

Cherry Creek Reservoir 2015 Water Year Aquatic Biological Nutrient Monitoring and Pollutant Reduction Facilities Monitoring

February 2016





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Submitted to:
Cherry Creek Basin Water Quality Authority
Clifton Larson Allen LLP
8390 East Crescent Parkway, Suite 500
Greenwood Village, CO 80111-2814

Submitted by:
GEI Consultants, Inc.
4601 DTC Boulevard, Suite 900
Denver, CO 80237

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Craig Wolf, Project Manager

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Table of Contents

Executive Summary	i
Temperature and Dissolved Oxygen.....	i
Total Phosphorous and Nitrogen in Cherry Creek Reservoir.....	ii
Chlorophyll a.....	ii
Chloride and Sulfate	ii
Phytoplankton.....	iii
Zooplankton.....	iii
Total Phosphorous and Nitrogen in Streams.....	iii
Mass Balance/Net Loading of Phosphorous and Nitrogen to the Reservoir	iv
Pollutant Reduction Facility Effectiveness.....	iv
Special Study: Cyanotoxin Monitoring.....	v
Special Study: Organic Carbon Monitoring	vi
 1. Historical Perspective	 1-1
 2. Study Area.....	 2-4
2.1 Sampling Sites.....	2-4
2.1.1 Cherry Creek Reservoir	2-4
2.1.2 Cherry Creek	2-6
2.1.3 Cottonwood Creek.....	2-7
2.1.4 McMurdo Gulch	2-8
 3. Methods.....	 3-9
3.1 Sampling Methodologies	3-9
3.1.1 Reservoir Sampling	3-9
3.1.2 Stream Sampling	3-11
3.1.3 Precipitation.....	3-11
3.1.4 Alluvial	3-12
3.1.5 Surface Hydrology	3-12
3.2 Laboratory Procedures	3-12
3.2.1 Nutrient Laboratory Analysis.....	3-12
3.2.2 Biological Laboratory Analysis	3-13
3.3 Evaluation of Long-Term Trends in Cherry Creek Reservoir.....	3-13
 4. Results and Discussion	 4-14
4.1 Reservoir Water Quality.....	4-14
4.1.1 2015 WY Transparency.....	4-14
4.1.2 Long-Term Secchi Transparency Trends in Cherry Creek Reservoir	4-14
4.1.3 2015 WY Temperature and Dissolved Oxygen	4-15
4.1.4 2015 WY Nutrients	4-27
4.1.5 Long-Term Phosphorus Trends in Cherry Creek Reservoir	4-29
4.1.6 Long-Term Nitrogen Trends in Cherry Creek Reservoir.....	4-30
4.1.7 2015 WY Chlorophyll a Levels.....	4-31

4.1.8	Long-term Chlorophyll a Trends in Cherry Creek Reservoir.....	4-32
4.1.9	2015 WY Sulfate.....	4-33
4.1.10	2015 WY Chloride	4-33
4.2	Reservoir Biology	4-34
4.2.1	2015 CY Phytoplankton	4-34
4.2.2	Long-Term Phytoplankton	4-40
4.2.3	2015 CY Zooplankton	4-41
4.2.4	Long-Term Zooplankton	4-43
4.3	Stream Water Quality	4-44
4.3.1	Stream Phosphorus.....	4-44
4.3.2	Stream Nitrogen	4-50
4.3.3	Stream Total Suspended Solids	4-53
4.3.4	2015 WY Sulfate.....	4-54
4.3.5	2015 WY Chloride	4-55
4.4	Reservoir Nutrient Loads and Export.....	4-55
4.4.1	Flow.....	4-55
4.4.2	Phosphorus	4-56
4.4.3	Nitrogen.....	4-60
4.5	Effectiveness of Pollutant Reduction Facilities	4-61
4.5.1	Cottonwood Creek Peoria Pond	4-61
4.5.2	Cottonwood Creek Perimeter Pond	4-63
4.5.3	McMurdo Stream Reclamation	4-65
4.6	2015 WY Special Studies	4-66
4.6.1	Cyanotoxin Monitoring in Cherry Creek Reservoir	4-66
4.6.2	TOC and DOC Analyses in Cherry Creek Reservoir and Tributaries	4-68
5.	References	5-70

List of Figures

Figure 2-1:	Sampling sites on Cherry Creek Reservoir and selected streams, 2015.....	2-5
Figure 2-2:	Sampling sites on McMurdo Gulch, 2015.....	2-6
Figure 4-1:	Patterns for mean whole-reservoir Secchi depth, 1% transmissivity, and chlorophyll a in Cherry Creek Reservoir, 2015 WY.....	4-14
Figure 4-2:	Whole-reservoir seasonal mean (July through September) Secchi depth (m) measured in Cherry Creek Reservoir. Error bars represent a 95% confidence interval for each mean.	4-15
Figure 4-3:	Temperature (°C) recorded at depth during routine monitoring at CCR-1 during the 2015 WY. Bottom depth is 7.2 to 8.8 m.....	4-16
Figure 4-4:	Dissolved oxygen (mg/L) recorded at depth during routine monitoring at CCR-1 during the 2015 WY. The dissolved oxygen basic standards table value for Class 1 warm water lakes and reservoirs is provided for comparison (5 mg/L). Bottom depth is 7.2 to 8.8 m.	4-17
Figure 4-5:	Temperature (°C) recorded at depth during routine monitoring at CCR-2 during the 2015 WY. Bottom depth is 7.2 to 8.8 m.....	4-17
Figure 4-6:	Dissolved oxygen (mg/L) recorded at depth during routine monitoring at CCR-2 during the 2015 WY. The dissolved oxygen basic standards table value for Class 1 warm water lakes and reservoirs is provided for comparison (5 mg/L). Bottom depth is 7.2 to 8.8 m.	4-18

Figure 4-7: Temperature (°C) recorded at depth during routine monitoring at CCR-3 during the 2015 WY. Bottom depth is 4.6 to 6.3 m.....	4-18
Figure 4-8: Dissolved oxygen (mg/L) recorded at depth during routine monitoring at CCR-3 during the 2015 WY. The dissolved oxygen basic standards table value for Class 1 warm water lakes and reservoirs is provided for comparison (5 mg/L). Bottom depth is 4.6 to 6.3 m.	4-19
Figure 4-9: Relative thermal resistance to mixing gradients and temperature profiles for Cherry Creek Reservoir, June – September, 2015.	4-20
Figure 4-10: Daily mean temperature (°C) recorded at depth for CCR-1 based on 15-minute interval data collected by temperature loggers, with USACE inflow in 2015. Shaded areas denote periods of thermal stratification.	4-22
Figure 4-11: Daily mean temperature (°C) recorded at depth for CCR-2 based on 15-minute interval data collected by temperature loggers, with USACE inflow in 2015. Shaded areas denote periods of thermal stratification.	4-22
Figure 4-12: Daily mean temperature (°C) recorded at depth for CCR-3 based on 15-minute interval data collected by temperature loggers, with USACE inflow in 2015. Shaded areas denote periods of thermal stratification.	4-23
Figure 4-13: Daily mean temperature (°C) recorded at Cherry Creek and Cottonwood Creek based on 15-minute interval data collected by temperature loggers.	4-23
Figure 4-14: Dissolved oxygen conditions in Cherry Creek Reservoir for three dates based on transect profile data during the 2015 WY.	4-24
Figure 4-15: Oxidation reduction potentials in Cherry Creek Reservoir for three dates based on transect profile data during the 2015 WY. The ORP scales for each transect are all relative to each other within and among sampling events.	4-26
Figure 4-16: Annual pattern of photic zone total phosphorus, total nitrogen and USACE inflow in Cherry Creek Reservoir, 2015 WY.....	4-27
Figure 4-17: Soluble phosphorus concentrations recorded for the photic zone and at depth during routine monitoring during the 2015 WY at CCR-2. Bottom depth is 7.2 to 8.8 m.	4-28
Figure 4-18: Total inorganic nitrogen (nitrate, nitrite, and ammonia) concentration recorded for the photic zone and at depth during routine monitoring for the 2015 WY at CCR-2. Bottom depth is 7.2 to 8.8 m.....	4-29
Figure 4-19: Seasonal mean (July through September) total phosphorus concentrations (µg/L) measured in Cherry Creek Reservoir, 1987 to 2015. Error bars represent a 95% confidence interval for each mean.	4-29
Figure 4-20: Seasonal mean (July through September) total nitrogen concentrations (µg/L) measured in Cherry Creek Reservoir, 1992 to 2015. Error bars represent a 95% confidence interval for each mean.	4-31
Figure 4-21: Concentration of chlorophyll <i>a</i> (µg/L) in Cherry Creek Reservoir, 2015 WY. Error bars represent a 95% confidence interval around each mean. Highlighted area denotes the seasonal period for the chlorophyll <i>a</i> standard.....	4-32
Figure 4-22: Seasonal mean (July through September) concentrations of chlorophyll <i>a</i> (µg/L) measured in Cherry Creek Reservoir, 1987 to 2015. Error bars represent a 95% confidence interval around each mean. The Reservoir destratification system was operated from 2008 through 2013.....	4-33
Figure 4-23: Percent relative density of algal groups for each routine photic zone composite sample collected in Cherry Creek Reservoir, 2015 CY.....	4-35
Figure 4-24: Percent relative biovolume of algal groups for each routine photic zone composite sample collected in Cherry Creek Reservoir, 2015 CY.....	4-40
Figure 4-25: Algal biovolume of major taxonomic groups in the photic zone composite samples in Cherry Creek Reservoir from 2011 through 2015, by CY. Chl values are seasonal mean chlorophyll <i>a</i> concentrations.	4-41
Figure 4-26: Total density of zooplankton groups and chlorophyll <i>a</i> concentration by sample date in Cherry Creek Reservoir, 2015 CY.....	4-42

Figure 4-27: Zooplankton biomass of major groups in Cherry Creek Reservoir from 2011 through 2015, by CY.....	4-44
Figure 4-28: Base flow and storm flow total phosphorus concentrations measured at CC-10, 1994 to 2015.....	4-48
Figure 4-29: Base flow and storm flow soluble reactive phosphorus concentrations measured at CC-10, 1994 to 2015.	4-48
Figure 4-30: Base flow and storm flow total phosphorus concentrations measured at CT-2, 1996 to 2015.....	4-49
Figure 4-31: Base flow and storm flow soluble reactive phosphorus concentrations measured at CT-2, 1996 to 2015.....	4-49
Figure 4-32: Total dissolved phosphorus and soluble reactive phosphorus concentrations measured at MW-9, 1994 to 2015.	4-50
Figure 4-33: Base flow and storm flow total nitrogen concentrations measured at CC-10, 1994 to 2015.....	4-51
Figure 4-34: Base flow and storm flow total inorganic nitrogen concentrations measured at CC-10, 1994 to 2015.....	4-51
Figure 4-35: Base flow and storm flow total nitrogen concentrations measured at CT-2, 1996 to 2015.....	4-52
Figure 4-36: Base flow and storm flow total inorganic nitrogen concentrations measured at CT-2, 1996 to 2015.....	4-52
Figure 4-37: Base flow and storm flow total suspended solids concentrations measured at CC-10, 1994 to 2015.....	4-54
Figure 4-38: Base flow and storm flow total suspended solids concentrations measured at CT-2, 1996 to 2015.....	4-54
Figure 4-39: Mass balance diagram of total phosphorus and total nitrogen loading in Cherry Creek Reservoir, 2015 WY.....	4-59
Figure 4-40: Cyanotoxin analyses for Cherry Creek Reservoir, May through September 2015.	4-67

List of Tables

Table 3-1: Sampling trips per sampling period, 2015 WY.....	3-9
Table 3-2: Number of storm samples collected from tributary streams to Cherry Creek Reservoir, 2015 WY. See Appendix C for sample dates.....	3-11
Table 3-3: Parameter list, method number, and detection limits for chemical and biological analyses of water collected from Cherry Creek Reservoir and tributaries.	3-12
Table 4-1: Comparison of water year mean and July through September mean phosphorus, nitrogen, and chlorophyll <i>a</i> levels in Cherry Creek Reservoir, 1988 to 2015.....	4-30
Table 4-2: Density (#/mL) of phytoplankton and total number of taxa for routine photic zone composite samples representative of the three samples sites on Cherry Creek Reservoir, and for opportunistic grab/composite samples in other Reservoir locations, 2015 CY.	4-36
Table 4-3: Comparison of median base flow and median storm flow concentrations of total phosphorus (TP), total nitrogen (TN), and total suspended solids (TSS) in tributaries to Cherry Creek Reservoir, 2015 WY.....	4-44
Table 4-4: Comparison of base flow median WY total phosphorus (TP), soluble reactive phosphorus (SRP), total nitrogen (TN), and total inorganic nitrogen (TIN) concentrations for CC-10 and CT-2 from 1995 to 2015.	4-45
Table 4-5: Comparison of storm flow median WY total phosphorus (TP), soluble reactive phosphorus (SRP), total nitrogen (TN), and total inorganic nitrogen (TIN) concentrations for CC-10 and CT-2 from 1995 to 2015.	4-47
Table 4-6: Normalized phosphorus loads and export (lbs/year) for Cherry Creek Reservoir, 1992 to 2015 WY.....	4-57

Table 4-7:	Flow-weighted total phosphorus (TP) and total nitrogen (TN) concentrations (µg/L) for Cherry Creek Reservoir, 1992 to 2015 WY.	4-58
Table 4-8:	Normalized nitrogen loads and export (lbs/year) for Cherry Creek Reservoir, 1992 to 2015 WY.....	4-60
Table 4-9:	Historical total phosphorus, total nitrogen, and total suspended solids concentrations upstream and downstream of the Cottonwood Creek – Peoria Pond, 2002 to 2015 WY.....	4-62
Table 4-10:	Historical total phosphorus, total nitrogen, and total suspended solids concentrations upstream and downstream of the Cottonwood Creek Perimeter Pond, 1997 to 2015 WY.....	4-64
Table 4-11:	Total organic carbon (TOC) and dissolved organic carbon (DOC) concentrations in Cherry Creek Reservoir and tributaries (CC-10 and CT-2), 2015 WY.....	4-68
Table C-1:	2015 Stream WQ Data	C-1
Table C-2:	CC-10 mean daily temperatures (°C).	C-8
Table C-3:	CT-2 mean daily temperatures (°C).	C-9
Table D-1:	Stage-discharge data used to develop rating curves for sites CC-10, CT-P1, CT-P2, and CT-1 in 2015.....	D-2
Table D-2:	Discharge (Q, cfs) and stage height (H, ft) relationships for all sites. Rating curves are developed for sites CC-10, CT-P1, and CT-1, while multi-level orifice and weir equations are used for sites EcoPark, CT-P2, and CT-2.	D-4
Table D-3:	Equations used to estimate missing daily mean data and percent of annual data estimated.	D-5
Table D-4:	Threshold flow value used to categorize base flows and storm flows in 2015.	D-6
Table D-5:	Monthly base flow and median annual storm flow TP and TN concentrations (µg/L) applied to respective flows in 2015.....	D-7
Table D-6:	Monthly unadjusted and final normalized flow.	D-11
Table D-7:	Monthly unadjusted and final normalized loads.	D-12
Table D-8:	Calculation of the monthly redistributed inflow and load values and the apportioning of these data to sites CC-10 and CT-2.....	D-13
Table E-1:	Quantity and size of fish stocked in Cherry Creek Reservoir, 1985 to 1995.....	E-1
Table E-2:	2015 Cherry Creek Reservoir phytoplankton data represented in numbers per milliliter (#/mL).	E-4
Table E-3:	Total reservoir phytoplankton density (cells/mL) and number of taxa in Cherry Creek Reservoir, 1984 to 2014.	E-6
Table E-4:	2015 Cherry Creek Reservoir zooplankton.	E-9
Table E-5:	2015 Routine cyanotoxin sampling events (values in µg/L).....	E-10
Table E-6:	2014 Opportunistic cyanotoxin sampling events(values in µg/L).	E-11
Table F-1:	MW-9 mean daily temperatures (°C).	F-1
Table F-2:	MW-9 mean water level (ft).	F-2

List of Photos

Photo 4-1:	Visible surface cyanobacteria near Site CCR-2 on 5/27/15 (microcystins = ND).	4-67
Photo 4-2:	Visible surface cyanobacteria at east boat launch on 9/22/15 (microcystins = ND). ...	4-67

List of Equations

Equation D-1: Nutrient loading. D-6

Equation D-2: Pounds of nutrients from precipitation..... D-8

Equation D-3: Alluvial nutrient loading. D-9

Equation D-4: Redistributed Inflow. D-10

List of Appendices

Appendix A Cherry Creek Reservoir Sampling and Analysis Plan

Appendix B 2015 WY Reservoir Water Quality Data

Appendix C 2015 WY Stream Water Quality and Precipitation Data

Appendix D 2015 WY Streamflow, Rainfall, Phosphorous and Nitrogen Loading Calculations
and Final Inflow and Load Data Normalized to the U.S. Army Corps of Engineers
Inflow Data

Appendix E 2015 Biological Data

Appendix F MW-9 Data

List of Acronyms & Abbreviations

ac	acute
ac-ft	acre-feet
APHA	American Public Health Association
C	celsius
CCBWQA	Cherry Creek Basin Water Quality Authority
CDPHE	Colorado Department of Public Health and Environment
CEC	Chadwick Ecological Consultants, Inc.
cfs	cubic feet per second
ch	chronic
CPW	Colorado Parks and Wildlife
CWQCC	Colorado Water Quality Control Commission
CY	calendar year
DM	daily maximum
DOC	dissolved organic carbon
DRCOG	Denver Regional Council of Governments
ed.(s)	editor(s)
ft	feet
ft ³ /sec	cubic feet per second
GEI	GEI Consultants, Inc.
JCHA	John C. Halepaska & Associates, Inc.
KAPA	Denver/Centennial Airport
km	kilometer
lb	pound
m	meter
mg	milligram
mg/L	milligrams per liter
mL	milliliter
mV	millivolt
MWAT	maximum weekly average temperature
ORP	oxidation reduction potential
PRF	pollutant reduction facilities
Reservoir	Cherry Creek Reservoir
RTRM	relative thermal resistance to mixing
SRP	soluble reactive phosphorus
TDP	total dissolved phosphorus
TIN	total inorganic nitrogen
TMAL	total maximum annual load
TMDL	total maximum daily load
TN	total nitrogen
TOC	total organic carbon
TP	total phosphorus
TSS	total suspended solids
TVSS	total volatile suspended solids
µg/L	micrograms per liter
µm ³	Cubic Micrometer
USACE	U.S. Army Corps of Engineers
WY	water year
yr	year

Executive Summary

The purpose of this report is to present the 2015 water year (WY) data collected by GEI Consultants, Inc. (GEI), on behalf of the Cherry Creek Basin Water Quality Authority (CCBWQA). The data were collected to evaluate Cherry Creek Reservoir (Reservoir) water quality conditions with respect to selected standards identified in Regulations No. 31 & 38 and goals identified in the Cherry Creek Reservoir Control Regulation No. 72, as well as to evaluate the effectiveness of the CCBWQA's pollutant reduction facilities (PRFs) on Cottonwood Creek and other stream reclamation projects within the Cherry Creek Basin. Additionally, this report summarizes data collected during special studies such as cyanotoxin and organic carbon monitoring as well as trends observed in the long-term monitoring data collected on behalf of the CCBWQA since 1987.

Temperature and Dissolved Oxygen

Water temperatures during routine profile measurements in the Reservoir ranged from 7.3°C on the reservoir bottom in mid-March 2015 to 25.3°C at the surface in late June. Temperature profile data indicated a fairly well-mixed reservoir in early spring with increasing stratification occurring from early April to late July.

The Reservoir is classified as a Class I Warm Water reservoir with temperature standards of 26.3°C (chronic, ch) and 29.5°C (acute, ac) for summer months (April-December) and 13.2°C (ch) and 14.8°C (ac) for winter months (January-March; CDPHE 2011). Based on 15-minute interval thermistor data, the summer CCR-2 daily maximum (DM; 25.6°C) and maximum weekly average temperatures (MWAT; 23.9°C) attained the warm water standards.

From mid-October, 2014 to late May, 2015, the dissolved oxygen concentrations throughout the water column remained greater than the Colorado dissolved oxygen standard for warm water lakes of 5 milligrams per liter (mg/L). While this standard, as written, only applies to the surface 0.5 m to 2.0 m water layers, it is important to note that the 5 m layers and deeper to the water/sediment interface were regularly less than 5 mg/L from early June through September. Dissolved oxygen at this concentration is low and offers little refuge to fish that typically seek deeper, cooler water as summer water temperatures increase.

Reservoir profiles were evaluated to determine the attainment of the dissolved oxygen standard. Over the course of the monitoring year, 72 vertical water column profiles were collected in the Reservoir. For each profile, the 1 m and 2 m dissolved oxygen values were averaged and evaluated for attainment of the Class 1 Warm Water table value standard (5 mg/L) for lakes and reservoirs that are greater than 5 m deep (CDPHE 2011). The Reservoir was in attainment of the dissolved oxygen standard for 68 of 72 profiles. The

exceedances occurred on August 4, with minimum mean dissolved oxygen values of 4.7 mg/L, 4.8 mg/L, and 4.9 mg/L at Site CCR-1, 2, and 3, respectively and on August 18 with a value of 4.6 mg/L at Site CCR-2. During the July to September growing season, the mean dissolved oxygen concentration of the upper layer was 6.4 mg/L for all vertical profiles.

Total Phosphorous and Nitrogen in Cherry Creek Reservoir

During the 2015 WY, the photic zone mean concentration of total phosphorus (TP) ranged from 46 to 121 µg/L with an overall water year mean of 79 µg/L. The seasonal (July through September) photic zone mean concentrations ranged from 65 to 121 µg/L, with a seasonal mean of 93 µg/L which is slightly greater than the long-term median value of 87 µg/L. The photic zone mean concentration of total nitrogen (TN) ranged from 648 to 1,097 µg/L with an overall water year mean of 825 µg/L. The seasonal photic zone mean concentrations ranged from 648 to 901 µg/L, with a seasonal mean of 759 µg/L which is less than the long-term median value of 923 µg/L.

Chlorophyll *a*

The annual pattern of chlorophyll *a* concentrations was quite variable throughout the 2015 WY. From October 2014 through September 2015, chlorophyll *a* concentrations ranged from 8.1 µg/L to 35.2 µg/L with a mean chlorophyll *a* concentration of 18.4 µg/L. During the regulatory growing season (July through September), three of the six Reservoir mean chlorophyll *a* concentrations were greater than 18 µg/L standard with a general increase through the growing season. The July through September seasonal mean chlorophyll *a* concentration was 16.0 µg/L, with a peak seasonal reservoir mean concentration of 23.7 µg/L in late September during an *Anabaena flos-aquae* bloom. Notably, the *A. flos-aquae* bloom in late May resulted in a reservoir mean chlorophyll *a* concentration of 22.5 µg/L. The Reservoir attained the site-specific chlorophyll *a* standard of 18 µg/L, although the Reservoir remains out of compliance with the allowable exceedance frequency, because 2015 was the first out of five consecutive years that the standard was attained.

Sulfate and Chloride

Sulfate and chloride analysis began in March 2015 and continued monthly through October. Mean photic composite sulfate concentrations for this time period ranged from 132 to 222 mg/L with an overall median of 154 mg/L. This median value is less than that for alluvial water at MW-9 for the same time period (214 mg/L) and is less than the drinking water standard of 250 mg/L. Mean photic composite chloride concentrations for this time period ranged from 123 to 214 mg/L with an overall median of 143 mg/L. This median value is less than that for alluvial water at MW-9 for the same time period (214 mg/L) and does not exceed the drinking water standard of 250 mg/L. Notably, the Reservoir is classified for water supply, but it is not a direct-use drinking water supply Reservoir. In addition, there are no sulfate or chloride standards for aquatic life use.

Phytoplankton

The 2015 summer season represented conditions in the reservoir after two years absent the influence of the destratification system and continuous mixing. Based on the calendar year, the photic assemblage was dominated in terms of density by cryptophytes (36%) followed by chlorophytes (green algae; 30%) and diatoms (bacillariophytes; 30%). The percent relative density of cyanobacteria (blue green algae) was 1%. The assemblage was dominated in terms of biovolume by diatoms (60%) followed by cryptophytes (18%) and chlorophytes (12%). The relative percent biovolume of cyanobacteria was 4%. Two opportunistic surface grab samples were collected during visually identified cyanobacteria blooms. *A. flos-aquae* was the dominant cyanobacteria collected and accounted for greater than 62% of the algae identified in each sample. Patterns in algal biovolume follow typical seasonal succession patterns of many temperate lakes and reservoirs with diatoms and cryptophytes being most abundant in the spring, while green algae were abundant throughout the year and comprising a larger component of the assemblage in winter and fall.

Zooplankton

Zooplankton density ranged from 17 organisms/L in late July to 471 organisms/mL in Mid-March. Over the calendar year, the zooplankton assemblage contained a total of 12 zooplankton crustacean species—eight cladocerans and four copepods including immature copepodids and nauplius—and seven species of rotifers collected during the 14 sampling events. The cladocerans *Bosmina longirostris* and *Skistodiaptomus pallidus* and immature copepods (copepodids and nauplius) were collected during all 15 sampling events. *Bosmina longirostris* have been found to be the dominant cladoceran in other eutrophic lakes. The copepod *Diacyclops thomasi* and the rotifer *Keratella cochlearis* were collected at 13 sampling events. All other taxa were collected in 10 or less sampling events. While the zooplankton assemblage is functionally (i.e. diet) related to the algal assemblages and biomass, no statistical correlation exists between zooplankton density and chlorophyll a (surrogate for algal biomass). Similarly, no correlation exists between zooplankton density and algal density or algal biovolume.

Total Phosphorous and Nitrogen in Streams

The median annual TP concentration for base flow conditions ranged from 47 µg/L at Site CT-P1 to 340 µg/L at Site MCM-1. At the two Reservoir inflow sites CC-10 and CT-2, the median annual TP concentrations were 202 µg/L and 63 µg/L, respectively. The median annual TP concentration for the Reservoir outflow was 73 µg/L. The median seasonal base flow TP concentrations at all sites were greater than their respective annual TP concentrations and ranged from 64 µg/L at Site CT-P1 to 540 µg/L at Site MCM-1. At all stream sites, except McMurdo Gulch and CC-Out where storm samples are not collected, storm flow TP concentrations were greater than their respective annual base flow concentrations. The annual median storm flow TP concentrations ranged from 97 µg/L at Site CT-2 to 301 µg/L at Site CC-10.

The median annual TN concentration for base flow conditions ranged from 319 µg/L at Site MCM-2 to 1,850 µg/L at Site CT-1. At the two Reservoir inflow sites CC-10 and CT-2, the median annual TP concentrations were 787 µg/L and 1,469 µg/L, respectively. The median annual TP concentration for the Reservoir outflow was 935 µg/L. The median seasonal base flow TN concentrations at Cherry Creek sites (EcoPark, CC-10, and CC-Out @ I225), CT-P1, CT-P2, and MCM-2 were greater than their respective annual TN concentrations while CT-1, CT-2, and MCM-1 were less. The median seasonal TN ranged from 393 µg/L at Site MCM-2 to 1,809 µg/L at Site CT-1. Storm flow TN concentrations at CC-10, CT-P1, CT-P2, and CT-2 were greater than their respective annual base flow concentrations while EcoPark and CT-1 were less. The annual median storm flow TN ranged from 1,054 µg/L at Site CC-10 to 1,685 µg/L at Site CT-1.

Mass Balance/Net Loading of Phosphorous and Nitrogen to the Reservoir

The U.S. Army Corps of Engineers calculated inflow was 27,662 ac-ft/yr, while GEI calculated stream inflow was 26,409 ac-ft/yr. Following the water mass balance and normalization process to account for different inflow methodologies, flow from Cherry Creek and Cottonwood Creek accounted for a TP load of 15,141 lbs and a TN load of 68,630 lbs to the Reservoir during the 2015 WY. The alluvial inflow contributed 1,033 lbs of phosphorus and 2,339 lbs of nitrogen, with precipitation events contributing 526 lbs of phosphorus and 8,546 lbs of nitrogen to the Reservoir. The total external load to the Reservoir in 2015 WY was 16,701 lbs of phosphorus and 79,515 lbs of nitrogen. The Reservoir export total load was 8,222 lbs of phosphorus and 58,186 lbs of nitrogen; therefore, the Reservoir retained 8,479 lbs of the total external phosphorous load and 21,329 lbs of the total external nitrogen load.

The flow-weighted concentration for all external sources of inflow to the Reservoir is 222 µg/L of TP and 1,057 of TN. The flow-weighted export concentration for the Reservoir is 121 µg/L of TP and 853 µg/L of TN. The difference of 101 µg/L of TP and 204 µg/L of TN was retained by the Reservoir.

Pollutant Reduction Facility Effectiveness

The Peoria Pond PRF continues to be effective in reducing the amount of TP and total suspended solids (TSS) in Cottonwood Creek. The flow-weighted TP concentration was 139 µg/L upstream of the PRF and 85 µg/L downstream indicating efficiency in removing phosphorus from flow. Over the life of the project, the PRF has reduced the flow-weighted TP concentration at the downstream site by approximately 20%. In 2015, the TSS concentration was reduced by approximately 36%, with the long-term reduction of 29%. In contrast, the 2015 flow-weighted TN concentration was 1,414 µg/L upstream of the PRF and 1,466 µg/L downstream which indicates that the RPF is not efficient in removing nitrogen from the system. This is consistent with the long term mean conditions which show that TN has increased by approximately 3% at the downstream site.

Site CT-1, above Perimeter Pond, was affected by beaver activity for nearly all of 2015 WY except for June and September. Therefore, only these two months were used to assess PRF efficiency, which greatly limits the assessment. Despite this, the PRF was effective in reducing the amount of TP, TN, and TSS in Cottonwood Creek as it passes through Perimeter Pond. The flow-weighted TP concentration was 149 µg/L upstream of the PRF and 88 µg/L downstream and the flow-weighted TN concentration was 1,617 µg/L upstream of the PRF and 1,342 µg/L downstream which indicates some effectiveness in removing TP and TN from flow. Over the life of the project, the PRF has reduced the flow-weighted TP concentration at the downstream site by an approximate mean 24% while it has only reduced the flow-weighted TN concentration at the downstream site by an approximate mean 5%. The TSS concentration was reduced by approximately 42% in 2015, with the long-term mean reduction of 33%.

Overall, the Cottonwood Creek Stream Reclamation project and the two PRF ponds, have been very effective in reducing flow-weighted total TP concentration and TSS load to the downstream PRF. Since the completion of the project, the combination of these three PRFs (treatment train approach) has effectively reduced the flow-weighted TP concentration entering the Reservoir, via Cottonwood Creek, from a pre-project WY average of 143 µg/L to a post-project WY average of 78 µg/L, nearly a 46% reduction. The two PRFs have shown mixed results in reducing TN, and the entire treatment train reach has shown an average increase in TN from upstream to downstream by approximately 20% since 2008.

Base flow water quality samples were collected on a monthly basis at sites MCM-1 and MCM-2 during the 2015 WY. The PRF was effective in reducing the amount of TP and TN in McMurdo Gulch as it passes through the reclamation area. The mean TP concentration was 392 µg/L upstream of the PRF and 272 µg/L downstream and the TN concentration was 547 µg/L upstream of the PRF and 305 µg/L downstream which indicates efficiency in removing TP and TN from flow. Over the past few years, the PRF has reduced the TP concentration at the downstream site by approximately 23% and TN concentration by approximately 41%. The PRF was not effective at removing TSS in 2015 WY and the concentration at MCM-2 was over four times that at MCM-1. This difference is consistent with the long-term means in which the 2012 to 2015 concentration at MCM-2 is three times that at MCM-1. No storm samples were collected at these sites.

Special Study: Cyanotoxin Monitoring

Cyanobacteria may rapidly grow in response to favorable reservoir conditions and form surface accumulations (scum) or remain mixed throughout the photic zone depending upon the type of cyanobacteria. The objective of the 2015 supplemental cyanotoxin monitoring program was to document the concentrations of cyanotoxins in the photic zone of the Reservoir and at the Swim Beach and to provide the CCBWQA and its stakeholders the opportunity to evaluate the risk to beneficial uses.

A total of 18 samples were collected for cyanotoxin analysis between May 27th and September 22nd, 2015. On May 27th, an *A. flos-aquae* cyanobacteria bloom (7,681,011 µm³/

mL biovolume) was observed throughout the Reservoir and multiple cyanotoxin samples were collected and analyzed for the suite of toxins (microcystins, anatoxins, saxitoxins, and cylindrospermopsins); however, no cyanotoxins were detected in any of the samples. On September 9th, the routine composite photic samples revealed microcystins concentration (0.18 µg/L) at just above the detection limit. Microcystin at this level is not considered a human health risk according to recreation thresholds established by World Health Organization. Despite this detection, the only cyanobacteria detected that day was *A. flos-aquae* at a very low biovolume (35,411 µm³/mL). On September 22nd, a late season *A. flos-aquae* bloom (84,528,910 µm³/mL, biovolume) was quite large and an opportunistic surface grab sample taken near the east boat dock, however, no microcystins were detected.

