USACE inflow and the GEI stream inflow was 789 acre-feet of water. This volume of water was reapportioned to both Cherry Creek and Cottonwood Creek, with a flow-weighted total phosphorus concentration being used to calculate the associated load of 317 lbs. The flow-weighted concentration was calculated using the three sources of external flow and loads (i.e., GEI stream inflow, alluvial inflow, and precipitation).

Following this adjustment to complete the water balance, in 2006, flow from the three tributary streams accounted for a total of 5,092 lbs of phosphorus to the Reservoir (Table 8). The alluvial inflow contributed 1,034 lbs of phosphorus, with precipitation events contributing 376 lbs to the Reservoir. The total external load of phosphorus to the Reservoir in 2006 was 6,502 lbs (Figure 23), which meets the TMAL of 14,270 lbs/yr.

The Reservoir outflow phosphorus load was estimated to be 3,278 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 0.51 lbs/ac-ft and the flow-weighted export concentration for the Reservoir is 0.29 lbs/ac-ft The difference of 0.22 lbs/ac-ft was retained by the Reservoir. The net external phosphorus load to the Reservoir was 3,224 lbs in 2006.

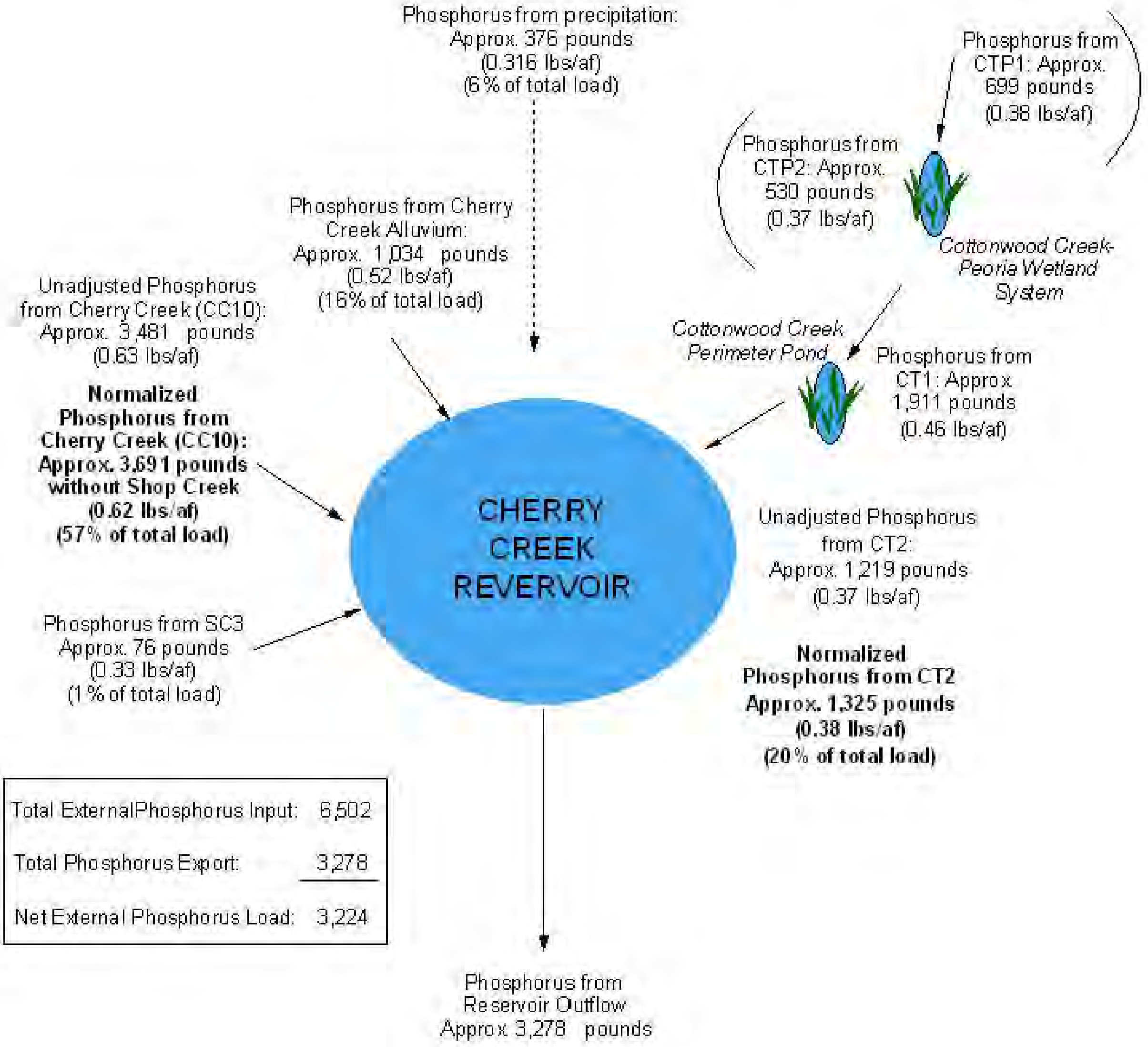


Figure 23: Mass balance diagram of phosphorus loading in Cherry Creek Reservoir, 2006.

4.5 Effectiveness of Pollutant Reduction Facilities

4.5.1 Cottonwood Creek Peoria Pond

The effectiveness of the Cottonwood Creek Peoria Pond is gaged by monitoring the concentrations of phosphorus and total suspended solids (TSS), and the 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. In 2006, the mean total phosphorus concentration both upstream and downstream of the PRF was nearly identical (Table 10). Total suspended solids were slightly greater downstream of the PRF system when compared to the upstream value (Table 10). Despite the comparable total phosphorus and total suspended solids values upstream and downstream of the PRF in 2006, the total phosphorus load downstream of the PRF system was reduced by 24 percent. This reduction in load is primarily a function of water loss due to the PRF, either by evapotranspiration or percolation into the shallow groundwater. The flow-weighted total phosphorus concentration upstream and downstream of the PRF was 0.38 lbs/ac-ft and 0.37 lbs/ac-ft, respectively, which indicates a low efficiency in removing phosphorus from flow despite the reduction in load.

Table 10: Historical total phosphorus and total suspended solids concentrations and total phosphorus loads upstream and downstream of the Cottonwood Creek - Peoria wetlands system, 2002 to 2006.

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
	Mean	**121**	**120**	**-0.8**	**-0.2**
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
	Mean	**54**	**53**	**-1**	**4.8**
Total Phosphorus Load (pounds)	2002	449	231	-228	-49
	2003	771	574	-197	-26
	2004	2,590	1,499	-1,091	-42
	2005	596	649	53	9
	2006	699	530	-169	-24
	Mean	**1021**	**697**	**-326**	**-26.4**

4.5.2 Cottonwood Creek Perimeter Pond

The effectiveness of the Cottonwood Creek storm water Perimeter Pond in reducing phosphorus loads to the Reservoir is similarly gaged by comparing data from sites upstream and downstream of the PRF (Table 11). During 2006, the mean concentration of total phosphorus slightly decreased from 170 to 161 µg/L after passing through the PRF, representing a 5 percent reduction in phosphorus concentration (Table 11). The mean concentration of TSS increased slightly, from 86 mg/L upstream to 95 mg/L downstream of the PRF. The total phosphorus load decreased downstream of the pond by 36 percent, with the flow-weighted concentration showing a reduction from 0.46 lbs/ac-ft to 0.37 lbs/ac-ft.

This PRF is effective in reducing the overall hydrologic load through this stretch of Cottonwood Creek, by evapotranspiration or percolation, and appears to be more efficient in removing phosphorus from stream flows than the Peoria Pond. The reduction in the flow-weighted concentration indicates that this PRF continues to be effective in reducing total phosphorus loads to Cherry Creek Reservoir.

In past years, greater flow-weighted concentrations observed at Site CT-1, when compared to Site CT-P2, indicated potential loading from stream channel erosion or additional inputs from Lonetree Creek, which is a tributary to Cottonwood Creek upstream of Site CT-1. In an effort to reduce phosphorus loading in the Reservoir from the stream itself, channel reconstruction was conducted on Cottonwood Creek downstream of the Cottonwood Creek - Peoria wetland system in 2004, with completion of Phase 2 pending. While the channel reconstruction or inputs from Lonetree Creek may have accounted for the increased loads observed between these two existing PRFs, the flow-weighted concentration downstream of the Cottonwood Creek Perimeter Pond indicates that this PRF continues to be effective in reducing the total phosphorus load to Cherry Creek Reservoir.

4.5.3 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 11: Historical total phosphorus and total suspended solids concentrations and total phosphorus loads upstream and downstream of the Cottonwood Creek stormwater detention pond (1997-2006).

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
	Mean	**185**	**149**	**-36**	**-18**
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
	Mean	**154**	**77**	**-77**	**-42**
Loading of Total Phosphorus (pounds)	1997	3,351	1,103	-2,248	-67
	1998	3,209	1,930	-1,279	-40
	1999	6,329	3,868	-2,461	-39
	2000	3,243	1,712	-1,531	-47
	2001	3,356	2,205	-1,151	-34
	2002	886	789	-97	-11
	2003	1,777	1,130	-647	-36
	2004	3,334	2,592	-742	-22
	2005	1,399	1,697	298	21
	2006	1,911	1,219	-692	-36
	Mean	**2880**	**1825**	**-1055**	**-31**

5.0 Summary and Conclusions

5.1 Transparency

The period in late May through June, and September 2006, represented a time when Reservoir water clarity was at its best. The whole-reservoir mean Secchi depth was 1.05 m during the July-to-September period. This value represents the deepest mean value since 1998, and is similar to the long-term mean value (Table 12). There was a significant negative relationship between water clarity and chlorophyll *a* concentration.

Table 12: Water quality and total phosphorus loads for Cherry Creek Reservoir, (1992 to 2006). Highlighted 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 *a* (µg/L)	Inflow (ac-ft)*	External Phosphorus Load (lbs/yr)*	Flow-weighted Concentration (lbs/ac-ft)
1992	0.95	66	970	17	7,474	5,857	0.78
1993	1.20	62	826	14.4	5,905	4,110	0.70
1994	1.10	59	1,144	6.2	7,001	4,049	0.58
1995	1.62	48	913	15.6	11,781	7,972	0.68
1996	1.60	62	944	20.5	7,644	4,715	0.62
1997	1.00	96	1,120	22.3	10,362	5,761	0.56
1998	1.09	89	880	26.5	20,903	13,577	0.65
1999	1.03	81	753	28.9	27,739	17,471	0.63
2000	0.96	81	802	25.2	18,610	12,593	0.68
2001	0.75	87	741	26.1	17,250	9,837	0.57
2002	0.91	74	858	18.8	7,498	4,246	0.57
2003	0.86	90	1,121	25.8	14,929	8,568	0.57
2004	0.85	102	977	18.4	17,177	12,512	0.73
2005	0.97	116	990	17.1	18,534	10,047	0.54
2006	1.05	87	914	14.7	12,799	6,502	0.51
Mean	**1.06**	**80**	**930**	**19.8**	**13,707**	**8,521**	**0.62**
Median	**1.00**	**81**	**914**	**18.8**	**12,799**	**7,972**	**0.62**

*Stream, alluvium, and precipitation.

5.2 Temperature and Dissolved Oxygen

The Reservoir was well mixed and oxygenated from March to early May 2006. From May through July the Reservoir showed signs of 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 4 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 profiles were also compared to the basic standards table value for Class 2 warm water lakes and reservoirs. As a conservative estimate, the mean dissolved oxygen concentration for the entire water column was computed for each sampling event, with each event showing that the Reservoir met the Class 2 warm water criteria for lakes and reservoirs.

5.3 Total Phosphorus

The July-to-September mean total phosphorus concentration ranged from 44 to 129 µg/L, with a mean of 87 µg/L (Table 12). Since 1987, the goal of 40 µg/L total phosphorus has only been met once in 1989. When evaluated on a monthly basis, Reservoir total phosphorus concentrations are significantly related to monthly phosphorus loads.

5.4 Chlorophyll *a*

Chlorophyll *a* concentrations ranged from 5.5 µg/L in late May to 41.6 µg/L in early November, with the annual mean chlorophyll *a* concentration being 15.9 µg/L. The seasonal (July-to-September) mean chlorophyll *a* concentration was 14.7 µg/L (Table 12), and is the first time in 12 years that the Reservoir met the chlorophyll *a* standard. Chlorophyll *a* concentrations were significantly correlated with Reservoir total nitrogen concentrations, but not with Reservoir phosphorus concentrations (TP or SRP). This result suggests that algal growth was limited by nitrogen in 2006.

5.5 Phosphorus Loading

The total inflow of gaged tributary streams and unmonitored surface water inflows was 9,611 ac-ft/yr, and accounted for 5,092 lbs of phosphorus to the Reservoir. Annual precipitation accounted for 1,189 ac-ft of water and contributed 376 lbs of phosphorus to the Reservoir. The alluvial inflow was set to a constant value of 2000 ac-ft/yr, and accounted for 1,034 lbs of phosphorus entering the Reservoir. The total external load to the Reservoir in 2006 was 6,502 lbs, which meets the phased TMAL of 14,270 lbs/yr. The 2006 external load is less than the long term median value of 7,972 lbs/yr, with a flow-weighted total phosphorus concentration of 0.51 lbs/ac-ft, which is the lowest value on record.

5.6 Pollutant Reduction Facility Effectiveness

The Cottonwood Creek Peoria Pond PRF was effective in removing 169 pounds or 24 percent of the phosphorus load from Cottonwood Creek. This load reduction is primarily the result of the reduced water load passing through the system, as the flow-weighted phosphorus concentrations upstream and downstream of the PRF were very similar. Historically, this PRF has not been as efficient as the Perimeter Pond in removing phosphorus or suspended solids from the surface flows, though its ability to reduce the water load directly reduces the phosphorus load. The Cottonwood Creek Perimeter Pond was effective in reducing the total phosphorus load to the Reservoir by 692 pounds or 36 percent in 2006. The effectiveness of the PRF lies in both reducing the water load through the system and removing phosphorus from the stream flows. The flow-weighted phosphorus concentration decreased by 20 percent from upstream to downstream of the system.

In past years, greater flow-weighted concentrations observed at Site CT-1, when compared to Site CT-P2, indicated potential loading from stream channel erosion or additional inputs from Lonetree Creek, which is a tributary to Cottonwood Creek upstream of Site CT-1. In an effort to reduce phosphorus loading to the Reservoir from the stream itself, channel reconstruction was conducted on Cottonwood Creek downstream of the Cottonwood Creek - Peoria wetland system in 2004, with completion of Phase 2 pending. While the channel reconstruction or inputs from Lonetree Creek may have accounted for the increased loads observed between these two existing PRFs, the flow-weighted concentration downstream of the Cottonwood Creek Perimeter Pond indicates that this PRF continues to be effective in reducing the total phosphorus load to Cherry Creek Reservoir.

6.0 References

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Chadwick Ecological Consultants, Inc. (CEC). 2003b. *Cherry Creek Reservoir Aquatic Biological and Nutrient Sampling and Laboratory Analyses, Sampling, Analysis, and Quality Assurance Work Plan. May 2003.* Prepared for the Cherry Creek Basin Water Quality Authority.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

LaZerte, B.D., and Nürnberg, G. 2000 *Cherry Creek Reservoir Dynamic Model*. Prepared for the Cherry Creek Basin Water Quality Authority.

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

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

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

Nürnberg, G., and LaZerte, B. 2000. *Modeling Future Scenarios for Cherry Creek Reservoir*. Prepared for the Cherry Creek Basin Water Quality Authority.

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

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

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

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

Appendix A

Cherry Creek Reservoir Sampling and Analysis Plan

CHERRY CREEK RESERVOIR

AQUATIC BIOLOGICAL AND NUTRIENT SAMPLING AND LABORATORY ANALYSES

SAMPLING, ANALYSIS, AND QUALITY ASSURANCE WORK PLAN

MAY 2003

Submitted to:

Cherry Creek Basin Water Quality Authority
℅ R.S. Wells Corporation
6040 Greenwood Plaza Blvd, Suite 120
Greenwood Village, Colorado 80111-4801

Prepared by:

Chadwick Ecological Consultants, Inc.
5575 South Sycamore Street, Suite 101
Littleton, Colorado 80120
www.ChadwickEcological.com

TABLE OF CONTENTS

INTRODUCTION

An inter-governmental agreement was executed in 1985 by several local governmental entities within the Cherry Creek basin to form the Cherry Creek Basin Water Quality Authority (Authority). The Authority initially created by an intergovernmental agreement, was specially authorized by legislation adopted in 1988. The Authority develops and implements the means to protect the water quality of Cherry Creek Basin and Reservoir. Following recent legislation, the Board was reconstituted in 2001 and now includes Arapahoe and Douglas Counties, 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. This 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 stormwater, 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).

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 2003. This Sampling and Analysis Plan sets out 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 nitrogen and phosphorus 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 pounds of phosphorus entering Cherry Creek Reservoir from streams and precipitation and leaving the reservoir through the outlet.

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.

This Sampling and Analysis Plan presents the proposed 2003 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.

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.

Project Manager

The Project Manager for the aquatic biological and field sampling portions of the study is responsible for fiscal oversight and technical management of the project and for ensuring that all work is conducted in accordance with 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, and whenever the data quality objective of 100% completeness is not met.
- Maintain a central file, which contains or indicates the location of all documents relating to this project.
- Review and update of this Sampling and Analysis Plan, as needed.
- Coordinate with the Authority, the WQCD, and the Authority's other consultants to ensure compliance with the Cherry Creek Reservoir Control Regulation No. 72.

Quality Assurance Manager

Quality Assurance oversight will be provided by a qualified individual with specific education and experience in water quality sampling and analysis. 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.

Analytical and Biological Laboratory Managers

The Analytical Laboratory Manager shall ensure that all water quality 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.

The Biological Laboratory Manager shall ensure that all biological samples are analyzed in a technically sound and timely manner. The Biological 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 Biological 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.

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 Project Manager. The Sampling Crew shall be responsible for following all procedures for sample collection, including complete and accurate documentation.

AQUATIC BIOLOGICAL AND NUTRIENT SAMPLING

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).

Cherry Creek Reservoir

CCR-1	This site is also called the Dam site and corresponds to the northwest trident when partitioning the lake by estimations of volume.
CCR-2	This site is also called the Swim Beach site and corresponds to the northeast trident when partitioning the lake by estimations of volume.
CCR-3	This site is also called the Inlet site and corresponds to the south trident when partitioning the lake by estimations of volume.