Special Study: Organic Carbon Monitoring

For reservoir model development purposes, total organic carbon (TOC) and dissolved organic carbon (DOC) concentrations were measured in the Reservoir, and in the Cherry Creek and Cottonwood Inflows. The organic carbon data was used to develop relationships with other water quality parameters to facilitate model development. In the photic zone at CCR-2, TOC concentrations ranged from 5.8 mg/L to 7.6 mg/L with a mean of 6.6 mg/L, and the DOC fraction was approximately 85% of the total fraction. At sites CC-10 and CT-2, the mean TOC concentrations were 4.9 mg/L and 6.6 mg/L, respectively, with DOC concentrations representing 88% and 84% of the total fraction.

1. Historical Perspective

An inter-governmental agreement was executed in 1985 by several local governmental entities within the Cherry Creek basin to form the Cherry Creek Basin Water Quality Authority (CCBWQA). The CCBWQA was created for the purpose of coordinating and implementing the investigations necessary to maintain the quality of water resources of the Cherry Creek basin while allowing for further economic development. Based on a clean lakes water study (Denver Regional Council of Governments [DRCOG] 1984), the Colorado Water Quality Control Commission (CWQCC) set standards for phosphorus, and a total maximum daily load (TMDL) for phosphorus. Cherry Creek Reservoir (Reservoir) was classified as Class 1 Warm Water for aquatic life, with an in-lake phosphorus standard of 35 micrograms per liter ($\mu\text{g/L}$) and seasonal mean chlorophyll *a* goal of 15 $\mu\text{g/L}$. Subsequently, a phosphorus TMDL was prepared for the Reservoir allocating loads among point sources, background sources, and nonpoint sources with a total maximum annual load (TMAL) of 14,270 pounds (lbs) total phosphorus (TP).

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 the Reservoir (Regulation #38) was changed to a seasonal July to September mean value of 15 $\mu\text{g/L}$ of chlorophyll *a* to be met 9 out of 10 years, with an underlying TP goal of 40 $\mu\text{g/L}$, also as a July to September mean value. In addition, the limit for wastewater effluent TP concentration was set at 50 $\mu\text{g/L}$, to be met as a 30-day mean value. In May 2001 at the CWQCC hearing, the Control Regulation (#72) was adopted for the Reservoir, which maintained the annual TMAL of 14,270 lbs/year as part of a phased TMDL for the Reservoir. During the March 2009 Rulemaking Hearing, Regulations 38 and 72 were again refined to reflect the most current feasibility-based chlorophyll *a* standard and flow-weighted inflow TP goal for Reservoir. The current chlorophyll *a* standard is 18 $\mu\text{g/L}$ with an exceedance frequency of once in 5 years. The control regulation changed from a phosphorus load-based TMAL to a flow-weighted concentration such that the annual flow-weighted TP concentration goal is 200 $\mu\text{g/L}$ for all combined sources of inflow to the Reservoir.

From 1993 to 1998, Dr. John Jones of the University of Missouri contributed greatly to the Reservoir’s annual monitoring program (Jones 1994 to 1999, 2001), and assisted with the

transition of the program to Chadwick Ecological Consultants, Inc. (CEC) in 1994. Results of the aquatic biological and nutrient analyses have been summarized in annual monitoring reports (CEC 1995 to 2006). In 2006, CEC merged with GEI Consultants, Inc. (GEI), and performed the annual monitoring duties of Reservoir from 2006 through 2015 (GEI 2007, 2008b, 2009 to 2016). The present study was designed to continue the characterization of the relationships between nutrient loading (both in-lake and external) and Reservoir productivity. The specific objectives of this annual monitoring study include the following:

- Determine base flow and storm flow concentrations for nitrogen and phosphorus fractions in tributary inflows, as well as concentrations in the Reservoir and the outflow.
- Determine the hydrological inflows and nutrient loads entering the Reservoir, including Reservoir exports. These data provide the necessary information to calculate flow-weighted nutrient concentrations for the Reservoir.
- Determine biological productivity in the Reservoir, as measured by algal biomass (chlorophyll *a* concentration). In addition, determine species composition of the algal assemblages to characterize the types of algae responsible for chlorophyll *a*, and determine zooplankton species composition to better characterize the plankton community.
- Evaluate relationships between the biological productivity and nutrient concentrations within the Reservoir and total inflows.
- Assess the effectiveness of pollutant reduction facilities (PRFs) on Cottonwood Creek, McMurdo Gulch, and Cherry Creek to reduce phosphorus loads into the Reservoir.
- Assess the effectiveness of the destratification system in minimizing periods of thermal stratification, increasing the dissolved oxygen concentrations in the deepest water layers, reducing the internal nutrient release of phosphorus and nitrogen from the sediments, reducing peak and seasonal mean chlorophyll *a* concentrations, and reducing the production of cyanobacteria (blue green algae) via vertical mixing.

In 2008, the CCBWQA implemented a new Reservoir destratification management strategy that was designed to increase the circulation of the water column, to promote a greater exchange of dissolved oxygen at the surface layer, and to circulate the reaerated water into the deeper depths of the Reservoir. A goal of this management strategy is to increase the dissolved oxygen concentrations near the water/sediment interface which should help reduce the internal phosphorus loading component of the Reservoir (AMEC 2005). The sediment phosphorus load accumulates over time from external sources, including from the Reservoir, and is geochemically transformed and released when the sediment surface becomes anoxic

(Nürnberg and LaZerte 2008). This internal release of phosphorus facilitates the growth of all algae; thus by reducing the internal load, algae growth should be reduced too. In addition, a goal of the design of the destratification system was to vertically mix algae and to disrupt the suitable habitat of large filamentous cyanobacteria which have the ability to regulate their buoyancy, fix atmospheric nitrogen, and rapidly grow at the surface of the Reservoir. In theory, when these design considerations are placed in the context of each other, the destratification system should have reduced chlorophyll *a* concentrations and helped to achieve the site-specific chlorophyll *a* standard while protecting the beneficial uses. However, after operating the destratification system for a period of 6 years, the reservoir appeared to have reached a new state of conditions that was characterized by internal nutrient loading and higher than expected algal biomass (chlorophyll *a*) conditions that resulted in the seasonal mean chlorophyll *a* concentration being exceeded 4 out of the 6 years. In addition, a laboratory change in 2009 resulted in phytoplankton data that was not comparable to historical data and confounded the comparison of algae species composition data. As a result, the destratification system was not operated in 2014 and 2015 to reassess the phytoplankton community dynamics in the absence of aeration and mixing and to better understand whether the destratification system was vertically mixing the algae and disrupting the suitable habitat for large filamentous cyanobacteria. The objectives of the annual monitoring study remained the same as stated above; although two special studies were included to better understand the potential concern for cyanotoxins in the context of beneficial uses and to better understand organic carbon dynamics in the system. The 2015 data will also be used to inform the development of the Reservoir hydrodynamic model.

2. Study Area

Cherry Creek was impounded in 1948 and the dam was completely finished in 1950 by the U.S. Army Corps of Engineers (USACE) to protect the City of Denver from flash floods that originated in the 995 square kilometers (km²) (385 square miles) drainage basin. The CCBWQA performed a bathymetric survey in November 2013, and the Reservoir surface area was 875 acres at the multipurpose storage pool elevation of 5,550 feet (ft). The volume of the Reservoir was 13,522 acre-feet (ac-ft). The Reservoir and surrounding state park has also become an important recreational site, providing activities that include fishing, boating, swimming, bicycling, bird watching, and walking.

2.1 Sampling Sites

Sampling during the 2015 water year (WY) was routinely conducted at 12 sites, including three sites in the Reservoir, eight sites on tributary streams, and one site on Cherry Creek downstream of the Reservoir (Figure 2-1; Figure 2-2). In addition to these routine monitoring sites, 10 transect sites (D1 to D10) were established from the approximate mid-point of the dam extending perpendicular across the destratification zone in the Reservoir, as well as three continuous temperature logging sites near the routine reservoir monitoring sites. The routine sampling sites are summarized below.

2.1.1 *Cherry Creek Reservoir*

- | | |
|-------|---|
| CCR-1 | This site is also called the Dam site, and was established in 1987. Site CCR-1 corresponds to the northwest area within the lake (Knowlton and Jones 1993). Sampling was discontinued at this site in 1996 following determination that this site exhibited similar characteristics to the other two sites in this polymictic Reservoir. Sampling recommenced in July 1998 at the request of consultants for Greenwood Village. |
| CCR-2 | This site is located near the Swim Beach, 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). |

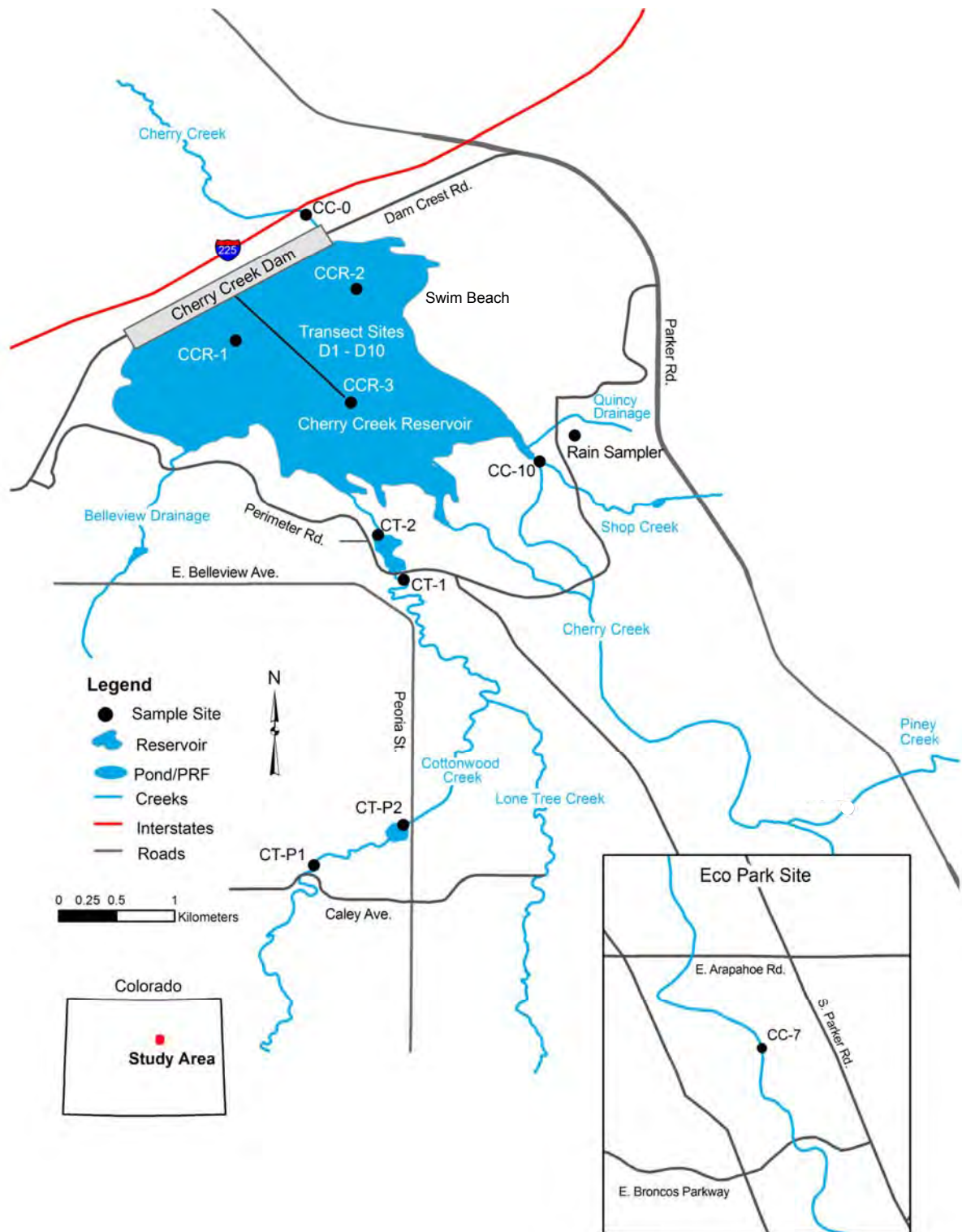


Figure 2-1: Sampling sites on Cherry Creek Reservoir and selected streams, 2015.

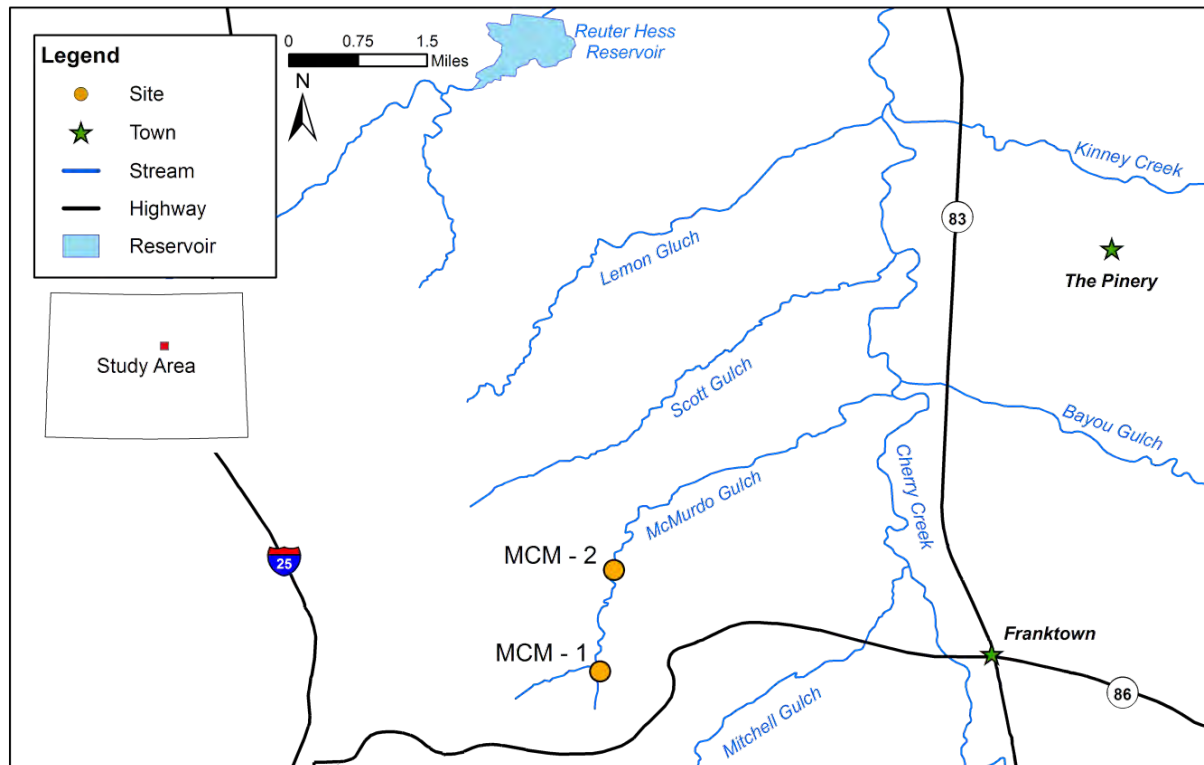


Figure 2-2: Sampling sites on McMurdo Gulch, 2015.

2.1.2 *Cherry Creek*

CC-7 (EcoPark) This site was established in 2013 on Cherry Creek at the downstream boundary of Cherry Creek Valley Ecological Park (EcoPark). This site is approximately 1.7 kilometers upstream of Arapahoe Road, and serves to monitor water quality conditions downstream of the EcoPark Stream Reclamation Project (PRF). This site also provides more accurate flow estimates in this reach of Cherry Creek.

CC-10 This site was originally established in 1987 on Cherry Creek near the historic U.S. Geological Survey Melvin gage, approximately 3.5 km upstream of the Reservoir (roughly due west of the intersection of Parker Road and Orchard Road). This location is in an area of Cherry Creek that frequently becomes dry during summer months as a result of the natural geomorphology and alluvial pumping for domestic water supply (John C. Halepaska & Associates, Inc. [JCHA] 1999 and 2000). In 1995, this site was relocated farther downstream between the Perimeter Road and the Reservoir, approximately 800 meters (m) upstream of the Reservoir. This site was moved still farther downstream in 1996, just upstream of the confluence with Shop Creek and closer to the Reservoir. In 1999, it was moved below the confluence with Shop Creek to eliminate

the effect of a stream crossing on the site's hydrograph. Since 1995, Cherry Creek has been monitored in a reach with perennial flow, allowing for more accurate monitoring of water quality and surface flow in Cherry Creek before entering the Reservoir. Historically, this site has been referred to as CC or CC-I (i.e., CC-Inflow), but was renamed Site CC-10 in 1997 to place it in context with concurrent monitoring in Cherry Creek mainstem upstream of the Reservoir (JCHA 1999 to 2007).

CC-O This site was established in 1987 on Cherry Creek downstream of the Reservoir and upstream of the Hampden Avenue-Havana Street junction in the Kennedy Golf Course near the historical U.S. Geological Survey gage (06713000). In 2007, Site CC-O (also identified as Site CC-Out @ I225) was relocated immediately downstream of the dam outlet structure and serves to monitor the water quality of the Reservoir outflow.

2.1.3 ***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 storm water sampler and pressure transducer is located inside the outlet structure. This site monitors the effectiveness of the PRF on water quality.

CT-1 This site was established in 1987 where the Cherry Creek Park Perimeter Road crosses Cottonwood Creek. It was chosen to monitor the water quality of Cottonwood Creek before it enters the Reservoir. During the fall/winter of 1996, a PRF, consisting of a water quality/detention pond and wetland system, was constructed downstream of this site. As a result of the back-flow from this pond inundating this site, this site was relocated approximately 250 m upstream near Belleview Avenue in 1997. In 2009, this site was relocated approximately 75 m upstream of the Perimeter Road as it crosses Cottonwood Creek, due to the stream reclamation project. This site is now approximately 200 m upstream of the PRF.

CT-2 This site was established in 1996 and was originally located downstream of the Perimeter Pond on Cottonwood Creek. The ISCO pressure transducer and staff gage was located in a section of the stream relatively unobstructed by vegetation, and approximately 50 m downstream of the PRF. However, over the years the growth of vegetation considerably increased along the channel, creating problems with accurately determining stream flow.

Eventually, when no accurate and reliable streamflow measurements could be performed in 2003, other locations were evaluated. In August 2004, the pressure transducer and staff gage were relocated inside of the outlet structure for the PRF to mitigate problems associated with streamflow measurements by providing a reliable multilevel weir equation. In 2013, modifications to the PRF overflow elevation and the partial closure of the downstream control gate changed the relationship of the multilevel weir equation, resulting in unreliable stream flow estimates. In April 2014, the weir and overflow elevations were surveyed and the control gate was fully opened, and adjustments were made to the weir equations accordingly. Water quality samples are collected from the outlet structure as well. This site monitors the effectiveness of the PRF on Cottonwood Creek water quality and provides information on the stream before it enters the Reservoir.

2.1.4 *McMurdo Gulch*

- MCM-1 This site was established in 2012 on McMurdo Gulch, approximately 150 m upstream of the McMurdo Gulch Stream Reclamation Project boundary. This site is also 120 m upstream of the confluence with an unnamed tributary that receives runoff from the Castle Oaks Subdivision. This site serves as the upstream monitoring location for the McMurdo Gulch Stream Reclamation Project.
- MCM-2 This site was established in 2012 on McMurdo Gulch, approximately 80 m upstream of the Castle Oaks Drive Bridge crossing of McMurdo Gulch, near the North Rocky View Road intersection. This site serves as the downstream monitoring location for the McMurdo Gulch Stream Reclamation Project. This site is located within the project boundary, and consistently maintained base flows, whereas the reach further downstream was often dry due to surface flow becoming subsurface.

3. Methods

3.1 Sampling Methodologies

Field sampling protocols and analytical methods used for monitoring the Reservoir and stream sites as outlined in the Cherry Creek Reservoir Sampling and Analysis Plan (CCBWQA 2015; Appendix A). Sampling and reporting of water quality parameters (reservoir and streams) were performed for the WY which is defined as October, 2014 through September, 2015. This time period was chosen because flows and nutrient input are minimal in the fall and the end of September generally marks the start of seasonal isothermal conditions in the Reservoir. Sampling and reporting of biological parameters (phytoplankton and zooplankton) were performed for the calendar year (CY) because biological activity generally lags behind water quality and is least active in winter.

3.1.1 Reservoir Sampling

The general sampling schedule included routine sampling events to the Reservoir at varying frequencies over the annual sampling period, as outlined below, with increased sampling frequency during the summer growing season (Table 3-1). A total of 14 reservoir sampling events were conducted during the 2015 WY. The December 2014 and January and February 2015 sampling events were not performed due to seasonal boat access closure and unsafe ice conditions at the Reservoir. Three main tasks were conducted during all sampling events on the Reservoir, including: 1) determining water clarity, 2) collecting physicochemical depth profiles, and 3) collecting water samples for chemical and biological analyses. In addition, supplemental cyanotoxin samples were collected during nine sampling events for a special study that was initiated in summer 2014. This special study was conducted to evaluate changes in cyanobacteria and cyanotoxins while the destratification system was not operated in 2014 and 2015.

Table 3-1: Sampling trips per sampling period, 2015 WY.

Sampling Period	Frequency	Planned Trips/Period	Actual Trips/Period
Oct - Apr	Monthly	7	4
May - Sept	Bi-Monthly	10	10
Total		17	14

3.1.1.1 Water Clarity

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

3.1.1.2 Profile Measurements

A Hydrolab MS5 Surveyor and Sonde was used for the collection of dissolved oxygen, temperature, conductivity, pH, and oxidation reduction potential (ORP) profile measurements at 1 m-intervals from the surface to the bottom of the Reservoir.

3.1.1.3 Chemical and Biological Data

Water samples of equal volumes were collected from the surface, 1 m, 2 m, and 3 m at the three Reservoir sites and composited to create a photic zone sample for each site. All photic zone samples were analyzed for nutrients (total nitrogen [TN], total dissolved nitrogen, nitrate and nitrite, ammonia, TP, total dissolved phosphorus [TDP], and soluble reactive phosphorus [SRP]), suspended solids (total suspended solids [TSS] and total volatile suspended solids [TVSS]), chloride, sulfate, and chlorophyll *a*. In addition, water samples of equal volumes were collected from 4 m, 5 m, 6 m, 7 m, and at the bottom of Site CCR-2 and were analyzed for nutrients, chloride, and sulfate. The CCR-2 photic and 7 m samples were also analyzed for total organic carbon (TOC) and dissolved organic carbon (DOC). Zooplankton tows (6 m depth at sites CCR-1 and CCR-2 and 4 m at Site CCR-3) were collected and composited to create one sample per event. Sample aliquots of equal volumes from each photic zone sample were composited to create one phytoplankton sample per event.

Sample event means are then used to calculate annual or seasonal mean values for key parameters such as chlorophyll *a*, TP, and, TN and to facilitate comparison with regulatory standards and goals that apply to the Reservoir. Depending upon the distributional characteristics of each parameter, annual values may be compared to either the long-term mean or median value. Secchi depth and chlorophyll *a* have normal distributions, thus it is more appropriate to compare annual values with the long-term mean. Conversely, the TP and TN data exhibit a log normal distribution; therefore it is more appropriate to compare annual values to the long-term median value. The Sampling and Analysis Plan (Appendix A) outlines the detailed methods used to collect lake water samples, as well as the laboratory methods in sample handling and preparation.

3.1.1.4 Cyanotoxin Data

Surface water grab samples were collected from the Swim Beach water area. These samples and the photic zone composite samples were analyzed for cyanotoxins during each sampling event from late May to late September. In addition, two “worst-case” surface water grab samples were collected from different locations within the reservoir where nuisance algal bloom conditions were visible and analyzed. Specifically, photic zone composite samples were only analyzed for microcystins, whereas the two “worst-case” samples were analyzed for anatoxins, microcystins, cylindrospermopsins, and saxitoxins. All samples were submitted to GreenWater Laboratories for cyanotoxin analysis.

3.1.1.5 Fish Population Data

Historically, this monitoring study has also reviewed fish stocking and population data collected by the Colorado Parks and Wildlife (CPW). The most recent fish population survey was conducted in the late summer 2015 by the CPW (personal communication with Paul Winkle, CPW). However, these data were not available to GEI at the time of finalizing the 2015 Cherry Creek Monitoring Report.

3.1.2 Stream Sampling

3.1.2.1 Base Flow Sampling

Base flow stream sampling was conducted on a monthly basis (12 events) at all stream sites in coordination with the routine Reservoir sampling trips to the Reservoir. This sampling was performed to characterize base flow conditions, which corresponds to the low-flow ambient samples collected in past studies. Monthly grab-samples are representative of non-storm, base flow periods on Cherry Creek, Cottonwood Creek, and McMurdo Gulch.

A Hydrolab MS5 Surveyor and Sonde was used for the collection of dissolved oxygen, temperature, conductivity, pH, and ORP at mid-water column. All grab-samples were analyzed for nutrient and suspended solids. Sites CT-2 and CC-10 were also analyzed for chloride, sulfate, TOC and DOC to assess surface, base flow water that is entering the Reservoir.

3.1.2.2 Storm Sampling

Wet weather sampling was conducted using ISCO Series 6700 or 6712 automated water samplers during storm events to characterize non-base flow conditions at the inflow sites and to assess the PRFs on Cherry Creek and Cottonwood Creek (Table 3-2). A detailed outline of wet weather (storm) automated sampling protocols can be found in the Sampling and Analysis Plan (Appendix A). Storm samples were not collected on McMurdo Gulch. Water samples were analyzed for nutrient and suspended solids to assess storm water that is entering the Reservoir.

Table 3-2: Number of storm samples collected from tributary streams to Cherry Creek Reservoir, 2015 WY. See Appendix C for sample dates.

	Sites					
	EcoPark	CC-10	CT-P1	CT-P2	CT-1	CT-2
Number of Storm Samples	3	6	7	7	5	7

3.1.3 Precipitation

Precipitation events were monitored by sampling bulk aeolian deposition and rainfall. Five rainfall samples were collected in 2015 and were analyzed for the suite of nutrients.

3.1.4 *Alluvial*

Site MW-9 was monitored monthly to assess alluvial groundwater entering the Reservoir. Groundwater was collected during the routine base flow sampling events and analyzed for the suite of dissolved inorganic nutrients, chloride, sulfate, TOC and DOC.

3.1.5 *Surface Hydrology*

Pressure transducers attached to ISCO Series 6700 or 6712 flowmeters measured and recorded water levels (stage) at six sites on the two tributaries to the Reservoir (Figure 2-1). These flow meters are programmed to record water level data on 15-minute intervals year round.

Streamflow (discharge) was calculated at CC-10, CT-1, and CT-P1 using a stage-discharge relationship developed for each stream site. For sites CT-2, CT-P2, and EcoPark, where the flow meters are located inside or connected to the concrete outlet structure, multi-level orifice and weir equations were used to estimate discharge. Periodic stream discharge measurements were collected during a range of flow conditions using a Marsh McBirney Model 2000 flowmeter to develop the stage-discharge relationships. For a complete description of streamflow determination, see Appendix D.

3.2 Laboratory Procedures

3.2.1 *Nutrient Laboratory Analysis*

Physicochemical and biological analyses from the Reservoir and stream water quality samples were performed by the GEI analytical laboratory (Table 3-3). Quality Assurance/Quality Control protocols for the low level nutrient analyses were performed by the GEI Laboratory, with all results being reported in Appendix B.

Table 3-3: Parameter list, method number, and detection limits for chemical and biological analyses of water collected from Cherry Creek Reservoir and tributaries.

Parameter	Method	Detection Limit
Total Phosphorus	QC 10-115-01-4-B	2 µg/L
Total Dissolved Phosphorus	QC 10-115-01-4-B	2 µg/L
Soluble Reactive Phosphorus	QC 10-115-01-1-T	2 µg/L
Total Nitrogen	QC 10-107-04-4-B	6 µg/L
Total Dissolved Nitrogen	QC 10-107-04-4-B	6 µg/L
Ammonium Ion	QC 10-107-06-2-A	5 µg/L
Nitrate and Nitrite	QC 10-107-04-1-C	2 µg/L
Nitrite as N	QC 10-107-04-1-C	2 µg/L
Total Suspended Solids	APHA 2540D	4 mg/L
Total Volatile Suspended Solids	APHA 2540E	4 mg/L
Total Organic Carbon	SM 5310B	0.16 µg/L
Dissolved Organic Carbon	SM 5310B	0.16 µg/L
Chloride	EPA 300.0/SW846 9056	--
Sulfate	EPA 300.0/SW846 9056	--

Parameter	Method	Detection Limit
Chlorophyll <i>a</i>	APHA 10200 H (modified)	0.1 µg/L
Phytoplankton	APHA 10200 C.2	--
Zooplankton	APHA 10200 G	--

Notes:

APHA = American Public Health Association, 1998.

3.2.2 **Biological Laboratory Analysis**

Biological analyses of the Reservoir phytoplankton samples were conducted by Aquatic Analysts, Friday Harbor, Washington. Aquatic Analysts performed phytoplankton identification and enumeration and biovolume (μm^3) per unit volume [#/milliliter (mL)], while GEI performed the chlorophyll *a* concentrations ($\mu\text{g/L}$). Water's Edge Scientific LLC, Baraboo, Wisconsin performed zooplankton identification, enumeration, and biomass ($\mu\text{g/L}$). Cyanotoxin samples were analyzed by GreenWater Laboratory, Palatka, Florida.

3.3 **Evaluation of Long-Term Trends in Cherry Creek Reservoir**

Long-term seasonal trends were evaluated for Secchi depth, chlorophyll *a*, and TP using whole-reservoir mean values from 1987 to 2015 and linear regression analysis (described below). Additionally, 95% confidence intervals provided information on data dispersal around the mean annual values. These analyses were used to determine whether there was significant long-term increasing or decreasing trends in Secchi depth, TP, and chlorophyll *a* levels.

Comparisons of biological and physical parameters for each site were conducted using NCSS 2007 statistical software (Hintze 2009). Basic descriptive statistics were used to evaluate the distributional characteristics of the data, and to determine whether a variable required transformation to meet the basic assumptions of normality or whether outliers existed in the data. Logarithmic transformations were used to increase the symmetry of the data about the mean, approximating a normal distribution. If the transformation did not improve normality, the untransformed data were used in subsequent analyses.

The least-squares linear regression was used to estimate slope, with analysis of variance 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. Results and Discussion

4.1 Reservoir Water Quality

4.1.1 2015 WY Transparency

The whole-reservoir mean Secchi depth varied from 0.74 m in mid-March and late September to 1.68 m in late May (Figure 4-1). The seasonal (July through September) whole-reservoir mean Secchi depth was 0.92 m. The depth at which 1% of photosynthetically active radiation penetrated the water column (i.e., photic zone depth) ranged from 2.33 m in late September to a maximum depth 3.68 m in late May (Figure 4-1). The greatest levels of whole-reservoir chlorophyll *a* concentration occurred in October and November, 2014 (35.2 and 33.4 $\mu\text{g/L}$, respectively) during low transparency and continued an increasing trend observed at the end of the 2015 WY.

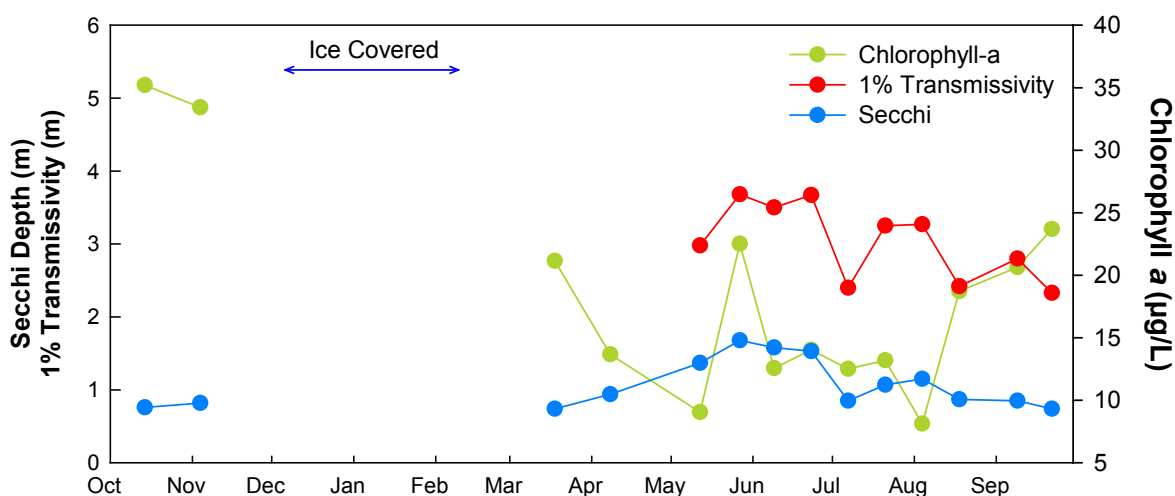


Figure 4-1: Patterns for mean whole-reservoir Secchi depth, 1% transmissivity, and chlorophyll *a* in Cherry Creek Reservoir, 2015 WY.

4.1.2 Long-Term Secchi Transparency Trends in Cherry Creek Reservoir

In general, seasonal mean (July through September) Secchi depths increased from 1987 to 1996, then decreased in 1997 to a level at which they have been relatively stable until recent years (Figure 4-2) when the destratification system was in operation and clarity decreased (2009-2012). The post destratification system (2014 and 2015) seasonal whole-reservoir mean Secchi depths were slightly less than near the long-term (1987 to present) mean value of 0.95 m. In terms of water clarity, the 2015 Reservoir conditions were very similar to historical conditions (i.e., prior to 2008) in the absence of destratification management.