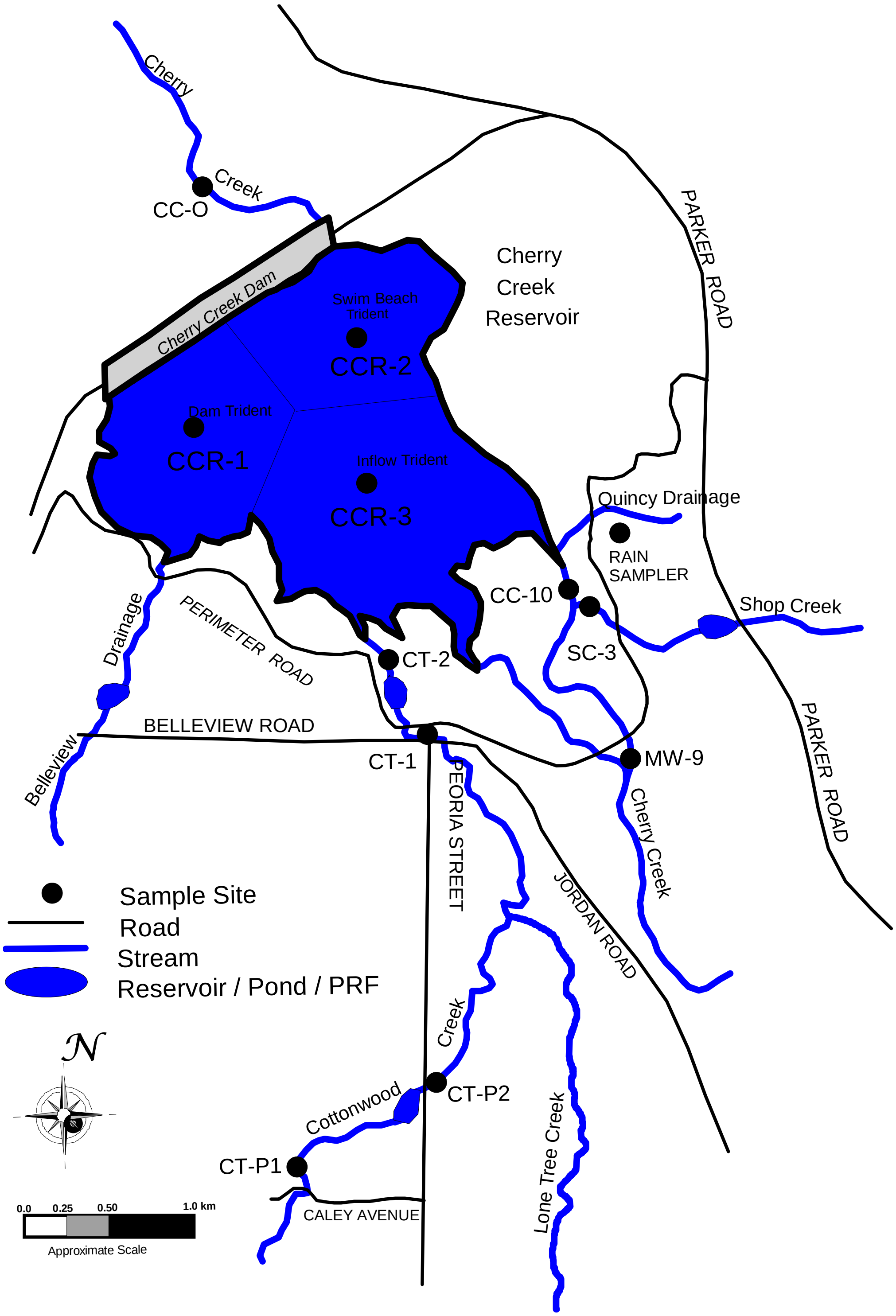


Figure 1: Sampling sites on Cherry Creek Reservoir and selected streams.

Stream Monitoring Sites

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 measures loads from Cherry Creek and Shop Creek that enter the reservoir.
CC-O	This site is on Cherry Creek downstream of Cherry Creek Reservoir near the USGS gaging station within the Kennedy Golf Course.

Cottonwood Creek

CT-2	This site is immediately downstream of the phosphorus control facility (PRF), upstream of Cherry Creek Reservoir (i.e., Perimeter Road Pond). Although this site also measures the performance of the Perimeter Road Pond PRF, it is included in the reservoir portion of the effort since it is needed to measure loads to the reservoir from Cottonwood Creek.

PRF Monitoring Sites

Shop Creek

SC-3	This site is downstream of the Shop Creek detention pond and wetland complex above the confluence with Cherry Creek mainstem, and downstream of the Perimeter Road.

Cottonwood Creek

CT-P1	This site is located on Cottonwood Creek upstream of the new detention pond PRF at Peoria Street.
CT-P2	This site is located on Cottonwood Creek just downstream of Peoria Street Pond PRF and in the upper end of the streambank stabilization reach.

CT-1 This site is on Cottonwood Creek just downstream of Belleview Avenue, upstream of the Cherry Creek Park Perimeter Road. Note that Site CT-2 is included in the reservoir monitoring requirements.

Precipitation Sampling Site

This site is located near the Quincy Drainage, upstream of the Perimeter Road. The sampler consists of a clean, inverted plastic trash can lid used to funnel rain into a one-gallon container.

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 analysis.

Analyte	Standard Methods*	Other Method Designations	Recommended Hold Times	Detection Limit
Manual Analyses				
pH		Denver Instrument pH/ATC Ag/AgCl combination electrode	24 hrs.	
Alkalinity	2320 B		24 hrs.	2 mg/$CaCO_3$/L
Hardness	2340 C (modified)	HACH Method 8266, ManVer 2 Buret Titration	24 hrs.	2 mg/$CaCO_3$/L
Total Suspended Solids	2540 D		7 days	4 mg/L
Total Volatile Suspended Solids	2540 E		7 days	4 mg/L
Chlorophyll	10200 H (modified)	Hot Ethanol Extraction	-24 hrs. before filtration	0.1 mg/m^3
Nutrient Analyses				
Orthophosphate	4500-P G	QuickChem 10-115-01-1-T	48 hrs.	3 µg/L
Total Phosphorus	4500-P G	QuickChem 10-115-01-1-U, with manual digestion	-24 hrs. before digestion	2 µg/L
Nitrate + Nitrite	4500-NO3 I	QuickChem 10-107-04-1-B	48 hrs.	5 µg/L
Total Nitrogen	4500-N B (modified)		-24 hrs. before digestion; -7 days after digestion	4 µg/L
Ammonia	none	QuickChem 10-107-06-3-D	24 hrs.	3 µg/L
Biological Analyses				
Phytoplankton	University of Colorado, Center for Limnology			

* From *Standard Methods for Examination of Water and Waste Water* (20th Edition).

Sampling Schedule

Reservoir Sampling

The general sampling schedule includes regular sampling trips to the reservoir at varying frequency over the annual sampling period, as outlined below. Sampling in our winter months (November - February) will depend on ice conditions and safety concerns.

TABLE 2: Reservoir Sampling Schedule

Sampling Period	Frequency	Trips/Period
January to April (not February)	Monthly	3
May to September	Every 2 Weeks	11
October to November (not December)	Monthly	2
	Total	16

Stream Sampling

Standard sampling is conducted monthly concurrent with the regular reservoir sampling trips when possible to generally provide information during non-storm event periods, corresponding to the low-flow ambient samples collected in earlier studies.

TABLE 3: Stream Sampling Schedule

Sampling Period	Frequency	Trips/Period
January to December	Monthly	12
	Total	12

Representative Storm Event Sampling

There are six stream sites for storm event sampling(i.e., S-3, CC-10, CT-1, CT-2, CT-P1, and CT-P2). 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..

Precipitation Sampling

Precipitation samples are to be collected after "significant" 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 insignificant amounts of precipitation contaminating the sample by allowing "dry-fall" to be washed into the sampler between significant events.

Field Methodologies

Reservoir Sampling

Transparency

Transparency shall be determined using a Secchi disk and a combined-deck photometer. The Secchi reading would be taken from the shady side of the boat. If this is not possible, sunglasses or other shading will be used to reduce glare. The disk is lowered slowly 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.

A second method to measure the depth of the euphotic zone is to determine the depth at which 1% of the light penetrates the water column. This is considered the point at which, on average, light no longer can sustain photosynthesis in excess of oxygen consumption from respiration (Goldman and Horne 1983). This is accomplished by using a double-deck photometer. One photocell remains on the surface, and the other is lowered into the water on the sunny side of the boat. Both photocells are attached to a data logger, which records the amount of light in micromoles per second per square meter. The underwater photocell is lowered until the value displayed on the data logger is 1% of the value of the surface photocell, and then the depth is recorded.

Depth Profile Measurements

Measurements for dissolved oxygen, temperature, conductivity, and pH shall be taken at 1 m intervals using a YSI meter, Model # 600XL multi-probe meter. This meter shall be calibrated at the C&A Laboratory prior to each sampling episode to ensure accurate readings. To determine maximum depth, a Secchi disk will be lowered until it reaches the bottom. This reading will be taken on the opposite side of the boat from where water samples are being taken to minimize chances of sample contamination from the sediment. Profile measurements are taken no deeper than 0.5 m off the bottom to minimize potential contamination of the probes.

Water Samples

A primary task is sampling of water for nutrient and biology analyses. An upper-reservoir composite sample shall be taken at each of the three reservoir sites, kept separate for each site, and analyzed individually for nutrients and chlorophyll. A composite comprised of equal contributed aliquots collected with a vertical Van Dorn water sampler (approximately 3 L) at 1 m increments beginning at the surface and continuing to the 3 m depth (the upper 3 m of the reservoir represents 71% of the lake volume).

Samples are collected using a vertical Van Dorn sampler (3 L volume) by lowering to the appropriate depth (as outlined above). A "messenger" is sent to trip the sampler, and the water is brought to the boat and transferred to a clean plastic bucket for splitting into aliquots, as described above. The sampler is rinsed thoroughly with lake water between samples and between sites. Aliquots are taken from the photic composite for chemical analyses consisting of three 4-L just (two for chlorophyll and one for nutrients).

Water sample depth profile sampling is also conducted at Site CCR-2 in the deepest area in the reservoir. At this site, additional water samples shall be obtained at the 4, 5, 6, and 7 m depths. The last sample (7 m) would be collected roughly 1 m off the bottom, to minimize disturbance of bottom sediments during sampling. With variation in reservoir elevation throughout the year, it may not be possible to actually collect a sample at the 7 m depth every sampling episode. Samples are collected using a vertical Van Dorn sampler (3 L volume). The sampler is lowered to the appropriate depth (as outlined above). A "messenger" is sent to trip the sampler, and the water is brought to the boat and transferred to a clean bucket for splitting into aliquots, as described above. The sampler is rinsed thoroughly with lake water between samples and between sites.

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

TABLE 4: Samples per Station/Sampling Episode

Location		Photic Composite	1-m Increment Depth Samples
Dam	(CCR-1)	1	0
Swim Beach	(CCR-2)	1	4
Inflow	(CCR-3)	1	0
Total Samples/Sample Episode		3	4
Grand Total		7	

Water Quality Analyses

1. Nutrients, alkalinity, hardness, and pH analyses conducted in all reservoir water samples.

2. Chlorophyll would be analyzed in the 3 m photic depth profile samples only from June - September, one set per month.

3. Phytoplankton would be sampled twice monthly from April - October, and monthly from November - March from the 0-3 m water composite samples.

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

Stream Sampling

One sample shall be collected from each of the stream sampling sites during the sampling period, when there is sufficient flow. Samples shall be taken as mid-stream mid-depth grab samples with a polyethylene scoop and composited in a 5-gallon plastic bucket. Aliquots shall be taken from the composite for chemical analyses consisting of two 4-L jugs for analysis of parameters, as listed in Table 5.

During these sampling episodes, water was collected from each of the seven stream sampling sites (sites on tributary streams and on Cherry Creek downstream of the reservoir) and analyzed for nutrients and suspended solids. No samples were collected at Site CC-O during January, February, October, and December due to lack of water. With the exception of Site SC-3 in July, flows were sufficient at each tributary site through the year to obtain all scheduled samples. Two samples were collected for chemical and suspended solids analysis from each of the stream sampling sites and consisted of a mid-stream, mid-column grab sample using two 1 L bottles. After collecting water samples, dissolved oxygen, temperature, conductivity, pH, and oxidation-reduction potential readings were taken at each stream site. Readings were taken with a YSI meter, model #600 XL multi-probe meter.

Automatic Sampler

Each stream sampling station upstream of the reservoir also contains an Authority-owned ISCO flow meter and sampling device, which is powered by a 12-volt battery. The flow meter is a pressure transducer that measures stream water level. Rating curves were developed for each sampling site by measuring stream discharge (ft^3/sec) with a Marsh McBirney Model # 2000 flowmeter, and recording the water level at the staff gage (ft) and ISCO flowmeter (ft). Discharge is measured using methods outlined in Harrelson *et al* 1994. To determine flow rate, the level must be translated into flow rate using a "stage-discharge" relationship. The Authority has developed such a relationship for each site over the years. Since stage-discharge relationships can change over the years, the relationship is calibrated annually using a flow meter to take stream flow measurements three to four times per year at a range of flows. These data shall be combined with previous data to validate and modify the stage-discharge relationship for that site.

Water level data are stored in the ISCO sampler and must be downloaded to calibrate the station. Downloading of the data shall occur at least monthly to minimize the risk of a bad battery or other power failure resulting in a loss of data. The flow data and stage-discharge rating curves shall be checked throughout the year by comparing calculated flow estimates to actual flow measurements taken in the field with a flowmeter. Flow at time of sampling shall be calculated using stage-discharge relationships and is used to develop the flow-to-phosphorus relationship necessary to calculate daily loads (which are totaled for monthly and annual loads). The Corps is also contacted and daily precipitation and inflows/outflows from the reservoir obtained.

Storm Event Sampling

Samples from stormwater flow events are collected with ISCO automatic samplers, which collects samples when the water reaches a pre-set level. The level is determined by analyzing annual hydrographs from each stream and determining storm levels. When the pre-set level 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 pre-set 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 shall be composited (timed composite) and transferred to water jugs 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 taken. During the seasons in which no storm samples are taken, the storm samplers are disabled.

Precipitation Sampling

After each significant storm, the sample bottle shall be removed and taken to a qualified laboratory for analysis of total phosphorus, total nitrogen, and nitrite-nitrate. If sufficient volume remains, samples shall be tested for alkalinity, water hardness, pH, and suspended solids. The sampler shall be inspected and cleaned of any accumulations of insignificant precipitation on a weekly basis. This will prevent extraneous "dry fall" from being washed into the sampler between significant storm events.

Field-Related Quality Assurance/Quality Control

To ensure data quality, a number of quality assurance checks will be used. During each standard sampling episode, 1-split from the reservoir and 1-split from the stream (i.e., 28 total samples) shall be shipped to CU laboratory for analysis.

Field sampling quality control will consist of the use of a field blank. This field blank shall contain laboratory-grade deionized water that will be carried through the entire sampling episode. The cap of this jug will be removed at a particular site and left open during the regular sampling effort, after which time the cap will be replaced. One field blank will be used for every sampling trip. The field blanks and trip duplicates will be analyzed for the same parameters as a routine sample and later compared to samples analyzed by a qualified laboratory to provide QA/QC checks. Chain of custody procedures will be observed during the field sampling and delivery of samples to a qualified laboratory and to the CU laboratory.

LABORATORY PROCEDURES

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 below.

TABLE 5: List of Analytes by Sample Depth

3-m Photic Composite Samples	1-m Increment Depth Samples	Stream Samples Precipitation Samples
pH, Conductivity, and Temperature	TP, TDP, SRP	TD, TDP, SRP
Total Phosphorus (TP), Total Dissolved Phosphorus (TDP), and Soluble Reactive Phosphorus (SRP)	TN, TDN, NO_3+NO_2, Ammonia	TN, TDN, NO_3+NO_2, Ammonia
Total Nitrogen (TN, Total Dissolved Nitrogen (TDN), NO_3+NO_2, and Ammonia		Total Suspended Solids (TSS)/ Total Volatile Suspended Solids (TVSS) (not on precipitation)
Chlorophyll		
Phytoplankton (sampled on reservoir sampling dates: twice monthly from April - October, and monthly from November - March from the 0-3 m water composite samples)		

Biological Laboratory Analysis

Biological analyses for the samples collected in the study, as described above, will be conducted at a qualified laboratory and analyzed for chlorophyll *a*. The methods of these analyses, with appropriate QA/QC procedures shall be in accordance with the methods provided in Table 1. Phytoplankton samples will be sent to the Colorado University Center for Limnology to be analyzed by Dr. Jim Saunders.

DATA VERIFICATION, REDUCTION, AND REPORTING

Data verification shall be conducted to insure 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 ten 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.

REFERENCES

American Public Health Association. 1998. *Standard Methods for Examination of Water and Wastewater*, 20th Edition. American Public Health Association, Washington, DC.

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

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

Hach Company. 1997. *Hach Water Analysis Handbook*, 3rd Edition. Hach Company, Loveland, CO.

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.