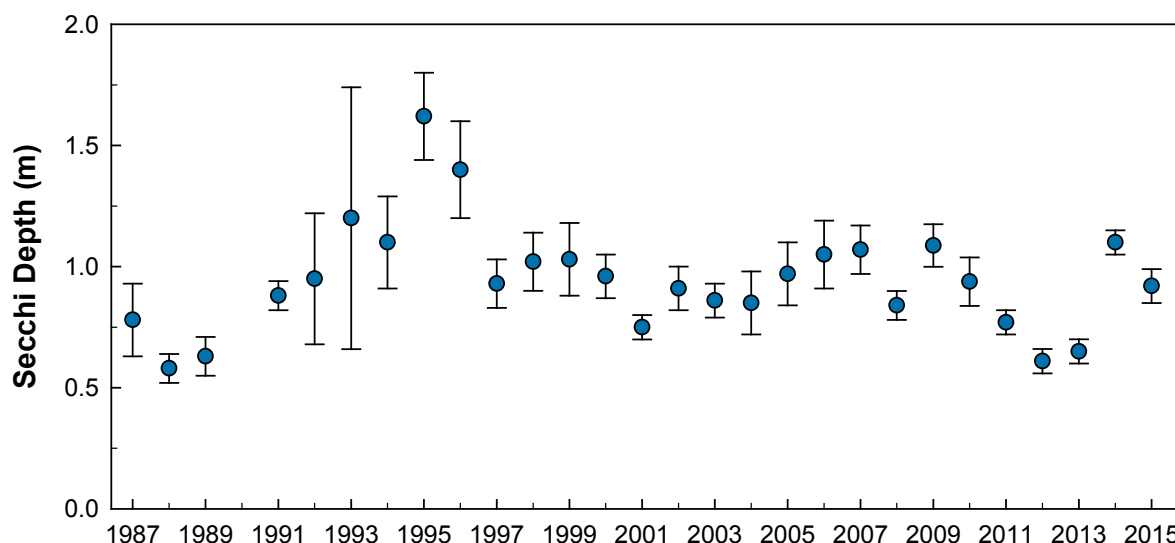


Figure 4-2: Whole-reservoir seasonal mean (July through September) Secchi depth (m) measured in Cherry Creek Reservoir. Error bars represent a 95% confidence interval for each mean.

4.1.3 2015 WY Temperature and Dissolved Oxygen

Analysis of past 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 indicate mixing (Jones 1998). This criterion is generally supported by the classical definition of a thermocline, as being the layer with the greatest rate of change in temperature or dt/dz greater than 1°C/m. However, given the relatively shallow nature of the Reservoir and the temperature-density relationships, the Reservoir can become stratified even though the greatest rate of change may be less than 1°C. In addition, relative thermal resistance to mixing (RTRM) can be used to evaluate stratification as a function of temperature differentials in the water column (Wetzel 2001). Dissolved oxygen profiles are also used to evaluate periods of stratification when temperature differences are less than 1°C.

Water temperatures during routine profile measurements in the Reservoir ranged from 7.3°C on the reservoir bottom (5 m at CCR-3) in mid-March 2015 to 25.3°C at the surface (CCR-1) in late June (Figure 4-3; Figure 4-5; Figure 4-7). Temperature profile data indicated a fairly well-mixed reservoir in early spring with increasing stratification occurring from early April to late July.

From mid-October 2014 to late May 2015, the dissolved oxygen concentrations throughout the water column remained greater than the Colorado dissolved oxygen standard for warm water lakes of 5 milligrams per liter (mg/L) (Figure 4-4; Figure 4-6; Figure 4-8). While this standard, as written, only applies to the surface 0.5 m to 2.0 m water layers, it is important to note that the 5 m layers and deeper to the water/sediment interface were consistently less

than 5 mg/L at CCR-1 and 2 from early June through September. At CCR-3, dissolved oxygen below 4 m depths was sporadically below the 5 mg/L threshold between June and November. Dissolved oxygen at this concentration is low and offers little refuge to fish that typically seek deeper, cooler water as summer water temperatures increase.

Reservoir profiles were also evaluated to determine the attainment of the dissolved oxygen standard. Over the course of the monitoring year, 72 vertical water column profiles were collected in the Reservoir. For each profile, the 1 m and 2 m dissolved oxygen values were averaged and evaluated for attainment of the Class 1 Warm Water table value standard (5 mg/L) for lakes and reservoirs that are greater than 5 m deep (CDPHE 2011). The Reservoir was in attainment of the dissolved oxygen standard for 68 of 72 profiles. The exceedances occurred on August 4, with minimum mean dissolved oxygen values of 4.7 mg/L, 4.8 mg/L, and 4.9 mg/L at Site CCR-1, 2, and 3, respectively and on August 18 with a value of 4.6 mg/L at CCR-2. During the July to September growing season, the mean dissolved oxygen concentration of the upper layer was 6.4 mg/L for all vertical profiles.

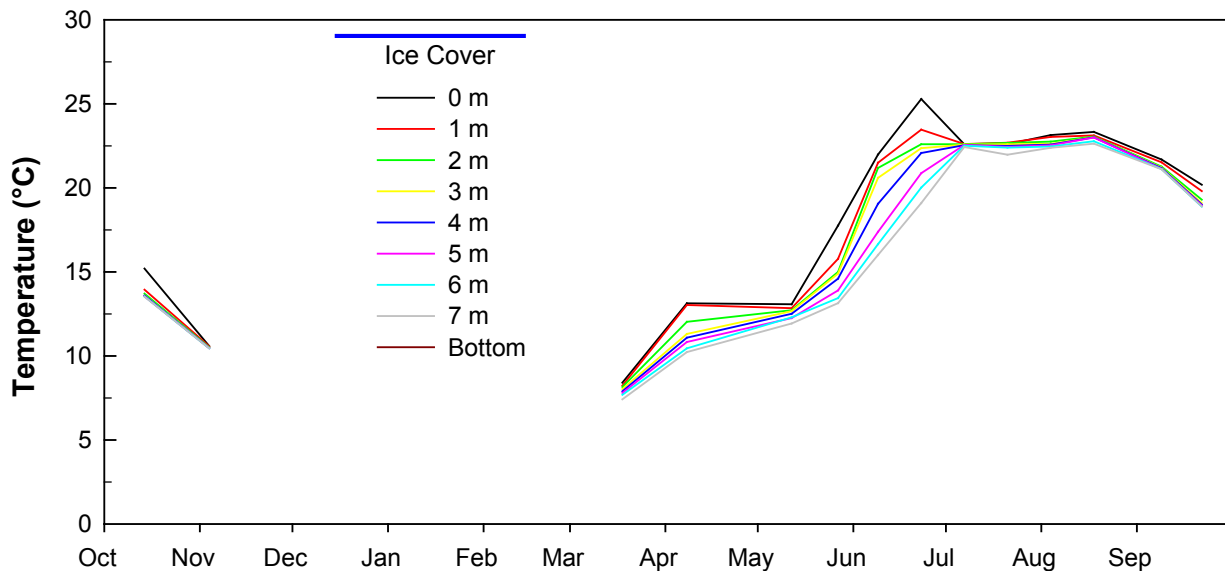


Figure 4-3: Temperature (°C) recorded at depth during routine monitoring at CCR-1 during the 2015 WY. Bottom depth is 7.2 to 8.8 m.

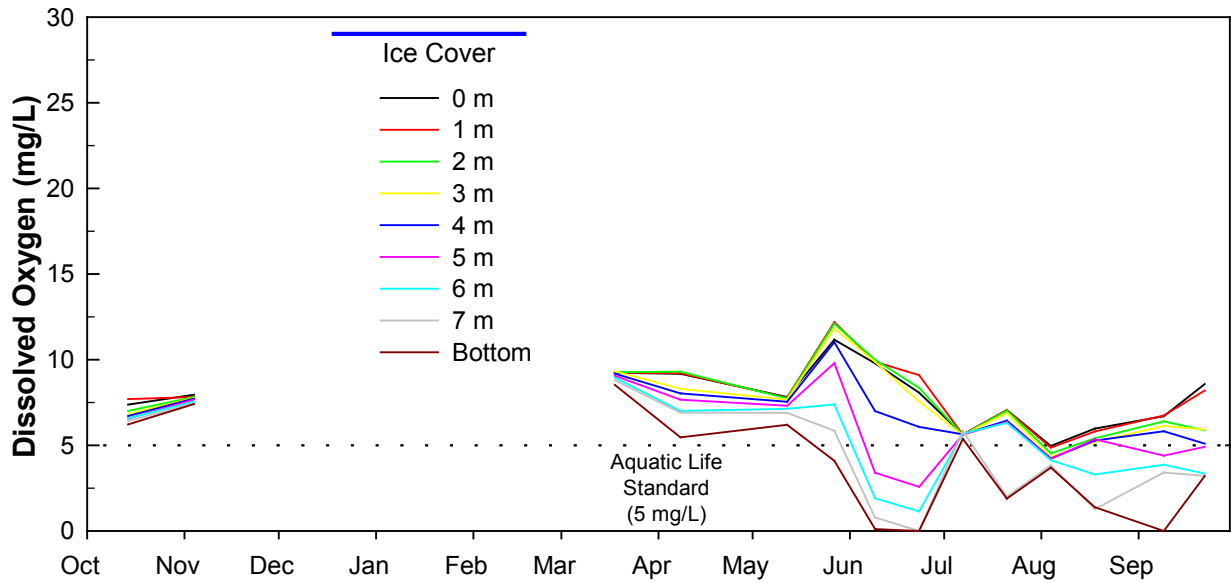


Figure 4-4: Dissolved oxygen (mg/L) recorded at depth during routine monitoring at CCR-1 during the 2015 WY. The dissolved oxygen basic standards table value for Class 1 warm water lakes and reservoirs is provided for comparison (5 mg/L). Bottom depth is 7.2 to 8.8 m.

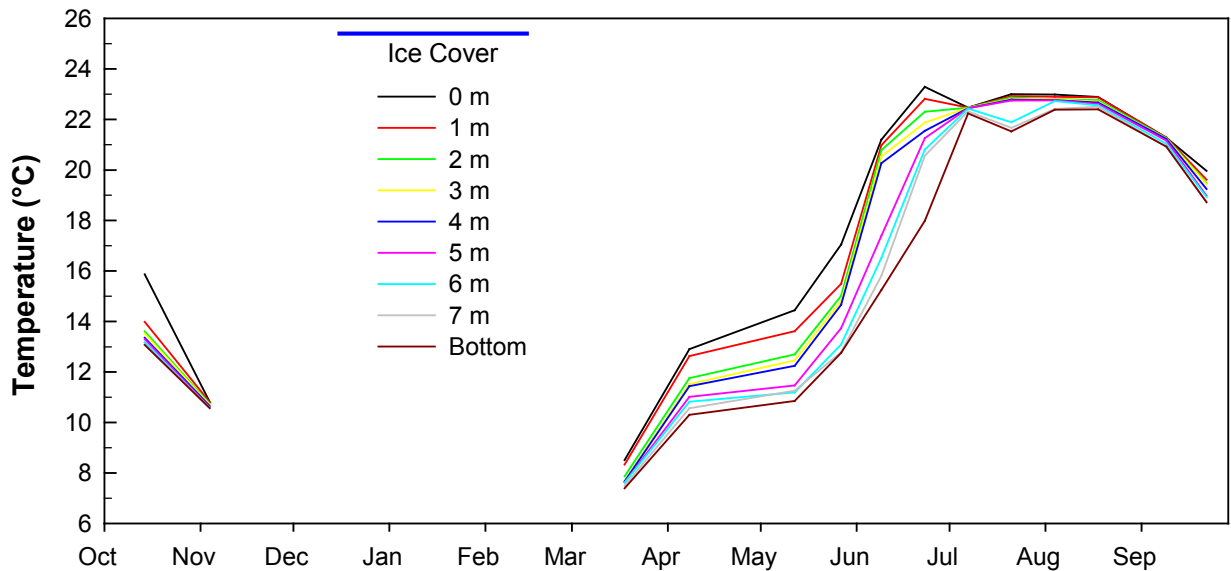


Figure 4-5: Temperature (°C) recorded at depth during routine monitoring at CCR-2 during the 2015 WY. Bottom depth is 7.2 to 8.8 m.

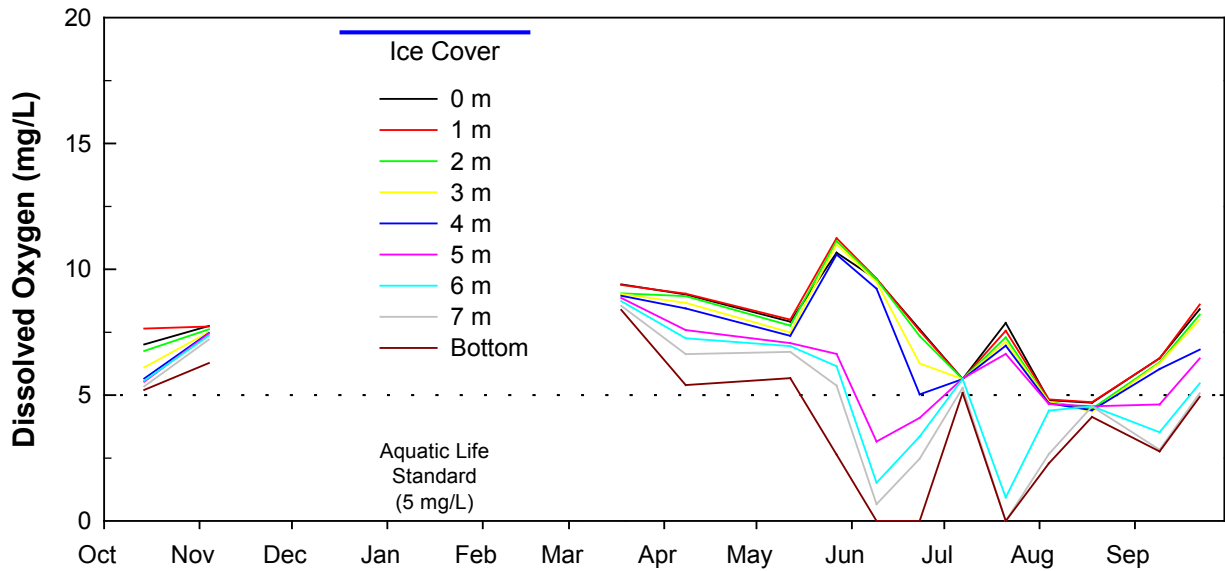


Figure 4-6: Dissolved oxygen (mg/L) recorded at depth during routine monitoring at CCR-2 during the 2015 WY. The dissolved oxygen basic standards table value for Class 1 warm water lakes and reservoirs is provided for comparison (5 mg/L). Bottom depth is 7.2 to 8.8 m.

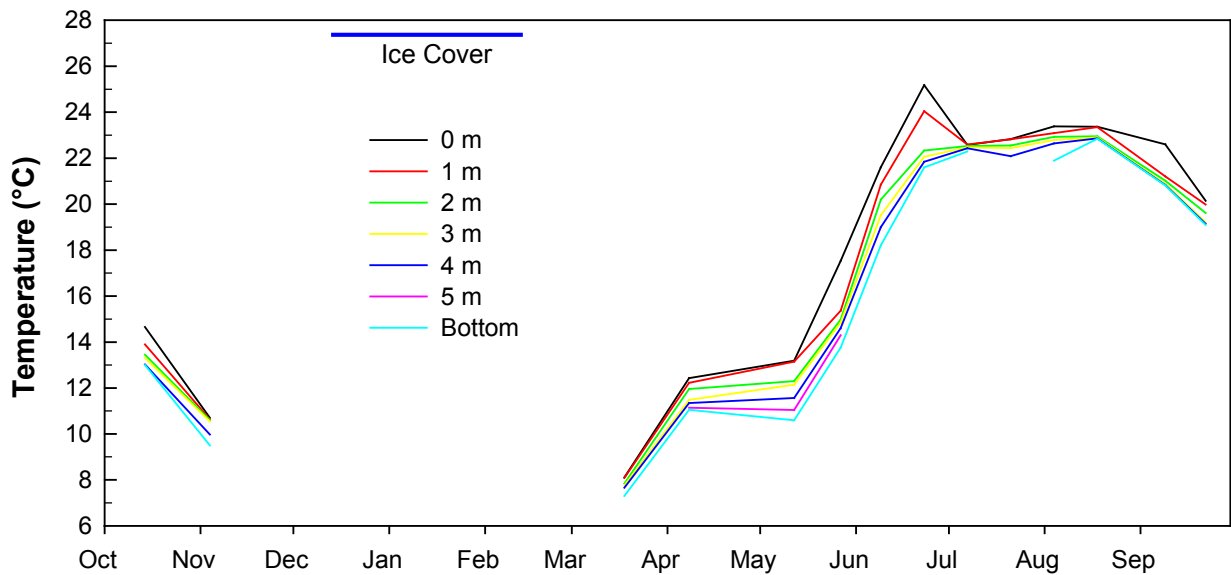


Figure 4-7: Temperature (°C) recorded at depth during routine monitoring at CCR-3 during the 2015 WY. Bottom depth is 4.6 to 6.3 m.

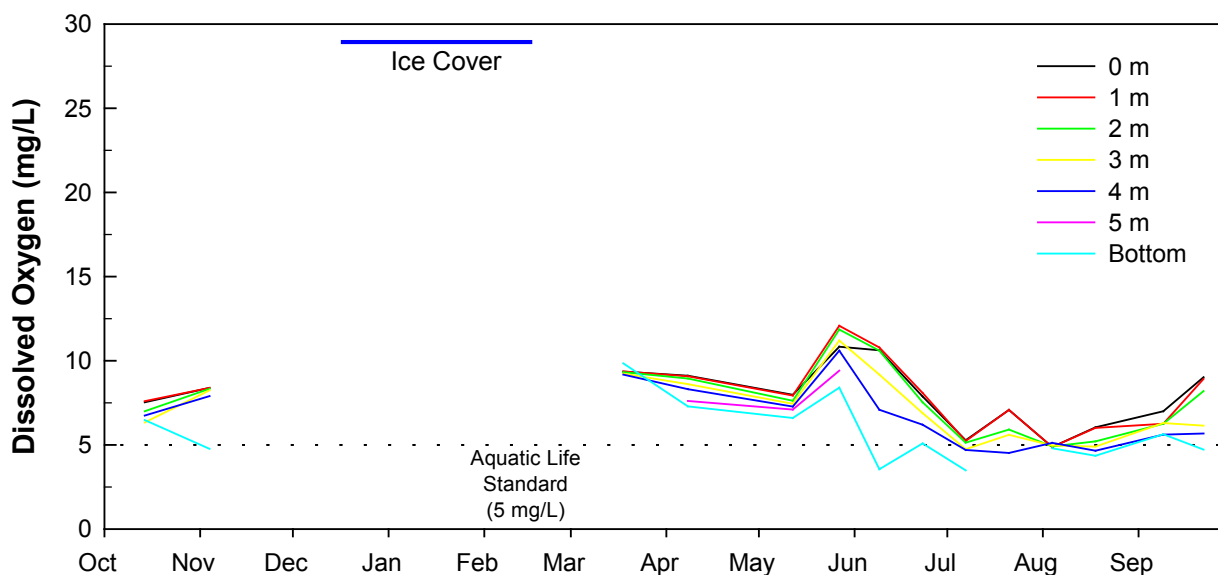


Figure 4-8: Dissolved oxygen (mg/L) recorded at depth during routine monitoring at CCR-3 during the 2015 WY. The dissolved oxygen basic standards table value for Class 1 warm water lakes and reservoirs is provided for comparison (5 mg/L). Bottom depth is 4.6 to 6.3 m.

The RTRM metric was calculated for Site CCR-2 to evaluate stratification as a function of density gradients in the water column (Figure 4-9). Widespread water column resistance to mixing was limited to May and June with density gradients occurring near the surface (1-3m) and mid-water column (4-6m) on May 12th and 27th, at mid-water column on June 9th and July 21st, and at the bottom (6-8m) on June 23rd. The greater RTRMs on these dates indicate a strong density gradient with limited mixing at the specified depths while other depths were only weakly stratified. Greater resistance at the surface can facilitate algae growth because algae is not actively mixed to deeper depths where photosynthesis is limited by available light. Very low RTRM values were calculated throughout the water column for November, March, early July, mid-August, and September indicating a well-mixed water column.

Throughout June, dissolved oxygen concentrations at depths greater than 5 m were less than the upper threshold that facilitates internal loading (2 mg/L) and created an anoxic environment near the water/sediment boundary (Figure 4-4; Figure 4-6; Figure 4-8). At this same time, the reservoir was not mixing, as evident by the dissolved oxygen and thermal stratification and high RTRMs throughout the water column. However, on July 7th, dissolved oxygen, temperature, and RTRMs profiles and a decrease in water clarity indicated that the water column had become well mixed due to a storm event in late June. By July 21st, dissolved oxygen concentrations had again decreased at depths greater than 6 m to values less than the upper threshold (2 mg/L; Figure 4-4; Figure 4-6; Figure 4-8). The Reservoir also became thermally stratified and resistant to mixing at depth (Figure 4-3; Figure 4-5; Figure 4-7). Another whole lake mixing event occurred by mid-August and the Reservoir remained mixed with low water clarity for the remainder of the water year.

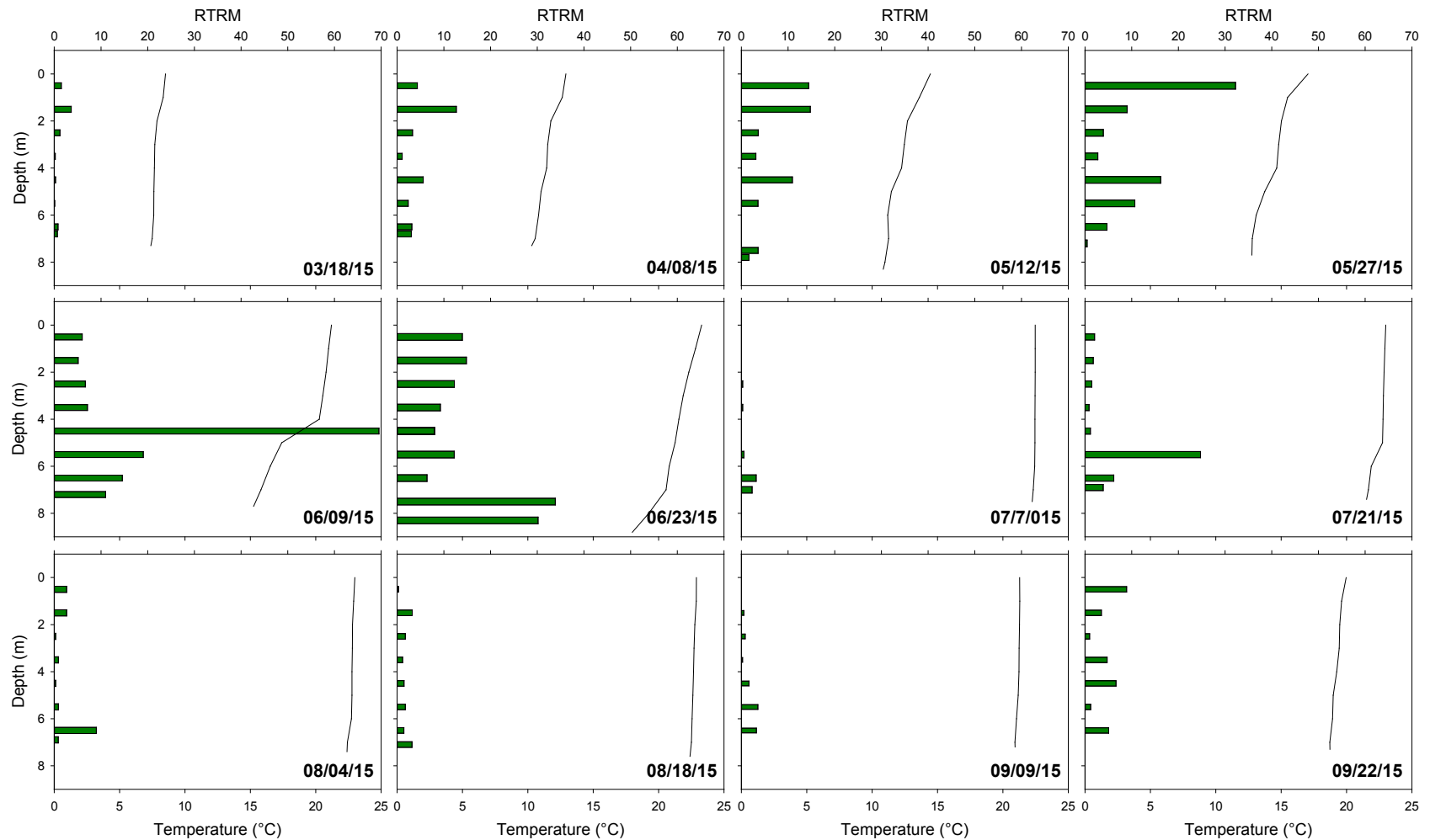


Figure 4-9: Relative thermal resistance to mixing gradients and temperature profiles for Cherry Creek Reservoir, June – September, 2015.

4.1.3.1 Continuous Temperature Monitoring

On April 9, 2015, continuous temperature loggers were deployed at CCR-1, 2, and 3 for monitoring the conditions indicative of thermal stratification. Using the $> 2^{\circ}\text{C}$ difference criteria from the surface to the bottom, the Reservoir was evaluated for periods of stratification using the continuous temperature record at depths for all three Reservoir sites from April 9th to November 9th (Figure 4-10; Figure 4-11; Figure 4-12). Temperature loggers at CCR-1 were inadvertently removed from the reservoir by State Park Personal from September 25th to November 13th and temperature data was not recorded. The Reservoir exhibited several periods of thermal stratification with conditions varying slightly by site throughout the monitoring period. Overall, the Reservoir exhibited several periods of thermal stratification that occurred from approximately April 30th - May 7th, May 11th, May 26th - July 5th, July 11th - July 17th, July 23rd - July 24th, July 26th - July 27th, August 11th - August 13th, and August 15th. These findings are in alignment with the temperature profiles and the evidence of stratification collected with the Hydrolab Sonde. Mixing events between periods of stratification through the end of May are largely attributed to inflow from storm events. Rainfall events in June had minimal effects on stratification because the reservoir volume greatly affected thermal characteristics. In 2015, the Reservoir was stratified for approximately 65 days between April 9th and November 9th and, in 2014, the Reservoir was stratified for approximately 46 days. Both years possessed a greater number of stratification events compared to 2013 which is due to the fact that the destratification system was not in operation during 2014 and 2015.

The Reservoir is classified as a Class I Warm Water reservoir which has a 1 m depth temperature standard of 26.3°C (chronic, ch) and 29.5°C (acute, ac) for summer months (April-December) and 13.2°C (ch) and 14.8°C (ac) for winter months (January-March; CDPHE 2011). The summer CCR-2 daily maximum (DM; 25.6°C) and maximum weekly average temperatures (MWAT; 23.9°C) attained the warm water standards. The temperature loggers were not in place for winter months.

Temperature loggers were also installed in Cherry Creek (CC-10), in Cottonwood Creek (just downstream of CT-2; Figure 4-13), at in the well at MW-9 to provide supplemental data temperature for the tributaries and groundwater (Appendix F). These tributary loggers operated from mid-March to late November and the MW-9 logger from early October, 2014 to late June. Cherry Creek and Cottonwood Creek are classified as warm water tier II streams which have a temperature standard of 28.6°C (ch) and 27.5°C (ac) for summer months. The summer DM and MWAT at CC-10 (23.2 and 18.8°C , respectively) and CT-2 (27.9 and 23.6°C , respectively) did not exceed the warm water standards. The temperature loggers were not in place for winter months. Alluvial DM (10.9°C) and MWAT (10.7°C) do not have a standard for comparison.

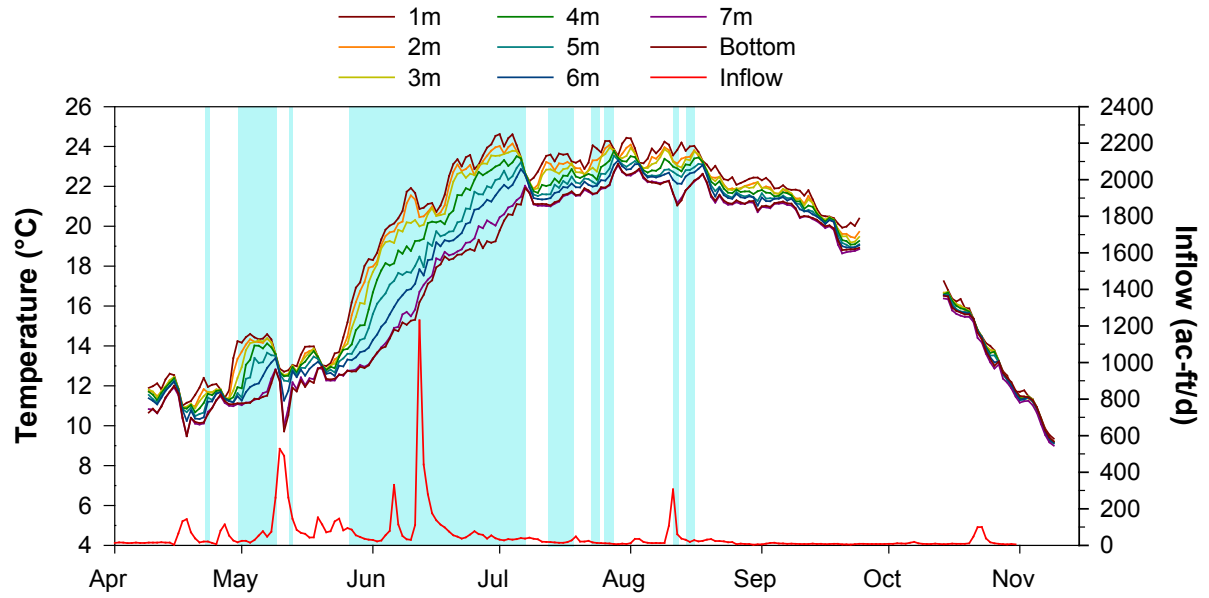


Figure 4-10: Daily mean temperature (°C) recorded at depth for CCR-1 based on 15-minute interval data collected by temperature loggers, with USACE inflow in 2015. Shaded areas denote periods of thermal stratification.

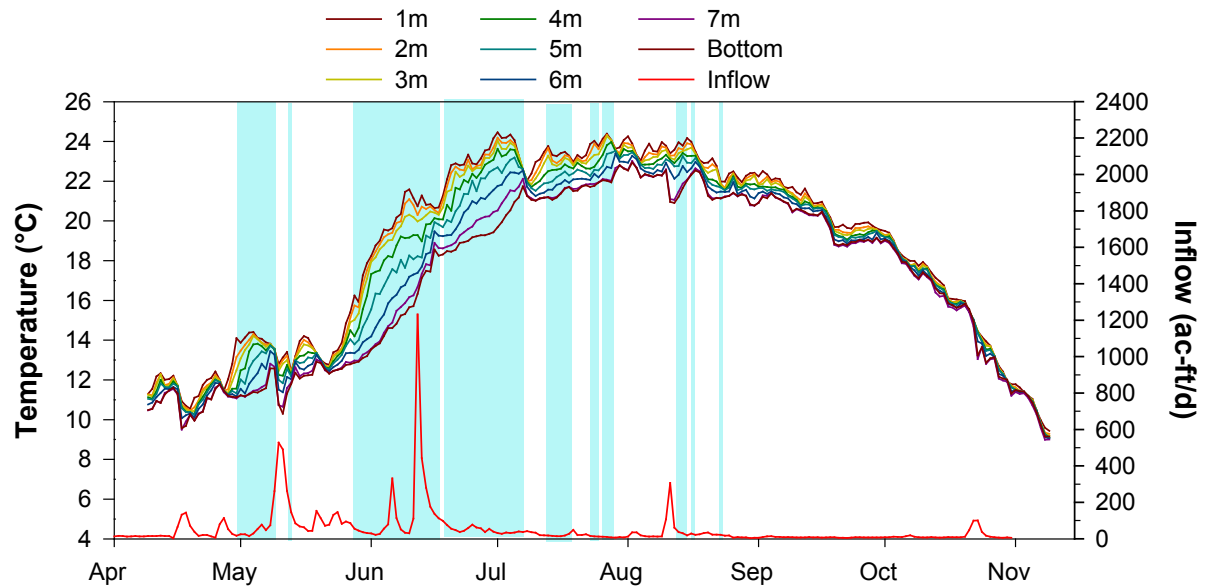


Figure 4-11: Daily mean temperature (°C) recorded at depth for CCR-2 based on 15-minute interval data collected by temperature loggers, with USACE inflow in 2015. Shaded areas denote periods of thermal stratification.

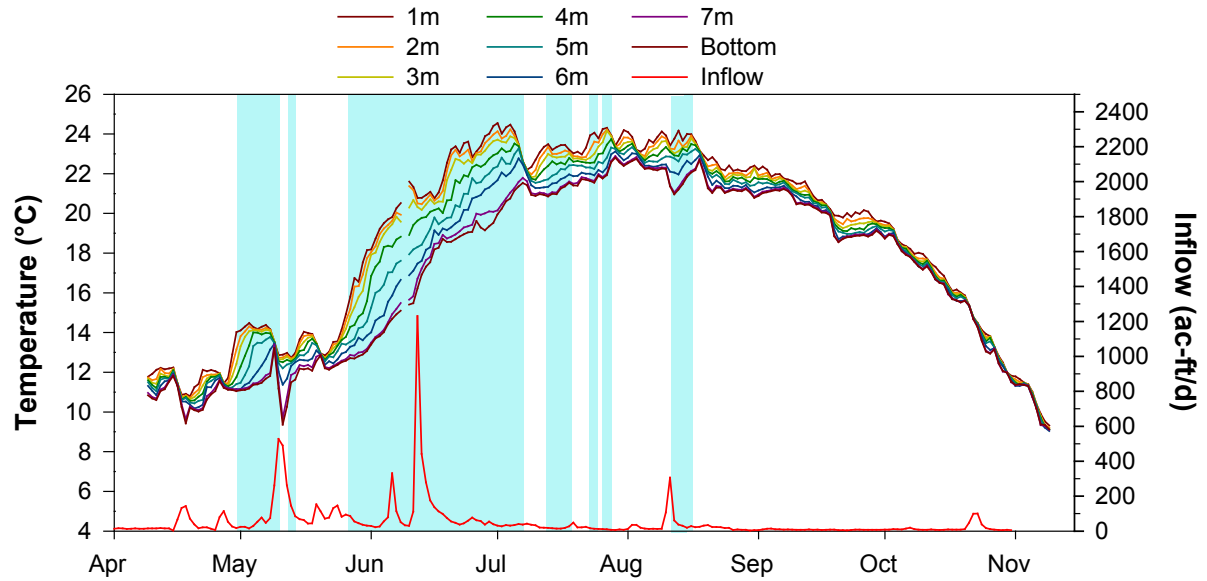


Figure 4-12: Daily mean temperature (°C) recorded at depth for CCR-3 based on 15-minute interval data collected by temperature loggers, with USACE inflow in 2015. Shaded areas denote periods of thermal stratification.

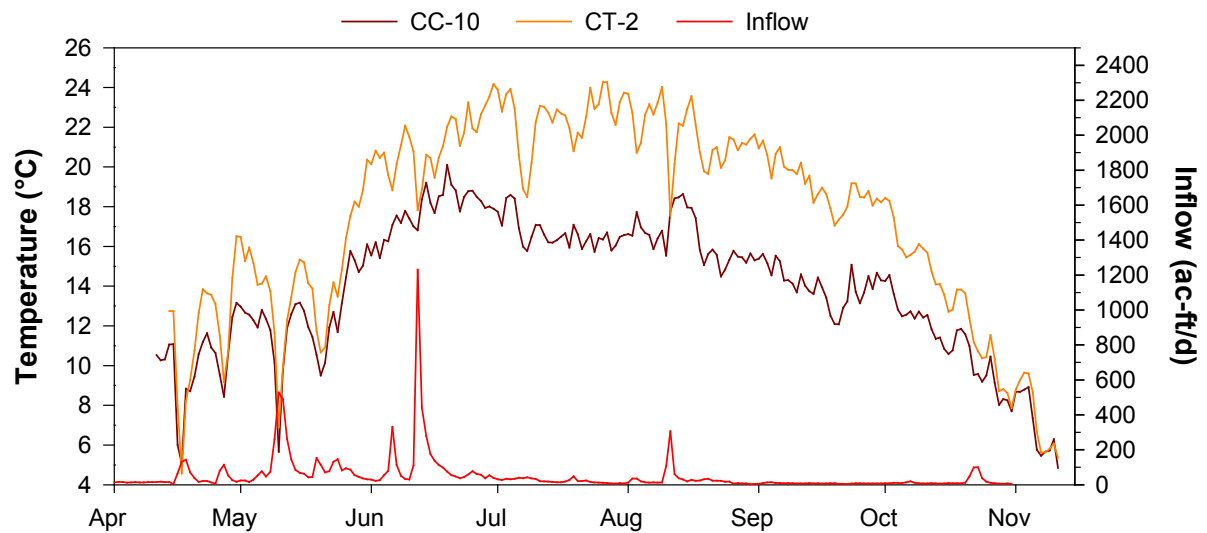


Figure 4-13: Daily mean temperature (°C) recorded at Cherry Creek and Cottonwood Creek based on 15-minute interval data collected by temperature loggers.

4.1.3.2 Dissolved Oxygen and Oxidation-Reduction Potential Transect

The water quality transect was established in the Reservoir originating from approximately the mid-point of the dam and extending southward across the Reservoir, towards the inlet region (see Figure 2-1). To evaluate the effect of the destratification system on reservoir mixing, water column dissolved oxygen and ORP profiles have been collected on three sample dates at 10 locations along the transect (Figure 4-14). These data document the areal extent of low dissolved oxygen and reducing conditions near the water/sediment interface. Low dissolved oxygen conditions (i.e., < 2 mg/L) facilitate the internal release of soluble nutrients that promotes algae growth during the summer.

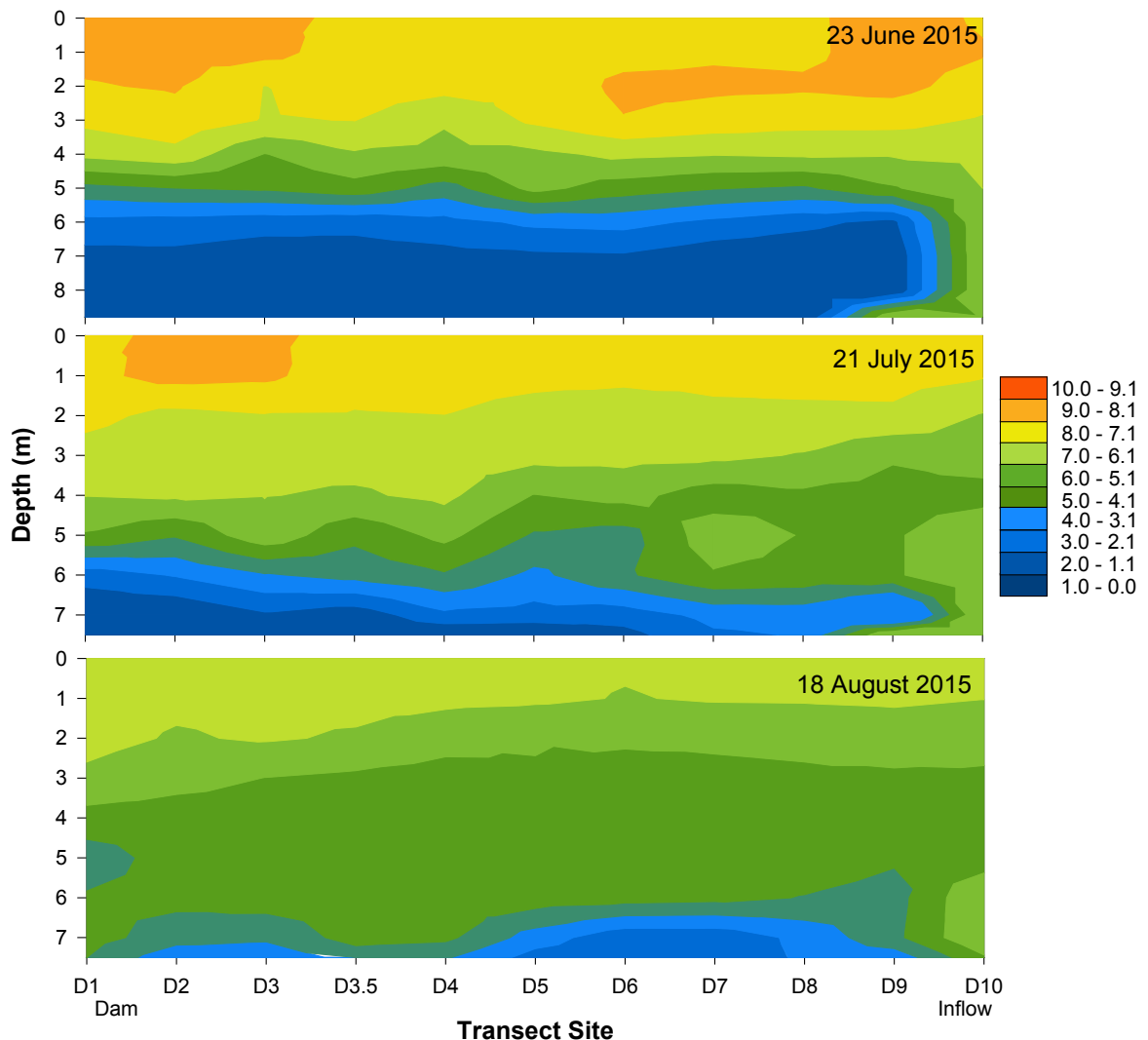


Figure 4-14: Dissolved oxygen conditions in Cherry Creek Reservoir for three dates based on transect profile data during the 2015 WY.

On June 23rd, the Reservoir was roughly a meter deeper than the normal operating level due to excessive rainfall. At this time the Reservoir was well oxygenated (i.e., > 5 mg/L) from the surface down to a depth of approximately 5 m (Figure 4-14). This pattern was consistent from

D1 near the dam to D10, at which point the maximum Reservoir depth is shallower. The mean dissolved oxygen concentration for the 1 m and 2 m depths along the transect was 7.9 mg/L indicating the Reservoir was in attainment of the dissolved oxygen standard. Low oxygen conditions (<2 mg/L) were evident near the bottom of the Reservoir (7 m, 8 m, and bottom) with a mean of 0.2 mg/L. The mean water/sediment interface was anoxic (i.e. 0 mg/L).

By July, the Reservoir had returned to the normal operating level and the July 21st transect documents a slightly less stratified Reservoir (Figure 4-14). The mean dissolved oxygen concentration of the 1 m and 2 m layer values along the transect was 7.2 mg/L which was slightly less than on June 23rd, and still in attainment of the warm water standard (5 mg/L). The lower portion of the Reservoir (6 m, 7 m, and bottom) was hypoxic (i.e. low dissolved oxygen) for most sites, with a mean dissolved oxygen concentration of 1.7 mg/L. The majority of water/sediment interface values indicated anoxia (0.5 mg/L).

The Reservoir was less stratified on August 18th than during the previous sample events (Figure 4-14). The mean dissolved oxygen concentration of the 1 m and 2 m layer was 5.9 mg/L which was considerably less than on July 21st, but still in attainment of the warm water standard. The dissolved oxygen concentrations in the lower portion of the Reservoir (6 m, 7 m, and bottom) increased greatly from the two previous sampling events to a level of 3.1 mg/L. In fact, the water/sediment dissolved oxygen concentration was not anoxic (2.1 mg/L). Findings on these three dates are in alignment with the dissolved oxygen profiles and the evidence of stratification collected with the Hydrolab Sonde.

Oxidation reduction potential measurements are used to quantify the exchange of electrons that occur during oxidation-reduction reactions (redox reactions). Electrical activity is reported in millivolts (mV) which is very similar to a pH probe. At the water/sediment boundary layer, microbial organisms facilitate the chemical reactions but do not actually oxidize or reduce the compounds. The redox reactions provide energy for microbial cells to carry out their metabolic processes (Wetzel 2001). The combination of microbial organisms and redox reactions are responsible for the breakdown of organic matter and development of anoxic conditions near the sediment boundary in reservoirs during the summer.

This interface between water and sediment acts as a barrier to the free exchange of soluble nutrients but (e.g., anoxic-reducing environment) phosphorus can be released (i.e., internal load) at rates as much as 1,000 times faster during anoxic conditions than during well oxygenated conditions (Horne and Goldman 1994). Although the rate of exchange of nutrients (mainly phosphorus) at this interface remains unknown for the Reservoir, this internal nutrient loading component of the Reservoir has been estimated to account for approximately 25% of the cumulative TP load from 1992 to 2006 (Nürnberg and LaZerte 2008).

In the Reservoir, the water column ORP measurements will often range between 100 to 300 mV depending upon the seasonal conditions. On any given date, the water column ORP conditions, from the surface waters down to approximately the 6 m layer, will be

relatively uniform because sufficient dissolved oxygen is in the water column to maintain compounds in their most oxidized state. However, when anoxic conditions exist at depths greater than 6 m or near the water/sediment interface, the redox potential will sharply decrease, often ranging from -200 to 0 mV. These conditions facilitate internal nutrient loading where soluble nutrients (nitrogen and phosphorus) and forms of iron, manganese, and sulfur are released from the sediment. When reviewing ORP profile measurements, the occurrence of a sharp inflection point (i.e., low or negative values) in the profile indicate where conditions are favorable for redox reactions to occur.

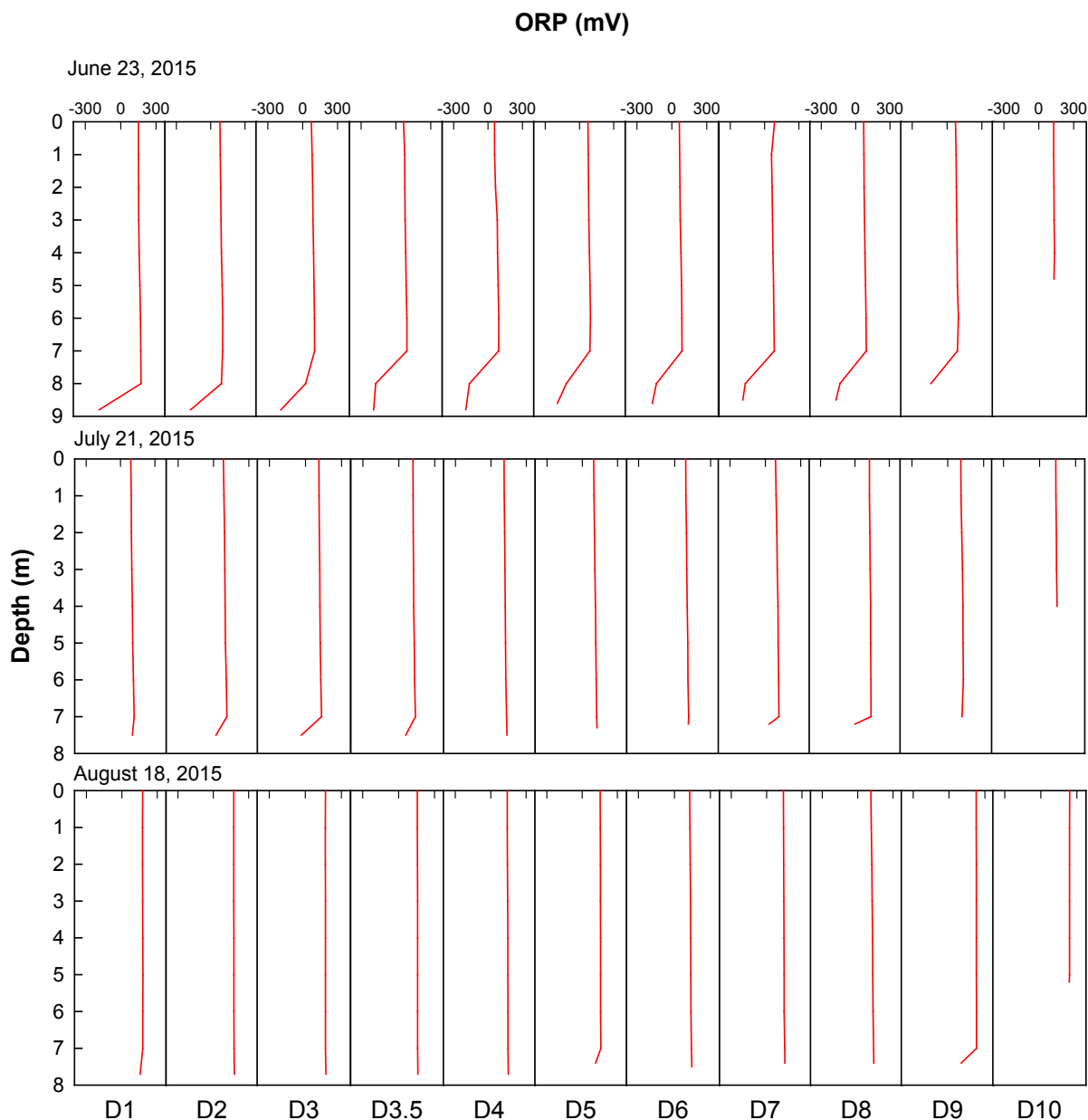


Figure 4-15: Oxidation reduction potentials in Cherry Creek Reservoir for three dates based on transect profile data during the 2015 WY. The ORP scales for each transect are all relative to each other within and among sampling events.

The June 23rd ORP conditions near the water/sediment interface indicated a strong reducing environment while those observed on July 21st were moderate (Figure 4-15). This is consistent with the anoxic bottom water and stratification and high RTRMs observed on those days. Alternatively, the August 18th ORP conditions indicated a weak reducing environment and sufficient dissolved oxygen with a thoroughly mixed water column.

4.1.4 2015 WY Nutrients

Monitoring at the Reservoir has focused on phosphorus and nitrogen concentrations because these inorganic nutrients are often the contributing or limiting factor in the growth of algae (Cole 1979; Horne and Goldman 1994; Wetzel 2001; Cooke et al. 1993). Excessive amounts of these nutrients in aquatic systems often result in algal blooms that create aesthetic problems as well as potentially unsuitable conditions for aquatic life. An imbalance in the nitrogen and phosphorous relationships (N:P ratio) in the Reservoir can result in one of these nutrients limiting algal growth and the limiting nutrient can change throughout the year. Ultimately, relatively low nutrient concentrations are necessary to greatly reduce algal biomass as measured by chlorophyll *a*.

During the 2015 WY, the photic zone mean concentration of TP ranged from 46 to 121 µg/L (Figure 4-16) with an overall water year mean of 79 µg/L. The seasonal photic zone mean concentrations ranged from 65 to 121 µg/L, with a seasonal mean of 93 µg/L. The photic zone mean concentration of TN ranged from 648 to 1,097 µg/L (Figure 4-16) with an overall water year mean of 825 µg/L. The seasonal photic zone mean concentrations ranged from 648 to 901 µg/L, with a seasonal mean of 759 µg/L. Storm-induced external loads likely contributed to the TP and TN content within the photic zone during May and June (Figure 4-16); however, other factors such as internal loading and algal uptake also affected the seasonal pattern in total phosphorous.

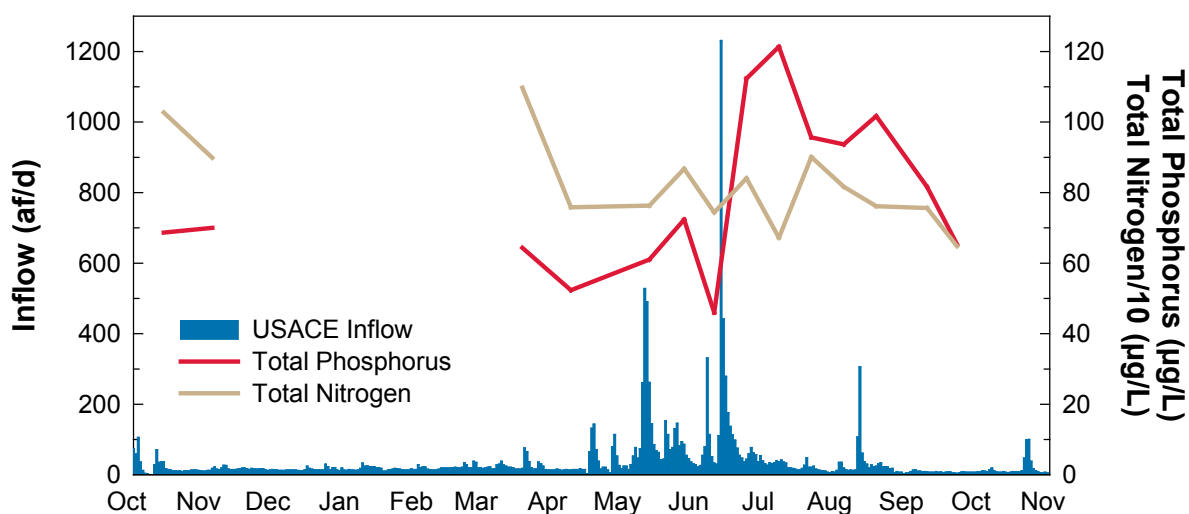


Figure 4-16: Annual pattern of photic zone total phosphorus, total nitrogen and USACE inflow in Cherry Creek Reservoir, 2015 WY.

Concentrations of bioavailable nutrients (SRP; nitrite, nitrate, and ammonia known collectively as total inorganic nitrogen [TIN]) collected during profile sampling at Site CCR-2 indicated a well-mixed Reservoir in late fall 2014 and early spring 2015, (Figure 4-17; Figure 4-18) which is consistent with temperature, dissolved oxygen, and RTRM data during that time. Elevated bioavailable nutrients occurred on most other sample dates through the rest of the water year and nutrient concentration typically increased with depth indicating an extended period of nutrient release from bottom sediments. Nutrient concentrations were relatively high at the water/sediment interface from mid-May to early Aug except for the mixing event that occurred in early July. Soluble reactive phosphorous remained elevated through the mixing event and was evenly distributed through the water column. The period of observed heightened nutrients at the Reservoir bottom suggest that even a few centimeters of anoxic water at the water/sediment interface, which sonde may not have captured, is sufficient for creating a reducing environment and internal load release of nutrients. Soluble reactive phosphorous at these depths accounted for approximately 41 to 81% of the TP content while TIN accounted for approximately 2 to 22% of the TN content. These percentages also indicate that soluble phosphorus and nitrogen was being released from the sediment during that time.

Prior to 2014 when the destratification system was operational, phosphorous and nitrogen were generally consistency within the upper layers of the water column due to the upward diffusion of nutrients from the sediment layer and the eventual circulation within the upper layers by the destratification system. In terms of nutrient concentrations, the destratification system appears to create a well-mixed layer from the surface down to approximately the 6 m depth (GEI 2013), which is slightly above the aerator heads (approximately 0.75 m above the sediment). However, this consistency in the upper layers of the Reservoir was not as apparent during June through September, 2014 and mid-May to mid-October, 2015 when the destratification system was not operating.

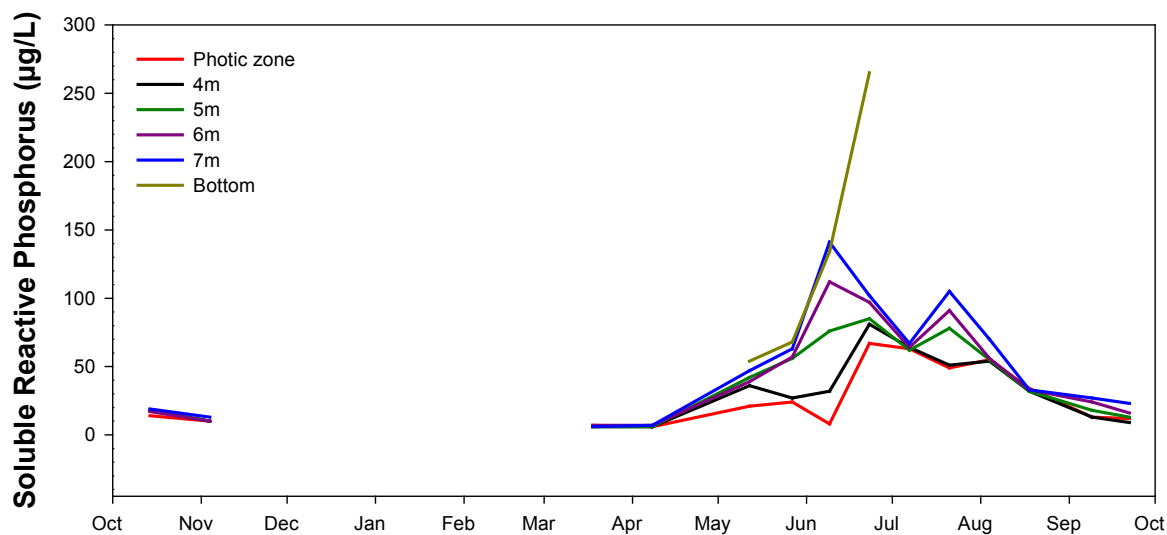


Figure 4-17: Soluble phosphorus concentrations recorded for the photic zone and at depth during routine monitoring during the 2015 WY at CCR-2. Bottom depth is 7.2 to 8.8 m.

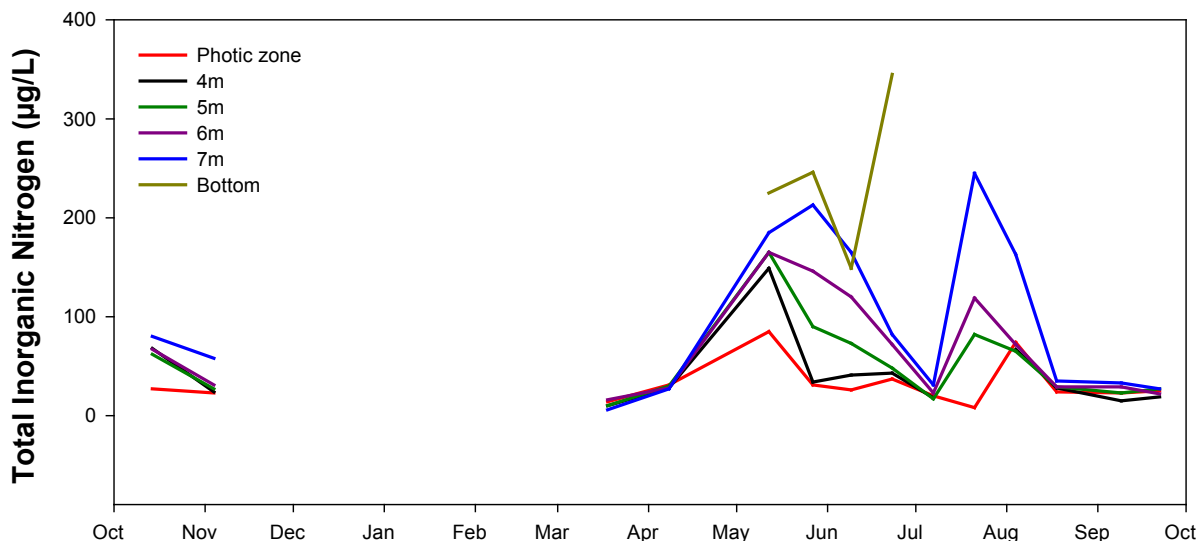


Figure 4-18: Total inorganic nitrogen (nitrate, nitrite, and ammonia) concentration recorded for the photic zone and at depth during routine monitoring for the 2015 WY at CCR-2. Bottom depth is 7.2 to 8.8 m.

4.1.5 Long-Term Phosphorus Trends in Cherry Creek Reservoir

Routine monitoring data collected since 1987 indicate a general increasing pattern in summer mean concentrations of TP in the photic zone of the Reservoir (Figure 4-19; Table 4-1). In 2015, the July through September mean concentration of TP was 93 µg/L. This value is slightly greater than last year's 87 µg/L concentration and the long-term median value of 87 µg/L. The 2015 seasonal mean TP concentration is less than the six years in which the destratification system was operational and within the range of historical conditions absent of destratification (i.e., prior to 2008). Regression analyses performed on 1997 to 2015 seasonal mean TP data indicates a significant ($p = 0.012$) increasing trend.

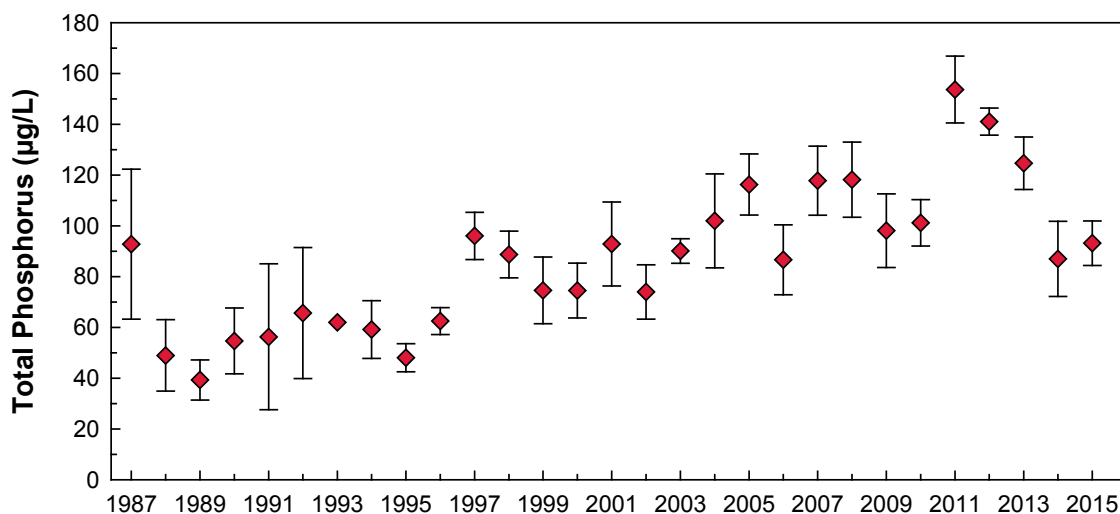


Figure 4-19: Seasonal mean (July through September) total phosphorus concentrations (µg/L) measured in Cherry Creek Reservoir, 1987 to 2015. Error bars represent a 95% confidence interval for each mean.

Table 4-1: Comparison of water year mean and July through September mean phosphorus, nitrogen, and chlorophyll a levels in Cherry Creek Reservoir, 1988 to 2015.

Year	Total Phosphorus (µg/L)		Total Nitrogen (µg/L)		Mean Chlorophyll a	
	WY	Jul-Sep	WY	Jul-Sep	WY	Jul-Sep
1988	52	49	902	1,053	21.8	31.8
1989	45	39	803	828	8.5	5.6
1990	58	55	600	--	2.3	8.6
1991	86	56	1,067	1,237	9.7	9.8
1992	52	66	931	970	12.2	17.4
1993	55	62	790	826	12.6	14.8
1994	53	59	1,134	1,144	11.4	15.4
1995	46	48	910	913	12.7	15.6
1996	35	62	889	944	13.4	18.2
1997	70	96	981	1,120	16.4	22.2
1998	77	89	763	880	18.4	26.6
1999	76	81	709	753	21.6	28.9
2000	80	81	774	802	22.3	25.1
2001	84	87	764	741	26.0	26.1
2002	70	74	825	858	21.7	18.8
2003	83	90	987	1,121	22.7	25.8
2004	85	102	929	977	19.1	18.4
2005	93	116	916	990	16.3	17.1
2006	96	87	874	914	13.7	14.7
2007	108	118	880	716	21.4	12.6
2008	92	118	795	800	15.8	16.6
2009	85	98	1,173	1,236	12.4	13.2
2010	92	101	925	974	23.6	31.0
2011	110	154	904	987	25.6	26.7
2012	114	141	891	923	24.0	27.1
2013	101	125	995	983	24.8	26.8
2014	86	87	951	904	23.4	24.4
2015	79	93	825	759	18.4	16.0
Mean	77	87	889	939	17.6	19.8
Median	82	87	897	923	18.4	18.3

4.1.6 Long-Term Nitrogen Trends in Cherry Creek Reservoir

Routine monitoring data collected since 1988 indicates variable seasonal mean concentrations of TN in the photic zone of the Reservoir (Figure 4-20; Table 4-1). In 2015, the July through September mean TN concentration was 759 µg/L. This value is less than last year's concentration (904 µg/L) and the long-term median value of 923 µg/L. The 2015 seasonal mean TN concentration is less than previous five years which includes four of the six years when the destratification system was operational. The 2015 concentration is within the range of historical conditions absent destratification (i.e., prior to 2008). Regression analyses performed on 1997 to 2015 seasonal mean TN data indicates no significant ($p = 0.844$) increasing or decreasing trend.

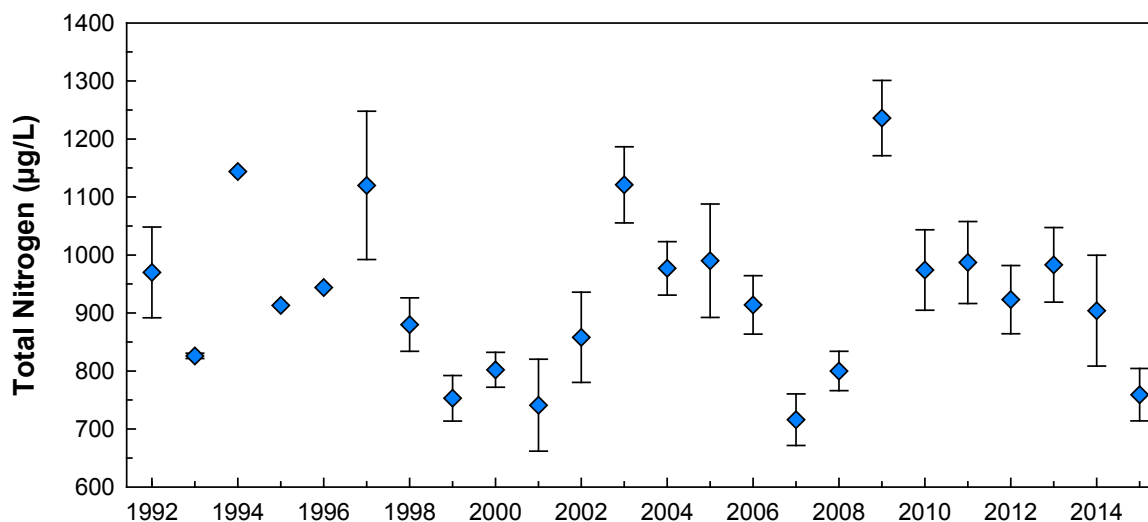


Figure 4-20: Seasonal mean (July through September) total nitrogen concentrations (µg/L) measured in Cherry Creek Reservoir, 1992 to 2015. Error bars represent a 95% confidence interval for each mean.