Appendix B

2006 Reservoir Water Quality Data

CCR-1 C&A Water Chemisty Data

	Analytical Detection Limits	2	2	2	2	2	2	3	
Sample Date	Sample Name/ Location	Total Phosphorus µg/L	Total Dissolved Phosphorus µg/L	Ortho-Phosphate µg/L	Total Nitrogen µg/L	Total Dissolved Nitrogen µg/L	Nitrate + Nitrite µg/L	Ammonia µg/L	Average Chlorophyll *a* (mg/m^3)
3/14/06	CCR-1 Photic	83	13	8	969	508	3	16	20.6
4/12/06	CCR-1 Photic	86	16	4	926	484	<2	10	18.1
5/8/06	CCR-1 Photic	72	30	19	582	368	8	82	7.2
5/24/06	CCR-1 Photic	58	26	14	720	544	<2	17	5.0
6/6/06	CCR-1 Photic	62	35	17	786	621	11	23	10.2
6/20/06	CCR-1 Photic	81	35	16	773	525	<2	25	8.7
7/5/06	CCR-1 Photic	118	51	34	866	594	<2	24	12.1
7/18/06	CCR-1 Photic	108	38	22	834	511	<2	10	11.5
8/1/06	CCR-1 Photic	72	20	12	1118	744	<2	32	19.8
8/15/06	CCR-1 Photic	96	21	9	853	463	<2	11	18.3
9/7/06	CCR-1 Photic	76	15	6	902	709	<2	14	12.4
9/19/06	CCR-1 Photic	40	21	10	859	717	<2	65	6.5
10/18/06	CCR-1 Photic	71	18	14	1031	680	5	53	40.5
11/8/06	CCR-1 Photic	72	25	8	1009	632	21	21	32.4

CCR-2 C&A Water Chemisty Data

Analytical Detection Limits		2	2	3	4	4	5	3	
Sample Date	Sample Name/ Location	Total Phosphorus μg/L	Total Dissolved Phosphorus μg/L	Ortho-Phosphate μg/L	Total Nitrogen μg/L	Total Dissolved Nitrogen μg/L	Nitrate + Nitrite μg/L	Ammonia μg/L	Average Chlorophyll *a* (mg/m^3)
3/14/06	CCR-2 photic	82	14	8	995	485	<2	7	17.2
3/14/06	CCR-2 4m	79	14	8	938	466	<2	7	ND
3/14/06	CCR-2 5m	77	14	8	922	468	<2	6	ND
3/14/06	CCR-2 6m	76	14	7	900	459	<2	7	ND
3/14/06	CCR-2 7m	73	14	8	937	480	<2	7	ND
4/12/06	CCR-2 photic	87	14	4	923	473	<2	9	16.2
4/12/06	CCR-2 4m	92	15	4	956	465	<2	10	ND
4/12/06	CCR-2 5m	89	18	4	954	469	<2	11	ND
4/12/06	CCR-2 6m	92	16	4	944	463	<2	7	ND
4/12/06	CCR-2 7m	96	15	5	951	461	<2	7	ND
5/8/06	CCR-2 photic	71	30	19	592	511	9	88	6.9
5/8/06	CCR-2 4m	78	31	19	540	399	8	76	ND
5/8/06	CCR-2 5m	71	30	19	498	424	8	79	ND
5/8/06	CCR-2 6m	67	30	19	423*	462*	8	80	ND
5/8/06	CCR-2 7m	66	29	19	613	446	8	79	ND
5/24/06	CCR-2 photic	60	26	13	755	546	<2	15	5.2
5/24/06	CCR-2 4m	59	25	14	770	534	<2	28	ND
5/24/06	CCR-2 5m	75	30	18	762	549	<2	35	ND
5/24/06	CCR-2 6m	115	75	67	874	706	<2	146	ND
5/24/06	CCR-2 7m	175	127	121	1040	801	<2	274	ND
6/6/06	CCR-2 photic	79	31	16	840	661	4	26	3.2
6/6/06	CCR-2 4m	80	35	19	790	557	4	28	ND
6/6/06	CCR-2 5m	80	46	30	852	553	5	44	ND
6/6/06	CCR-2 6m	80	50	38	701	552	5	74	ND
6/6/06	CCR-2 7m	178	121	112	976	691	6	242	ND
6/20/06	CCR-2 photic	78	62	14	770	522	<2	26	9.4
6/20/06	CCR-2 4m	101	45	28	776	512	<2	22	ND
6/20/06	CCR-2 5m	152	89	75	838	575	<2	68	ND
6/20/06	CCR-2 6m	163	111	96	851	632	<2	114	ND
6/20/06	CCR-2 7m	267	161	149	1125	704	2	201	ND

* "ND" denotes "No Data"

CCR-2 C&A Water Chemisty Data

Analytical Detection Limits		2	2	3	4	4	5	3	
Sample Date	Sample Name/ Location	Total Phosphorus μg/L	Total Dissolved Phosphorus μg/L	Ortho- Phosphate μg/L	Total Nitrogen μg/L	Total Dissolved Nitrogen μg/L	Nitrate + Nitrite μg/L	Ammonia μg/L	Average Chlorophyll *a* (mg/m^3)
7/5/06	CCR-2 Photic	125	52	36	848	532	<2	13	15.3
7/5/06	CCR-2 4m	125	54	37	750	459	<2	9	ND
7/5/06	CCR-2 5m	127	52	37	782	474	<2	10	ND
7/5/06	CCR-2 6m	144	55	40	818	471	<2	19	ND
7/5/06	CCR-2 7m	268	93	71	1089	604	3	166	ND
7/18/06	CCR-2 Photic	106	34	14	1147	690	<2	20	11.2
7/18/06	CCR-2 4m	100	31	14	850	517	<2	15	ND
7/18/06	CCR-2 5m	114	29	13	904	491	<2	12	ND
7/18/06	CCR-2 6m	163	34	22	987	460	<2	8	ND
7/18/06	CCR-2 7m	296	59	44	1300	463	<2	10	ND
8/1/06	CCR-2 Photic	67	18	11	921	548	<2	16	18.4
8/1/06	CCR-2 4m	63	17	11	811	467	<2	12	ND
8/1/06	CCR-2 5m	70	19	13	797	479	<2	23	ND
8/1/06	CCR-2 6m	79	26	20	760	469	<2	16	ND
8/1/06	CCR-2 7m	92	28	23	768	454	<2	12	ND
8/15/06	CCR-2 Photic	112	29	10	1007	490	<2	13	29.5
8/15/06	CCR-2 4m	97	20	12	826	451	<2	10	ND
8/15/06	CCR-2 5m	106	19	11	828	433	<2	9	ND
8/15/06	CCR-2 6m	117	21	12	788	419	<2	9	ND
8/15/06	CCR-2 7m	122	24	14	852	432	<2	8	ND
9/7/06	CCR-2 Photic	70	13	6	933	577	<2	14	12.8
9/7/06	CCR-2 4m	62	16	6	855	506	<2	9	ND
9/7/06	CCR-2 5m	79	20	13	801	506	<2	36	ND
9/7/06	CCR-2 6m	101	23	16	822	497	<2	41	ND
9/7/06	CCR-2 7m	93	32	17	942	526	<2	44	ND
9/19/06	CCR-2 Photic	41	19	8	767	588	<2	24	4.9
9/19/06	CCR-2 4m	37	16	7	669	506	<2	17	ND
9/19/06	CCR-2 5m	36	15	6	679	515	<2	15	ND
9/19/06	CCR-2 6m	44	15	9	721	528	<2	29	ND
9/19/06	CCR-2 7m	62	18	11	739	524	<2	35	ND

* "ND" denotes "No Data"

CCR-2 C&A Water Chemisty Data

Sample Date	Sample Name/ Location	Total Phosphorus µg/L	Total Dissolved Phosphorus µg/L	Ortho-Phosphate µg/L	Total Nitrogen µg/L	Total Dissolved Nitrogen µg/L	Nitrate + Nitrite µg/L	Ammonia µg/L	Average Chlorophyll *a* (mg/m^3)
Analytical Detection Limits		2	2	3	4	4	5	3	
10/18/06	CCR-2 photic	92	15	13	1198	683	7	101	33.0
10/18/06	CCR-2 4m	87	13	12	1098	648	490	98	ND
10/18/06	CCR-2 5m	63	13	11	962	639	505	95	ND
10/18/06	CCR-2 6m	71	9	9	971	639**	933**	101	ND
10/18/06	CCR-2 7m	55	8	8	851	622**	860**	99	ND
11/8/06	CCR-2 photic	76	25	7	1090	610	<2	16	31.1
11/8/06	CCR-2 4m	65	23	8	877	548	<2	11	ND
11/8/06	CCR-2 5m	56	23	7	896	537	<2	15	ND
11/8/06	CCR-2 6m	45	16	6	727	525	<2	15	ND
11/8/06	CCR-2 7m	46	18	6	719	533	2	23	ND

* "ND" denotes "No Data"

CCR-3 C&A Water Chemisty Data

Sample Date	Sample Name/ Location	Total Phosphorus μg/L	Total Dissolved Phosphorus μg/L	Ortho-Phosphate μg/L	Total Nitrogen μg/L	Total Dissolved Nitrogen μg/L	Nitrate + Nitrite μg/L	Ammonia μg/L	Average Chlorophyll *a* (mg/m^3)
	Analytical Detection Limits	2	2	3	4	4	5	3	
3/14/06	CCR-3 Photic	77	14	8	959	483	<2	7	17.2
4/12/06	CCR-3 Photic	102	18	4	972	482	<2	9	17.0
5/8/06	CCR-3 Photic	83	31	19	546	497	11	84	6.5
5/24/06	CCR-3 Photic	62	28	16	860	649	<2	35	6.2
6/6/06	CCR-3 Photic	49	23	11	720	525	3	9	6.0
6/20/06	CCR-3 Photic	94	36	18	772	491	<2	16	10.8
7/5/06	CCR-3 Photic	144	51	32	907	496	<2	11	15.5
7/18/06	CCR-3 Photic	112	33	16	1066	645	<2	13	15.1
8/1/06	CCR-3 Photic	71	17	11	907	514	<2	13	19.8
8/15/06	CCR-3 Photic	84	24	9	862	490	<2	9	24.6
9/7/06	CCR-3 Photic	67	15	6	915	563	<2	13	9.4
9/19/06	CCR-3 Photic	51	15	7	742	534	<2	17	6.6
10/18/06	CCR-3 Photic	62	12	9	891	669	578	103	12.7
11/8/06	CCR-3 Photic	87	35	13	1529	611	2	10	61.3

CCR University of Colorado Water Chemisty Data

Sample Date	Sample Name/ Location	Total Phosphorus µg/L	Total Dissolved Phosphorus µg/L	Ortho-Phosphate µg/L	NO3+NO2-N µg/L	NH4-N µg/L
Analytical Detection Limits		2	2	3	5	3
3/14/06	CCR-2 4m	61.5	21.4	3.4	0	40.4
4/12/06	CCR-3 photic	63.2	20.7	3.1	0	8.2
5/8/06	CCR-2 7m	58.5	35.2	19.5	6.5	90.2
5/24/06	CCR-1 photic	41.6	16.6	11.2	0	32.9
6/6/06	CCR-3 photic	55.9	37.8	17.4	0	14.7
6/20/06	CCR-3 photic	76.3	36.6	14.5	0	15.9
7/5/06	CCR-3 photic	94.7	48.1	29.7	0	14.0
7/18/06	CCR-2 photic	75.9	34.3	11.1	0	11.3
8/1/06	CCR-1 photic	67.7	21.4	5.0	0	38.7
9/7/06	CCR-2 photic	58.7	20.8	2.7	*	17.5
9/19/06	CCR-1 photic	37.8	21.8	8.3	0	69.4
10/18/06	CCR-1 photic	50.7	28.3	4.4	0	59.3
11/8/06	CCR-1 photic	59.3	27.4	1.9	11.8	61.8

CCR C&A Water Chemisty Data

Sample Date	Sample Name/ Location	Total Phosphorus µg/L	Total Dissolved Phosphorus µg/L	Ortho-Phosphate µg/L	NO3+NO2-N µg/L	NH4-N µg/L
Analytical Detection Limits		2	2	3	5	3
3/14/06	CCR-2 4m	79	14	8	<2	7
4/12/06	CCR-3 photic	102	18	4	<2	9
5/8/06	CCR-2 7m	66	29	19	8	79
5/24/06	CCR-1 photic	58	26	14	<2	17
6/6/06	CCR-3 photic	49	23	11	3	9
6/20/06	CCR-3 photic	94	36	18	<2	16
7/5/06	CCR-3 photic	144	51	32	<2	11
7/18/06	CCR-2 photic	106	34	14	<2	20
8/1/06	CCR-1 photic	72	20	12	<2	32
9/7/06	CCR-2 photic	70	13	6	<2	14
9/19/06	CCR-1 photic	40	21	10	<2	65
10/18/06	CCR-1 photic	71	18	14	5	53
11/8/06	CCR-1 photic	72	25	8	21	21

CHERRY CREEK
D.O. DATA, 2006
Site CCR-1

Date 03/14/06
Secchi 1.25 m
1% 2.90 m

Depth (m)	Temp oC	Cond.	DO	pH
0	4.59	596	5.38	6.00
1	4.55	596	5.97	6.01
2	4.54	596	5.69	6.01
3	4.49	596	5.27	6.01
4	4.38	594	5.80	6.02
5	4.27	592	5.75	6.04
6	4.29	594	4.81	6.04

Date 04/12/06
Secchi 0.74 m
1% 2.60 m

Depth (m)	Temp oC	Cond.	DO	pH
0	11.01	719	11.95	7.14
1	10.44	701	11.96	6.48
2	10.36	698	11.66	6.44
3	10.33	698	11.31	6.35
4	10.34	698	11.16	6.32
5	10.33	698	11.98	6.28
6	10.24	696	10.81	6.19

Date 05/08/06
Secchi 1.25 m
1% 3.44 m

Depth (m)	Temp oC	Cond.	DO	pH
0	13.45	838	9.03	8.14
1	13.34	836	9.18	8.13
2	13.34	836	9.23	8.13
3	13.26	833	9.25	8.13
4	13.24	833	9.28	8.13
5	13.25	834	9.31	8.13
6	13.22	833	9.33	8.13

Date 05/24/06
Secchi 1.77 m
1% 4.60 m

Depth (m)	Temp oC	Cond.	DO	pH
0	19.13	845	10.53	8.32
1	18.08	823	10.38	8.32
2	17.90	819	10.22	8.33
3	17.85	817	10.22	8.35
4	17.81	817	10.22	8.34
5	17.77	815	10.15	8.34
6	15.58	782	5.05	8.20

Date 06/06/06
Secchi 2.00 m
1% 4.85 m

Depth (m)	Temp oC	Cond.	DO	pH
0	21.18	893	10.25	8.30
1	20.92	882	10.53	8.29
2	20.42	872	10.37	8.26
3	19.94	863	9.01	8.20
4	19.53	855	7.63	8.07
5	19.09	847	5.70	8.02
6	18.13	831	3.83	8.07

Date 06/20/06
Secchi 1.45 m
1% 3.80 m

Depth (m)	Temp oC	Cond.	DO	pH
0	23.05	969	12.11	8.51
1	22.10	947	12.53	8.48
2	21.50	935	11.64	8.44
3	20.96	929	8.82	8.27
4	20.43	921	5.37	8.11
5	20.18	917	3.84	8.07
6	20.09	915	3.47	8.10

Date 07/05/06
Secchi 1.17 m
1% 3.00 m

Depth (m)	Temp oC	Cond.	DO	pH
0	23.10	968	7.85	8.43
1	22.00	950	6.44	8.31
2	21.91	949	6.42	8.28
3	21.86	948	6.26	8.26
4	21.83	948	6.22	8.23
5	21.76	946	5.40	8.10
6	21.50	947	5.14	8.07

Date 07/18/06
Secchi 1.00 m
1% 3.00 m

Depth (m)	Temp oC	Cond.	DO	pH
0	23.14	923	7.71	8.00
1	22.90	918	7.59	8.05
2	22.78	916	6.94	8.04
3	22.74	915	6.70	8.04
4	22.72	914	6.58	8.04
5	22.66	914	6.27	8.03
6	22.55	912	6.11	8.02

CCR-1 DO Data Continued

Date 08/01/06
Secchi 0.90 m
1% 2.62 m

Depth (m)	Temp oC	Cond.	DO	pH
0	24.28	984	8.28	8.16
1	24.10	979	7.68	8.10
2	23.93	977	6.89	8.06
3	23.84	978	6.58	8.01
4	23.65	975	6.03	7.90
5	23.42	971	1.99	7.79
6	22.96	966	0.50	7.80

Date 08/15/06
Secchi 0.80 m
1% 2.60 m

Depth (m)	Temp oC	Cond.	DO	pH
0	23.27	944	9.03	8.55
1	23.08	938	9.52	8.61
2	22.84	931	7.46	8.43
3	22.54	931	7.17	8.36
4	22.51	930	6.82	8.33
5	22.48	930	6.74	8.33
6	22.41	929	6.40	8.32

Date 09/07/06
Secchi 0.97 m
1% 3.00 m

Depth (m)	Temp oC	Cond.	DO	pH
0	19.84	988	8.60	8.34
1	19.74	987	8.43	8.37
2	19.46	989	7.81	8.32
3	19.38	991	7.41	8.26
4	19.30	992	7.23	8.24
5	19.21	993	6.52	8.18
6	19.13	994	5.21	8.06

Date 09/19/06
Secchi 1.80 m
1% 4.46 m

Depth (m)	Temp oC	Cond.	DO	pH
0	17.24	852	8.16	8.26
1	16.59	838	7.91	8.31
2	16.46	836	7.83	8.27
3	16.41	835	7.77	8.26
4	16.34	834	7.70	8.24
5	16.31	834	7.70	8.23
6	16.29	834	7.76	8.23

Date 10/18/06
Secchi 0.90 m
1% 2.75 m

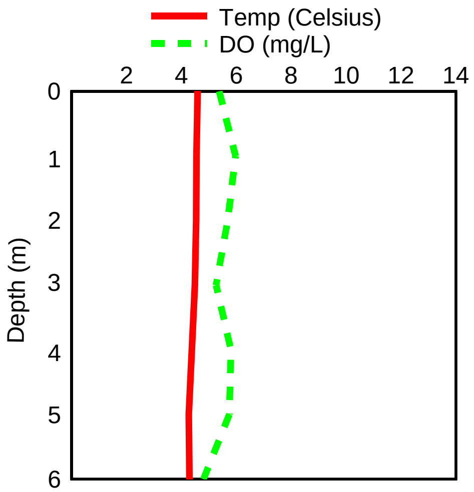
Depth (m)	Temp oC	Cond.	DO	pH
0	11.73	762	14.75	8.24
1	11.71	761	12.10	8.30
2	11.67	761	11.04	8.31
3	11.65	761	10.51	8.31
4	11.32	755	9.80	8.26
5	11.21	753	9.57	8.25
6	11.19	753	9.42	8.25

Date 11/08/06
Secchi 1.35 m
1% 3.60 m

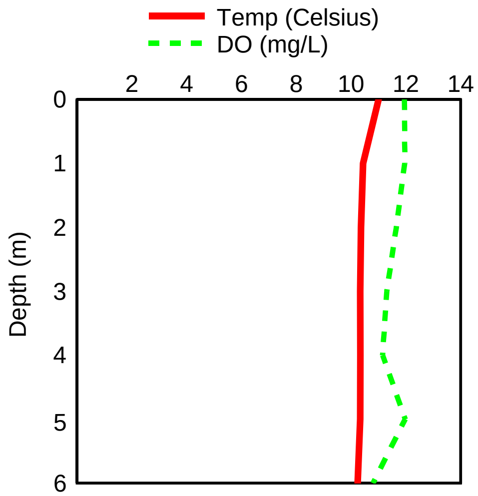
Depth (m)	Temp oC	Cond.	DO	pH
0	8.40	654	10.49	8.52
1	7.82	642	9.72	8.53
2	7.65	640	9.46	8.49
3	7.62	639	8.80	8.47
4	7.56	637	8.70	8.45
5	7.44	635	8.43	8.45
6	7.40	634	8.34	8.45

CCR-1

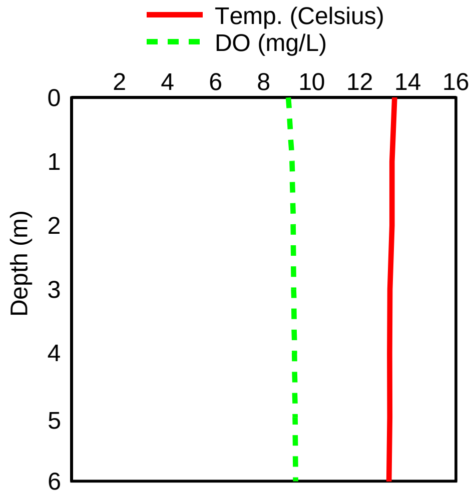
March 14, 2006



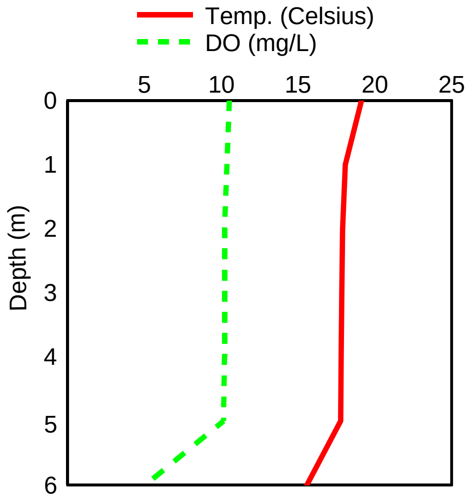
April 12, 2006



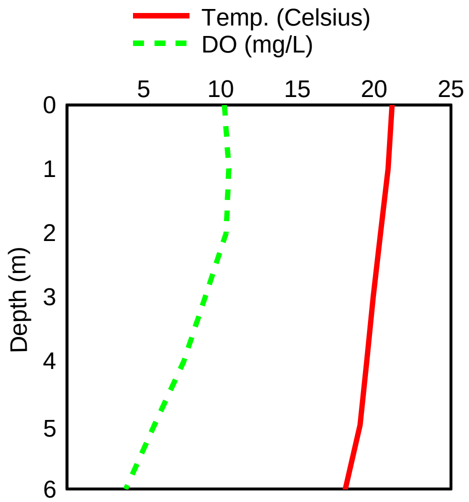
May 8, 2006



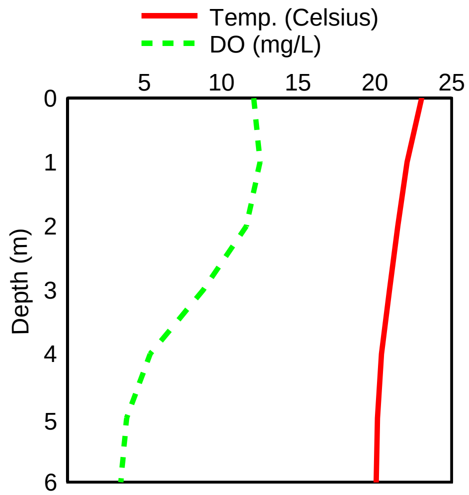
May 24, 2006



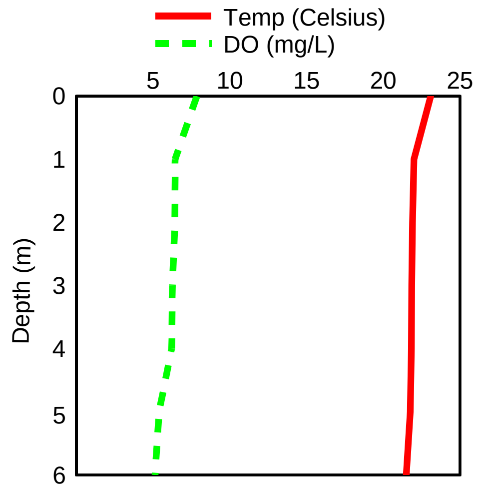
June 6, 2006

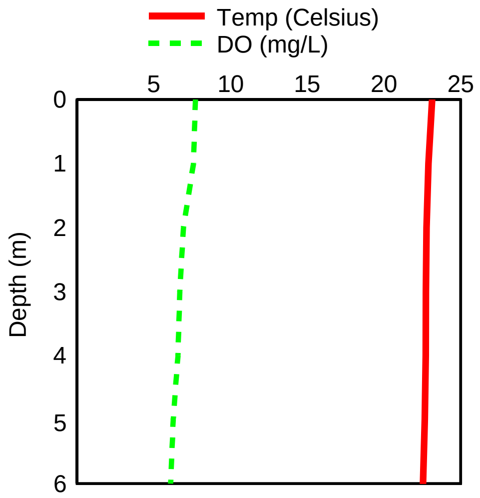


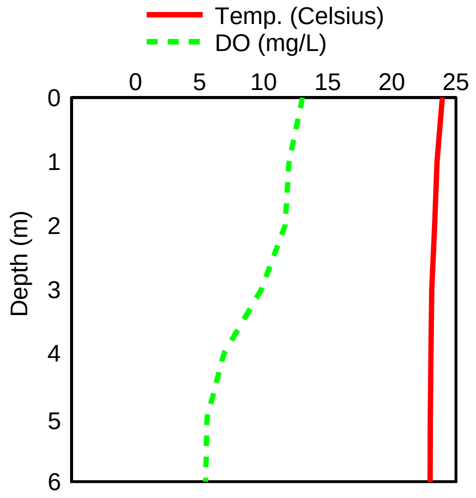
June 20, 2006

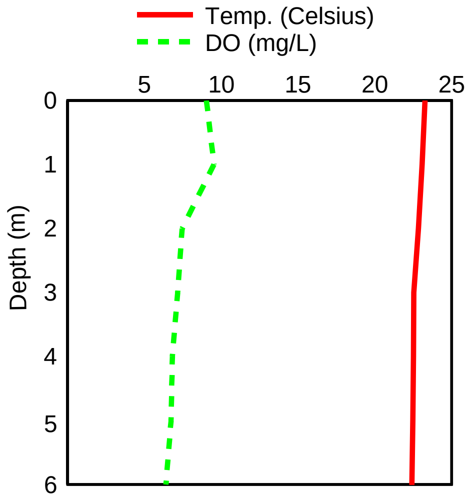


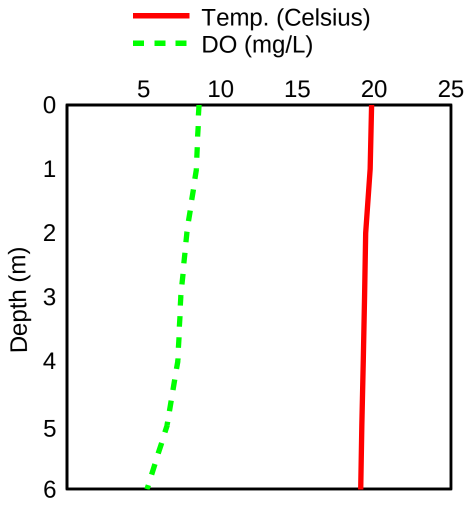
CCR-1

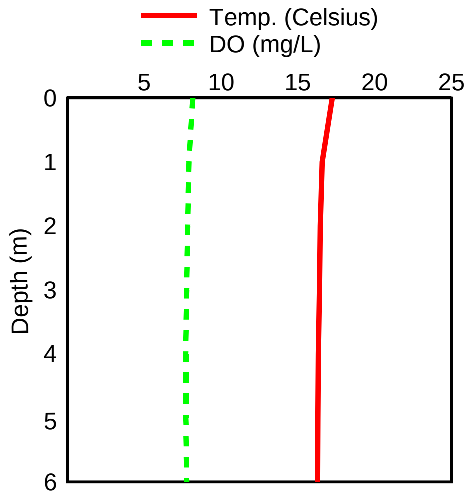

July 5, 2006


July 18, 2006

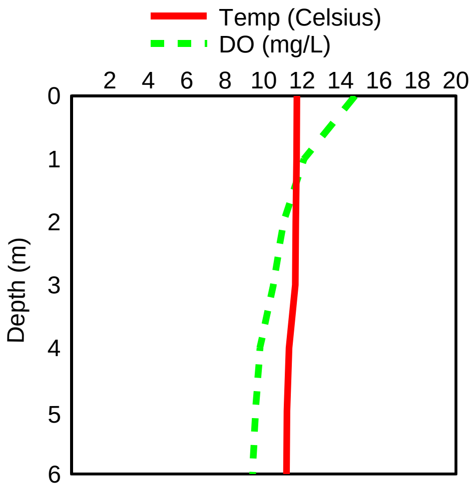

August 1, 2006


August 15, 2006

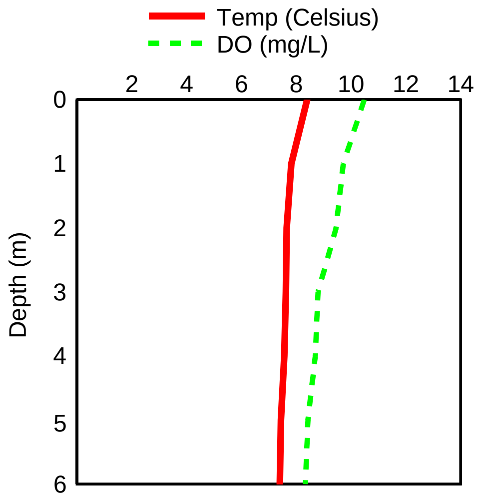

September 7, 2006


September 19, 2006

CCR-1



October 18, 2006



November 8, 2006

CHERRY CREEK
D.O. DATA, 2006
Site CCR-2

Date 03/14/06
Secchi 1.30 m
1% 3.00 m

Depth (m)	Temp oC	Cond.	DO	pH
0	4.94	593	7.10	5.99
1	4.91	592	6.83	5.98
2	4.87	591	6.78	5.95
3	4.84	592	6.94	5.96
4	4.84	592	6.74	5.97
5	4.84	592	6.88	5.97
6	4.82	592	6.00	5.96
7	4.82	592	5.88	5.97

Date 04/12/06
Secchi 0.69 m
1% 2.40 m

Depth (m)	Temp oC	Cond.	DO	pH
0	11.61	727	11.95	6.56
1	10.44	700	11.87	6.56
2	10.29	698	11.96	6.49
3	10.13	695	11.56	6.19
4	10.11	695	11.37	6.12
5	10.10	694	11.29	6.12
6	10.08	692	11.20	6.10
7	10.04	693	11.14	6.09

Date 05/08/06
Secchi 1.28 m
1% 3.53 m

Depth (m)	Temp oC	Cond.	DO	pH
0	13.67	842	9.54	8.16
1	13.64	842	9.57	8.17
2	13.61	841	9.65	8.17
3	13.51	839	9.65	8.17
4	13.27	834	9.47	8.17
5	13.22	832	9.40	8.16
6	13.15	831	9.30	8.15
7	13.11	831	9.23	8.15

Date 05/24/06
Secchi 1.74 m
1% 4.72 m

Depth (m)	Temp oC	Cond.	DO	pH
0	18.77	835	10.68	8.35
1	18.28	824	10.72	8.34
2	18.16	822	10.71	8.34
3	18.11	820	10.70	8.37
4	18.03	819	10.63	8.37
5	17.84	816	10.25	8.36
6	15.74	781	5.11	8.14
7	15.34	776	2.02	8.05

Date 06/06/06
Secchi 1.95 m
1% 4.95 m

Depth (m)	Temp oC	Cond.	DO	pH
0	21.04	883	11.03	8.36
1	20.62	874	11.24	8.35
2	20.48	872	10.85	8.32
3	20.39	870	10.37	8.27
4	20.07	864	9.19	8.19
5	19.68	857	7.69	8.11
6	18.92	842	5.89	8.02
7	17.63	817	1.65	7.93

Date 06/20/06
Secchi 1.53 m
1% 3.74 m

Depth (m)	Temp oC	Cond.	DO	pH
0	22.79	962	12.41	8.62
1	22.65	959	12.35	8.60
2	21.49	936	12.02	8.52
3	21.17	930	10.33	8.42
4	20.90	927	8.29	8.32
5	20.38	920	5.31	8.18
6	20.26	917	4.30	8.13
7	19.88	901	0.62	8.08

Date 07/05/06
Secchi 0.98 m
1% 2.82 m

Depth (m)	Temp oC	Cond.	DO	pH
0	22.72	951	7.99	8.40
1	22.04	950	7.29	8.38
2	21.86	946	6.99	8.37
3	21.80	944	6.87	8.35
4	21.78	942	6.68	8.34
5	21.70	940	6.39	8.33
6	21.65	941	5.58	8.30
7	21.36	940	4.40	8.28

Date 07/18/06
Secchi 1.00 m
1% 2.70 m

Depth (m)	Temp oC	Cond.	DO	pH
0	23.96	942	7.18	8.11
1	23.25	925	7.21	8.09
2	22.96	919	6.56	8.08
3	22.91	918	6.36	8.09
4	22.86	917	6.44	8.10
5	22.83	917	6.66	8.11
6	22.17	901	3.24	7.97
7	21.97	898	1.33	7.87

CCR-2 DO Data Continued

Date 08/01/06
Secchi 0.90 m
1% 2.75 m

Depth (m)	Temp oC	Cond.	DO	pH
0	24.23	980	8.92	8.22
1	23.94	977	8.38	8.20
2	23.84	976	7.79	8.18
3	23.81	975	7.46	8.14
4	23.68	974	6.51	8.04
5	23.53	972	5.12	7.94
6	23.34	969	2.98	7.90
7	22.77	969	0.51	7.94

Date 08/15/06
Secchi 0.75 m
1% 2.50 m

Depth (m)	Temp oC	Cond.	DO	pH
0	23.97	952	10.95	9.05
1	22.71	930	9.56	8.83
2	22.47	927	7.5	8.66
3	22.32	924	6.66	8.59
4	22.17	922	6.16	8.56
5	22.07	920	6.81	8.63
6	21.98	918	5.93	8.53
7	21.91	918	5.79	8.49

Date 09/07/06
Secchi 1.10 m
1% 4.10 m

Depth (m)	Temp oC	Cond.	DO	pH
0	19.50	988	8.98	8.52
1	19.81	988	8.76	8.52
2	19.77	989	8.66	8.51
3	19.59	991	7.86	8.44
4	19.43	993	6.30	8.31
5	19.16	996	4.36	8.13
6	19.01	998	3.58	7.95
7	19.01	997	2.70	7.71

Date 09/19/06
Secchi 1.78 m
1% 4.30 m

Depth (m)	Temp oC	Cond.	DO	pH
0	17.05	850	8.21	8.34
1	16.51	838	8.37	8.37
2	16.46	835	8.21	8.36
3	16.38	835	8.12	8.33
4	16.34	834	8.09	8.32
5	16.29	833	8.07	8.31
6	16.09	830	7.51	8.27
7	16.02	826	7.27	8.21

Date 10/18/06
Secchi 0.80 m
1% 2.50 m

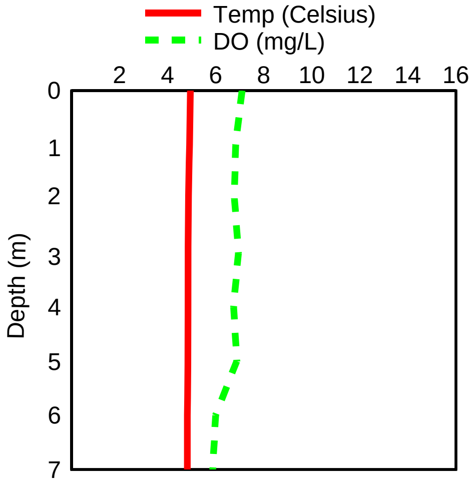
Depth (m)	Temp oC	Cond.	DO	pH
0	12.15	766	12.07	8.43
1	12.14	772	9.47	8.41
2	12.08	772	9.15	8.39
3	12.03	770	8.82	8.38
4	12.00	770	8.69	8.38
5	11.96	769	8.60	8.36
6	11.93	768	8.41	8.35
7	11.76	765	8.26	8.34

Date 11/08/06
Secchi 1.30 m
1% 3.30 m

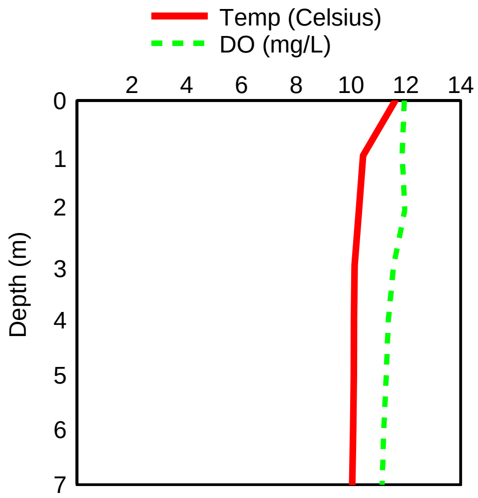
Depth (m)	Temp oC	Cond.	DO	pH
0	9.38	672	10.16	8.60
1	8.52	655	10.22	8.64
2	8.26	651	10.01	8.59
3	8.16	649	9.58	8.55
4	8.14	649	9.32	8.55
5	8.12	648	9.22	8.55
6	8.08	647	9.07	8.54
7	8.05	648	8.81	8.52