4.1.7 2015 WY Chlorophyll *a* Levels

The annual pattern of chlorophyll *a* concentrations was quite variable throughout the 2015 WY (Figure 4-21). From October 2014 through September 2015, chlorophyll *a* concentrations ranged from 8.1 µg/L to 35.2 µg/L with a mean chlorophyll *a* concentration of 18.4 µg/L. During the regulatory growing season (July through September), three of the six Reservoir mean chlorophyll *a* concentrations were greater than 18 µg/L standard with a general increase through the growing season. The July through September seasonal mean chlorophyll *a* concentration was 16.0 µg/L, with a peak seasonal reservoir mean concentration of 23.7 µg/L in late September during an *Anabaena flos-aquae* bloom. Notably, the *A. flos-aquae* bloom in late May resulted in a reservoir mean chlorophyll *a* concentration of 22.5 µg/L.

Many factors contribute to increases and decreases in chlorophyll *a*, however, many of the concentrations recorded in 2015 can be linked to the Reservoirs physical and chemical characteristics. The 2014 autumn (October and November) chlorophyll *a* concentrations were the highest observed and continued an increasing chlorophyll *a* trend observed at the end of the 2014 WY. Another peak in Chlorophyll *a* was observed in late May which was likely a result of an increase in SRP, high water transparency, and low surface water mixing. Alternatively, Chlorophyll *a* concentration was lowest in early August following a long period of surface water mixing in which phytoplankton was likely mixed in to deeper water where they could not photosynthesize as efficiently. Overall, an increase in chlorophyll *a* from mid-May through September resulted from the internal loading that occurred in June and July. The bioavailable nutrients were mixed throughout the water column in early July and mid-August and fueled the growth of algae into autumn. This pattern is typical of historical conditions, absent the destratification system.

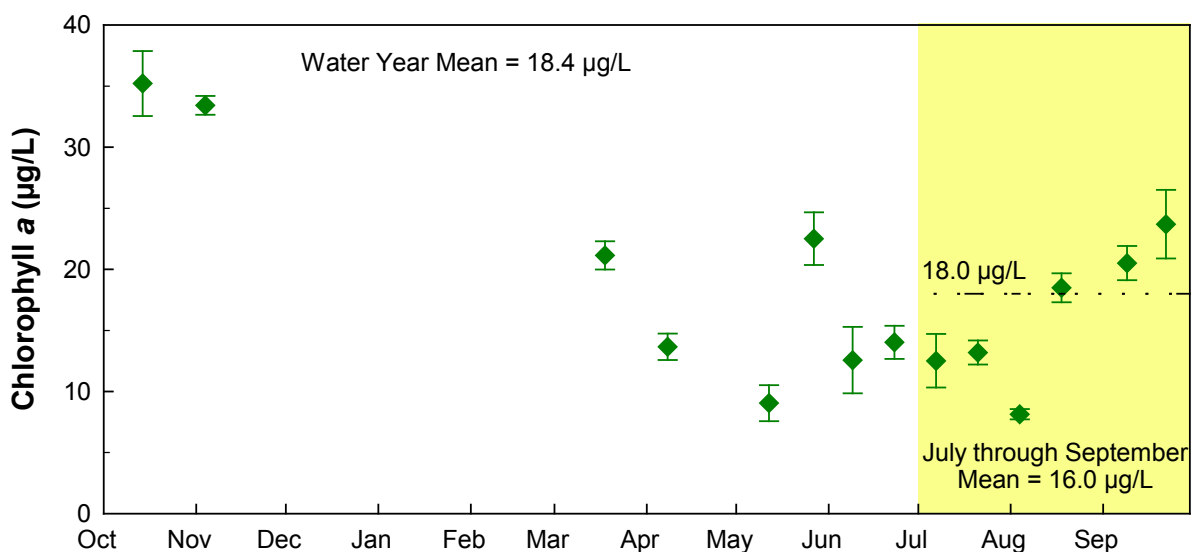


Figure 4-21: Concentration of chlorophyll *a* (µg/L) in Cherry Creek Reservoir, 2015 WY. Error bars represent a 95% confidence interval around each mean. Highlighted area denotes the seasonal period for the chlorophyll *a* standard.

4.1.8 Long-term Chlorophyll *a* Trends in Cherry Creek Reservoir

Routine monitoring data collected since 1988 indicates variable summer mean concentrations of chlorophyll *a* in Reservoir (Figure 4-22; Table 4-1). In 2015, the July through September mean concentration of chlorophyll *a* was 16.0 µg/L. This value is less than last year's 24.4 µg/L concentration and the long-term median value of 18.3 µg/L. Regression analyses performed on 1988 to 2015 seasonal mean chlorophyll *a* data indicates no significant ($p = 0.1521$) increasing or decreasing trend although patterns in the data correspond to different annual conditions (e.g. dry summer, 2002; wet summers, 2007, 2009, and 2015) or operation of the destratification system (2008-2013).

Under destratification management, the period from 2010 through 2013 represented a new state of conditions for the Reservoir. The 2010 seasonal mean chlorophyll *a* concentration (31.0 µg/L) was the highest seasonal level observed during destratification operation or for the history of the Reservoir and highlights the propensity of algae to respond to optimal growing conditions. The 2011 through 2013 seasonal mean chlorophyll *a* concentration was 26.9 µg/L, and each month considerably greater than the chlorophyll *a* standard. In 2014, the first year the destratification system was not operated, the chlorophyll *a* concentration remained relative high at 24.4 µg/L and close to that of the previous 4 years. The 2015 seasonal mean chlorophyll *a* in 2015 was, however, much lower than the previous five years, below the standard, and less than five of six years during operation of the destratification system.

For regulatory assessment purposes (i.e. 303d listing), the site-specific chlorophyll *a* standard has two assessment components – a numeric level and an allowable exceedance frequency. In essence, the Reservoir is allowed to exceed the numerical standard one time over a 5-year

sequential period (CDPHE 2011). The 2015 seasonal mean chlorophyll *a* concentration represents the first in five years the Reservoir achieved the numeric standard but will remain on the 303d list until both components of the standard are met.

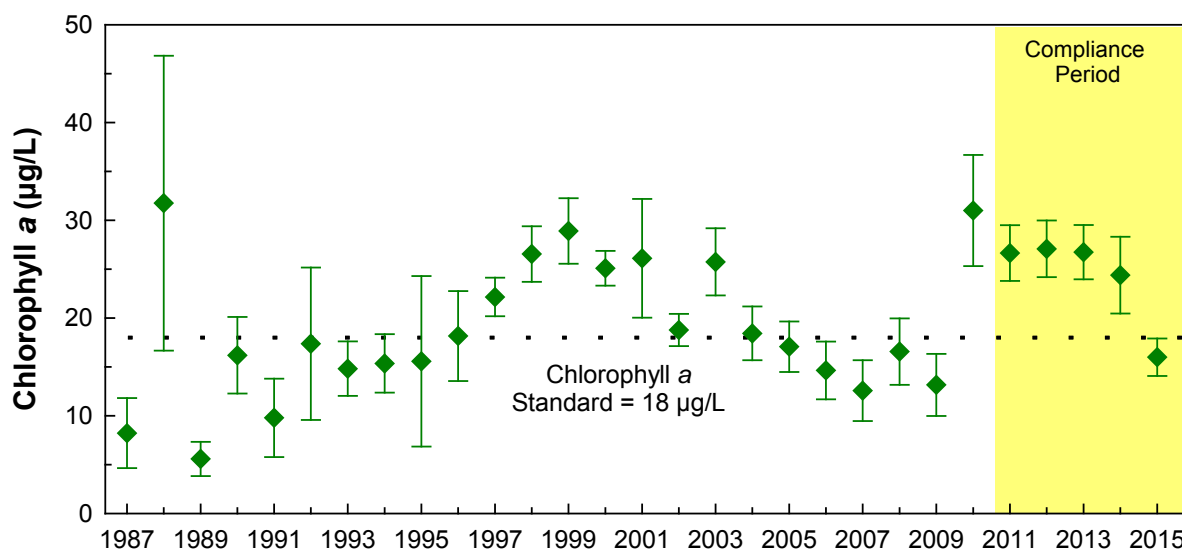


Figure 4-22: Seasonal mean (July through September) concentrations of chlorophyll *a* (µg/L) measured in Cherry Creek Reservoir, 1987 to 2015. Error bars represent a 95% confidence interval around each mean. The Reservoir destratification system was operated from 2008 through 2013.

4.1.9 2015 WY Sulfate

Sulfate analysis began in March 2015 and continued monthly through October. Mean photic composite sulfate concentrations for this time period ranged from 132 to 222 mg/L with an overall median of 154 mg/L. This median value is less than that for alluvial water at MW-9 for the same time period (214 mg/L) and does not exceed the drinking water standard of 250 mg/L.

4.1.10 2015 WY Chloride

Chloride analysis began in March 2015 and continued monthly through October. Mean photic composite chloride concentrations for this time period ranged from 123 to 214 mg/L with an overall median of 143 mg/L. This median value is less than that for alluvial water at MW-9 for the same time period (214 mg/L) and does not exceed the drinking water standard of 250 mg/L.

4.2 Reservoir Biology

4.2.1 2015 CY Phytoplankton

The 2015 summer season represented conditions in the reservoir after two years absent the influence of the destratification system and continuous mixing. Phytoplankton total density in the photic zone (upper 3 m of the water column) composite samples (CCR-1, CCR-2, and CCR-3) ranged from 1,346 #/mL on August 4th to 15,693 #/mL on November 10th (Table 4-2). The number of algal taxa present during each of these sampling events ranged from 10 on May 12th, to 28 on September 22nd. Phytoplankton density and chlorophyll *a* concentrations were highly correlated ($r = 0.837$).

Opportunistic surface grab samples were collected on May 27th near the dam tower and on September 22nd near the east boat ramp during observed cyanobacteria blooms (visible surface scum). A total phytoplankton density of 4,858 #/mL was calculated and 14 taxa were detected in the May 27th sample while a density of 40,402 #/mL was calculated and 17 taxa were detected in the September 22nd sample. In both opportunistic samples, *A. flos-aquae* (large filamentous cyanobacteria containing gas vacuoles) was the dominant cyanobacteria collected and accounted for greater than 62% of the algae identified.

Based on the 2015 calendar year, the photic assemblage was dominated in terms of density by cryptophytes (36%) followed by chlorophytes (green algae; 30%) and diatoms (bacillariophytes; 30%; Figure 4-23). The percent relative density of cyanobacteria (blue green algae) was 1%. Chlorophytes generally increased from mid-May (9%) to dominance in early October (58%). Cryptophytes were most abundant in early May (88%) with a general decrease in density through early September (20%). Diatom density was often high but variable throughout the year with peaks in early June (62%), early September (78%), and mid-August (62%). Chrysophyte (golden algae) percent relative density was highest in mid-March (13%) and cyanobacteria was highest in late May (7%) while percent relative density for these taxa in all other samples were <4%. All samples for dinoflagellates and euglenoids were also <4%.

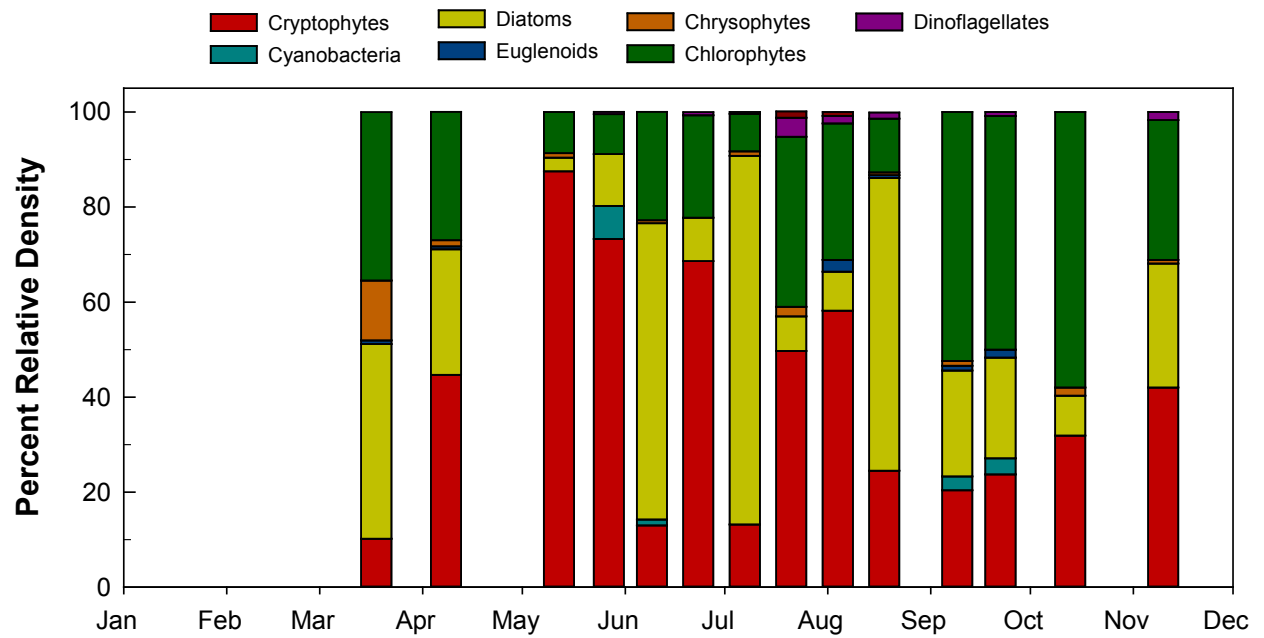


Figure 4-23: Percent relative density of algal groups for each routine photic zone composite sample collected in Cherry Creek Reservoir, 2015 CY.

Table 4-2: Density (#/mL) of phytoplankton and total number of taxa for routine photic zone composite samples representative of the three samples sites on Cherry Creek Reservoir, and for opportunistic grab/composite samples in other Reservoir locations, 2015 CY.

Sample Date	Taxonomic Group									Total Taxa
	Cryptophytes	Cyanobacteria	Diatoms	Euglenoids	Chrysophytes	Chlorophytes	Dinoflagellates	Unidentified Flagellates	Total Density	
Routine Photic Zone Composite Samples (CCR1,2,3)										
3/18/2015	574	--	2,295	44	706	1,986	--	--	5,604	23
4/8/2015	2,599	--	1,538	37	73	1,574	--	--	5,821	20
5/12/2015	2,460	--	81	--	27	243	--	--	2,812	10
5/27/2015	4,498	425	669	--	--	517	30	--	6,139	15
6/9/2015	650	62	3,129	--	31	1,146	--	--	5,018	19
6/23/2015	2,506	--	334	--	--	787	24	--	3,651	19
7/7/2015	1,098	--	6,479	--	73	659	37	--	8,346	14
7/21/2015	2,273	--	333	--	91	1,637	182	61	4,577	20
8/4/2015	783	--	110	33	--	386	22	11	1,346	19
8/18/2015	1,496	--	3,758	38	38	690	77	--	6,098	21
9/9/2015	740	106	810	35	35	1,903	--	--	3,629	22
9/22/2015	1,774	253	1,584	127	--	3,674	63	--	7,474	28
10/13/2015	3,710	--	976	--	195	6,736	--	--	11,617	20
11/10/2015	6,594	--	4,088	--	132	4,615	264	--	15,693	22
Opportunistic Surface Grab Samples										
5/27/2015a	1,023	3,017	102	102	26	588	--	--	4,858	14
9/22/2015b	2,349	30,771	4,698	--	--	2,584	--	--	40,402	17

^a **Notes:**

^b Surface grab between CCR-2 and Dam.

^c Surface grab at East Boat Ramp.

The size of each alga taxa (e.g., biovolume) was also determined (Figure 4-24). Algal biovolume in the routine photic zone composite samples ranged from 340,798 $\mu\text{m}^3/\text{mL}$ on August 4th to 11,370,592 on September 7th while the opportunistic surface grab sample collected on May 27th contained a biovolume of 8,110,304 $\mu\text{m}^3/\text{mL}$ and the sample on September 22nd contained 86,506,733 $\mu\text{m}^3/\text{mL}$. As with density, *A. flos-aquae* accounted for greater than 94% of the algae biovolume on September 22. Unlike the strong relationship between phytoplankton density and chlorophyll *a*, there was no relationship between phytoplankton biovolume and chlorophyll *a*; however, the diatom blooms observed on June 9th and July 7th greatly affected the relationship. When these two blooms were removed from the analysis, there was a strong correlation ($r = 0.820$) between phytoplankton biovolume and chlorophyll *a* concentration. The relationship also improved between phytoplankton density and chlorophyll *a* ($r = 0.906$) when the two diatom events were removed from the analysis.

In 2015, the assemblage was dominated in terms of biovolume by diatoms (60%) followed by cryptophytes (18%) and chlorophytes (12%). The relative percent biovolume of cyanobacteria was 4%. Diatom biovolume was often high but variable throughout the year with peaks in mid-March (65%), early June (90%), and early September (95%) and a general decrease through mid-October (6%). Chlorophytes generally increased from late May (3%) to dominance in mid-October (54%). Cryptophytes were most abundant in mid-May (68%) with a general decrease in biovolume through early September (<1%) followed by a late year increase through early November (47%). Chrysophyte biovolume was highest in mid-March (6%) and very low throughout the rest of the year. Cyanobacteria biovolume was highest in late May (23%) and late September (19%) and not detected on most other dates. Dinoflagellates bloomed from late September to mid-August but were less than 6% or not detected the remainder of the year. Euglenoid biovolume was largest in early August (16%) but low the remainder of the year and not detected May through July, September, and October. Overall, patterns in algal biovolume follow typical seasonal succession patterns of many temperate lakes and reservoirs with diatoms and cryptophytes being most abundant in the spring, while green algae were abundant throughout the year and comprising a larger component of the assemblage in winter and fall.

Over the course of the sampling season, *Cryptomonas erosa* density was dominant in seven of the fourteen samples collected during the CY and accounted for 12.6% of all taxa collected. The biovolume of this taxa was also dominant in nine of the samples collected and accounted for 16.6% of all taxa collected. The density of *Rhodomonas minuta* was also relatively large in ten of the fourteen samples collected during the year and accounted for 23.5% of all taxa collected. *Fragilaria crotonensis* accounted for the largest biovolume in three of the samples collected during the year, representing 34.0% of all taxa collected.

In mid-March and early April, diatoms, primarily *Nitzschia acicularis*, were the most abundant phytoplankton in terms of biovolume followed by *Synedra radians* in early April. Diatoms grows well in cooler water and it is common to see large abundances this time of year for the Reservoir. The cryptophyte *C. erosa* were relatively dominant in early April and

marked a period of transition from diatoms to cryptophytes. A reduction in diatoms is often associated with increased stratification (Tsukada 2006) which was beginning to occur in early March as evident by temperature and dissolved oxygen concentrations. In addition, cryptophyte biovolume has been observed to increase as diatom biovolume decreases (Tsukada 2006). Diatom biovolume in the early May sample was substantially lower than in April.

In late May, *A. flos-aquae* was the most dominant alga in terms of biovolume and was the dominant cyanobacteria identified in 2015. At this time, Reservoir water transparency, temperature, and nutrient data all suggest stratification of the water column and that internal nutrient loading was beginning to occur. These conditions were also conducive to *C. erosa* which photosynthesize near the water surface during the day and then vertically migrate to deeper water (Knapp et al. 2003) where TIN was more readily available. *A. flos-aquae*, alternatively, contains gas vacuoles which they use to maintain position at the water's surface where they have the ability to fix atmospheric nitrogen (Komárek et al. 2003). These physiological characteristics allowed this species to grow very rapidly at the surface of the Reservoir and create a visible algal biovolume layer that covered much of the Reservoir surface. Cyanobacteria typically dominate late summer algal assemblages (Whitton and Potts 2000; James et al. 1992; Padisák 1985, Konopka and Brock 1978; Pollinger 1987) which makes the *A. flos-aquae* bloom in late May this year and early June last year unique. The presence of *A. flos-aquae*, *A. formosa*, and *C. erosa* in late May resulted in the one of the largest chlorophyll *a* concentration (22.5 µg/L) collected during spring and summer of 2015.

The June and July samples differed from the May samples and are most abundant in diatoms biomass. The early June sample consisted almost exclusively of the diatom *Aulacoseira granulata* (formerly *Melosira granulata*) which typically proliferate in the fall (Tsukada 2006; Kelly et al. 2005). The diatom *F. crotonensis* was the most dominant taxa in the late June and the July samples. This species prefers mixed water (Bailey-Watts 1986) and is typically at its largest abundance during spring before stratification (Reynolds, 1983). While this largest abundance of *F. crotonensis* did occur during the Reservoir's most substantial mixing event detected in early July, this species also prefers high nutrient water and moderately large biovolumes were collected in the late June and late July samples during two of the Reservoir's most stratified periods. *C. erosa* were also abundant in late June and the dinoflagellates *Glenodinium sp.* and *Peridinium cinctum* were also abundant in the late July sample.

The early August sample was the only event when dinoflagellates, mostly *Ceratium hirundinella*, were dominant in terms biovolume. *C. hirundinella* continued to be the most dominant taxa in terms of biovolume in the mid-August. The presence of this species in late summer warm water is typical, however, they prefer lower nutrient levels (Harris, 1986; Heaney et al., 1988; Reynolds, 1997) which was the case in mid-August but not early August.

Algal assemblage dominance in autumn was more variable between months than during spring and summer. In early September, chlorophytes were the most abundant phytoplankton

in terms of biovolume while diatoms were the most abundant in late September, chlorophytes in mid-October, and cryptophytes in early November. Chlorophytes, cryptophytes, and cyanobacteria, were also abundant in late September and cryptophytes were the also abundant in mid-October. The presence of cryptophytes in autumn is typical (Tsukada 2006). As for taxa, *C. erosa* was the most abundant in all four sampling event. *Chlamydomonas sp.* was also abundant in September and mid-October and the diatom *Gomphoneis herculeana* and *A. flos-aquae* were abundant in late September. The presence of these taxa led to four of the five largest chlorophyll *a* concentrations detected in 2015 with maximum of 37.5 µg/L in early November.

Cyanobacteria abundance is typically large in late summer algal assemblages (Whitton and Potts 2000; James et al. 1992; Padisák 1985, Konopka and Brock 1978; Pollinger 1987), and was observed to occur in the Reservoir this year. However, the late September *A. flos-aquae* bloom occurred under much different conditions than the late May bloom. Water temperature was slightly warmer, transparency was low, the Reservoir had recently mixed as evident by the thermistors, and SRP and TIN was relatively low throughout the water column.

The observed successional patterns in algae dominance are closely coupled with reservoir conditions such as cooler water temperature during the spring followed by the warmer water and longer photoperiod conditions of the summer and the cool down during the fall. In addition, nutrient resources are a key component to the successional pattern as well as the ability of each taxon to outcompete other taxa for the resources. Other biological factors such as zooplankton and forage fish grazing can influence the algal succession pattern as well.

A key aspect in the algal successional patterns is that cyanobacteria were not dominant during 2015. On May 27 and September 22, the days on which blooms were observed, this group comprised less than 7% of the assemblage in terms of density (Figure 4-23) and approximately 24% in terms of biovolume (Figure 4-24).

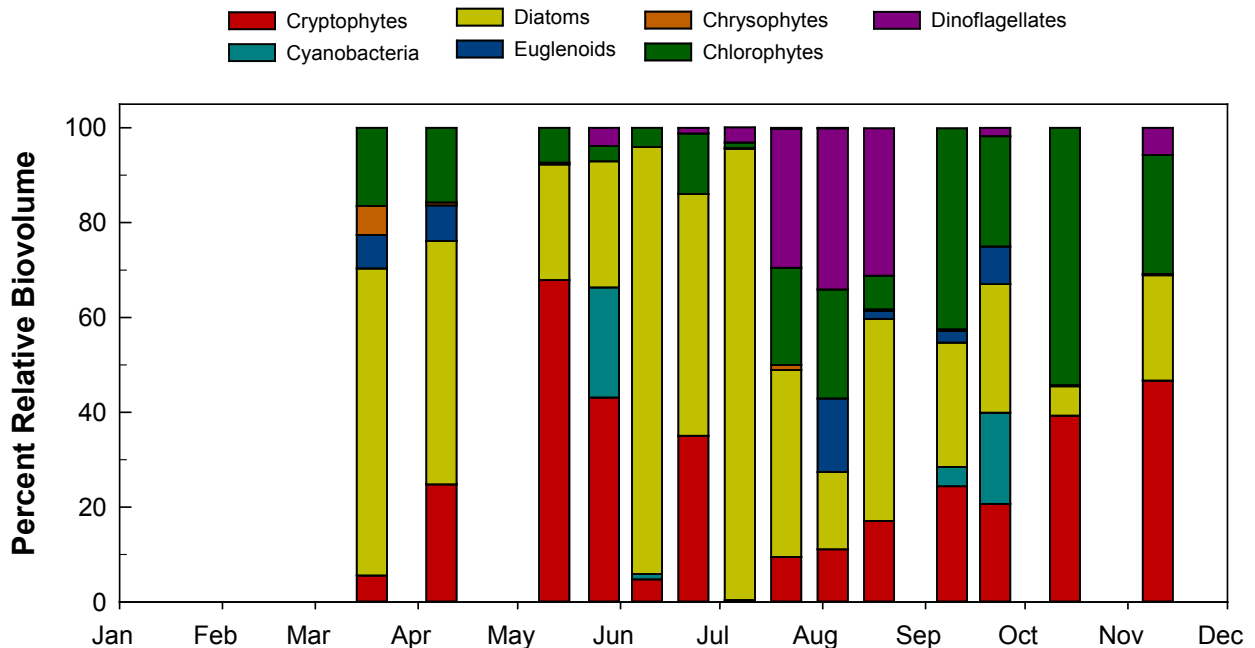


Figure 4-24: Percent relative biovolume of algal groups for each routine photic zone composite sample collected in Cherry Creek Reservoir, 2015 CY.

4.2.2 Long-Term Phytoplankton

In previous years, phytoplankton data was compared based on the pre- and post-destratification system timeframe. However, due to circumstances in 2009, the laboratory used for phytoplankton analyses was changed which confounded the pre/post destratification results. After extensive discussion regarding the datasets and laboratory methodologies, it was determined that the differences resulted in non-comparable density data. The methodological differences centered on each laboratory's ability to document picoplankton to the genus/species level and to document biovolume estimates for all types of algae. Neither laboratory was able or is able to document both types of information. The current laboratory provides both density and biovolume data to adequately characterize the large filamentous cyanobacteria which are the "algae of concern" and which destratification management is designed to control or reduce. This data also adequately characterizes the algae assemblage including algae contribution to the chlorophyll *a* concentration (algae biomass) and provides data suitable for modeling purposes.

Therefore, phytoplankton data collected prior to 2009 are not discussed in the context of long-term phytoplankton analyses, and the focus has shifted to the period from 2009-2015 with the current laboratory. This period contains 5 years of data with destratification and two years without destratification, and for the purpose of this report the analyses are limited to the last five years of data.

Algal biovolume in the photic zone composite samples has been more variable in the past few years (2014 and 2015) as compared to the previous three years when the destratification system was operated (Figure 4-25). Annual mean chlorophyll *a* concentration from 2011 through 2014 was relatively consistent with a mean concentration of 23.2 $\mu\text{g/L}$ while the 2015 annual mean concentration was 18.4 $\mu\text{g/L}$ despite the increased algal biovolume for diatoms. Diatoms were the most dominant algal group, in terms of biovolume, from 2011 through 2015 (20-42%) followed by green algae (Chlorophyte) 18-29%, and Cryptophytes, 15-26% (Figure 4-25). Cyanobacteria biovolume averaged 7.2% of the total algal biovolume, and in terms of dominance, they were the 6th most dominant type of algae observed in the Reservoir from 2011 through 2015. However, this group revealed periods of dominance in many years, such as 2012 mid to late summer period and spring 2014.

In general, the past two years have resulted in more variable conditions with respect to algal biovolume as compared to the previous years during destratification. In 2015, the total phytoplankton biovolume was larger than any other year, primarily due to diatoms, yet the annual chlorophyll *a* concentration was approximately 7 $\mu\text{g/L}$ less than in previous years. Chlorophyll *a* concentration in 2014 (23.4 $\mu\text{g/L}$) was below the 2010 to 2013 range. Diatoms and chlorophytes remained dominant in the photic zone composite samples in 2014 and 2015 when the destratification system was not in operation (Figure 4-25).

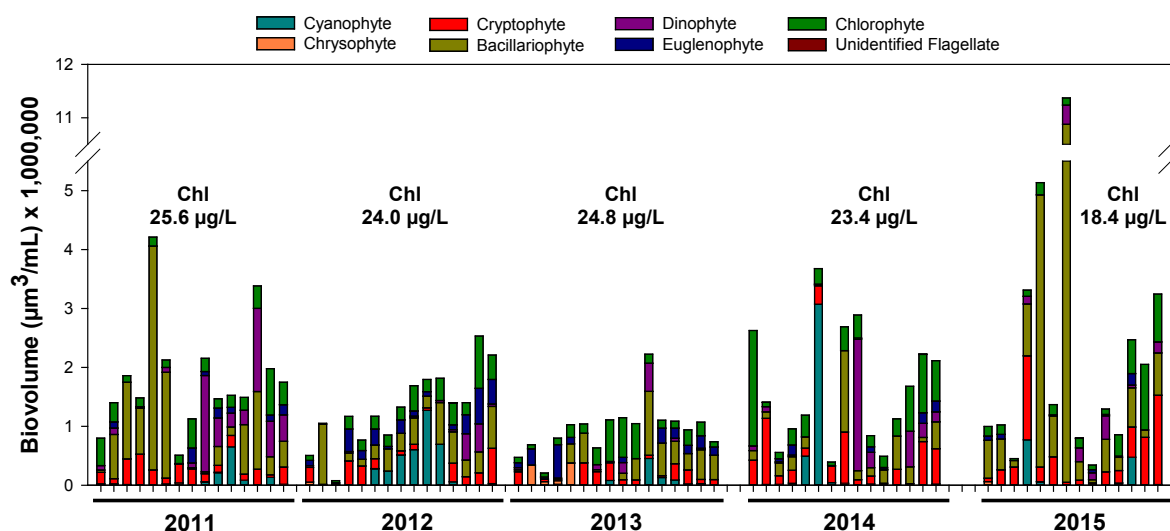


Figure 4-25: Algal biovolume of major taxonomic groups in the photic zone composite samples in Cherry Creek Reservoir from 2011 through 2015, by CY. Chl values are annual mean chlorophyll *a* concentrations.

4.2.3 2015 CY Zooplankton

Zooplankton density ranged from 17 organisms/L in late July to 471 organisms/L in Mid-March (Figure 4-26). Over the CY, the zooplankton assemblage contained a total of 12 zooplankton crustacean species—eight cladocerans and four copepods including immature copepodids and nauplius—and seven species of rotifers collected during the 14 sampling

events (Appendix E). The cladocerans *Bosmina longirostris* and *Skistodiaptomus pallidus* and immature copepods (copepodids and nauplius) were collected during all 14 sampling events. *Bosmina longirostris* have been found to be the dominant cladoceran in other eutrophic lakes (Harman et al. 1995). The copepod *Diacyclops thomasi* and the rotifer *Keratella cochlearis* were collected at 13 sampling events. All other taxa were collected in 10 or less sampling events.

Cladoceran density was relatively low and variable throughout the year with increases in mid-May, early August, and early September. Copepods comprised the majority of the zooplankton assemblage during most sampling events. Maximum density occurred in mid-March and decreased through late July and returned to greater levels in early August and early September. Rotifer density was low throughout the year except for mid-March and June. June zooplankton density was low during and after the even larger diatom bloom in early July. In addition, zooplankton density decreased from early September through early November while phytoplankton biovolume increased from early August through early November.

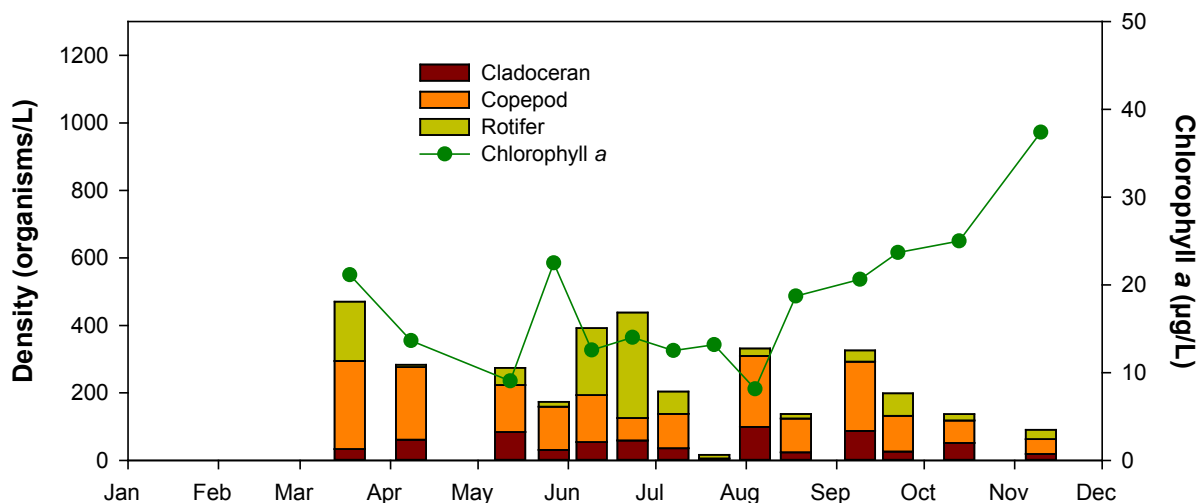


Figure 4-26: Total density of zooplankton groups and chlorophyll a concentration by sample date in Cherry Creek Reservoir, 2015 CY.