CCR-2

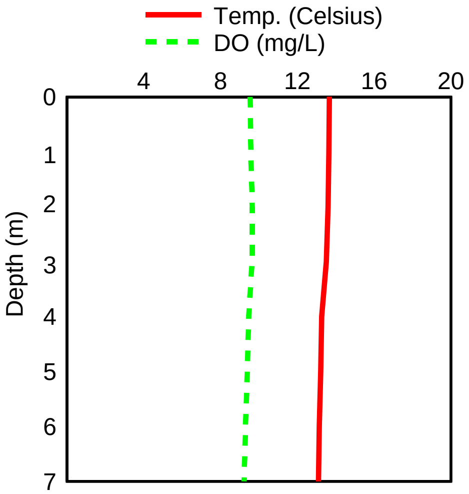
March 14, 2006



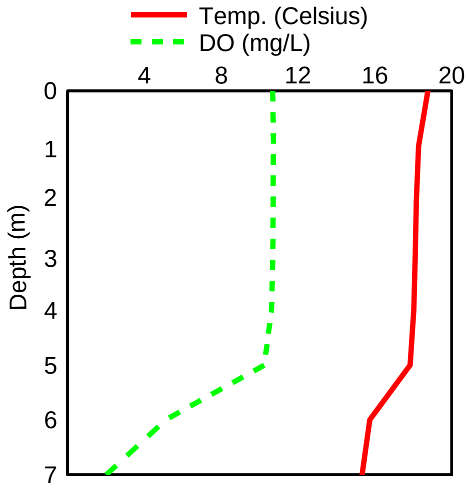
April 12, 2006



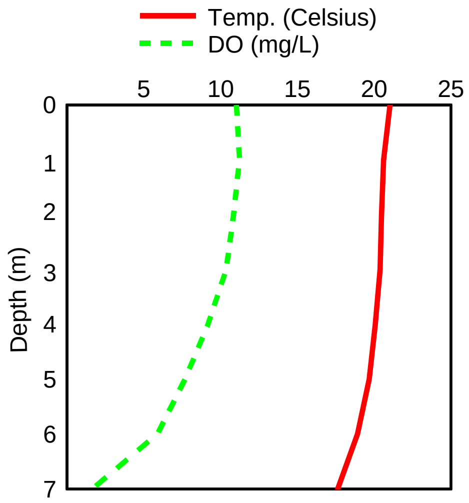
May 8, 2006



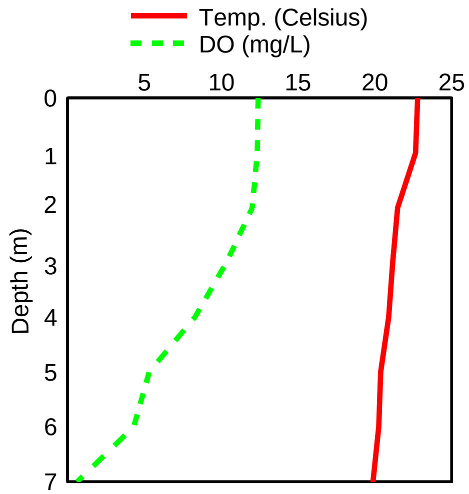
May 24, 2006



June 6, 2006

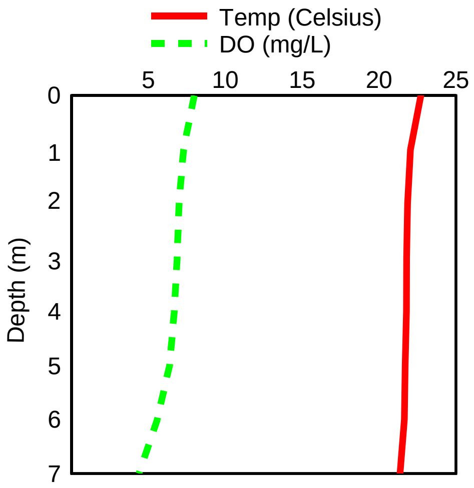


June 20, 2006

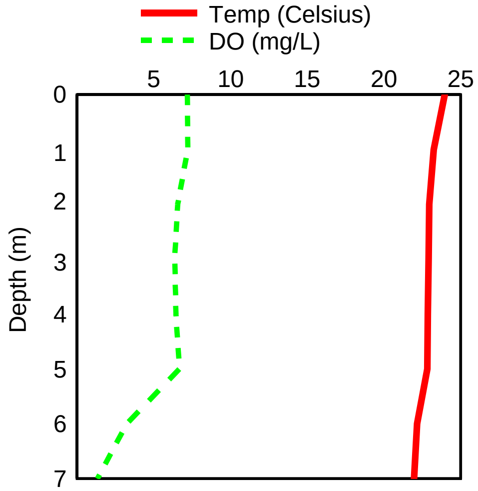


CCR-2

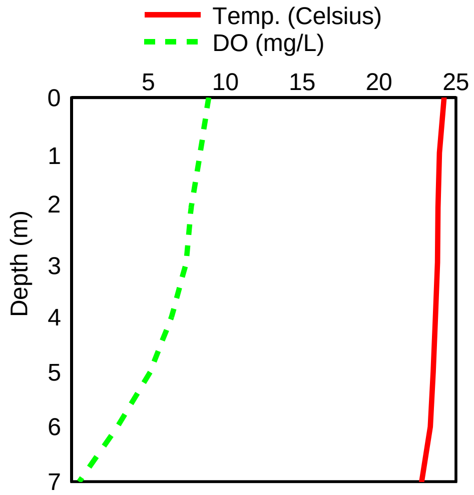
July 5, 2006



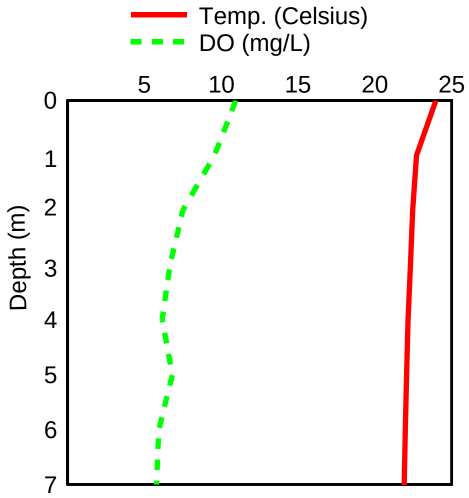
July 18, 2006



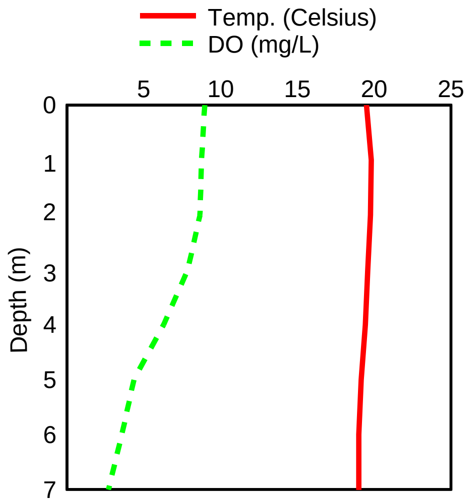
August 1, 2006



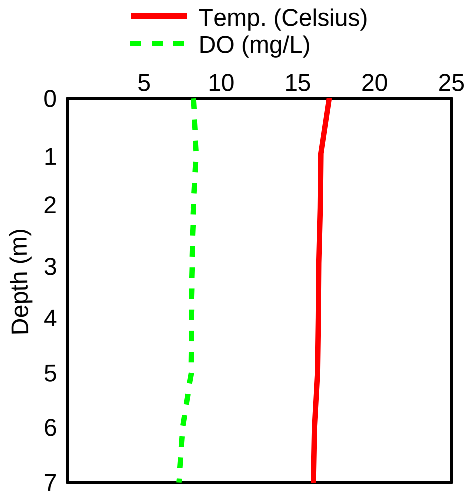
August 15, 2006



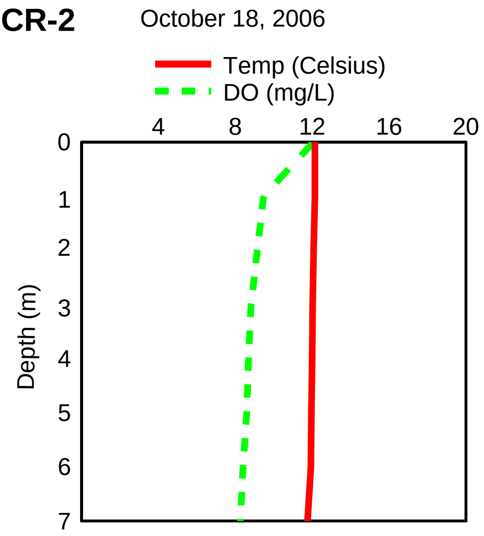
September 7, 2006

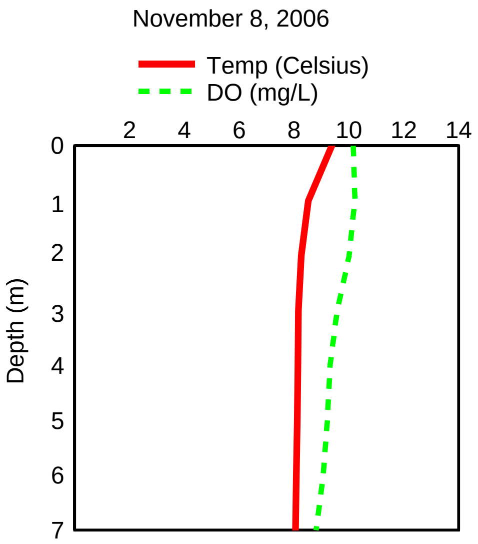


September 19, 2006



CCR-2


October 18, 2006
Temp (Celsius)
DO (mg/L)
4
8
12
16
20
0
1
2
3
4
5
6
7
Depth (m)


November 8, 2006
Temp (Celsius)
DO (mg/L)
2
4
6
8
10
12
14
0
1
2
3
4
5
6
7
Depth (m)

CHERRY CREEK
D.O. DATA, 2006
Site CCR-3

Date	03/14/06			
Secchi	1.12	m		
1%	2.98	m		
Depth (m)	**Temp oC**	**Cond.**	**DO**	**pH**
0	4.58	582	11.45	6.00
1	4.55	582	11.30	5.98
2	4.53	582	11.20	5.91
3	4.51	582	10.87	5.92
4	4.48	582	10.80	5.91
5	4.48	582	10.02	5.88

Date	04/12/06			
Secchi	0.69	m		
1%	2.20	m		
Depth (m)	**Temp oC**	**Cond.**	**DO**	**pH**
0	11.01	713	12.28	6.59
1	10.85	710	12.55	6.65
2	10.24	698	12.09	6.32
3	10.16	697	11.65	6.13
4	9.96	695	10.61	6.04
5	9.78	690	9.37	6.01

Date	05/08/06			
Secchi	1.18	m		
1%	3.25	m		
Depth (m)	**Temp oC**	**Cond.**	**DO**	**pH**
0	13.60	842	9.49	8.19
1	13.59	842	9.49	8.19
2	13.57	842	9.50	8.19
3	13.39	837	9.42	8.19
4	12.88	829	9.16	8.18
5	12.84	828	8.99	8.17

Date	05/24/06			
Secchi	1.95	m		
1%	4.80	m		
Depth (m)	**Temp oC**	**Cond.**	**DO**	**pH**
0	19.15	839	10.68	8.37
1	18.15	823	10.65	8.34
2	17.80	815	10.64	8.36
3	17.60	813	10.58	8.36
4	17.37	808	10.21	8.35
5	17.05	803	9.03	8.31

Date	06/06/06			
Secchi	1.98	m		
1%	4.25	m		
Depth (m)	**Temp oC**	**Cond.**	**DO**	**pH**
0	21.79	892	10.99	8.38
1	21.29	889	11.01	8.37
2	20.83	879	10.96	8.35
3	20.74	878	10.46	8.31
4	20.48	874	8.60	8.19
5	19.44	855	4.22	8.12

Date	06/20/06			
Secchi	1.35	m		
1%	3.40	m		
Depth (m)	**Temp oC**	**Cond.**	**DO**	**pH**
0	22.53	959	11.63	8.60
1	21.97	947	12.01	8.61
2	21.22	932	10.81	8.55
3	20.92	928	9.54	8.51
4	20.80	926	8.71	8.49
5	20.35	920	7.12	8.46

Date	07/05/06			
Secchi	0.82	m		
1%	2.00	m		
Depth (m)	**Temp oC**	**Cond.**	**DO**	**pH**
0	23.13	967	8.56	8.46
1	22.17	941	8.13	8.42
2	21.80	925	7.62	8.38
3	21.64	923	7.19	8.34
4	21.56	915	6.10	8.31
5	21.39	905	5.11	8.26

Date	07/18/06			
Secchi	1.00	m		
1%	2.75	m		
Depth (m)	**Temp oC**	**Cond.**	**DO**	**pH**
0	24.40	948	9.10	8.23
1	23.21	926	8.72	8.26
2	22.88	916	7.29	8.20
3	22.62	912	6.50	8.17
4	22.35	909	6.74	8.17
5	22.01	903	0.64	8.03

CCR-3 DO Data Continued

Date 08/01/06
Secchi 1.00 m
1% 2.80 m

Depth (m)	Temp oC	Cond.	DO	pH
0	24.41	985	9.20	8.32
1	24.10	979	8.90	8.27
2	23.80	974	7.65	8.21
3	23.67	975	6.70	8.18
4	23.43	969	6.74	8.16
5	22.47	957	0.77	8.12

Date 08/15/06
Secchi 0.76 m
1% 3.00 m

Depth (m)	Temp oC	Cond.	DO	pH
0	24.03	952	10.03	8.80
1	22.52	926	8.53	8.69
2	22.33	923	7.13	8.60
3	22.23	924	5.28	8.46
4	21.78	916	5.94	8.49
5	21.54	906	4.26	8.30

Date 09/07/06
Secchi 0.85 m
1% 2.75 m

Depth (m)	Temp oC	Cond.	DO	pH
0	20.50	992	8.94	8.59
1	19.81	990	8.87	8.57
2	19.13	995	4.92	8.21
3	19.01	997	3.99	8.03
4	19.00	997	3.43	7.93
5	18.99	980	0.50	7.52

Date 09/19/06
Secchi 1.30 m
1% 3.85 m

Depth (m)	Temp oC	Cond.	DO	pH
0	17.35	854	8.49	8.34
1	16.41	834	8.73	8.41
2	16.16	830	8.19	8.35
3	16.02	826	7.97	8.30
4	15.96	825	7.71	8.28
5	15.92	825	7.43	8.27

Date 10/18/06
Secchi 0.90 m
1% 2.80 m

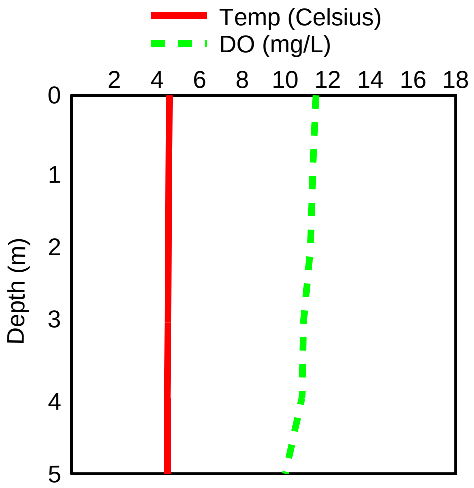
Depth (m)	Temp oC	Cond.	DO	pH
0	11.93	768	11.01	8.41
1	11.94	768	9.07	8.41
2	11.77	764	8.65	8.39
3	11.18	753	8.32	8.37
4	11.08	751	8.14	8.35
5	10.87	749	8.01	8.32

Date 11/08/06
Secchi 1.10 m
1% 2.10 m

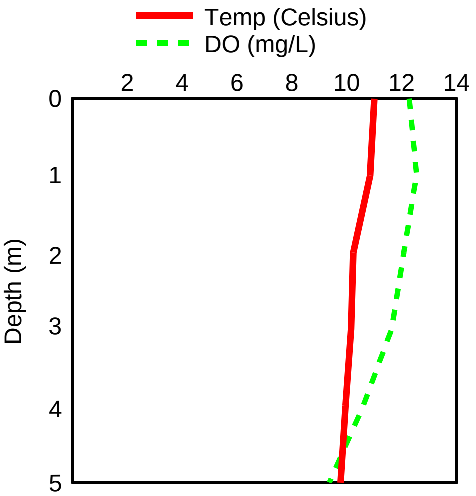
Depth (m)	Temp oC	Cond.	DO	pH
0	9.98	684	10.29	8.61
1	8.49	650	10.90	8.75
2	7.83	643	9.89	8.55
3	7.81	642	9.14	8.53
4	7.76	642	8.76	8.51
5	7.70	641	7.82	8.44

CCR-3

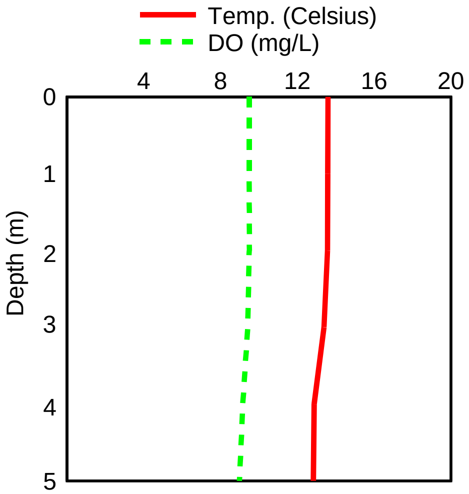
March 14, 2006



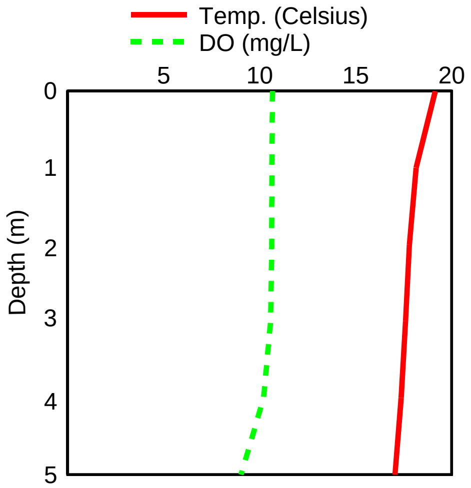
April 12, 2006



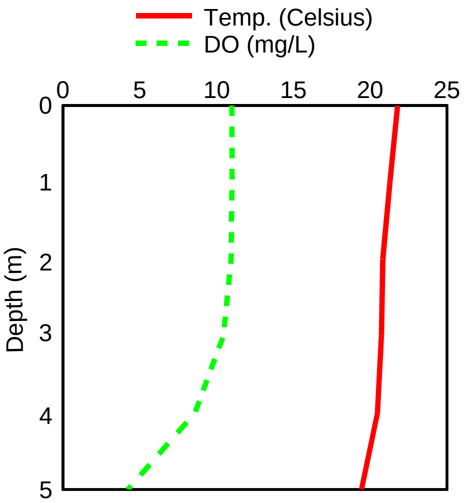
May 8, 2006



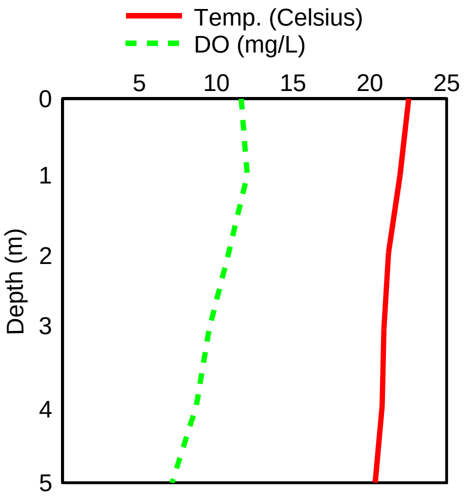
May 24, 2006



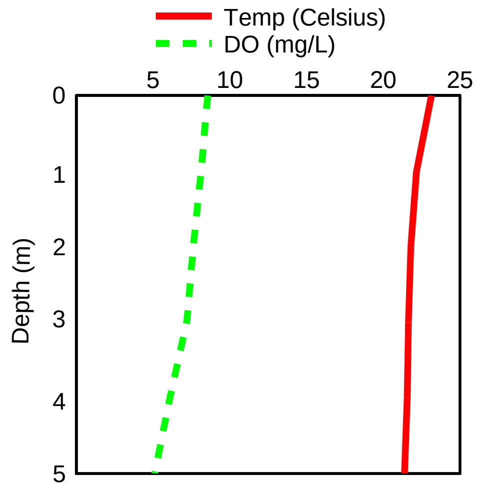
June 6, 2006

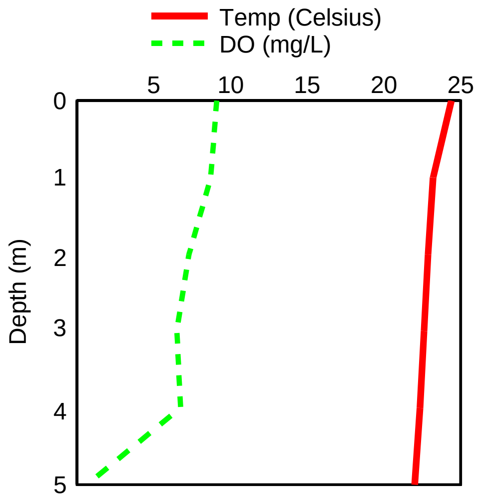


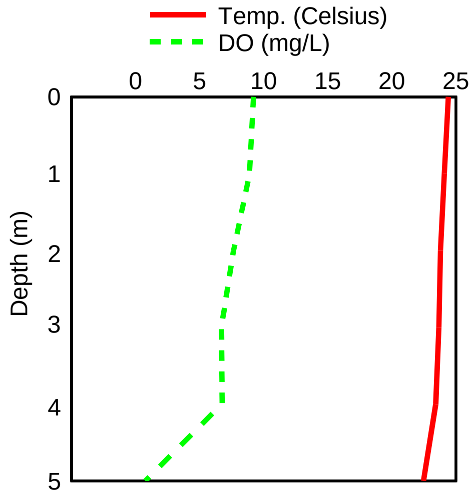
June 20, 2006

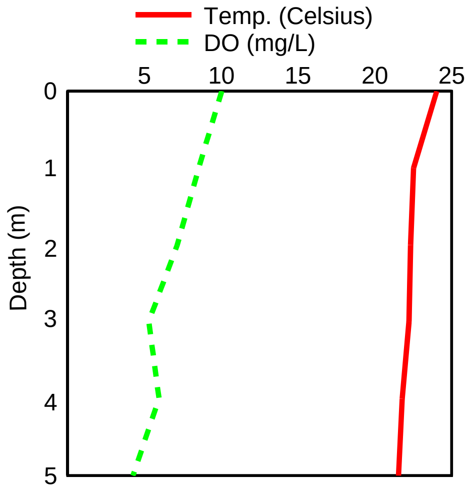


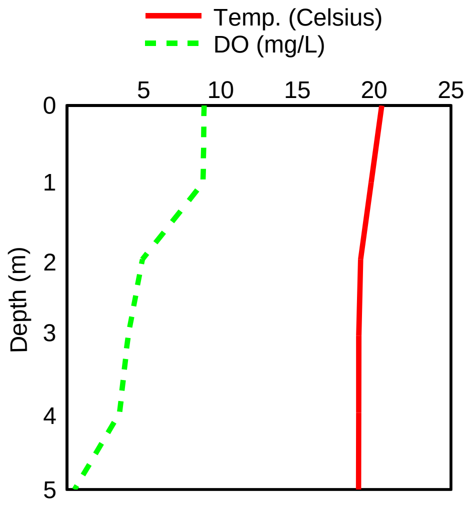
CCR-3

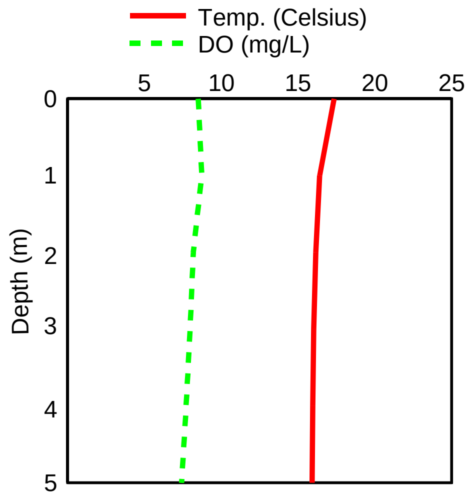

July 5, 2006


July 18, 2006

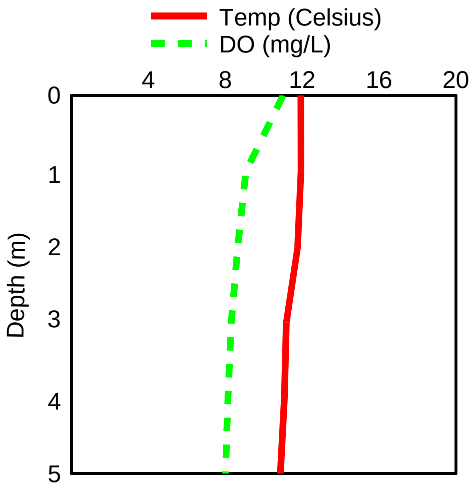

August 1, 2006

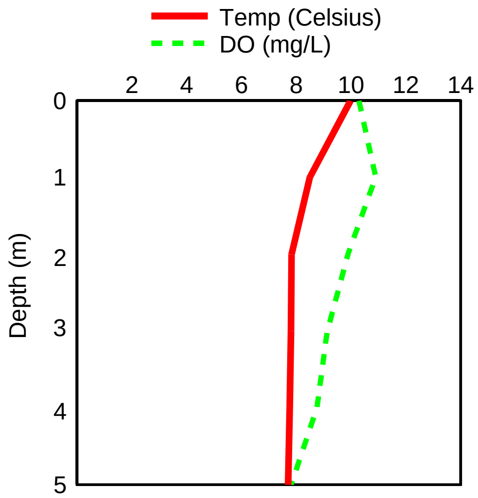

August 15, 2006


September 7, 2006


September 19, 2006

CCR-3


October 18, 2006


November 8, 2006

Cherry Creek Reservoir Secchi and 1% Transmissivity Depths for 2006

CCR-1				CCR-2				CCR-3			
Date	**Secchi (m)**	**1% Trans (m)**	**Ratio**	**Date**	**Secchi (m)**	**1% Trans (m)**	**Ratio**	**Date**	**Secchi (m)**	**1% Trans (m)**	**Ratio**
3/14/06	1.25	2.90	2.32	3/14/06	1.30	3.00	2.31	3/14/06	1.12	2.98	2.66
4/12/06	0.74	2.60	3.51	4/12/06	0.69	2.40	3.48	4/12/06	0.69	2.20	3.19
5/8/06	1.25	3.44	2.75	5/8/06	1.28	3.53	2.76	5/8/06	1.18	3.25	2.75
5/24/06	1.77	4.60	2.60	5/24/06	1.74	4.72	2.71	5/24/06	1.95	4.80	2.46
6/6/06	2.00	4.85	2.43	6/6/06	1.95	4.95	2.54	6/6/06	1.98	4.25	2.15
6/20/06	1.45	3.80	2.62	6/20/06	1.53	3.74	2.44	6/20/06	1.35	3.40	2.52
7/5/06	1.17	3.00	2.56	7/5/06	0.98	2.82	2.88	7/5/06	0.82	2.00	2.44
7/18/06	1.00	3.00	3.00	7/18/06	1.00	2.70	2.70	7/18/06	1.00	2.75	2.75
8/1/06	0.90	2.62	2.91	8/1/06	0.90	2.75	3.06	8/1/06	1.00	2.80	2.80
8/15/06	0.80	2.60	3.25	8/15/06	0.75	2.50	3.33	8/15/06	0.76	3.00	3.95
9/7/06	0.97	3.00	3.09	9/7/06	1.10	4.10	3.73	9/7/06	0.85	2.75	3.24
9/19/06	1.80	4.46	2.48	9/19/06	1.78	4.30	2.42	9/19/06	1.30	3.85	2.96
10/18/06	0.90	2.75	3.06	10/18/06	0.80	2.50	3.13	10/18/06	0.90	2.80	3.11
11/8/06	1.35	3.60	2.67	11/8/06	1.30	3.30	2.54	11/8/06	1.10	2.10	1.91
Average	1.24	3.37	2.80	**Average**	1.22	3.38	2.86	**Average**	1.14	3.07	2.78
Median	1.21	3.00	2.71	**Median**	1.19	3.15	2.74	**Median**	1.05	2.89	2.75

Appendix C

2006 Stream Water Quality and Precipitation Data

CC-10 C&A Water Chemisty Data

Sample Date	Sample Name/ Location	Total Phosphorus µg/L	Total Dissolved Phosphorus µg/L	Ortho-Phosphate µg/L	Total Nitrogen µg/L	Total Dissolved Nitrogen µg/L	Nitrate + Nitrite µg/L	Ammonia µg/L	TSS mg/L	TVSS mg/L
	Analytical Detection Limits	2	2	3	4	4	5	3	4	4
1/24/06	CC-10	155	112*	114*	1654	1505	1151	39	20.0	5.4
2/21/06	CC-10	156	113	116	1626	1487	1175	43	18.3	<4.0
3/14/06	CC-10	143	113*	116*	1003	944	669	22	20.4	5.8
4/12/06	CC-10	163	135	113	956	855	321	44	21.6	4.6
5/8/06	CC-10	217	164	151	666	577	365	65	21.6	5.2
6/6/06	CC-10	225	184	179	862	711	382	29	19.0	6.4
8/1/06	CC-10	155	150*	151*	769	618	292	29	13.7	8.0
9/7/06	CC-10	176	143*	151*	616	541	300	12	7.0	4.0
10/18/06	CC-10	192	148	147	839	777	547	29	17.2	4.0
11/8/06	CC-10	157	131*	134*	857	794	423	24	8.8	<4.0
12/12/06	CC-10	151	120*	127*	1266	1187	923	48	17.6	<4.0
4/28/06	CC-10 storm	274	175	161	1080	844	473	93	41.6	5.6
7/5/06	CC-10 storm	709	399	380	1539	993	322	29	201.0	38.0
7/10/06	CC-10 storm	398	270	256	1271	941	312	11	63.0	11.7
8/2/06	CC-10 storm	944	270*	291*	2734	1280	698	34	645.0	69.0
8/7/06	CC-10 storm	242	160*	177*	842	645	268	24	49.0	11.0
9/21/06	CC-10 storm	555	188	186	1990	1398	787	23	181.2	16.6

* Data within acceptable (10%) difference between parameters.
"ND" denotes "No Data"

CC-O C&A Water Chemisty Data

Sample Date	Sample Name/ Location	Total Phosphorus µg/L	Total Dissolved Phosphorus µg/L	Ortho-Phosphate µg/L	Total Nitrogen µg/L	Total Dissolved Nitrogen µg/L	Nitrate + Nitrite µg/L	Ammonia µg/L	TSS mg/L	TVSS mg/L
	Analytical Detection Limits	2	2	3	4	4	5	3	4	4
1/24/06	CC-O	68	11	7	928	491	27	24	10.2	6.4
2/21/06	CC-O	60	8	3	903	522	62	26	6.2	4.5
3/14/06	CC-O	68	13	8	901	480	11	8	12.2	6.8
4/12/06	CC-O	96	23	4	935	523	<2	8	24.6	7.6
5/8/06	CC-O	93	25	9	655	403	5	14	34.6	6.4
6/6/06	CC-O	197	150	136	962	715	25	201	15.6	5.2
7/5/06	CC-O	190	102	83	1159	830	86	123	30.0	12.0
8/1/06	CC-O	200	57	37	910	747	6	12	19.3	8.7
9/7/06	CC-O	80	18	8	809	511	5	9	18.4	6.0
10/18/06	CC-O	92	34	25	1567	1350	508	234	23.4	7.2
10/19/06	CC-O	101	29	25	1679	1377	376	344	20.4	6.4
11/2/06	CC-O	83	31	7	998	670	44	80	ND	ND
11/8/06	CC-O	62	25	7	1281	825	3	35	10.2	4.8
12/12/06	CC-O	53	15	5	971	554	4	28	16.2	7.8

* Data within acceptable (10%) difference between parameters.
"ND" denotes "No Data"

CT-1 C&A Water Chemisty Data

Sample Date	Sample Name/ Location	Total Phosphorus μg/L	Total Dissolved Phosphorus μg/L	Ortho-Phosphate μg/L	Total Nitrogen μg/L	Total Dissolved Nitrogen μg/L	Nitrate + Nitrite μg/L	Ammonia μg/L	TSS mg/L	TVSS mg/L
	Analytical Detection Limits	2	2	3	4	4	5	3	4	4
1/24/06	CT-1	101	8	7	4221	3720	3050	99	38.2	6.4
2/21/06	CT-1	83	24	20	4014	3721	2901	197	35.0	4.2
3/14/06	CT-1	77	23	19	2789	2600	1894	159	32.8	7.6
4/12/06	CT-1	72	17	3	5058	4713	2059	1999	29.2	<4.0
5/8/06	CT-1	60	19	10	2397	2190	1402	301	22.8	4.4
6/6/06	CT-1	28	13	5	1523	1407	846	25	13.2	5.4
8/1/06	CT-1	37	16	13	3074	2888	2315	124	8.0	4.0
9/7/06	CT-1	73	14	8	3026	2671	2136	8	29.4	5.6
10/18/06	CT-1	111	28	28	1663	1511	935	142	55.8	8.4
11/8/06	CT-1	61	19	13	2522	2395	1706	59	18.0	<4.0
12/12/06	CT-1	76	35	17	4572	4252	2246	1571	40.4	4.8
4/28/06	CT-1 storm	225	17	7	2833	2274	938	1660	171.3	16.3
7/5/06	CT-1 storm	417	123	102	1738	966	458	9	198.5	46.5
7/10/06	CT-1 storm	242	109	94	1227	904	383	35	72.7	12.3
8/2/06	CT-1 storm	571	164	148	2042	1148	1408	89	384.0	64.0
8/7/06	CT-1 storm	248	62	56	1248	751	395	5	152.5	25.5
9/21/06	CT-1 storm	403	127	120	3053	2645	1835	37	161.7	16.7

* Data within acceptable (10%) difference between parameters.
"ND" denotes "No Data"

CT-2 C&A Water Chemisty Data

Sample Date	Sample Name/ Location	Total Phosphorus µg/L	Total Dissolved Phosphorus µg/L	Ortho-Phosphate µg/L	Total Nitrogen µg/L	Total Dissolved Nitrogen µg/L	Nitrate + Nitrite µg/L	Ammonia µg/L	TSS mg/L	TVSS mg/L
	Analytical Detection Limits	2	2	3	4	4	5	3	4	4
1/24/06	CT-2	67	9	8	4134	3807	3097	85	22.0	6.8
2/21/06	CT-2	61	18	15	4114	3730	3076	188	20.8	<4.0
3/14/06	CT-2	71	8	7	2634	2368	1756	140	40.0	8.0
4/12/06	CT-2	74	14	3	4384	4083	1803	1526	30.6	5.2
5/8/06	CT-2	63	12	3	1765*	1878*	1354	298	30.6	6.6
6/6/06	CT-2	51	8	2	1597	1296	527	148	27.4	5.4
8/1/06	CT-2	60	14	12	2700	2418	1571	380	39.3	12.0
9/7/06	CT-2	82	10	7	2373	2061	1459	76	37.8	7.0
10/18/06	CT-2	87	24*	26*	1618	1452	862	139	38.8	8.0
11/8/06	CT-2	45	11	6	1991	1753	1327	68	41.0	7.4
12/12/06	CT-2	64	15	11	3810	3557	1940	1104	58.4	7.2
4/28/06	CT-2 storm	64	8	4	4295	3914	1744	3090	34.7	8.7
7/5/06	CT-2 storm	320	114	96	1770	1072	480	70	92.0	25.5
7/10/06	CT-2 storm	197	109	93	1225	918	364	61	41.3	12.3
8/2/06	CT-2 storm	913	86*	93*	2866	1365	697	113	782.0	90.0
8/7/06	CT-2 storm	347	55	54	1669	893	430	6	201.5	31.5
9/21/06	CT-2 storm	179	30	11	2186	1693	942	62	74.3	13.3

* Data within acceptable (10%) difference between parameters.
"ND" denotes "No Data"

CT-P1 C&A Water Chemisty Data

Sample Date	Sample Name/ Location	Total Phosphorus µg/L	Total Dissolved Phosphorus µg/L	Ortho-Phosphate µg/L	Total Nitrogen µg/L	Total Dissolved Nitrogen µg/L	Nitrate + Nitrite µg/L	Ammonia µg/L	TSS mg/L	TVSS mg/L
	Analytical Detection Limits	2	2	3	4	4	5	3	4	4
1/24/06	CT-P1	77	7	7	1744	1237	774	6	25.0	8.6
2/21/06	CT-P1	15	5	5	1685	1567	1078	45	5.0	<4.0
3/14/06	CT-P1	36	9	6	990	832	388	23	14.0	6.2
4/12/06	CT-P1	52	18	3	826	638	112	22	7.6	<4.0
5/8/06	CT-P1	64	17	4	635	610	133	100	11.6	6.4
6/6/06	CT-P1	82	28	17	1124	915	285	57	33.0	7.8
8/1/06	CT-P1	104	33	31	3084	756	247	21	20.7	8.7
9/7/06	CT-P1	87	18	11	1020	778	301	27	ND	ND
10/18/06	CT-P1	89	31*	32*	1572	1299	580	149	14.6	5.2
11/8/06	CT-P1	37	12	7	1132	971	570	47	9.2	<4.0
12/12/06	CT-P1	37	33	10	1365	1155	829	33	9.0	<4.0
4/28/06	CT-P1 storm	161	17	6	1240	582	80	33	66.5	18.0
7/5/06	CT-P1 storm	378	150	131	1885	1027	459	77	105.5	30.0
7/10/06	CT-P1 storm	269	156	142	1514	1157	457	122	41.1	12.3
8/2/06	CT-P1 storm	411	146*	158*	1881	1114	644	94	162.0	44.0
8/7/06	CT-P1 storm	185	62	54	1386	830	360	5	55.5	15.5
9/21/06	CT-P1 storm	155	25	15	1955	1437	552	252	27.0	9.2

* Data within acceptable (10%) difference between parameters.
"ND" denotes "No Data"

CT-P2 C&A Water Chemisty Data

Sample Date	Sample Name/ Location	Total Phosphorus µg/L	Total Dissolved Phosphorus µg/L	Ortho-Phosphate µg/L	Total Nitrogen µg/L	Total Dissolved Nitrogen µg/L	Nitrate + Nitrite µg/L	Ammonia µg/L	TSS mg/L	TVSS mg/L
	Analytical Detection Limits	2	2	3	4	4	5	3	4	4
1/24/06	CT-P2	42	6*	7*	1826	1547	1085	7	17.0	4.6
2/21/06	CT-P2	20	4*	5*	1938	1805	1355	35	8.3	<4.0
3/14/06	CT-P2	53	8	6	1233	1055	640	13	18.2	4.2
4/12/06	CT-P2	61	14	3	974	776	357	13	29.0	6.2
5/8/06	CT-P2	64	17	7	852	820	527	72	28.2	6.6
6/6/06	CT-P2	34	12	2	969	809	235	26	13.4	4.0
8/1/06	CT-P2	80	26	25	1343	757	531	25	37.7	12.3
9/7/06	CT-P2	ND	ND	ND	ND	ND	ND	ND	24.2	5.6
10/18/06	CT-P2	84	32*	35*	1233	1074	548	154	19.2	6.2
11/8/06	CT-P2	51	13	9	1378	1200	839	25	19.0	4.6
12/12/06	CT-P2	22	7	5	1604	1418	1167	21	20.2	4.8
4/28/06	CT-P2 storm	227	51	38	1529	1046	343	268	75.5	14.5
7/5/06	CT-P2 storm	300	131	107	1618	986	429	63	82.5	25.5
7/10/06	CT-P2 storm	209	136	121	1323	1048	442	74	21.1	7.7
8/2/06	CT-P2 storm	535	119*	128*	2194	1244	794	69	332.0	60.0
8/7/06	CT-P2 storm	179	64*	68*	1215	776	371	6	39.0	8.5
9/21/06	CT-P2 storm	162	51	42	2026	1608	652	288	22.0	7.0

* Data within acceptable (10%) difference between parameters.
"ND" denotes "No Data"

SC-3 C&A Water Chemisty Data

Sample Date	Sample Name/ Location	Total Phosphorus µg/L	Total Dissolved Phosphorus µg/L	Ortho-Phosphate µg/L	Total Nitrogen µg/L	Total Dissolved Nitrogen µg/L	Nitrate + Nitrite µg/L	Ammonia µg/L	TSS mg/L	TVSS mg/L
	Analytical Detection Limits	2	2	3	4	4	5	3	4	4
1/24/06	SC-3	40	33	30	2752	2591	2295	14	<4.0	<4.0
3/14/06	SC-3	30	20	17	1711	1645	1368	13	7.2	<4.0
4/12/06	SC-3	101	73	61	551	497	183	23	8.0	<4.0
5/8/06	SC-3	146	75	59	360	344	41	22	98.4	7.6
9/7/06	SC-3	113	92	87	391	334	<2	6	5.4	<4.0
10/18/06	SC-3	93	54	30	1698	1484	1185	22	7.0	4.0
11/8/06	SC-3	34	28	26	594	559	324	12	12.6	<4.0
4/28/06	SC-3 storm	295	72	63	1016	579	176	59	344.5	21.0
7/5/06	SC-3 storm	192	180	156	980	907	568	55	10.8	<4.0
7/10/06	SC-3 storm	174	171	154	805	765	397	11	8.0	<4.0
8/2/06	SC-3 storm	144	102	99	1269	1075	606	29	104.0	26.0
8/7/06	SC-3 storm	147	137*	144*	552	529	68	14	4.0	<4.0
9/21/06	SC-3 storm	128	83	77	2309	2079	1473	13	9.8	<4.0

* Data within acceptable (10%) difference between parameters.
"ND" denotes "No Data"

Rain Gauge C&A Water Chemisty Data

	Analytical Detection Limits	2	2	3	4	4	5	3
Sample Date	Sample Name/ Location	Total Phosphorus µg/L	Total Dissolved Phosphorus µg/L	Ortho-Phosphate µg/L	Total Nitrogen µg/L	Total Dissolved Nitrogen µg/L	Nitrate + Nitrite µg/L	Ammonia µg/L
4/28/06	Rain Gauge	62	47	38	1781	1708	475	1763
8/2/06	Rain Gauge	42	32	28	1313	1142	356	1066
8/7/06	Rain Gauge	22	8	8	876	796	411	272
9/12/06	Rain Gauge	42	9	<2	2597	2104	1085	807
9/21/06	Rain Gauge	105	71	58	3860	3265	1248	1686

* Data within acceptable (10%) difference between parameters.
"ND" denotes "No Data"

Appendix D

2006 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 (ft^3/sec) with a Marsh McBirney Model 2000 flowmeter, and recording the water level at the staff gage and ISCO flowmeter (Table D-1).