While the zooplankton assemblage is functionally (i.e. diet) related to the algal assemblages and biomass, no statistical correlation exists between zooplankton density and chlorophyll *a* (surrogate for algal biomass; $r = -0.370$). Similarly, no correlation exists between zooplankton density and algal density ($r = -0.519$) or algal biovolume ($r = -0.113$). Ideally, the pattern between zooplankton density and chlorophyll *a* (algal biomass) should be inversely related, as herbivorous zooplankton could theoretically affect algal biomass via grazing pressure, provided planktivorous fish are not suppressing the zooplankton populations (Harman et al. 1995). Communities dominated by large zooplankton populations tend to have reduced algal biomass yields as these herbivores effectively reduce the number of algae in the water column (Sarnelle 1992; Mazumder 1994; Mazumder and Lean 1994). In the Reservoir, the zooplankton population appeared to not effectively exert top-down

controls on the algal population conditions. The large gizzard shad (forage fish) population likely over-grazed the zooplankton population such that algae growth remained unchecked during their peak 2015 growing period. In the event of reduced top-down pressure such as low zooplankton grazing, the algal assemblage can maximize their relative density given the influence of the bottom-up factors.

In addition, grazing by zooplankton is selective and can be affected by phytoplankton shape and size. For example, if the algal assemblage is dominated by filamentous or colonial cyanobacteria, zooplankton will preferentially graze on smaller (e.g. less biomass) and preferred algae such as diatoms, cryptophytes, and green algae (Vanni and Temte 1990). This condition was apparent during early July when the zooplankton assemblage responded to the large abundance of diatoms.

4.2.4 Long-Term Zooplankton

Routine zooplankton collection began in 2011. Density data from during destratification (2011-2013) indicate that cladocerans were dominant in 2011 (36%) and rotifers were dominant in 2012 and 2013 (36 and 46%, respectively; Figure 4-27). For all three years, cladocerans were dominant in biomass (81, 75, and 82%, respectively). After deactivation of the destratification system, copepods were dominant in density and biomass in both 2014 (53 and 49%, respectively) and 2015 (51 and 62%, respectively). These values are not consistent with dominance during destratification nor within the range of that observed from 2011 to 2013. Overall, since the destratification system was deactivated, zooplankton density has been within the range of that previously observed while biomass has not. The two lowest biomasses recorded occurred in 2014 and 2015. The changes in zooplankton assemblage from operation of the destratification system to deactivation is likely related to the changes in the phytoplankton assemblage, however, the fact that phytoplankton abundance increased while zooplankton decreased, suggests that fish grazing was a large factor.

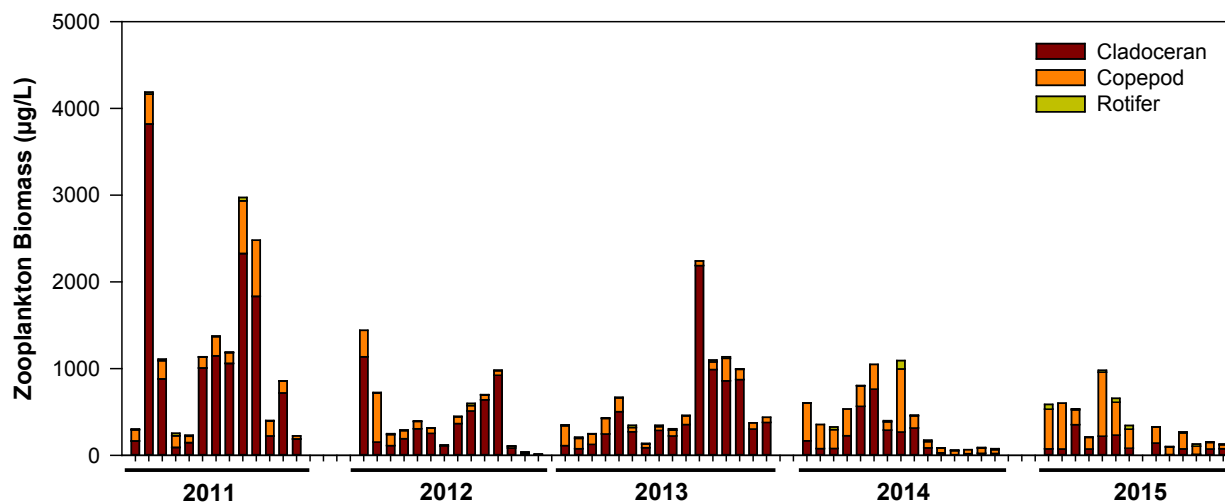


Figure 4-27: Zooplankton biomass of major groups in Cherry Creek Reservoir from 2011 through 2015, by CY.

4.3 Stream Water Quality

4.3.1 Stream Phosphorus

4.3.1.1 2015 WY Phosphorus Concentrations in Streams

The median annual TP concentration for base flow conditions ranged from 47 µg/L at Site CT-P1 to 340 µg/L at Site MCM-1 (Table 4-3). The median seasonal base flow TP concentrations at all sites were greater than their respective annual TP concentrations and ranged from 64 µg/L at Site CT-P1 to 540 µg/L at Site MCM-1. At all stream sites, except McMurdo Gulch and CC-Out where storm samples are not collected, storm flow TP concentrations were greater than their respective annual base flow concentrations. The annual median storm flow TP concentrations ranged from 97 µg/L at Site CT-2 to 301 µg/L at Site CC-10.

Table 4-3: Comparison of median base flow and median storm flow concentrations of total phosphorus (TP), total nitrogen (TN), and total suspended solids (TSS) in tributaries to Cherry Creek Reservoir, 2015 WY.

Stream/Site	Base Flow						Storm Flow		
	July - September			Annual			Annual		
	TP (µg/L)	TN (µg/L)	TSS (mg/L)	TP (µg/L)	TN (µg/L)	TSS (mg/L)	TP (µg/L)	TN (µg/L)	TSS (mg/L)
Cherry Creek									
EcoPark	183	1,677	16	109	1,526	8	171	1,396	40
CC-10	373	806	32	202	787	9	301	1,054	110
CC-Out @ I225	202	1,297	24	73	935	15	--	--	--
Cottonwood Creek									
CT-P1	64	1,269	17	47	1,120	14	209	1,567	116
CT-P2	68	1,653	21	51	1,336	19	152	1,568	46
CT-1	91	1,809	41	86	1,850	34	204	1,685	96
CT-2	74	1,272	25	63	1,469	22	97	1,515	33
McMurdo Gulch									
MCM-1	540	509	0	340	530	0	--	--	--
MCM-2	369	393	17	248	319	6	--	--	--

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

Long-term patterns (1995 to 2015) in TP and SRP concentrations for both base flow and storm flow conditions were evaluated for Cherry Creek and Cottonwood Creek which are tributaries to the Reservoir (Figure 4-28; Figure 4-29; Figure 4-30; Figure 4-31; Table 4-4; Table 4-5). The long-term median annual base flow TP concentration for Cherry Creek (Site CC-10) is 202 µg/L. The long-term median annual storm flow TP concentrations is approximately 75%

greater at 354 µg/L. In Cottonwood Creek (Site CT-2), the long-term median annual base flow TP concentration is 68 µg/L. The long-term median storm flow concentration is approximately 157% greater at 175 µg/L. Cherry Creek long-term median annual base flow SRP fraction is approximately 81% of the long-term median TP concentrations while the Cottonwood Creek (Site CT-2) SRP fraction is approximately 15% of TP concentrations.

A precedence exists in the Colorado's standard level regulatory proceedings to only consider the most recent five years of data because conditions may change over time. Therefore, median values for this period are often compared to long-term statistics (2011 through 2015, Tables 7 and 8). In Cherry Creek, the five year annual TP and SRP and the storm flow SRP median concentrations are very similar to the long-term metrics indicating little change through the years. Storm flow TP median concentrations, however, have recently increased by approximately 55 µg/L when compared to the long-term metric which is likely due to increased development which can affect peak hydrograph and erosion characteristics in the watershed. In Cottonwood Creek, the five year annual and storm flow TP and SRP median concentrations are lower than their respective long-term (Tables 7 and 8). This recent decrease is largely due to the CCBWQA's efforts in stream reclamation to reduce erosion, the reductions in nutrient discharges from point sources, and other storm management practices implemented within the watershed. Base flow TP and SRP concentrations have significantly decreased at sites CC-10 and CT-2 from 1995 to 2015 ($p < 0.024$). This decreasing trend and greatly reduced variability in TP concentrations at both sites and SRP at Site CT-2 is the result of the watershed erosion and discharge management and PRFs installed near the Perimeter Road and Peoria Street and the stream reclamation project along Cottonwood Creek. A seasonal pattern in phosphorus concentration exists at all sites but it is not specifically addressed in the trend analysis.

Table 4-4: Comparison of base flow median WY total phosphorus (TP), soluble reactive phosphorus (SRP), total nitrogen (TN), and total inorganic nitrogen (TIN) concentrations for CC-10 and CT-2 from 1995 to 2015.

Water Year	CC-10					CT-2				
	TP (µg/L)	SRP (µg/L)	TN (µg/L)	TIN (µg/L)	TSS (mg/L)	TP (µg/L)	SRP (µg/L)	TN (µg/L)	TIN (µg/L)	TSS (mg/L)
1995	218	169	--	325	--	--	--	--	--	--
1996	145 ^a	153 ^a	--	305	--	97	77	--	675	--
1997	176	170	--	375	--	108	64	--	750	--
1998	291	231	--	310	--	108	66	--	750	--
1999	258	200	920	368	--	94	39	1,233	393	--
2000	247	195	1,021	300	--	83	24	1,424	468	--
2001	239	168	987	298	36	84	22	2,177	1,326	30
2002	191	144	1,052	275	33	69	13	2,425	942	46
2003	213	158	1,177	387	29	83	13	1,780	861	42
2004	214	164	881	253	30	92	8	3,255	1,231	41
2005	200	163	931	248	20	66	10	3,619	1,379	35
2006	162	134	956	206	20	67	7	2,700	976	34

2007	217	160	1,095	336	21	65	11	2,344	786	39
2008	200	143	1,137	353	21	69	5	3,024	1,162	37
2009	176	129	1,246	360	34	50	6	2,367	804	31
2010	217	168	1,180	439	19	61	7	1,469	388	28
2011	226	165	1,474	515	22	56	7	1,007	150	23
2012	181	147	1,000	315	17	56	6	1,440	443	25
2013	181	141	1,059	296	15	53	7	1,743	460	19
2014	197	176	886	245	9	48	12	1,209	307	15
2015	202	170	787	220	9	63	9	1,469	394	22
Median (1995-2015)	202	164	1,021	310	21	68	11	1,780	750	31
Median (2011-2015)	197	165	1,000	296	15	56	7	1,440	394	22

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

Table 4-5: Comparison of storm flow median WY total phosphorus (TP), soluble reactive phosphorus (SRP), total nitrogen (TN), and total inorganic nitrogen (TIN) concentrations for CC-10 and CT-2 from 1995 to 2015.

Water Year	CC-10					CT-2				
	TP (µg/L)	SRP (µg/L)	TN (µg/L)	TIN (µg/L)	TSS (mg/L)	TP (µg/L)	SRP (µg/L)	TN (µg/L)	TIN (µg/L)	TSS (mg/L)
1995	181	161	--	560	--	--	--	--	530	--
1996	323	270	--	390	--	336	160	--	880	--
1997	402	316	--	420	--	391	221	--	550	--
1998	378	277	--	350	--	314	108	--	423	--
1999	348	247	1,375	495	--	118	58	1,409	297	--
2000	673	274	2,361	470	--	277	93	1,737	271	--
2001	293	172	1,906	381	52	209	33	1,611	592	70
2002	251	171	1,405	394	43	175	21	2,078	310	90
2003	365	171	1,244	285	173	204	35	1,733	401	87
2004	285	237	1,149	177	63	208	35	2,155	538	94
2005	354	187	1,450	389	98	175	26	2,074	340	73
2006	477	221	1,405	229	63	259	74	1,978	471	74
2007	366	195	1,597	353	83	230	27	2,021	423	61
2008	271	207	1,365	373	39	79	14	1,375	312	48
2009	378	180	1,452	344	150	78	24	1,391	401	32
2010	307	178	1,455	369	97	97	24	1,526	287	28
2011	409	197	1,637	411	116	113	29	1,499	321	29
2012	471	210	1,723	411	110	110	19	1,584	448	50
2013	414	197	1,330	326	63	60	16	1,697	393	25
2014	326	171	1,064	228	84	97	8	1,653	392	23
2015	301	170	1,054	231	110	97	12	1,515	530	33
Median (1995-2015)	354	197	1,405	373	84	175	28	1,653	401	50
Median (2011-2015)	409	197	1,330	326	110	97	16	1,584	393	29

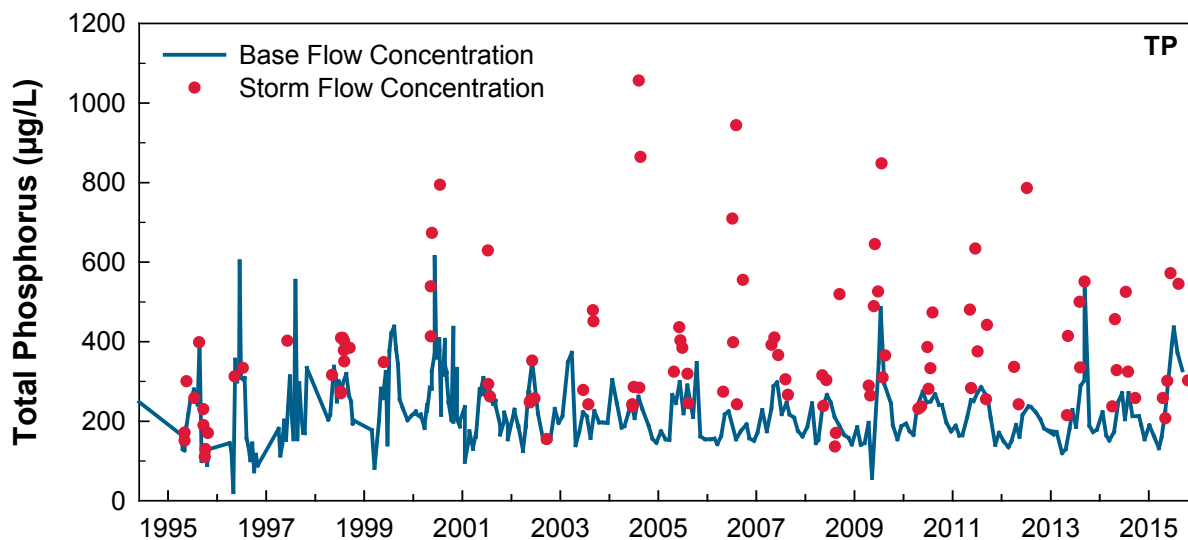


Figure 4-28: Base flow and storm flow total phosphorus concentrations measured at CC-10, 1994 to 2015.

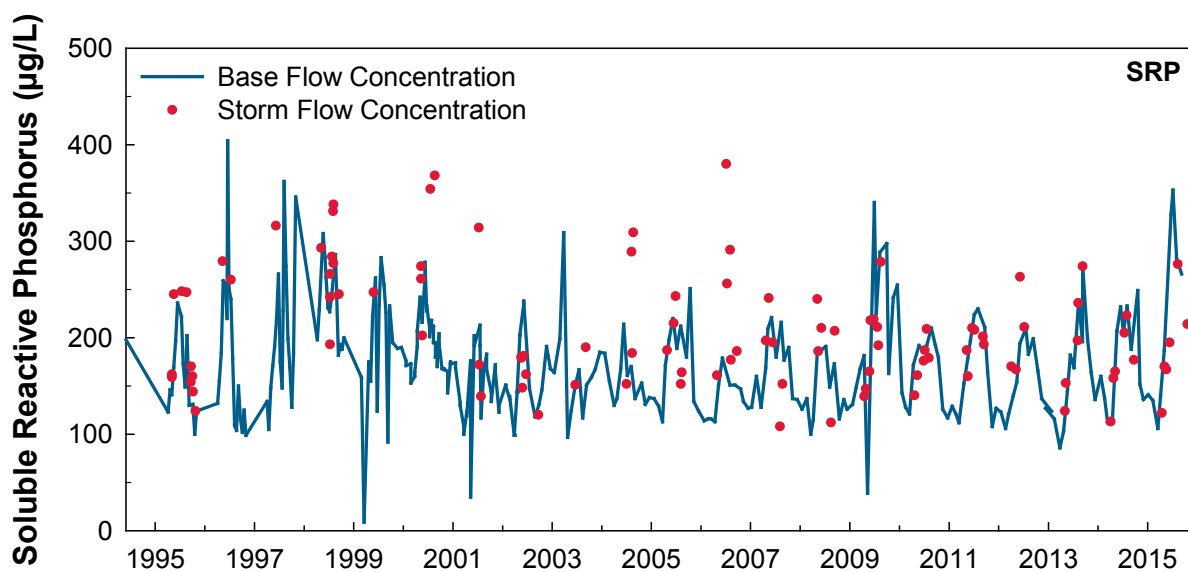


Figure 4-29: Base flow and storm flow soluble reactive phosphorus concentrations measured at CC-10, 1994 to 2015.

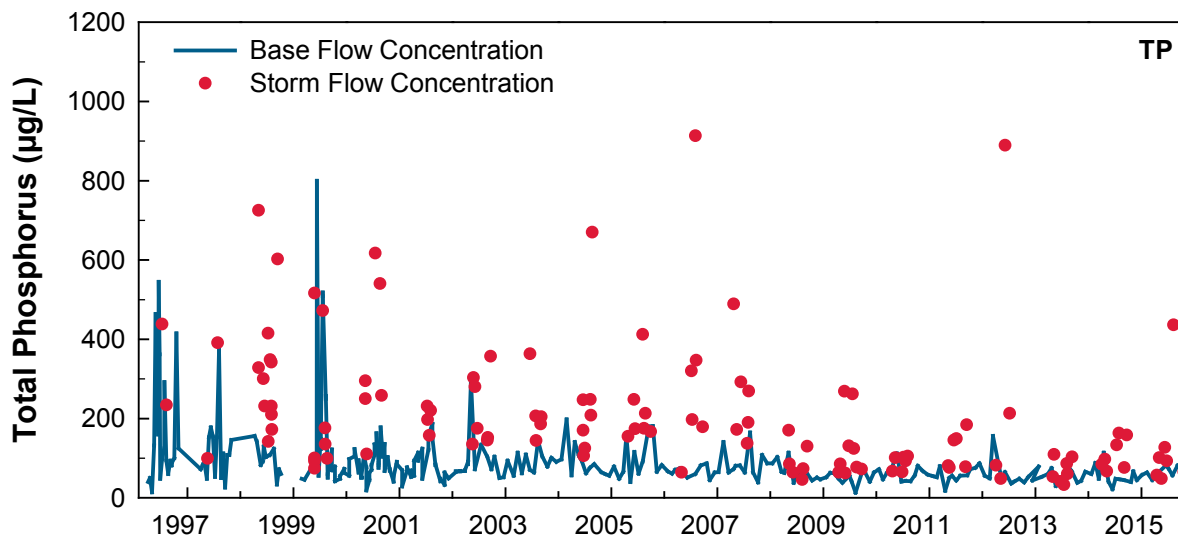


Figure 4-30: Base flow and storm flow total phosphorus concentrations measured at CT-2, 1996 to 2015.

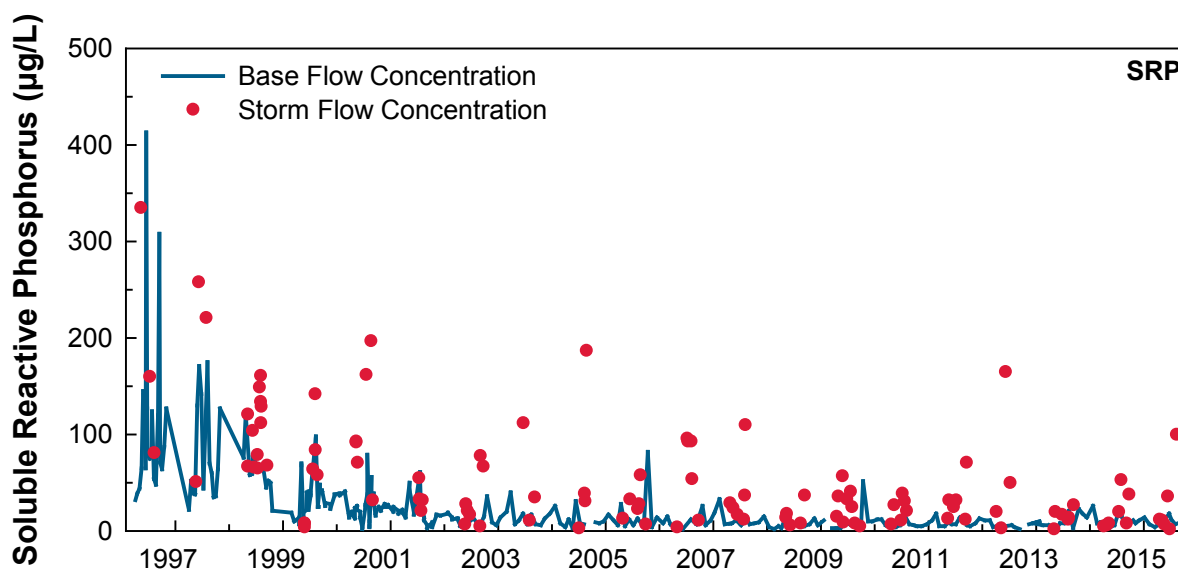


Figure 4-31: Base flow and storm flow soluble reactive phosphorus concentrations measured at CT-2, 1996 to 2015.

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

In April 2014, monthly sampling began at Site MW-9 to better characterize the alluvial nutrient concentrations upstream of the Reservoir and to provide additional information for the Reservoir model development. Total dissolved phosphorous is used as a surrogate to TP because the alluvium filters out the particulate fraction common to surface water. Monthly TDP concentrations ranged from 162 to 215 µg/L (Figure 4-32) with a median concentration of 197 µg/L which is similar to the long-term median of 190 µg/L. Alluvial phosphorus data for

Site MW-9 were used to estimate the alluvial phosphorus load component, as summarized in Appendix D (JCHA 2001 through 2010; GEI 2012 - 2015).

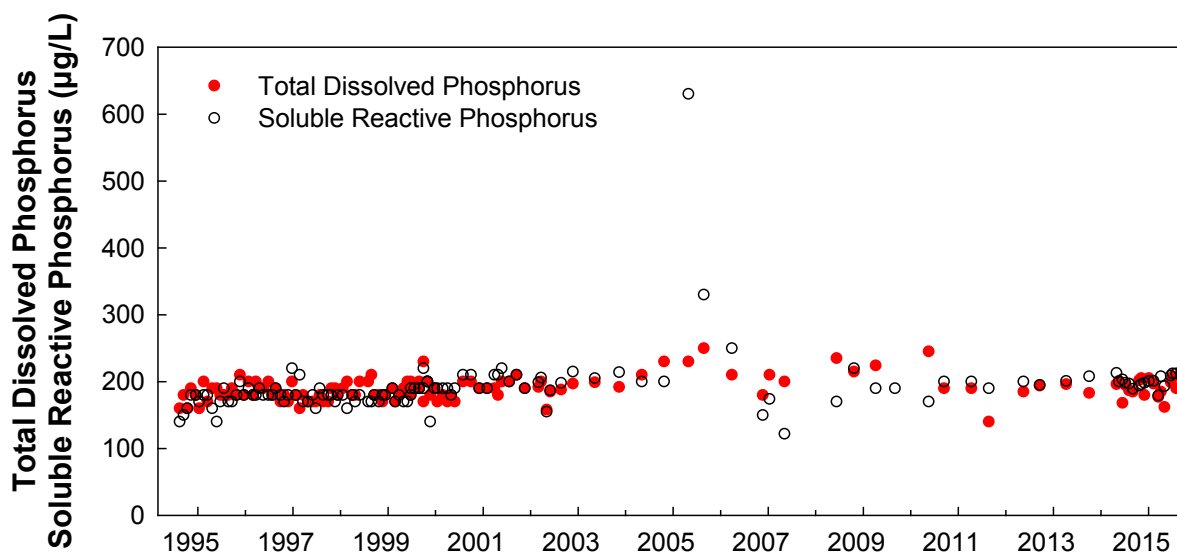


Figure 4-32: Total dissolved phosphorus and soluble reactive phosphorus concentrations measured at MW-9, 1994 to 2015.

4.3.2 Stream Nitrogen

4.3.2.1 2015 WY Nitrogen Concentrations in Streams

The median annual TN concentration for base flow conditions ranged from 319 µg/L at Site MCM-2 to 1,850 µg/L at Site CT-1 (Table 4-3). The median seasonal base flow TN concentrations at Cherry Creek sites (EcoPark, CC-10, and CC-Out @ I225), CT-P1, CT-P2, and MCM-2 were greater than their respective annual TN concentrations while CT-1, CT-2, and MCM-1 were less. The median seasonal TN ranged from 393 µg/L at Site MCM-2 to 1,809 µg/L at Site CT-1. Storm flow TN concentrations at CC-10, CT-P1, CT-P2, and CT-2 were greater than their respective annual base flow concentrations while EcoPark and CT-1 were less. The annual median storm flow TN ranged from 1,054 µg/L at Site CC-10 to 1,685 µg/L at Site CT-1.

4.3.2.2 Long-Term Trends in Nitrogen Concentrations in Cherry Creek Reservoir Tributaries

Long-term patterns (1995 to 2015) in TN and TIN concentrations for both base flow and storm flow conditions were evaluated for Cherry Creek and Cottonwood Creek (Figure 4-33; Figure 4-34; Figure 4-35; Figure 4-36; Table 4-4; Table 4-5). The long-term median annual base flow TN concentration for Cherry Creek (Site CC-10) is 1,021 µg/L. The long-term median annual storm flow TN concentrations is approximately 38% greater at 1,405 µg/L. In Cottonwood Creek (Site CT-2), the long-term median annual base flow TN concentration is 1,780 µg/L. The long-term median storm flow concentration is approximately 7% less at 1,653 µg/L. Cherry Creek long-term median annual base flow TIN fraction is approximately

30% of the long-term median TN concentrations while the Cottonwood Creek (Site CT-2) SRP fraction is approximately 42% of TN concentrations.

In both Cherry Creek and Cottonwood Creek, the five year annual and storm flow median TN and TIN concentrations are less than their respective long-term median concentrations. Base flow TN concentrations at CT-2 have significantly decreased ($p = 0.026$) and data has become less variable from 1995 to 2015. In contrast, TIN concentrations at CC-10 have significantly increased ($p = 0.000$) over time and TN at CC-10 and TIN at CT-2 have not significantly changed ($p > 0.186$). A seasonal pattern in nitrogen concentration exists at all sites but it is not specifically addressed in the trend analysis.

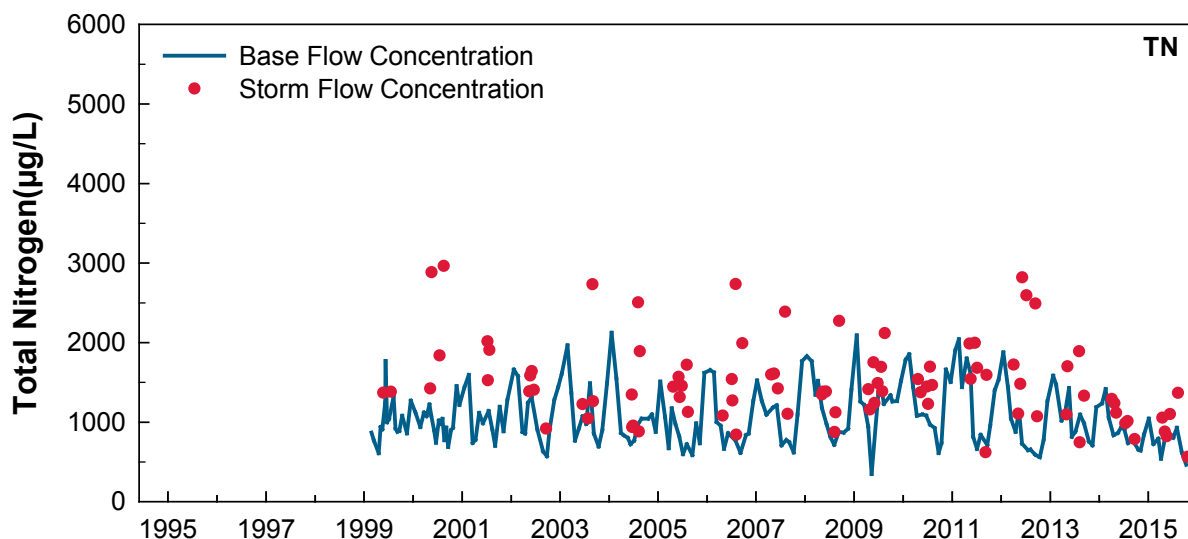


Figure 4-33: Base flow and storm flow total nitrogen concentrations measured at CC-10, 1994 to 2015.

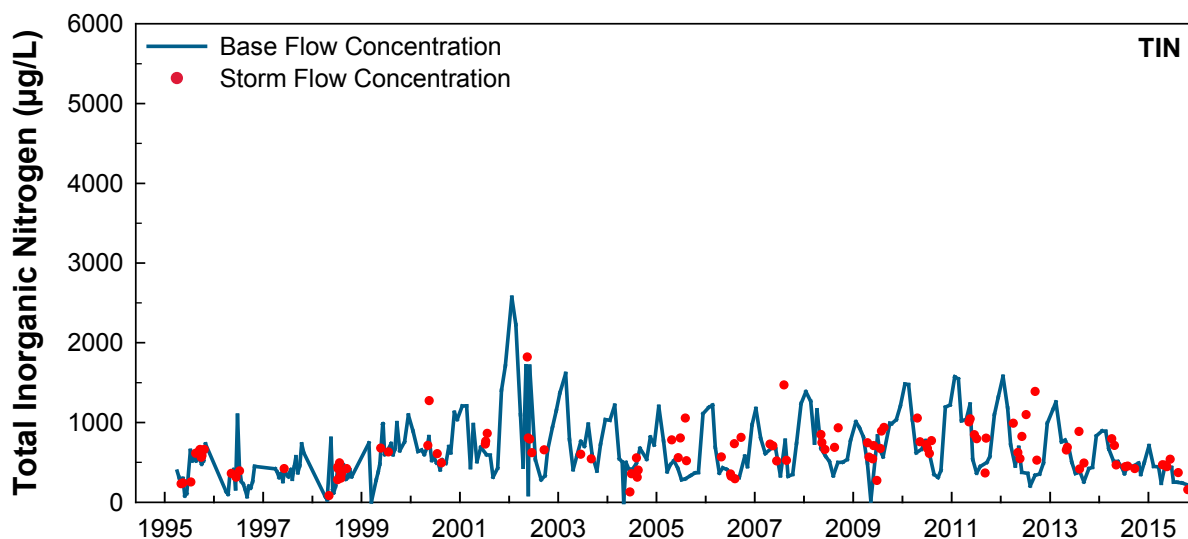


Figure 4-34: Base flow and storm flow total inorganic nitrogen concentrations measured at CC-10, 1994 to 2015.

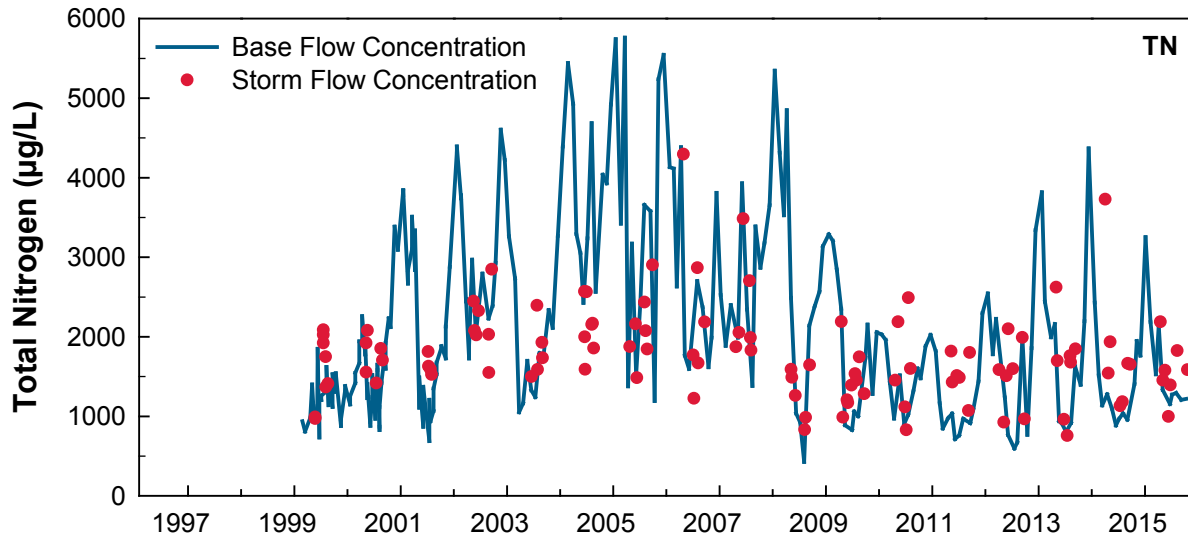


Figure 4-35: Base flow and storm flow total nitrogen concentrations measured at CT-2, 1996 to 2015.