Stage-discharge data collected in 2006 were combined with data collected during previous years to adjust rating curves previously developed 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 2006 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 and SC-3 a two-stage rating curve was developed to more accurately estimate low flows at these sites. A rating curve was also developed for Site CT-P2, but was only used for quality control purposes 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), designers of the outlet structures.

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 flow meter malfunction, dead battery, icing, or flooding. To estimate mean daily water levels for periods of missing data, stage relationships were evaluated among nearby sites, with the best-fit linear regression model being used to estimate the missing level data (Table D-3). At Site CT-2, transducer and module problems resulted in a long period of poor quality data (1 January to 11 April). During this time, the transducer probe was replaced twice before ISCO representatives could determine the exact problem with the flow meter module. In April, Teledyne Systems replaced the flow meter and transducer probe and the system worked well, except for an extreme ice buildup period in December 2006. In 2006, Site CC-10 revealed no strong relations with any of the GEI monitored stream sites. Therefore, a model was developed with the USGS Cherry Creek Gage near Parker (#393109104464500), using only data from January 2006 to March 2006, to estimate levels for CC-10 in February 2006. Site SC-3 also showed no strong relationships with any stream site; therefore, the best-fit model was used to estimate periods of missing data. Additionally, precipitation events and average flow of recorded data were considered when estimating the missing data.

Table D-1: Stage-discharge data used to develop rating curves for sites CC-10, SC-3, CT-P1, CT-P2, and CT-1 in 2006.

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
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
CT-P1	2002	27-Jun-02	0.45	0.430	0.80
CT-P1	2002	11-Jul-02	0.60	0.580	2.43
CT-P1	2002	04-Sep-02	0.36	0.359	0.43
CT-P1	2003	04-Feb-03	0.50	0.502	1.35
CT-P1	2003	18-Jun-03	1.10	1.072	12.04
CT-P1	2003	30-Jul-03	0.72	0.726	3.18
CT-P1	2003	20-Nov-03	0.53	0.530	0.70
CT-P1	2004	09-Jan-04	0.49	0.483	0.42
CT-P1	2004	24-Feb-04	0.54	0.552	0.87
CT-P1	2004	27-May-04	0.51	0.508	0.71
CT-P1	2004	22-Jun-04	0.89	0.890	5.08
CT-P1	2004	23-Jun-04	0.69	0.677	1.99
CT-P1	2004	24-Aug-04	0.59	0.595	1.44
CT-P1	2005	01-Apr-05	0.66	0.655	1.88
CT-P1	2005	14-Apr-05	1.16	1.188	13.36
CT-P1	2005	25-Apr-05	1.39	1.369	15.62
CT-P1	2005	19-May-05	0.56	0.549	1.06
CT-P1	2005	26-May-05	0.55	0.575	0.77
CT-P1	2005	01-Jun-05	0.73	0.739	2.74
CT-P1	2005	16-Aug-05	0.96	1.120	7.40
CT-P1	2005	13-Oct-05	0.94	0.934	7.73
CT-P1	2006	20-Apr-06	0.55	0.540	0.64
CT-P1	2006	13-Jun-06	0.51	0.515	0.47
CT-P1	2006	12-Jul-06	0.66	0.631	1.57

Site	Year	Date	Staff Gage Level (ft)	Transducer Level (ft)	Discharge (cfs)
CT-P1	2006	08-Aug-06	0.83	0.844	4.97
CT-P1	2006	27-Dec-06	0.76	--	2.16
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
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-1	2005	01-Apr-05	1.86	1.947	5.51
CT-1	2005	14-Apr-05	2.80	2.780	17.92
CT-1	2005	25-Apr-05	3.08	3.046	20.94
CT-1	2005	19-May-05	1.81	1.757	2.50
CT-1	2005	26-May-05	1.70	1.750	2.08
CT-1	2005	01-Jun-05	2.07	1.960	5.81
CT-1	2005	16-Aug-05	2.52	2.530	19.45
CT-1	2005	13-Oct-05	2.51	2.467	13.00
CT-1	2006	20-Apr-06	1.79	1.777	2.06
CT-1	2006	13-Jun-06	1.80	1.823	2.07
CT-1	2006	12-Jul-06	2.06	1.900	6.53
CT-1	2006	08-Aug-06	2.40	2.435	8.65
CT-1	2006	27-Dec-06	2.50	2.522	6.37

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

Site	Stage Interval	Discharge Equations	R^2
CC-10	< 2.60	Q = EXP((H+0.5613)/0.9233)	0.80
	> 2.60	Q = EXP((H+6.2908)/2.1862)-23.0292	0.90
SC-3	< 0.15	Q = EXP((H-0.4814)/0.1372)	0.73
	> 0.15	Q = EXP((H+0.7553)/0.9430)-2.4998	0.90
CT-P1		Q = EXP((H+0.3633)/0.5472)-4.2520	0.95
CT-P2	< 0.60	Q = (3.3)*(1)*(H)^(1.5)	
	0.61 - 1.09	Q = (0.60)*(0.50)*((2*32.2*(H_{adj}))^(0.5)	
	1.10 - 1.99	Q = (0.60)*(0.50)*((2*32.2*(H_{adj}))^(0.5))+((3.33)*(1)*(H-1.0)^(1.5)	
	2.00 - 2.59	Q = (0.60)*(0.50)(2*32.2*(H_{adj}))^(0.5)+((0.60)*(0.50)*((2*32.2*(H_{adj}-1.0))^(0.5))+((3.33) *(1)*(H-2.0)^(1.5)	
	2.60 - 2.99	Q = (0.60)*(0.50)(2*32.2*(H_{adj}))^(0.5)+((0.60)*(0.50)*((2*32.2*(H_{adj}-1.0))^(0.5))+((0.60) *(0.50)*(H_{adj}-2.0)^(0.5)	
	3.00 - 3.59	Q = (0.60)*(0.50)(2*32.2*(H_{adj}))^(0.5)+((0.60)*(0.50)*((2*32.2*(H_{adj}-1.0))^(0.5))+((0.60) *(0.50)*(H_{adj}-2.0)^(0.5))+((3.3)*(1)*(H-3.0)^(1.5)	
	3.60 - 3.99	Q = (0.60)*(0.50)(2*32.2*(H_{adj}))^(0.5)+((0.60)*(0.50)*((2*32.2*(H_{adj}-1.0))^(0.5))+((0.60) *(0.50)*(H_{adj}-2.0)^(0.5))+((0.60)*(0.50)*(2*32.2*(H_{adj}-3.0)^(0.5)	
	4.00 - 4.49	Q = (0.60)*(0.50)(2*32.2*(H_{adj}))^(0.5)+((0.60)*(0.50)*((2*32.2*(H_{adj}-1.0))^(0.5))+((0.60) *(0.50)*(H_{adj}-2.0)^(0.5))+((0.60)*(0.50)*(2*32.2*(H_{adj}-3.0)^(0.5))+((3.3)(1)(H-4.0))^(1.5)	
	4.50 - 5.19	Q = (0.60)*(0.50)(2*32.2*(H_{adj}))^(0.5)+((0.60)*(0.50)*((2*32.2*(H_{adj}-1.0))^(0.5))+((0.60) *(0.50)*(H_{adj}-2.0)^(0.5))+((0.60)*(0.50)*(2*32.2*(H_{adj}-3.0)^(0.5))+((0.60)(0.50)(2*32.2*H_{adj}-4.0))^(0.5)	
	5.20 - 6.80	Q = (0.60)*(0.50)(2*32.2*(H_{adj}))^(0.5)+((0.60)*(0.50)*((2*32.2*(H_{adj}-1.0))^(0.5))+((0.60) *(0.50)*(H_{adj}-2.0)^(0.5))+((0.60)*(0.50)*(2*32.2*(H_{adj}-3.0)^(0.5))+((0.60)(0.50)(2*32.2*H_{adj}-4.0))^(0.5))+((3.3)(1)(H-5.2)^(1.5)	
CT-1		Q = EXP((H-0.560)/0.8593)-5.1769	0.86
CT-2	< 0.95	Q = ((3.3)*(2)*(H)^(1.5))	
	0.95 - 1.35	Q = ((7.2)+(3.3)*(2)*(H)^(1.5))	
	> 1.35	Q = ((7.2)+(3.3)*(2)*(H)^(1.5))+((3.3)*(2)*(H-1.0)^(1.5))+((3.3)*(2)*(H-0.50)^(1.5))	

H_{adj} = Mean daily level - 0.25 ft

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

Site	Equations	R^2	Percent of Annual Data Estimated
CC-10	CC-10 Level = 0.8167(Parker Level)-0.9578	0.60	8%
SC-3	SC-3 Level = (0.2583*CT-P2 Level) + 0.0096	0.13	10%
CT-P1	CT-P1 Level = (CT-P2 Level + 1.4438)/3.3981	0.83	4%
CT-P2	CT-P2 level = 3.3981(CT-P1 Level) - 1.4438	0.83	3%
CT-1	CT-1 Level = 1.5469*(CT-P1 Level)+1.0287	0.86	12%
CT-2	CT-2 Level = 0.2955*(CT-P2 Level)+0.4845	0.79	35%*

* ISCO flow meter and transducer probe problems led to an extensive period of missing data from January to April.

Phosphorus Loading

During the past year, there has been extensive dialogue with the CDPHE/WQCD regarding the partitioning of loads to the Reservoir, which has led to methodological changes in the load calculations. 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 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 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.

In recent years, GEI treated the difference between the USACE inflow (minus precipitation) and GEI inflow as a residual inflow term that was identified as the alluvial component, which included both ground water inflow (alluvial flow) and seepage from the wetlands that occurs during storm events. GEI's treatment of the adjusted inflow may have been "loosely" applied to the alluvial component, if for no other reason than using, what we believed, was the most appropriate phosphorus concentration when applying a load value to the unmonitored flow through the wetland. However, given the concerns raised by the WQCD regarding the partitioning of this load and the desire to use a consistent database for modeling and future regulatory (watershed modeling) decisions, the ground water source or "true alluvial inflow" was removed from the residual inflow term and set as a constant source of water (2000 ac-ft/yr, per WQCD) to the Reservoir. The remainder of the residual term - seepage and unmonitored inflow component - was redefined as "Redistributed Inflow" and apportioned among the two primary surface inflow streams (Cherry Creek and Cottonwood Creek). The alluvial inflow constant (2000 ac-ft/yr) still utilized phosphorus concentrations from the MW-9 to estimate associated loads, while the redistributed inflow utilizes a flow-weighted phosphorus concentration derived from loads and inflow from Sites CC-10 and CT-2, precipitation, and the alluvium.

In an effort to maintain a seasonality component in phosphorus loads and exports for the Reservoir, the redistributed inflow component was calculated on a monthly basis and apportioned accordingly. 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.

Once the redistributed inflow and loads are apportioned to sites CC-10 and CT-2, according to their relative stream flow contribution, the final loads are identified as "Normalized" to the

USACE reported inflow. Notably, other sites upstream of CT-2 or on Shop Creek are not normalized. Furthermore, only raw loading 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. For the Cherry Creek mainstem site (CC-10), the annual record was divided into two parts (Jan-Apr, and May-Dec), because there was a noticeable shift in base flow conditions (potentially due to alluvial pumping upstream), with 90th percentiles being calculated for both subsets.

Table D-4: Threshold flow value used to categorize base flows and storm flows in 2006.

Site	90th Percentile (cfs)
CC-10 (Jan-Apr)	12.56
CC-10 (May-Dec)	8.27
SC-3	0.72
CT-1	7.84
CT-2	4.54
CTP-1	3.87
CTP-2	3.46

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

EQUATION 1:

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

where:

L_{day} = pounds per day phosphorus loading,

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

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

Table D-5: Monthly base flow TP concentrations (µg/L) and median annual storm flow TP concentration (µg/L) applied to respective flows in 2006.

Month	CC-O	CC-10	SC-3	CT-P1	CT-P2	CT-1	CT-2
January	68	155	40	77	42	101	67
February	60	156	35	15	20	83	61
March	68	143	30	36	53	77	71
April	96	163	101	52	61	72	74
May	93	217	146	64	64	60	63
June	197	225	138	82	34	28	51
July	190	190	130	93	57	33	56
August	200	155	121	104	80	37	60
September	80	176	113	87	82	73	82
October	92	192	93	89	84	111	87
November	73	157	34	37	51	61	45
December	53	151	49	37	22	76	64
Annual storm flow median	--	477	161	227	218	326	259

Note: Shaded cells represent interpolated data. The July base flow samples were categorized as storm flow samples (see methods for discussion)

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. To estimate the load associated with Reservoir outflows, only the monthly base flow TP concentration, collected from Site CC-O, was applied to respective flows (Equation 1).

Precipitation

Precipitation data collected at Centennial Airport (KAPA), located immediately south of the Reservoir and in the Cherry Creek basin, was used to estimate phosphorus loading due to precipitation in 2006 (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:

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

where:

L_{precip} = pounds of phosphorus from precipitation,

PR = rainfall precipitation in inches,

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

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

Alluvium

The alluvial water component remains one of the unmonitored sources of inflow to the Reservoir; however there is currently agreement among the Authority’s consultants and WQCD that the annual flow is relatively constant given the boundaries of the 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 2006 alluvial component was defined as a constant source of water to the Reservoir that accounts for 2000 ac-ft/yr, with no seasonal fluctuations. The long-term (1994-2005) median total dissolved phosphorus concentration for MW-9 (190 µg/L) was used to estimate the alluvial load component (Equation 3).

EQUATION 3:

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

where:

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

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

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

Redistributed Inflows

In 2006, 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 can either be a positive or negative value depending on the monthly balance.

EQUATION 4:

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

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

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

Additionally, when the redistributed inflow is greater than 1000 ac-ft/mo, the first 1000 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	1,265	1,220	741	19	66	66	179	187	31	170	850	215
February	1,004	1,027	628	72	55	43	168	172	26	153	647	177
March	1,349	1,365	679	16	89	82	232	210	42	170	868	269
April	1,117	837	538	6	96	83	196	193	70	164	650	233
May	668	1,037	291	9	91	68	242	193	40	170	276	183
June	337	722	258	3	42	29	144	164	13	164	98	62
July	1,872	1,333	745	22	496	388	884	666	315	170	733	655
August	1,186	1,029	314	20	295	264	663	513	273	170	282	462
September	498	220	175	22	112	90	263	211	61	164	124	149
October	1,200	486	324	21	251	174	444	382	144	170	406	480
November	1,010	1,071	392	3	110	71	262	212	18	164	537	290
December	1,293	944	402	16	127	90	433	230	156	170	615	352
Annual Total	**12,799**	**11,292**	**5,487**	**230**	**1,830**	**1,449**	**4,110**	**3,333**	**1,189**	**2,000**	**6,086**	**3,525**

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	--	226	445	4	14	8	49	34	10	88	501	48
February	--	168	266	29	2	2	38	29	8	79	274	31
March	--	252	357	2	9	19	49	50	13	88	445	77
April	--	219	284	2	29	29	38	48	22	85	335	67
May	--	262	172	4	16	12	39	33	13	88	165	29
June	--	387	222	1	9	3	11	23	4	85	99	0
July	--	689	876	9	287	205	656	395	99	88	867	387
August	--	560	224	7	157	129	427	276	86	88	207	248
September	--	48	84	7	33	28	67	57	19	85	63	32
October	--	122	265	6	116	80	263	192	46	88	313	248
November	--	211	182	0	11	10	43	26	6	85	237	56
December	--	136	180	5	17	5	231	57	49	88	263	104
Annual Total	**--**	**3,278**	**3,557**	**76**	**699**	**530**	**1,911**	**1,219**	**376**	**1,034**	**3,767**	**1,325**

Shaded cells denotes negative load value for Site CT-2, which was set to zero and the remaining -34 lbs being subtracted from Site CC-10

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)	Flow-weighted concentration applied to Redistributed Inflow (lbs/ac-ft)	Redistri-buted Load (lbs/mo)	CC-10 % of GEI Inflow	CT-2 % of GEI Inflow	CC-10 Redistri-buted Flow (ac-ft/mo)	CT-2 Redistri-buted Flow (ac-ft/mo)	CC-10 Redistri-buted Load (lbs/mo)	CT-2 Redistri-buted Load (lbs/mo)
January	1,064	928	137	0.511	70	80%	20%	109	28	56	14
February	824	800	24	0.391	9	79%	21%	19	5	7	2
March	1,137	889	248	0.461	115	76%	24%	190	59	88	27
April	883	731	151	0.455	69	74%	26%	111	40	51	18
May	458	484	-26	0.440	-11	60%	40%	-16	-10	-7	-5
June	160	422	-262	0.557	-146	61%	39%	-161	-102	-89	-57
July	1,388	1,411	-23	0.770	-18	53%	47%	-12	-11	-9	-8
August	744	826	-83	0.531	-44	38%	62%	-31	-51	-17	-27
September	272	386	-114	0.401	-46	45%	55%	-52	-62	-21	-25
October	886	707	179	0.579	104	46%	54%	82	97	48	56
November	827	604	223	0.379	85	65%	35%	145	78	55	30
December	967	632	335	0.390	130	64%	36%	213	122	83	47
Annual Total	**9,611**	**8,821**	**790**	**--**	**317**	**--**	**--**	**598**	**192**	**244**	**73**