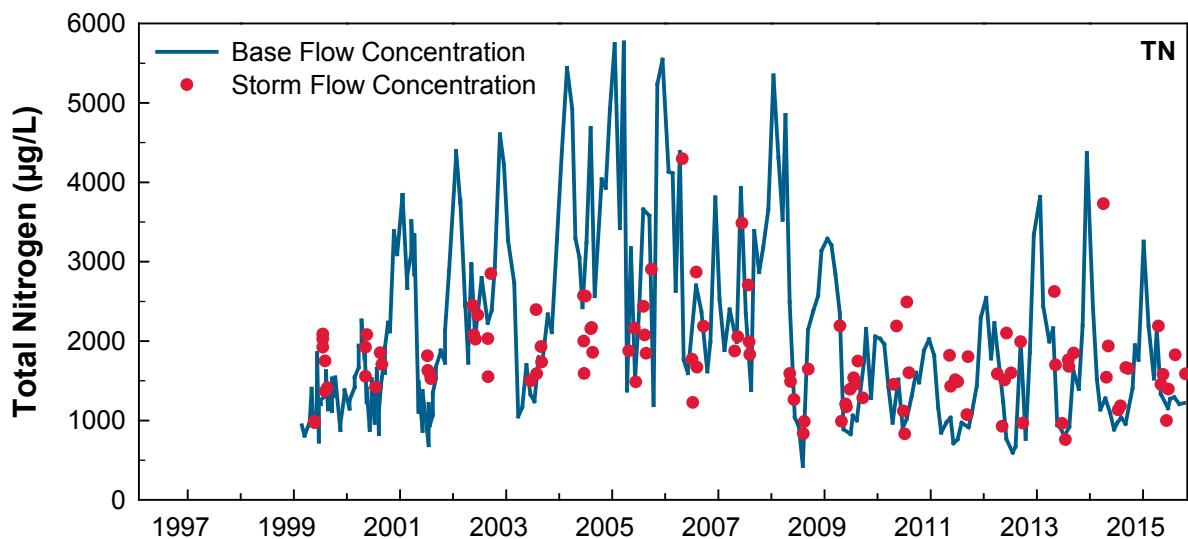


Figure 4-36: Base flow and storm flow total inorganic nitrogen concentrations measured at CT-2, 1996 to 2015.

4.3.2.3 Long-Term Trends in Nitrogen Concentrations in Cherry Creek Reservoir Alluvium

Total inorganic nitrogen is analyzed in ground water because the alluvium filters out the particulate fraction of TN common to surface water. Nitrate was analyzed because it is the primary component of TIN and were rarely above historic detection limits. Monthly nitrate concentration in the 2015 WY ranged from 69 to 264 µg/L with a median concentration of 129 µg/L which is greater than the long-term median of 480 µg/L (1994-2015). Alluvial nitrogen data for Site MW-9 were used to estimate the alluvial nitrogen load component, as summarized in Appendix D (JCHA 2001 through 2010; GEI 2012 - 2015).

4.3.3 ***Stream Total Suspended Solids***

4.3.3.1 2015 WY Total Suspended Solids Concentrations in Streams

Total suspended solids were generally low during base flow conditions in 2015 WY. The median annual TSS concentrations for base flow conditions ranged from 0 mg/L at MCM-1 to 34 mg/L at CT-1 (Table 4-3). The median seasonal base flow TSS concentrations were greater than or equal to their respective annual median concentrations at all sites and ranged from 0 mg/L at Site MCM-1 to 41 mg/L at Site CT-1. At all stream sites, except McMurdo Gulch and CC-Out, the storm flow TSS concentration was greater than their respective annual base flow concentrations. The annual median storm flow TSS concentrations ranged from 33 mg/L at Site CT-2 to 116 mg/L at Site CT-P1.

4.3.3.2 Long-Term Trends Total Suspended Solids in Cherry Creek Reservoir Tributaries

Long-term patterns (2001 to 2015) in TSS concentrations for both base flow and storm flow conditions were evaluated for Cherry Creek and Cottonwood Creek (Figure 4-37; Figure 4-38; Table 4-4; Table 4-5). The long-term median annual base flow TSS concentration for Cherry Creek (Site CC-10) is 21 µg/L. The long-term median annual storm flow TSS concentrations is 371% greater at 84 µg/L. In Cottonwood Creek (Site CT-2), the long-term median annual base flow TSS concentration is 31 µg/L. The long-term median storm flow concentration is approximately 58% greater at 50 µg/L.

In Cherry Creek, the five year median annual flow TSS concentration is less than its long-term annual flow median concentration while the five year median storm flow TSS concentration is greater than its long-term storm flow median concentrations. Both the five year median annual and storm flow TSS concentrations in Cottonwood Creek are less than their respective long-term median flow concentrations which is likely due to recent PRFs installations and stream reclamation. However, both flow TSS concentrations at Cherry Creek and Cottonwood Creek have not shown a significantly trend from 2001 to 2015 ($P > .588$). A seasonal pattern in nitrogen concentration exists at all sites but it is not specifically addressed in the trend analysis.

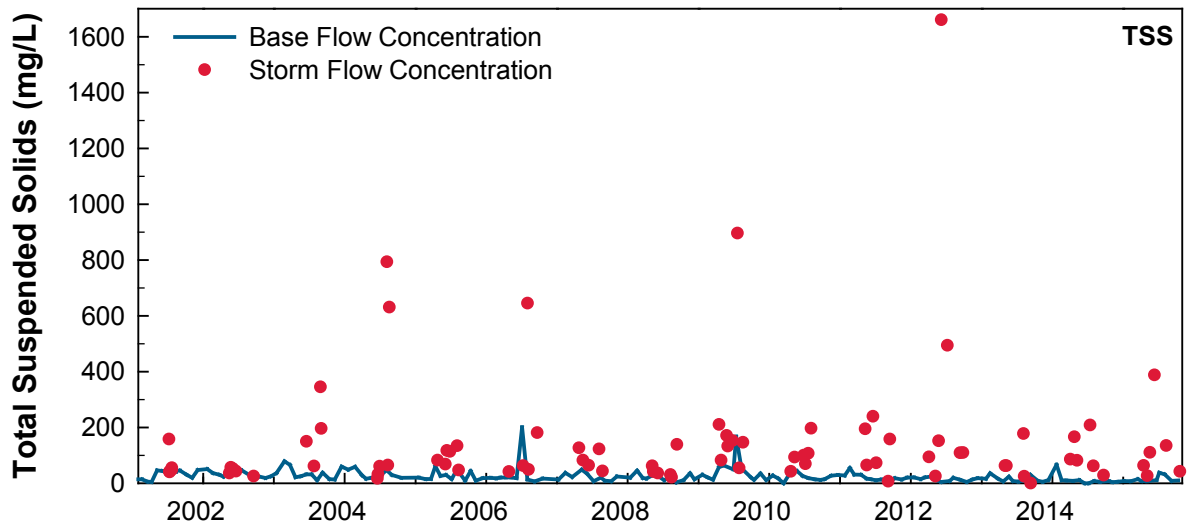


Figure 4-37: Base flow and storm flow total suspended solids concentrations measured at CC-10, 1994 to 2015.

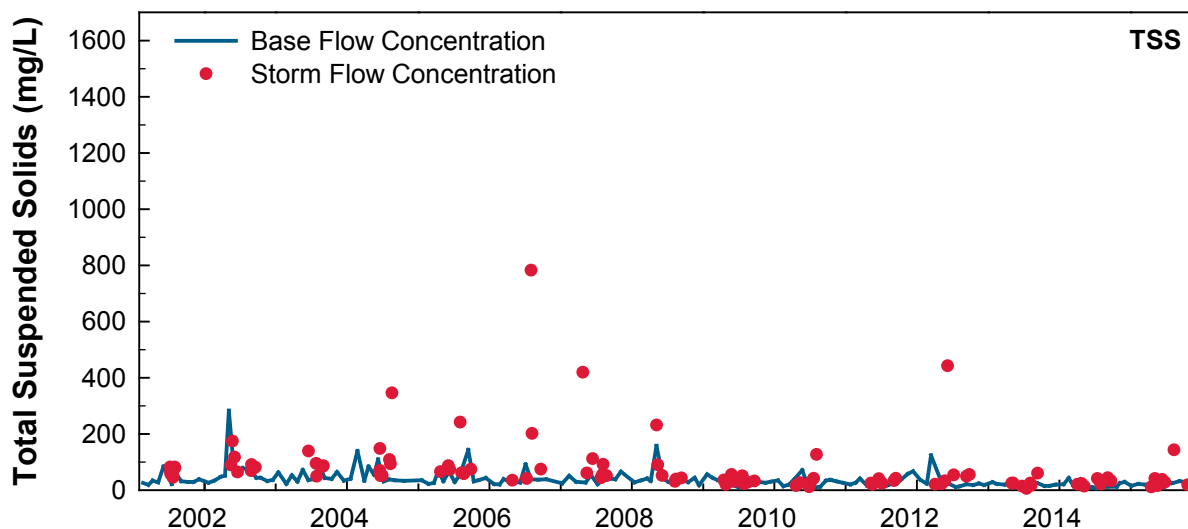


Figure 4-38: Base flow and storm flow total suspended solids concentrations measured at CT-2, 1996 to 2015.

4.3.4 2015 WY Sulfate

Sulfate analysis began in March 2015 and continued monthly through October. Sulfate concentrations for this time period ranged from 156 to 240 mg/L with an overall median of 197 mg/L at CC-10 and 247 to 382 mg/L with an overall median of 293 mg/L at CT-2. The CC-10 median value is less than that for alluvial water at MW-9 for the same time period (214 mg/L) and does not exceed the site-specific drinking water standard of 250 mg/L. The CT-2 median value, however, is greater than both the alluvial water and standard.

4.3.5 2015 WY Chloride

Chloride analysis began in March 2015 and continued monthly through October. Chloride concentrations for this time period ranged from 128 to 177 mg/L with an overall median of 159 mg/L at CC-10 and 196 to 427 mg/L with an overall median of 305 mg/L at CT-2. The CC-10 median value is less than that for alluvial water at MW-9 for the same time period (214 mg/L) and does not exceed the site-specific drinking water standard of 250 mg/L. The CT-2 median value, however, is greater than both the alluvial water and standard.

4.4 Reservoir Nutrient Loads and Export

Nutrients that limit or enhance algal growth in the Reservoir have many sources, both within the Reservoir (internal loading) or from outside the Reservoir (external loading). The direct release of nutrients from sediment, fish and plankton excrement, and the decay of organic matter are all internal sources of nutrients in a reservoir (Horne and Goldman 1994). In fact, the release of SRP from sediment during anoxic water conditions accounts for approximately 2,000 pounds per year (lbs/yr) in the Reservoir (Nürnberg and LaZerte 2008). Other studies evaluating internal loading from the sediments suggest lower estimates of internal phosphorus loading ranging between 810 lbs/yr and 1,590 lbs/yr (AMEC 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 the Reservoir was generally phosphorus limited (DRCOG 1985). However, a more recent nutrient enrichment study by Lewis et al. (2004) indicated that nitrogen was often the primary limiting nutrient in the 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 have focused on just phosphorus loading and flow-weighted phosphorus concentrations. Beginning in the 2015 WY, however, nitrogen loading and flow-weighted phosphorus concentrations were calculated to provide nutrient availability data and for regulatory purposes. Nutrient loads were determined for several primary sources, including the tributary streams Cherry Creek and Cottonwood Creek and from precipitation and alluvium (Appendix D). The flow-weighted concentration represents the relationship between the total annual phosphorus load divided by total annual flow at a site.

4.4.1 Flow

The USACE calculates daily inflow to the Reservoir as a function of change in storage (i.e., reservoir volume) based on: 1) changes in reservoir level; 2) measured outflow; 3) precipitation; and 4) evaporation. This method for calculating reservoir volume accounts for groundwater inflow via alluvium, but does not directly quantify the flow. GEI monitors

surface water inflow to the Reservoir using gaged stations on the two main surface inflows, Cherry Creek and Cottonwood 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. Flow calculation and data are outlined in Appendix D.

During the 2015 WY, the USACE calculated inflow was 27,662 ac-ft/yr, while GEI calculated stream inflow was 26,409 ac-ft/yr. To compare these two inflow values, the USACE inflow was adjusted for precipitation and alluvial inflows. During the 2015 WY, a total of 21.4 inches of precipitation was recorded at the Denver/Centennial Airport (KAPA) meteorological station located at Centennial Airport. When scaled to the areal extent of the Reservoir (875 ac), precipitation accounted for a total of 1,561 ac-ft of inflow to the Reservoir. The alluvial inflow constant, as calculated from data collected at MW-9, was 2,000 ac-ft/yr. These two adjustments resulted in an adjusted USACE inflow of 24,101 ac-ft/yr. The difference between the adjusted USACE inflow and the GEI stream inflow was -2,309 ac-ft of water. This water volume difference was reapportioned between Cherry Creek (77%), Cottonwood Creek (23%). The total outflow from the Reservoir as measured by the USACE was 25,070 ac-ft during the 2015 WY and is not adjusted.

Flow-weighted nutrient concentrations for Cherry Creek and Cottonwood Creek were used to calculate the combined reapportioned loads. Monthly base flow nutrient concentrations, along with the annual storm flow median concentration were applied to their respective flow to estimate loads for each stream site. Stream flows that were greater than the 90th percentile of all flows measured during the respective year and for that site were categorized as storm flows.

4.4.2 Phosphorus

4.4.2.1 Phosphorus Load from Tributary Streams

The greatest proportion (81%) of the normalized TP load to the Reservoir was from Cherry Creek mainstem base and storm flows (13,501 lbs; Table 4-6). Cottonwood Creek accounted for 6% of the phosphorus load (935 lbs). During the 2015 WY, the TP load to the Reservoir from tributary streams and ungagged restricted flow was 15,141 lbs.

4.4.2.2 Phosphorus Export from Reservoir Outflow

Monthly TP data collected from Site CC-Out @ I225 near the dam outlet was used to estimate the phosphorus outflow at 8,222 lbs/yr for the Reservoir in the 2015 WY (Table 4-6).

4.4.2.3 Phosphorus Load from Precipitation

The long-term (1992 to 2015) median TP concentration of 124 µg/L was used to calculate the 2015 WY TP load of 526 lbs/yr (Table 4-6). This long-term median TP concentration

represents a combination of dry fall and precipitation as measured at the KAPA meteorological station. The long-term median TP load from precipitation events collected from 1993 to 2015 is 379 lbs.

4.4.2.4 Phosphorus Load from Alluvium

The long-term (1994 to 2015) median TDP concentration of alluvial flows from Site MW-9 is 190 µg/L. The alluvial phosphorus load to the Reservoir was estimated using the inflow constant to be 1,033 lbs in the 2015 WY (Table 4-6).

Table 4-6: Normalized phosphorus loads and export (lbs/year) for Cherry Creek Reservoir, 1992 to 2015 WY.

Water Year	Cherry Creek Load	Cottonwood Creek Load	Stream & Ungaged Residual Load	Cherry Creek Alluvial Load	Direct Precipitation Load	External Load	Cherry Creek Export	Net External Load
1992*	3,024	334	3,620	750	360	4,796	1,328	3,468
1993	1,521	229	1,750	1,024	313	3,162	1,000	2,162
1994	2,525	168	2,692	874	271	3,907	964	2,943
1995	2,064	1,396	3,886	992	608	5,556	1,366	4,190
1996	2,548	600	3,147	935	353	4,509	1,382	3,126
1997	2,131	616	2,747	1,008	447	4,299	1,129	3,171
1998	10,007	1,838	11,925	1,033	449	13,574	4,139	9,434
1999	10,495	1,290	14,830	1,033	540	16,403	6,388	10,015
2000	11,801	1,379	13,180	1,034	368	14,582	4,113	10,469
2001	6,283	2,101	8,627	1,033	408	10,068	5,524	4,544
2002	2,091	438	2,530	913	303	3,746	1,971	1,776
2003	6,199	1,052	7,868	1,033	457	9,359	4,774	4,584
2004	4,307	1,640	5,965	1,034	379	7,377	2,682	4,695
2005	8,757	1,347	10,104	1,033	382	11,518	3,964	7,554
2006	3,568	1,224	4,792	1,033	349	6,174	3,251	2,923
2007	15,987	2,072	18,189	1,033	379	19,601	7,891	11,710
2008	7,254	832	8,085	1,015	283	9,384	4,785	4,599
2009	13,591	936	14,584	1,033	435	16,052	9,483	6,569
2010	12,049	1,037	13,086	1,003	399	14,488	7,880	6,609
2011	7,341	652	7,992	1,024	285	9,301	4,114	5,187
2012	5,531	588	6,119	1,020	323	7,462	3,478	3,984
2013	6,043	846	7,164	1,033	391	8,588	3,378	5,210
2014	5,567	508	6,076	1,033	310	7,419	4,408	3,011
2015	13,501	935	15,141	1,033	526	16,701	8,222	8,479
Median (1993-2015)	6,199	936	7,868	1,033	379	9,301	4,113	4,599
Median (2011-2015)	6,043	652	7,164	1,033	323	8,588	4,114	5,187

* 1992 WY totals are calculated using January through September data and not included in the median calculation.

4.4.2.5 Mass Balance/Net Loading of Phosphorus to the Reservoir

Following flow-weighted “normalization” process, flow from Cherry Creek and Cottonwood Creek accounted for a TP load of 15,141 lbs to the Reservoir during the 2015 WY (Figure 4-39; Table 4-6). The alluvial inflow contributed 1,033 lbs of phosphorus, with precipitation events contributing 526 lbs to the Reservoir. The total external load of phosphorus to the Reservoir in 2015 WY was 16,701 lbs.

The Reservoir outflow phosphorus load was estimated to be 8,222 lbs. The flow-weighted TP concentration for all external sources of inflow to the Reservoir is 222 µg/L and the flow-weighted export concentration for the Reservoir is 121 µg/L (Table 4-7). The difference of 101 µg/L was retained by the Reservoir. The net external phosphorus load to the Reservoir was 8,479 lbs during the 2015 WY (Table 4-6).

Table 4-7: Flow-weighted total phosphorus (TP) and total nitrogen (TN) concentrations (µg/L) for Cherry Creek Reservoir, 1992 to 2015 WY.

Water Year	Cherry Creek Flow-weighted Concentration		Cottonwood Creek Flow-weighted Concentration		Inflow Flow-weighted Concentration		Outflow Flow-weighted Concentration	
	TP	TN	TP	TN	TP	TN	TP	TN
1992	270	--	170	--	246	--	91	--
1993	251	--	187	--	198	--	92	--
1994	248	--	88	--	196	--	73	--
1995	189	--	203	--	178	--	63	--
1996	232	--	332	--	208	--	87	--
1997	264	--	184	--	200	--	88	--
1998	279	--	178	--	237	--	81	--
1999	268	1,088	135	1,353	234	464	102	868
2000	312	1,224	159	1,565	265	1,245	83	718
2001	257	1,506	130	1,990	198	1,582	127	1,011
2002	221	1,289	88	2,850	171	1,542	107	868
2003	287	1,145	138	1,877	229	1,275	140	919
2004	247	1,050	157	2,937	201	1,584	96	964
2005	247	1,166	120	3,046	208	1,525	78	803
2006	231	1,236	132	3,033	187	1,677	115	913
2007	295	1,367	149	2,281	254	1,494	115	843
2008	205	1,423	84	2,489	177	1,548	104	912
2009	276	1,272	62	1,873	218	1,371	148	948
2010	239	1,410	78	1,528	200	1,389	115	907
2011	263	1,572	81	1,373	212	1,420	108	843
2012	244	1,412	91	1,572	200	1,344	118	972
2013	291	1,261	59	1,817	190	1,401	120	1,058
2014	231	999	73	1,625	190	1,106	119	987
2015	268	910	75	1,592	222	1,057	121	853
Median (1992-2015)	254	1,261	131	1,873	201	1,401	106	912
Median (2011-2015)	263	1,261	75	1,592	200	1,344	119	972

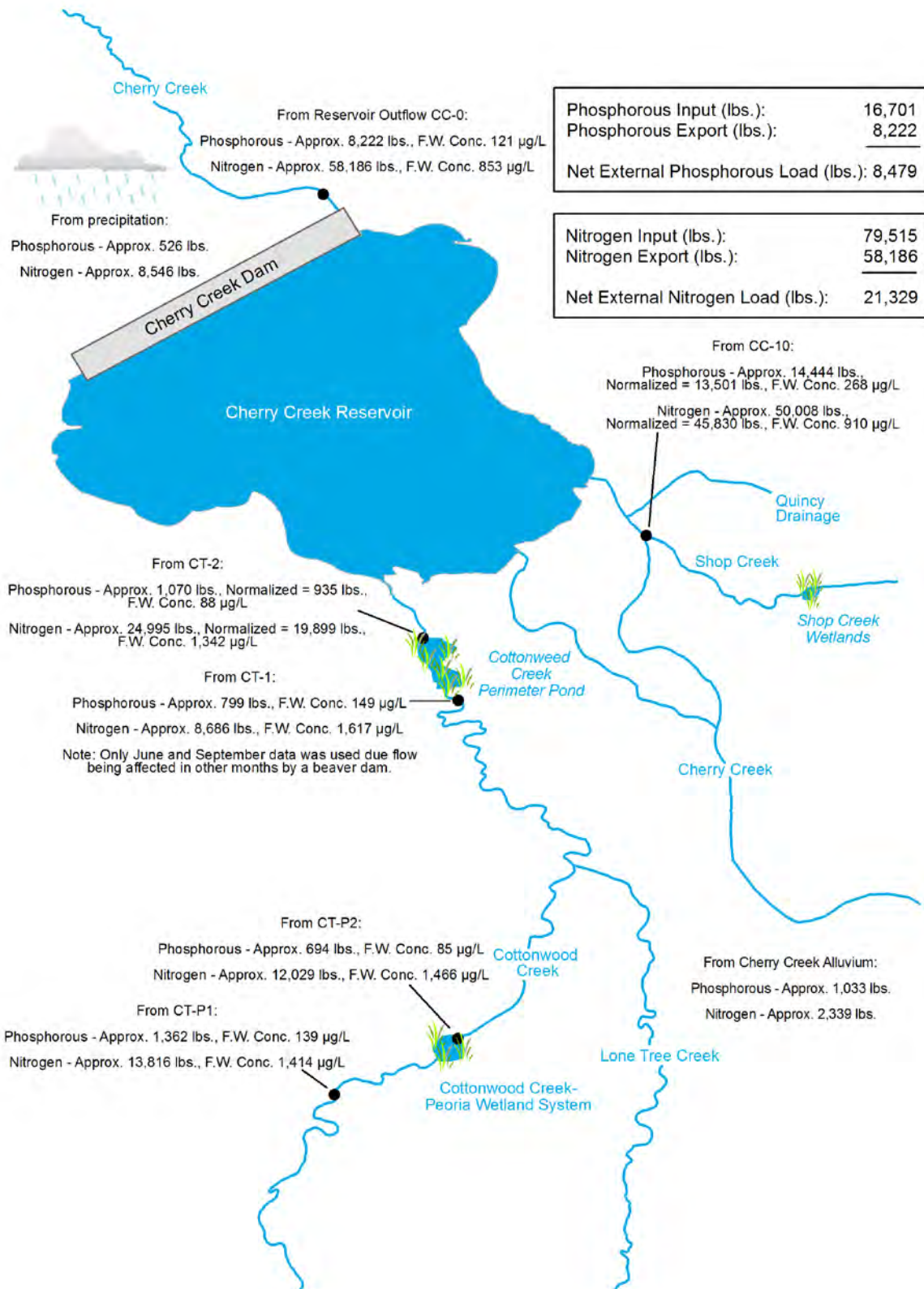


Figure 4-39: Mass balance diagram of total phosphorus and total nitrogen loading in Cherry Creek Reservoir, 2015 WY.

4.4.3 Nitrogen

4.4.3.1 Nitrogen Load from Tributary Streams

The greatest proportion (58%) of the normalized TN load to the Reservoir was from Cherry Creek mainstem base and storm flows (45,830 lbs; Table 4-8). Cottonwood Creek accounted for 25% of the TN load (19,899 lbs). During the 2015 WY, the TN load to the Reservoir from tributary streams and ungagged residual inflow was 68,630 lbs.

Table 4-8: Normalized nitrogen loads and export (lbs/year) for Cherry Creek Reservoir, 1992 to 2015 WY

Water Year	Cherry Creek Load	Cottonwood Creek Load	Stream & Ungagged Residual Load	Cherry Creek Alluvial Load	Direct Precipitation Load	External Load	Cherry Creek Export	Net External Load
1999	34,138	10,726	59,573	1,550	7,624	68,747	25,365	43,382
2000	46,268	13,602	59,870	2,340	6,382	68,592	35,727	32,865
2001	36,855	32,225	71,146	2,337	7,081	80,564	44,150	36,414
2002	12,227	14,168	26,395	2,067	5,265	33,727	16,048	17,679
2003	24,772	14,346	41,871	2,339	7,931	52,141	31,344	20,796
2004	18,306	30,762	49,197	2,340	6,570	58,107	26,970	31,136
2005	41,414	34,251	75,665	2,337	6,626	84,627	40,761	43,866
2006	19,066	28,128	47,194	2,339	6,063	55,596	25,868	29,728
2007	74,158	31,791	106,629	2,339	6,578	115,545	57,798	57,747
2008	50,473	24,508	74,980	2,298	4,913	82,191	42,072	40,119
2009	62,651	28,372	91,349	2,337	7,549	101,234	60,724	40,510
2010	71,138	20,248	91,387	2,270	6,929	100,586	61,891	38,695
2011	43,936	11,043	54,978	2,318	4,938	62,234	32,120	30,114
2012	32,035	10,186	42,221	2,307	5,612	50,141	28,706	21,434
2013	26,223	26,079	54,126	2,337	6,782	63,244	29,804	33,441
2014	23,695	11,406	35,100	2,339	5,720	43,159	36,627	6,532
2015	45,830	19,899	68,630	2,339	8,546	79,515	58,186	21,329
Median (1999-2015)	36,855	20,248	59,573	2,337	6,578	68,592	35,727	32,865
Median (2011-2015)	32,035	11,406	54,126	2,337	5,720	62,234	32,120	21,434

4.4.3.2 Nitrogen Export from Reservoir Outflow

Monthly TN data collected from Site CC-Out @ I225 near the dam outlet was used to estimate the nitrogen outflow at 58,186 lbs/yr for the Reservoir in the 2015 WY (Table 4-8).

4.4.3.3 Nitrogen Load from Precipitation

The long-term (1999 to 2015) median TN concentration of 2,013 µg/L was used to calculate the 2015 WY TN load of 8,546 lbs/yr (Table 4-8). This long-term median TN concentration represents a combination of dry fall and precipitation as collected using the precipitation

collection system. The long-term median TN load from precipitation events collected from 1999 to 2015 is 6,578 lbs.

4.4.3.4 Nitrogen Load from Alluvium

The long-term (1999 to 2015) median TIN concentration of alluvial flows from Site MW-9 is 430 µg/L. The alluvial nitrogen load to the Reservoir was estimated using the constant inflow volume and calculated to be 2,339 lbs in the 2015 WY (Table 4-8).

4.4.3.5 Mass Balance/Net Loading of Nitrogen to the Reservoir

Following the normalization process with the USACE inflow data, flow from Cherry Creek, Cottonwood Creek, and the ungagged residual inflows accounted for a TN load of 68,630 lbs to the Reservoir during the 2015 WY (Figure 4-39; Table 4-8). The alluvial inflow contributed 2,339 lbs of nitrogen, with precipitation events contributing 8,546 lbs to the Reservoir. The total external load of nitrogen to the Reservoir in 2015 WY was 79,515 lbs.

The Reservoir outflow nitrogen load was estimated to be 58,186 lbs. The flow-weighted TN concentration for all external sources of inflow to the Reservoir is 1,057 µg/L and the flow-weighted export concentration for the Reservoir is 853 µg/L (Table 4-7). The difference of 204 µg/L was retained by the Reservoir. The net external nitrogen load to the Reservoir was 21,329 lbs during the 2015 WY (Table 4-8).

4.5 Effectiveness of Pollutant Reduction Facilities

The effectiveness of the PRFs was assessed by monitoring TP, TN, and TSS upstream and downstream of the facility and comparing concentrations. Total phosphorous and TN loads were used to evaluate the effectiveness of Peoria and Perimeter Pond on Cottonwood Creek and are not affected by the “normalization” of GEI inflow to USACE inflow values for the Reservoir. Total phosphorous and TN concentrations at McMurdo Gulch and TSS concentrations all sites were used to evaluate the effectiveness of their respective PRFs.

4.5.1 Cottonwood Creek Peoria Pond

The PRF continues to be effective in reducing the amount of TP and TSS in Cottonwood Creek as it passes through Peoria Pond. The flow-weighted TP concentration was 139 µg/L upstream of the PRF and 85 µg/L downstream which indicates efficiency in removing phosphorus from flow (Table 4-9). Over the life of the project, the PRF has reduced the flow-weighted TP concentration at the downstream site by approximately 20%. In 2015, the TSS concentration was reduced by approximately 36%, with the long-term reduction of 29%. In contrast, the 2015 flow-weighted TN concentration was 1,414 µg/L upstream of the PRF and 1,466 µg/L downstream which indicates that the RPF is not efficient in removing nitrogen from the system. This is consistent with the long term mean conditions which show that TN has increased by approximately 3% at the downstream site. It should be noted that the PRFs were not designed to target TN reduction, thus concentrations are not expected to decrease.

This PRF was particularly effective at reducing the TP concentration and TSS concentration in Cottonwood Creek flows during multiple storm events on April 17th, May 5th and 19th, June 12th and 25th, and August 11th. Total phosphorous reduction during these events ranged from 12 to 47%, except for the June 25th event in which TP increased by 240%, and TSS reduction ranged from 26 to 65%. For example, during the April 17th storm event, the inflow TP concentration at Site CT-P1 was 219 mg/L while the outflow concentration was 115 mg/L indicating an approximate 47% removal of TP. Similarly, the TSS concentration entering the PRF during this storm event was 107 µg/L while the outflow concentration was 46 µg/L indicating an approximately 57% removal of TSS. Peoria Pond was not substantially effective at reducing TN concentration in Cottonwood Creek flows during storm events and results ranged from a 9% decrease to a 24% increase in TN.

Table 4-9: Historical total phosphorus, total nitrogen, and total suspended solids concentrations upstream and downstream of the Cottonwood Creek – Peoria Pond, 2002 to 2015 WY.

Parameter	Water Year	CT-1	CT-2	Difference	Percent Change Downstream
Flow-weighted Total Phosphorus Concentration (µg/L)	2002	142	118	-24	-17
	2003	117	109	-8	-7
	2004	132	132	0	0
	2005	129	119	-10	-8
	2006	146	140	-6	-4
	2007	156	120	-36	-23
	2008*	128	92	-36	-28
	2009	114	83	-31	-27
	2010	106	96	-10	-9
	2011	153	131	-22	-14
	2012	193	127	-66	-34
	2013	267	113	-154	-58
	2014	145	135	-10	-7
	2015	139	85	-54	-39
	Mean	148	114	-33	-20
Flow-weighted Total Nitrogen Concentration (µg/L)	2002	1,578	1,436	-142	-9
	2003	1,350	1,354	4	0
	2004	1,352	1,487	135	10
	2005	1,304	1,429	125	10
	2006	1,485	1,435	-50	-3
	2007	1,425	1,374	-52	-4
	2008*	1,354	1,397	42	3
	2009	1,231	1,281	51	4
	2010	1,260	1,466	206	16
	2011	1,385	1,450	65	5
	2012	1,395	1,457	62	4
	2013	1,679	1,510	-169	-10
	2014	1,267	1,369	101	8
	2015	1,414	1,466	52	4
	Mean	1,391	1,422	31	3

Parameter	Water Year	CT-1	CT-2	Difference	Percent Change Downstream
Mean Total Suspended Solids (mg/L)	2002	81	74	-7	-9
	2003	30	33	3	10
	2004	104	51	-53	-51
	2005	50	53	3	6
	2006	13	13	0	0
	2007	78	41	-37	-47
	2008*	36	34	-2	-6
	2009	48	27	-21	-44
	2010	34	26	-8	-24
	2011	48	30	-18	-38
	2012	121	55	-66	-55
	2013	97	35	-62	-64
	2014	66	39	-27	-41
	2015	68	43	-25	-36
	Mean	62	40	-23	-29

* Eight months of operation.

4.5.2 Cottonwood Creek Perimeter Pond

Site CT-1, above Perimeter Pond, was affected by beaver activity for nearly all of 2015 WY except for June and September. Therefore, only these two months were used to assess PRF efficiency, which greatly limits the assessment. Considering only these months, the PRF was effective in reducing the amount of TP, TN, and TSS in Cottonwood Creek as it passes through Perimeter Pond. The flow-weighted TP concentration was 149 µg/L upstream of the PRF and 88 µg/L downstream and the flow-weighted TN concentration was 1,617 µg/L upstream of the PRF and 1,342 µg/L downstream which indicates some effectiveness in removing TP, as well as TN (Table 4-10). Over the life of the project, the PRF has reduced the flow-weighted TP concentration at the downstream site by an approximate mean 24% while it has only reduced the flow-weighted TN concentration at the downstream site by an approximate mean 5%. The TSS concentration was reduced by approximately 42% in 2015, with the long-term mean reduction of 33%.