Appendix E

Biological Data

Table E-1: 2006 Cherry Creek Reservoir Phytoplankton

Organisms	3/14/2006	4/12/2006	5/8/2006	5/24/2006	6/6/2006	6/20/2006	7/5/2006	7/18/2006	8/1/2006	9/7/2006	9/19/2006	10/18/2006	11/8/2006
BACILLARIOPHYTA													
Order Centrales													
Aulacoseira italica												125	
Aulacoseira italica var. *tenuissima*	40			8	42	690	270			8	300	1445	370
Cyclotella meneghiniana							10						
Cyclotella ocellata	160							520					
Cyclotella sp.	80	7440								8	40		200
Skeletonema sp.		240											
Stephanodiscus agassizensis		20							5				
Stephanodiscus hantzschii						120	2160						40
Stephanodiscus niagarae						10	10		10			2	8
Stephanodiscus parvus								880	5840			400	120
Order Pennales													
Asterionella formosa	70	205	2163		80	220	170						
Cymbella sp.											20		
Fragilaria crotonensis			40	1250	160	3530	560		30				
Nitzschia draveillensis							120					2	
Nitzschia gracilis	70	1120					40						3
Nitzschia nana										1			
Nitzschia tubicola												20	
Puncticulata bodanica													40
Synedra delicatissima var. *angustissima*	70	335											
Synedra rumpens var. *familiaris*	10	40						5				5	5
Synedra rumpens var. *fragilarioides*							30						1
CHLOROPHYTA													
Ankyra judayi				80	400	10							
Chlamydomonas globosa	240				880	40		80	1280			1440	
Chlamydomonas reinhardtii								120		40			
Chlorella minutissima	40000	50000	31500	40000	70000	7500	1750	2500	78500	16000	500	20000	15000
Chlorella sp.	20							280					
Chlorogonium sp.								10	160	320			
Chlorogonium tetragamum									320				
Chloromonas sp.								30					
Choricystis sp.	31000	500000	625	6000	5000	21000	137500	180250	1000	500	2815	2500	
Closterium acutum var. *variabile*					1		20						1
Cosmarium bioculatum var. *depressum*						2							
Coelastrum microporum			30	100	26							480	
Coelastrum sphaericum							960			320		30	
Coenochloris fottii				400									
Crucigenia quadrata						160			320				
Crucigenia tetrapedia			160	4080						960	960	960	
Crucigeniella apiculata											310		
Dictyosphaerium ehrenbergianum				720									
Dictyosphaerium pulchellum		320				540				1280			
Diplochloris lunata		1920								8240	320	1760	240
Elakatothrix viridis	20	20	5									4	
Kirchneriella dianae		560											
Diplochloris lunata									320				
Kirchneriella lunaris									1120				
Kirchneriella obesa			40			40					20		
Lagerheimia genevensis										80			
Micractinium pusillum							160		480				
Monoraphidium contortum								40		80	60		
Monoraphidium irregulare	6400	720					40	40	320				
Monoraphidium minutum		800	40				160	120					
Monoraphidium sp.													280
Nephrocytium agardhianum					20					320	80		

Organisms	3/14/2006	4/12/2006	5/8/2006	5/24/2006	6/6/2006	6/20/2006	7/5/2006	7/18/2006	8/1/2006	9/7/2006	9/19/2006	10/18/2006	11/8/2006
CHLOROPHYTA (cont.)													
Oocystis borgei				720	10		2560	160					
Oocystis lacustris			83	1480	6	20							
Oocystis solitaria										20	60		
Pandorina smithii					46	1710							
Pediastrum boryanum			20	25	14								80
Pediastrum duplex var. *duplex*				270	74	400		20			38		
Pediastrum simplex						40		40					
Pediastrum tetras		120								60	20	20	
Phacotus lenticularis											15	160	
Pseudodictyosphaerium sp.	1600	3000	4125				320			11500	1250	960	
Quadricoccus sp.	2000												
Raphidocelis contorta		320	40										
Raphidocelis microscopica							240	240	2500	2400	180	80	
Scenedesmus acuminatus								10	640	20			
Scenedesmus armatus	40									320	140	480	
Scenedesmus bicaudatus			10		40								
Scenedesmus communis	40	1600	100	20		40	40	20	480	800			
Scenedesmus ecornis			40										
Scenedesmus ellipticus				60	910	22		40				80	
Scenedesmus intermedius			120					240	640	320	440	320	160
Scenedesmus obliquus										40	120		30
Scenedesmus subspicatus		320	160			60	160	80				640	
Schroederia setigera						5		5				2	
Spermatozopsis exsultans	160	80						120					
Staurastrum chaetoceras		10	1	2				5					
Staurastrum sp.				1									
Tetraedron caudatum			5					10	20	20			
Tetraedron minimum	10	80	25	240			40	160	160	40		80	40
Tetraspora lemmermannii						800							
Tetrastrum elegans		640											80
Tetrastrum staurogeniaeforme		320	160				320			40		320	160
CYANOPHYTA													
Anabaena flos-aquae			26		18	540							
Anabaena sp.							340						
Anabaenopsis elenkinii								130	1400	445			
Aphanizomenon flos-aquae					16	440							
Aphanocapsa delicatissima										7500			
Aphanocapsa incerta										99500			
Aphanocapsa planctonica		14000					22500	9000	4960				
Aphanothece clathrata									250000	50000			
Aphanothece smithii	40000		3500		8750	45000						2000	9500
Cyanobium sp.									2000				
Dactylococcopsis acicularis	800	600							40				
Dactylococcopsis sp.	1600	4520					80	840	1200	2720	20		40
Geitlerinema lemmermannii		110											
Merismopedia tenuissima	16000	6000					8500	8000		3000			
Myxobaktron sp.										18560			
Planktolyngbya limnetica								320	10732	80			
Pseudanabaena limnetica					14		580	375	1760	6240	200		
Pseudanabaena sp.		400											
Synechococcus sp.								160	640				
CHRYSOPHYTA													
Chromulina sp.													125
Dinobryon divergens							380					10	
Kephyrion sp.				2									
Mallomonas sp.			5										
Ochromonas sp.						20							

Organisms	3/14/2006	4/12/2006	5/8/2006	5/24/2006	6/6/2006	6/20/2006	7/5/2006	7/18/2006	8/1/2006	9/7/2006	9/19/2006	10/18/2006	11/8/2006
EUGLENOPHYTA													
Euglena acus							5	10		20		1	
Euglena oxyuris									10				
Euglena polymorpha								10	10	113			
Euglena sp. 1						2	20	10	480	160	1		
Euglena viridis							10					1	
Phacus pleuronectes								10		1			
Trachelomonas hispida var. *coronata*								5					
Trachelomonas hispida var. *crenulatocelis*								5					
Trachelomonas varians								5	320				
Trachelomonas volvocina	20								160	160			
CRYPTOPHYTA													
Campylomonas marsonii		5	3	20	85	1							480
Campylomonas reflexa	10	55	175	250	105	1	20		60		200		1840
Chroomonas coerulea	880		5	10				360	240	1520	20	160	120
Chroomonas nordstedtii			10						160				
Chroomonas sp.	40												
Cryptomonas erosa	40	20	83		30				430	240	60	960	120
Cryptomonas ovata			8				30				140	480	280
Cryptomonas rostratiformis	10		10		15	1		10	10		35	240	120
Hemiselmis virescens							4						
Komma caudata	4080	4880	40	60	20					2800	480	4000	3000
Plagioselmis sp.	240	80	1200	500	1700	640	3600	1240	800	40	20		480
cyst												400	
HAPTOPHYTA													
Chrysochromulina parva	960	800						320					
DINOPHYTA													
Bernardinium sp.										30		5	
Ceratium hirundinella					3	15	5	10	70				
Peridiniopsis edax								15					
Peridiniopsis kulczynskii	110	35				2							20
Peridiniopsis polonicum							10						
PRASINOPHYTA													
Nephroselmis olivacea							10	240	480				
Pedinomonas sp.	80												
Scourfieldia complanata		160					20						
Tetraselmis cordiformis	10	15					30	800	20	800	25	80	
XANTHPHYTA													
Goniochloris mutica		5											
TOTAL DENSITY (cells/mL)	146,910	601,915	44,557	56,298	88,465	83,621	183,784	207,900	370,127	237,666	8,889	40,652	32,983
NUMBER OF TAXA	35	41	34	24	28	33	41	49	43	46	31	38	31

Table E-2: Reservoir mean phytoplankton density (cells/mL) and number of taxa in Cherry Creek Reservoir, 1984 to 2006.

Metric	1984	1985	1986	1987	1988	1989	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	Long term median
Blue-Green Algae																							
Density	71,780	66,496	99,316	168,259	155,180	273,175	307,691	77,516	15,708	10,015	18,194	16,599	19,716	44,951	15,263	164,290	148,691	941	54,114	165,677	79,154	665,696	54,114
Taxa Richness	7	7	6	18	24	24	14	16	7	3	7	9	10	11	8	19	12	3	21	27	19	19	12
Green Algae																							
Density	5,864	11,760	25,595	11,985	19,177	55,415	18,688	41,899	1,198	314	355	738	2,461	1,809	898	43,881	33,217	1,973	55,190	56,236	189,777	1,358,248	18,688
Taxa Richness	11	10	13	58	76	66	46	48	16	2	11	11	18	18	18	71	56	27	70	75	66	63	46
Diatoms																							
Density	1,776	3,863	5,428	10,677	12,880	9,311	4,160	1,243	946	194	2,189	2,354	1,109	628	838	12,019	5,256	978	2,026	1,720	3,610	32,036	2,026
Taxa Richness	6	4	7	34	30	31	21	11	15	2	15	13	8	18	16	34	22	24	22	26	24	21	21
Golden-Brown Algae																							
Density	--	7	125	469	56	505	821	93	158	3	63	249	227	56	--	391	1,346	34	44	57	335	542	193
Taxa Richness	--	1	1	6	4	7	5	4	1	1	2	4	2	2	--	14	13	3	5	5	4	5	4
Euglenoids																							
Density	514	135	208	251	276	108	89	23	231	196	304	409	838	698	1,252	126	91	22	308	24	39	1,549	196
Taxa Richness	2	1	1	9	9	6	3	5	2	1	2	3	3	3	1	6	4	3	9	11	8	10	3
Dinoflagellates																							
Density	--	13	19	19	83	28	23	54	--	31	5	21	--	18	45	80	157	193	20	57	60	330	45
Taxa Richness	--	1	1	2	4	3	2	2	--	1	2	4	--	2	2	8	6	5	3	5	6	5	3
Cryptomonads																							
Density	1,513	718	1,113	1,090	2,689	1,689	628	529	332	450	919	1,104	1,487	1,393	559	2,472	2,851	355	3,282	3,158	3,293	40,511	1,393
Taxa Richness	2	3	3	6	4	5	2	3	1	1	1	1	1	1	1	4	6	4	8	8	9	12	3
Miscellaneous																							
Density	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1,923	5,714	15	1,294	164	2,014	4,855	1,923
Taxa Richness	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	1	1	3	6	6	6	3
Total Density	81,447	82,992	131,804	192,750	190,341	340,231	332,100	121,357	18,573	11,203	22,029	21,474	25,838	49,553	18,855	225,182	197,323	4,511	116,278	227,093	278,282	2,103,767	116,278
Total Taxa	28	27	32	133	151	142	93	89	42	11	40	45	42	55	46	157	120	70	141	163	142	141	89

Table E-3: Quantity and size of fish stocked in Cherry Creek Reservoir, 1985 to 2006.

Year	Species	Size (inches)	Number
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
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

Year	Species	Size (inches)	Number
	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	–	46
	Rainbow trout	4.5-20.3	180,166
	Rainbow/Cutthroat trout hybrid	–	5,600
	Tiger musky	8	4,086
	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

Year	Species	Size (inches)	Number
	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 × 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

Appendix F

Quality Assurance/Quality Control

Independent Laboratory QC Results

Duplicate water quality samples analyzed by the University of Colorado, Center for Limnology were generally within acceptable limits (i.e., overall less than 25 percent relative difference for an analyte). While most paired analyses were generally in close agreement, the relationship between both laboratories for the total phosphorus raised concern. The slope of the relationship was 1.65, with the University of Colorado results generally less than GEI results. One possible explanation for this difference is the total phosphorus methods used by each laboratory. GEI uses an automated LACHAT method (QC 10-115-01-1-U) to analyze total phosphorus, whereas the University of Colorado calculates the total phosphorus content as the sum of total particulate phosphorus and total dissolved phosphorus, based upon manual colorimetric methods (Lagler and Hendrix, 1982, Murphey and Riley, 1962, and Valderrama 1981). While both methods use similar digestion techniques, the automated method is not necessarily more accurate than the manual method. However, the automated method is subject to less variability because it eliminates the errors associated with analyzing large batches of samples by hand. Furthermore, additional error may also be introduced by the manual methods, given the summation of two individual analyses. In an effort to evaluate the potential bias within GEI analyses, GEI re-evaluated each batch QC standard, spikes, and blanks with all samples passing the 20 percent relative difference requirement. GEI also purchased total phosphorus standards from Wibby Environmental (DMRQA Nutrient #2, TKN-TP standard, Lot# 8502-11) to compare in-house results with the known concentration. All results were within 10 percent of the known standard. Therefore, GEI elected to use their total phosphorus results rather than computing the mean value of the duplicate samples when estimating total phosphorus loads.

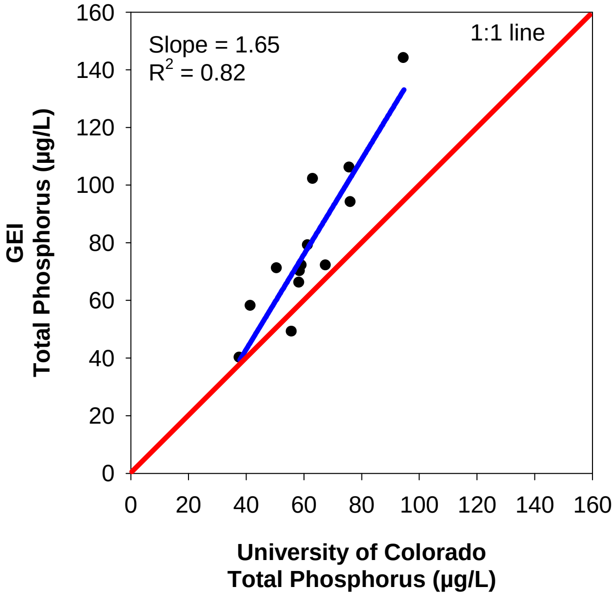


Figure F-1: Relationship between GEI total phosphorus and University of Colorado total phosphorus for 2006.

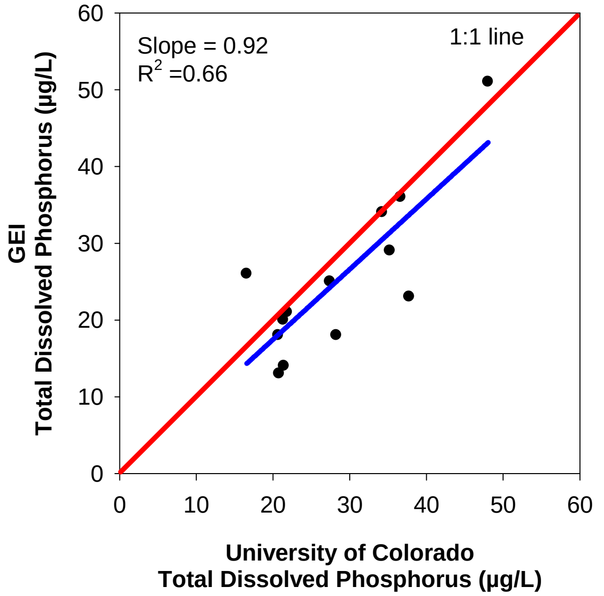


Figure F-2: Relationship between GEI total dissolved phosphorus and University of Colorado total dissolved phosphorus for 2006.

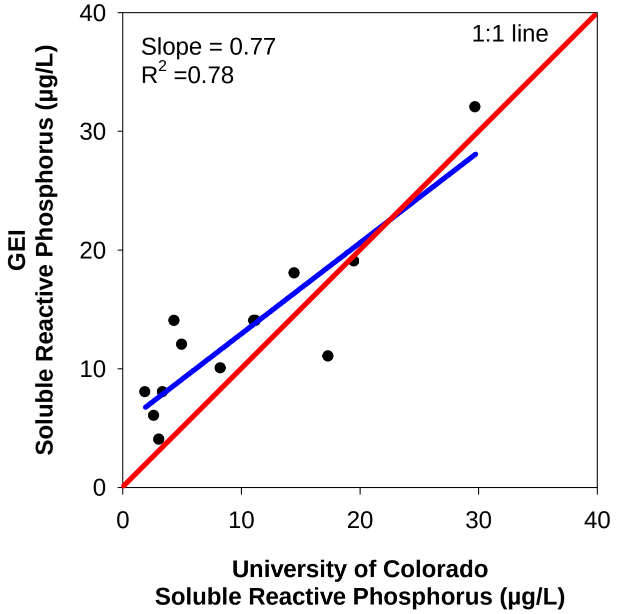


Figure F-3: Relationship between GEI soluble reactive phosphorus and University of Colorado soluble reactive phosphorus for 2006.

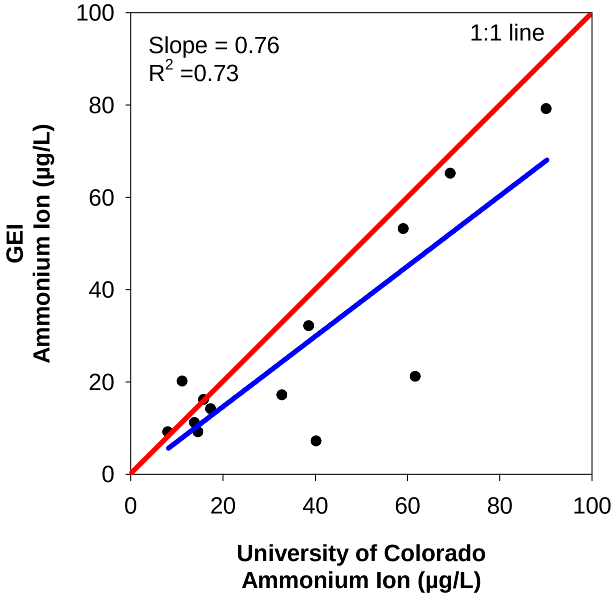


Figure F-4: Relationship between GEI ammonium ion and University of Colorado ammonium ion for 2006.

Reference:

Lagler, C. L., and P. F. Hendrix. 1982. Evaluation of persulfate digestion method for particulate nitrogen and phosphorus. Water Res. 16: 145 l-l 454.

Murphy, J. and J. Riley. 1962. A modified single solution for the determination of phosphate in natural waters. Anal. Chim. Acta v.27 p.31-36.

VALDERRAMA, J. C. 198 1. Simultaneous analysis of total nitrogen and total phosphorus in natural waters. Mar. Chem. 10: 109-122.