This PRF showed limited success at reducing the TP concentration and TSS concentration in Cottonwood Creek flows during multiple storm events on April 17th, June 12th and 25th, and August 11th. Total phosphorous reduction during these events ranged from 5 to 47% and TSS reduction ranged from 13 to 70%. For example, during the June 25th storm event, the inflow TP concentration at Site CT-1 was 167 mg/L while the outflow concentration was 93 mg/L indicating an approximate 44% removal of TP. Similarly, the TSS concentration entering the PRF during this storm event was 97 µg/L while the outflow concentration was 29 µg/L indicating an approximately 70% removal of TSS. Perimeter Pond was not substantially effective at reducing TN concentration in Cottonwood Creek flows during storm events and results ranged from a 28% decrease to a 53% increase in TN.

Table 4-10: Historical total phosphorus, total nitrogen, and total suspended solids concentrations upstream and downstream of the Cottonwood Creek Perimeter Pond, 1997 to 2015 WY.

Parameter	Water Year	CT-1	CT-2	Difference	Percent Change Downstream
Flow-weighted Total Phosphorus Concentration (µg/L)	1997	485	183	-302	-62
	1998	311	176	-135	-43
	1999	143	129	-14	-10
	2000	266	161	-105	-39
	2001	163	146	-17	-10
	2002	124	105	-19	-15
	2003	193	124	-69	-36
	2004	194	149	-45	-23
	2005	141	120	-21	-15
	2006	165	135	-30	-18
	2007	170	148	-22	-13
	2008 ^a	87	86	-1	-1
	2009	70	61	-9	-13
	2010	77	77	0	0
	2011	101	81	-20	-20
	2012 ^b	NA	NA	NA	NA
	2013	119	59	-62	-52
	2014	112	81	-31	-28
	2015 ^c	149	88	-61	-41
	Mean	171	117	-53	-24
Flow-weighted Total Nitrogen Concentration (µg/L)	1997	NA	NA	NA	NA
	1998	NA	NA	NA	NA
	1999	1,475	1,363	-112	-8
	2000	1,821	1,586	-235	-13
	2001	2,206	1,810	-397	-18
	2002	2,669	2,594	-75	-3
	2003	2,075	2,399	323	16
	2004	3,072	2,909	-162	-5
	2005	3,165	3,093	-72	-2
	2006	2,864	2,866	2	0
	2007	2,456	2,262	-194	-8
	2008 ^a	2,555	2,578	23	1
	2009	1,609	1,752	142	9
	2010	1,569	1,521	-47	-3
	2011	1,442	1,339	-103	-7
	2012 ^b	NA	NA	NA	NA
	2013	1,937	1,752	-186	-10
	2014	1,590	1,516	-73	-5
	2015 ^c	1,617	1,342	-275	-17
	Mean	2,097	2,005	-90	-5

Parameter	Water Year	CT-1	CT-2	Difference	Percent Change Downstream
Mean Total Suspended Solids (mg/L)	1997	207	87	-120	-58
	1998	311	129	-182	-59
	1999	267	68	-199	-75
	2000	96	64	-32	-33
	2001	79	43	-36	-46
	2002	150	86	-64	-43
	2003	83	58	-25	-30
	2004	156	128	-28	-18
	2005	123	65	-58	-47
	2006	31	20	-11	-35
	2007	93	64	-29	-31
	2008 ^a	31	59	28	90
	2009	31	32	1	3
	2010	33	33	0	0
	2011	48	30	-18	-38
	2012 ^b	NA	NA	NA	NA
	2013	57	21	-36	-63
	2014	56	22	-34	-61
	2015 ^c	51	30	-22	-42
	Mean	106	58	-48	-33

^a Nine months of operation^b Offline for maintenance^c Two months of operation due to beaver dam.

4.5.3 **McMurdo Stream Reclamation**

Before extensive land use development occurs along McMurdo Gulch, the town of Castle Rock and the CCBWQA used a proactive approach to control stream erosion and implemented a stream reclamation project along three miles of McMurdo Gulch between the Cobblestone Ranch and Castle Oaks subdivisions. Reclamation activities were completed in fall 2011 and two water quality monitoring sites were established on McMurdo Gulch by the CCBWQA in January 2012. Site MCM-1, which serves as the upstream monitoring location, was established approximately 150 m upstream of the McMurdo Gulch Stream Reclamation Project Boundary and 120 m upstream of the confluence with an unnamed tributary that receives runoff from the Castle Oaks Subdivision. Site MCM-2 was established approximately 80 m upstream of the Castle Oaks Drive Bridge crossing of McMurdo Gulch, near the North Rocky View Road intersection and serves as the downstream monitoring location for the McMurdo Gulch Stream Reclamation Project. This site is located within the project boundary, and consistently maintains base flows, whereas reaches further downstream were dry due to flow going subsurface.

Base flow water quality samples were collected on a monthly basis at sites MCM-1 and MCM-2 during the 2015 WY. The PRF was effective in reducing the amount of TP and TN in McMurdo Gulch as it passes through the reclamation area. The mean TP concentration was

392 µg/L upstream of the PRF and 272 µg/L downstream and the TN concentration was 547 µg/L upstream of the PRF and 305 µg/L downstream which indicates efficiency in removing TP and TN from flow. Over the past few years, the PRF has reduced the TP concentration at the downstream site by approximately 23% and TN concentration by approximately 41%. The PRF was not effective at removing TSS in 2015 WY and the concentration at MCM-2 was over four times that at MCM-1. This difference is consistent with the long-term means in which the 2012 to 2015 concentration at MCM-2 is three times that at MCM-1. No storm samples were collected at these sites.

4.6 2015 WY Special Studies

4.6.1 *Cyanotoxin Monitoring in Cherry Creek Reservoir*

The change in the operation of the destratification system in 2014 was intended to address two objectives: 1) monitor changes to the cyanobacteria assemblage in the absence of aeration, and 2) monitor changes in the seasonal chlorophyll *a* concentration. In the absence of aeration, cyanobacteria may rapidly grow in response to favorable reservoir conditions and form surface accumulations (scum) or remain mixed throughout the photic zone depending upon the type of cyanobacteria. These favorable reservoir conditions include warm calm surface water conditions with available nutrients and light in the photic zone. One objective of the destratification system is to vertically mix the water column and disrupt the favorable habitat conditions for large filamentous cyanobacteria. Because the destratification system was not operated during the 2014 and 2015 summer growing season, there was a concern that cyanobacteria would thrive under more favorable growing conditions and potentially produce toxins that may affect the beneficial uses of the Reservoir. Notably, cyanobacteria blooms have occurred during the operation of the destratification, but not to the extent observed in both 2014 and 2015. The objective of the 2015 supplemental cyanotoxin monitoring program was to document the concentrations of microcystins, anatoxins, saxitoxins, and cylindrospermopsins in the photic zone of the Reservoir and at the Swim Beach and to provide the CCBWQA and its stakeholders the opportunity to evaluate the risk to beneficial uses.

A total of 18 samples were collected for cyanotoxin analysis between May 27th and September 22nd, 2015 (Figure 4-40). On May 27th, an *A. flos-aquae* cyanobacteria bloom (7,681,011 µm³/mL biovolume) was evident throughout the Reservoir and multiple cyanotoxin samples were collected and analyzed for the suite of toxins (microcystins, anatoxins, saxitoxins, and cylindrospermopsins); however, no cyanotoxins were detected in any of the samples (Photo 4-1). On September 9th, the routine composite photic samples revealed microcystins concentration (0.18 µg/L) at just above the detection limit. Microcystin at this level is not considered a human health risk according to recreation thresholds established by World Health Organization microcystins. Despite this detection, the only cyanobacteria detected that day was *A. flos-aquae* at a very low biovolume (35,411 µm³/mL). *A. flos-aquae* biovolume was quite large on September 22nd (84,528,910 µm³/mL) in the opportunistic surface grab sample taken at the east dock during a suspected bloom, however,

no microcystins were detected (Photo 4-2). Long-term cyanotoxin data is presented in Appendix E.

Photo 4-1: Visible surface cyanobacteria near Site CCR-2 on 5/27/15 (microcystins = ND).



Photo 4-2: Visible surface cyanobacteria at east boat launch on 9/22/15 (microcystins = ND).

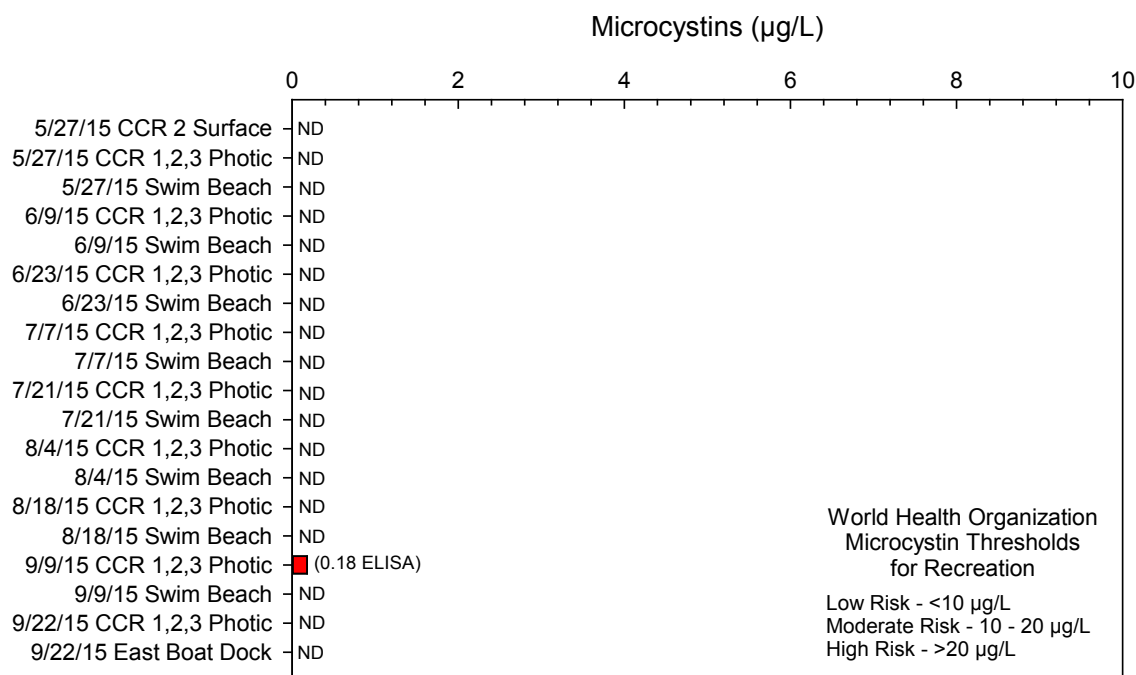


Figure 4-40: Cyanotoxin analyses for Cherry Creek Reservoir, May through September 2015.

4.6.2 TOC and DOC Analyses in Cherry Creek Reservoir and Tributaries

For reservoir model development purposes, TOC/DOC concentrations were measured at the Reservoir surface (photic zone), at the bottom of CCR-2 near the water/sediment interface, and at the two tributaries (CC-10 and CT-2) for the 2015 WY. In the photic zone at CCR-2, TOC concentrations ranged from 5.8 mg/L in mid-May to 7.6 mg/L in mid-March with a mean of 6.6 mg/L. DOC concentrations ranged from 5.1 mg/L in early November 2014 and early September 2015 to 6.7 mg/L in late July with a mean of 5.6 mg/L (Table 4-11). At the reservoir bottom, TOC concentrations ranged from 5.9 mg/L in mid-October and early November to 7.0 mg/L in early April with a mean of 6.4 mg/L. DOC concentrations ranged from 4.8 mg/L in mid-March to 6.6 mg/L in late June with a mean of 5.4 mg/L. These concentrations are similar to the TOC and DOC concentrations recorded in the photic zone at CCR-2. At CC-10, TOC concentrations ranged from 3.7 mg/L in early December and early April to 9.5 mg/L in early August with a mean of 4.9 mg/L. DOC concentrations ranged from 3.2 mg/L in early April to 7.2 mg/L in early August with a mean of 4.2 mg/L. At CT-2, TOC concentrations ranged from 4.8 mg/L in early December to 9.5 mg/L in early July with a mean of 6.6 mg/L. DOC concentrations ranged from 4.3 mg/L in early December to 7.8 mg/L in early July with a mean of 5.5 mg/L.

Table 4-11: Total organic carbon (TOC) and dissolved organic carbon (DOC) concentrations in Cherry Creek Reservoir and tributaries (CC-10 and CT-2), 2015 WY.

Sample Date	Sample	TOC (mg/L)	DOC (mg/L)	DOC/TOC (%)
CCR-2 Photic	10/14/2014	6.2	5.3	84.7
	11/4/2014	6.0	5.1	84.2
	3/18/2015	7.6	5.6	73.0
	4/8/2015	7.2	5.7	79.2
	5/12/2015	5.8	5.9	100.9
	5/27/2015	6.7	5.3	78.4
	6/9/2015	7.1	5.5	77.3
	6/23/2015	7.1	6.5	92.2
	7/7/2015	6.2	5.5	87.9
	7/21/2015	7.3	6.7	92.4
	8/4/2015	6.7	5.6	83.6
	8/18/2015	6.7	5.5	82.1
	9/9/2015	6.0	5.1	84.9
	9/22/2015	6.4	5.6	88.2
	Mean	6.6	5.6	84.9

Sample Date	Sample	TOC (mg/L)	DOC (mg/L)	DOC/TOC (%)
CCR-2 Bottom	10/14/2014	5.9	5.2	88.9
	11/4/2014	5.9	5.2	88.9
	3/18/2015	6.0	4.8	79.8
	4/8/2015	7.0	5.1	72.7
	5/12/2015	6.0	5.9	99.2
	5/27/2015	6.1	5.3	86.1
	6/9/2015	6.3	5.4	84.9
	6/23/2015	6.9	6.6	95.7
	7/7/2015	6.5	5.6	85.4
	7/21/2015	6.7	5.6	82.8
	8/4/2015	6.4	5.6	88.2
	8/18/2015	6.7	5.3	79.1
	9/9/2015	6.6	5.1	77.3
	9/22/2015	6.3	5.4	85.6
	Mean	6.4	5.4	85.3
CC-10	10/21/2014	4.6	3.7	80.4
	11/6/2014	3.9	3.6	91.0
	12/1/2014	3.7	3.5	93.2
	1/5/2015	4.2	3.7	88.1
	2/9/2015	4.1	3.4	82.9
	3/17/2015	4.2	3.7	86.9
	4/6/2015	3.7	3.2	87.7
	5/4/2015	4.4	4.1	94.3
	6/22/2015	5.4	5.7	105.6
	7/6/2015	6.0	5.4	90.8
	8/3/2015	9.5	7.2	75.3
	9/8/2015	5.2	4.0	76.7
	Mean	4.9	4.2	87.7
CT-2	10/21/2014	5.4	4.4	81.3
	11/6/2014	5.1	4.7	91.2
	12/1/2014	4.8	4.3	88.5
	1/5/2015	5.0	4.8	97.0
	2/9/2015	6.1	4.9	80.3
	3/17/2015	6.4	4.9	75.8
	4/6/2015	7.1	5.4	75.9
	5/4/2015	7.4	5.8	78.2
	6/22/2015	7.4	6.9	92.6
	7/6/2015	9.5	7.8	82.5
	8/3/2015	7.4	6.1	82.3
	9/8/2015	7.6	5.9	78.1
	Mean	6.6	5.5	83.6

5. References

- Advanced Sciences, Inc. 1994a. *Cherry Creek Basin, Annual Water-Quality Monitoring Report, 1993 Water Year*. Project No. 8970. Prepared for the Cherry Creek Basin Water Quality Authority.
- Advanced Sciences, Inc. 1994b. 1993 Cherry Creek Basin Water Quality Authority Contract: Project 8790. Exhibits A through H (amended).
- AMEC, Earth and Environmental, Inc., Alex Horne Associates, and Hydrosphere Resource Consultants, Inc. 2005. *Cherry Creek Reservoir Destratification*. Feasibility report prepared for the Cherry Creek Basin Water Quality Authority.
- American Public Health Association (APHA). 1998. *Standard Methods for the Examination of Water and Wastewater*, 20th Edition. Prepared and published jointly by the American Public Health Association, American Water Works Association, and Water Pollution Control Federation, Washington, DC.
- Bailey-Watts, A.E. 1986. The ecology of planktonic diatoms, especially *Fragilaria crotonensis*, associated with artificial mixing of a small Scottish loch in summer. *Diatom Research* 1: 153-168.
- 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). 1998. *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). 2003. *Cherry Creek Reservoir 2002 Annual Aquatic Biological and Nutrient Monitoring Study and Cottonwood Creek Phosphorus Reduction Facility Monitoring*. Prepared for the Cherry Creek Basin Water Quality Authority.
- Chadwick Ecological Consultants, Inc. (CEC). 2004. *Cherry Creek Reservoir 2003 Annual Aquatic Biological and Nutrient Monitoring Study and Cottonwood Creek Phosphorus Reduction Facility Monitoring*. Prepared for the Cherry Creek Basin Water Quality Authority.
- Chadwick Ecological Consultants, Inc. (CEC). 2005. *Cherry Creek Reservoir 2004 Annual Aquatic Biological and Nutrient Monitoring Study and Cottonwood Creek Phosphorus Reduction Facility Monitoring*. Prepared for the Cherry Creek Basin Water Quality Authority.
- Chadwick Ecological Consultants, Inc. (CEC). 2006. *Cherry Creek Reservoir 2005 Annual Aquatic Biological and Nutrient Monitoring Study and Cottonwood Creek Phosphorus Reduction Facility Monitoring*. Prepared for the Cherry Creek Basin Water Quality Authority.
- Cole, G. A. 1979. *Textbook of Limnology*, 2nd Edition. The C.V. Mosby Company, St. Louis, MO.
- Colorado Department of Public Health and Environment (CDPHE). 2011. *Section 303(d) Listing Methodology: 2012 Listing Cycle*. Water Quality Control Division, Denver, CO.
- Cooke, D. C., E. B. Welch, S. A. Peterson, and P.R. Newroth. 1993. *Restoration & Management of Lakes & Reservoirs*, 2nd Edition. Lewis Publishers, Boca Raton, FL.
- Denver Regional Council of Governments (DRCOG). 1984. *Cherry Creek Reservoir Clean Lakes Study*. Denver Regional Council of Governments, Denver, CO.

- Denver Regional Council of Governments (DRCOG). 1985. *Cherry Creek Basin Water Quality Management Master Plan*. Prepared in Cooperation with Counties, Municipalities, Water and Sanitation Districts in the Cherry Creek Basin and Colorado Department of Health.
- GEI Consultants, Inc. (GEI). 2007. *Cherry Creek Reservoir 2006 Annual Aquatic Biological and Nutrient Monitoring Study and Cottonwood Creek Phosphorus Reduction Facility Monitoring*. Prepared for the Cherry Creek Basin Water Quality Authority.
- GEI Consultants, Inc. (GEI). 2008b. *Cherry Creek Reservoir 2007 Annual Aquatic Biological and Nutrient Monitoring Study and Cottonwood Creek Phosphorus Reduction Facility Monitoring*. Prepared for the Cherry Creek Basin Water Quality Authority.
- GEI Consultants, Inc. (GEI). 2009. *Cherry Creek Reservoir 2008 Annual Aquatic Biological and Nutrient Monitoring Study and Cottonwood Creek Phosphorus Reduction Facility Monitoring*. Prepared for the Cherry Creek Basin Water Quality Authority.
- GEI Consultants, Inc. (GEI). 2010. *Cherry Creek Reservoir 2009 Annual Aquatic Biological and Nutrient Monitoring Study and Cottonwood Creek Phosphorus Reduction Facility Monitoring*. Prepared for the Cherry Creek Basin Water Quality Authority.
- GEI Consultants, Inc. (GEI). 2011. *Cherry Creek Reservoir 2010 Annual Aquatic Biological and Nutrient Monitoring Study and Cottonwood Creek Phosphorus Reduction Facility Monitoring*. Prepared for the Cherry Creek Basin Water Quality Authority.
- GEI Consultants, Inc. (GEI). 2012. *Cherry Creek Reservoir 2011 Annual Aquatic Biological and Nutrient Monitoring Study and Cottonwood Creek Phosphorus Reduction Facility Monitoring*. Prepared for the Cherry Creek Basin Water Quality Authority.
- GEI Consultants, Inc. (GEI). 2013. *Cherry Creek Reservoir 2012 Annual Aquatic Biological and Nutrient Monitoring Study and Cottonwood Creek Phosphorus Reduction Facility Monitoring*. Prepared for the Cherry Creek Basin Water Quality Authority.
- GEI Consultants, Inc. (GEI). 2014. *Cherry Creek Reservoir 2013 Annual Aquatic Biological and Nutrient Monitoring Study and Cottonwood Creek Phosphorus Reduction Facility Monitoring*. Prepared for the Cherry Creek Basin Water Quality Authority.
- GEI Consultants, Inc. (GEI). 2015. *The Cherry Creek Basin Water Quality Authority Routine Sampling and Analysis Plan/Quality Assurance Project Plan*. Prepared for the Cherry Creek Basin Water Quality Authority.
- Harman, C. D., D. R. Bayne, and M. S. West. 1995. Zooplankton trophic state relationships in four Alabama-Georgia reservoirs. *Lake and Reservoir Management*, 11:4 299-309.

- Harris, G.P. 1986. *Phytoplankton Ecology. Structure Function and Fluctuation*. Chapman and Hall, London.
- Heaney, S.I., J.W.G. Lund, H.M. Canter, and K. Grey. 1988. Population dynamics of *Ceratium spp.* in three English lakes, 1945–1985. *Hydrobiologia*, 161, 133–148.
- Hintze, J. L. 2009. NCSS and PASS. Number Cruncher Statistical Systems, Kaysville, UT.
- Horne, A. J. and C. R. Goldman. 1994. *Limnology*. McGraw-Hill Company, NY.
- 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).
- James, W. F., W. D. Taylor, J. W. Barko. 1992. Production and vertical migration of *Ceratium hirundinella* in relation to phosphorus availability in Eau Galle Reservoir, Wisconsin. *Canadian Journal of Fisheries and Aquatic Sciences* 49:694-700.
- John C. Halepaska & Associates, Inc. (JCHA). 1999. *1998 Annual Report, Phase I Baseline Water Quality Data Collection Study for the Upper Cherry Creek Basin*. Prepared for the Cherry Creek Basin Water Quality Authority, Project No. 5601:6.
- John C. Halepaska & Associates, Inc. (JCHA). 2000. *1999 Annual Report, Phase I Baseline Water Quality Data Collection Study for the Upper Cherry Creek Basin*. Prepared for the Cherry Creek Basin Water Quality Authority.
- John C. Halepaska & Associates, Inc. (JCHA). 2001. *2000 Annual Report, Baseline Water Quality Data Collection Study for the Upper Cherry Creek Basin*. Prepared for the Cherry Creek Basin Water Quality Authority.
- John C. Halepaska & Associates, Inc. (JCHA). 2002. *2001 Annual Report, Baseline Water Quality Data Collection Study for the Upper Cherry Creek Basin*. Prepared for the Cherry Creek Basin Water Quality Authority.
- John C. Halepaska & Associates, Inc. (JCHA). 2003. *2002 Annual Report, Baseline Water Quality Data Collection Study for the Upper Cherry Creek Basin*. Prepared for the Cherry Creek Basin Water Quality Authority.
- John C. Halepaska & Associates, Inc. (JCHA). 2004. *2003 Annual Report, Baseline Water Quality Data Collection Study for the Upper Cherry Creek Basin*. Prepared for the Cherry Creek Basin Water Quality Authority.
- John C. Halepaska & Associates, Inc. (JCHA). 2005. *2004 Annual Report, Baseline Water Quality Data Collection Study for the Upper Cherry Creek Basin*. Prepared for the Cherry Creek Basin Water Quality Authority.

- John C. Halepaska & Associates, Inc. (JCHA). 2006. *2005 Annual Report, Baseline Water Quality Data Collection Study for the Upper Cherry Creek Basin*. Prepared for the Cherry Creek Basin Water Quality Authority.
- John C. Halepaska & Associates, Inc. (JCHA). 2007. *2006 Annual Report, Baseline Water Quality Data Collection Study for the Upper Cherry Creek Basin*. Prepared for the Cherry Creek Basin Water Quality Authority.
- John C. Halepaska & Associates, Inc. (JCHA). 2008. *2007 Annual Report, Baseline Water Quality Data Collection Study for the Upper Cherry Creek Basin*. Prepared for the Cherry Creek Basin Water Quality Authority.
- John C. Halepaska & Associates, Inc. (JCHA). 2009. *2008 Annual Report, Baseline Water Quality Data Collection Study for the Upper Cherry Creek Basin*. Prepared for the Cherry Creek Basin Water Quality Authority.
- John C. Halepaska & Associates, Inc. (JCHA). 2010. *2009 Annual Report, Baseline Water Quality Data Collection Study for the Upper Cherry Creek Basin*. Prepared for the Cherry Creek Basin Water Quality Authority.
- Jones, J. R. 1994. *Report on Cherry Creek Reservoir, Summer 1993*. Report to Cherry Creek Basin Water Quality Authority.
- Jones, J. R. 1995. *Report on Cherry Creek Reservoir, Summer 1994*. Report to Cherry Creek Basin Water Quality Authority.
- Jones, J. R. 1996. *Report on Cherry Creek Reservoir, 1995 Sampling Season*. Report to Cherry Creek Basin Water Quality Authority.
- Jones, J. R. 1997. *Report on Cherry Creek Reservoir, 1996 Sampling Season*. Report to Cherry Creek Basin Water Quality Authority.
- Jones, J. R. 1998. *Report on Cherry Creek Reservoir, 1997 Sampling Season*. Report to Cherry Creek Basin Water Quality Authority.
- Jones, J. R. 1999. *Report on Cherry Creek Reservoir, 1998 Sampling Season*. Report to Cherry Creek Basin Water Quality Authority.
- Jones, J. R. 2001. *Report on Cherry Creek Reservoir, 1992-2001 and Historical Data*. Report to Cherry Creek Basin Water Quality Authority.
- Kelly M.G., H. Bennion, E.J. Cox, B. Goldsmith, J. Jamieson, S. Juggins D.G. Mann and R.J. Telford. 2005. Common freshwater diatoms of Britain and Ireland: an interactive key. Environment Agency, Bristol.

- Knapp, C.W., J. deNoyelles, D.W. Graham, S. Bergin. 2003. Physical and chemical conditions surrounding the diurnal vertical migration of *Cryptomonas* spp. (Cryptophyceae) in a seasonally stratified midwestern reservoir (USA). *Journal of Phycology* 39:855-861.
- Knowlton, M. R., and J. R. Jones. 1993. *Limnological Investigations of Cherry Creek Lake*. Final report to Cherry Creek Basin Water Quality Authority.
- Komárek, J., H. Kling, and J. Komáaková. 2003. Filamentous Cyanobacteria. Pp 117-196 in Wehr, J. D. and R. G. Sheath (eds.). *Freshwater Algae of North America: Ecology and Classification*. Academic Press, Burlington, MA.
- Konopka, A. and T. D. Brock. 1978. Effect of temperature on blue-green algae (Cyanobacteria) in Lake Mendota. *Applied and Environmental Microbiology* 36:572-576.
- Kugrens, P. and B. L. Clay. 2003. Cryptomonads. Pp. 715-755 in Wehr, J. D. and R. G. Sheath (eds.). *Freshwater Algae of North America: Ecology and Classification*. Academic Press, Burlington, MA.
- 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.
- Lund, J.W.G. 1949. Studies on *Asterionella*: I. The origin and nature of the cells producing seasonal maxima. *Journal of Ecology*, 37, 389-419; II.
- Mazumder, A. 1994. Phosphorus-chlorophyll relationships under contrasting zooplankton community structure: potential mechanisms. *Canadian Journal of Fisheries and Aquatic Sciences* 51:401-407.
- Mazumder, A. and D. R. S. Lean. 1994. Consumer dependent responses of lake ecosystems to nutrient loading. *Journal of Plankton Research* 16:1567-1580.
- Nürnberg, G., and LaZerte, B. 2008. *Cherry Creek Reservoir Model and Proposed Chlorophyll Standard*. Prepared for the Cherry Creek Basin Water Quality Authority.

- Padisák, J. 1985. Population dynamics of the freshwater dinoflagellate *Ceratium hirundinella* in the largest shallow lake of Central Europe, Lake Balaton, Hungary. *Freshwater Biology* 15:43-52.
- Pollinger, U. 1987. Freshwater ecosystems, in Taylor, F. J. R. (ed.). *The Biology of Dinoflagellates*. Blackwell Science, Malden, MA.
- Reynolds, C.S. 1983. A physiological interpretation of the dynamic responses of populations of a planktonic diatom to physical variability of the environment. *New Phytologist* 95: 41-53.
- Reynolds, C.S. 1997. *Vegetation Processes in the Pelagic: A Model for Ecosystem Theory*. Ecology Institute, Oldendorf/Luhe, Germany.
- Sarnelle, O. 1992. Nutrient enrichment and grazer effects on phytoplankton in lakes. *Ecology* 73:51-56.
- Tsukada H., S. Tsujimura, H. Nakahara. 2006. Seasonal succession of phytoplankton in Lake Yogo over 2 years: effect of artificial manipulation. *Limnology* 7:3-14.
- Vanni, M. J., and J. Temte. 1990. Seasonal patterns of grazing and nutrient limitation of phytoplankton in a eutrophic lake. *Limnology and Oceanography* 35:697-709.
- Wetzel, R. G. 2001. *Limnology*, 3rd Edition. Academic Press, San Diego, CA.
- Whitton, B. A. and M. Potts (eds.). 2000. *The Ecology of Cyanobacteria: Their diversity in time and Space*. Kluwer Academic, Boston, MA.

Appendix A Cherry Creek Reservoir Sampling and Analysis Plan



2015

**THE CHERRY CREEK BASIN WATER QUALITY AUTHORITY
ROUTINE SAMPLING AND ANALYSIS PLAN/
QUALITY ASSURANCE PROJECT PLAN
SAP | QAPP**

Table of Contents

1.0 Introduction	3
2.0 Purpose	3
3.0 Sampling Program Objectives	4
4.0 Regulation No. 72 Requirements	5
5.0 Review and Updates	5
6.0 Timeline.....	6
7.0 Project Description.....	6
7.1 Sample Site Locations	7
7.1.1 Cherry Creek Reservoir Monitoring Sites.....	7
7.1.2 Stream Monitoring Sites	7
7.1.2.1 Cherry Creek	7
7.1.2.2 Cottonwood Creek	9
7.1.2.3 Piney Creek	10
7.1.2.4 McMurdo Gulch	10
7.1.3 Precipitation Sampling Site	10
7.1.4 Alluvial Groundwater Sites.....	10
7.2 Sampling Parameters and Frequency	14
7.3 Authority Roles and Participation.....	16
7.4 Sampling Teams and Structure	16
7.4.1 Project Manager	16
7.4.2 Quality Assurance Manager.....	16
7.4.3 Analytical and Biological Laboratory Managers.....	17
7.4.4 Sampling Crew	17
7.5 Field Methodologies	17
7.5.1 Reservoir Sampling	17
7.5.1.1 Transparency.....	17
7.5.1.2 Depth Profile Measurements.....	18
7.5.1.3 Continuous Temperature Monitoring.....	18
7.5.1.4 Water Samples	18
7.5.1.5 Zooplankton Samples.....	19

7.5.2 Stream Sampling	20
7.5.2.1 Monthly Base Flow Sampling	20
7.5.2.2 Storm Event Sampling	20
7.5.2.3 Continuous Water Level Monitoring	20
7.5.3 Watershed Surface Water Sampling	21
7.5.4 Alluvial Groundwater Sampling	21
7.5.5 Precipitation Sampling	22
8.0 Laboratory Procedures.....	22
9.0 Program Quality Assurance/Quality Control Protocols	24
Field Sampling	24
Laboratory	25
10.0 Data Validation and Usability.....	25
11.0 Data Verification, Reduction, and Reporting	25
12.0 References	26
APPENDIX A – Sampling Site Locations	27
APPENDIX B –Abandoned Sampling Sites	29

1.0 Introduction

The Cherry Creek Basin Water Quality Authority (Authority) was formally created in 1988 by the Colorado State Legislature by statute (see Colorado Revised Statutes (C.R.S.) 25.8.5-101 et seq.). The Authority was created as a quasi-municipal corporation and political subdivision of the state, and was provided with specific authorities. The Authority is tasked with improving, protecting, and preserving the water quality of Cherry Creek and Cherry Creek Reservoir as well as achieving and maintaining state water quality standards for the reservoir and watershed. The Authority has the power to develop and implement plans and studies for water quality controls for the reservoir and watershed to achieve and maintain the water quality standards, and make recommendations regarding water quality projects and programs to achieve water quality standards. The Sampling and Analysis Plan (SAP) and Quality Assurance Project Plan (QAPP) includes long-term monitoring of nutrient levels within the reservoir and its tributaries, nutrient levels in precipitation and groundwater, and chlorophyll *a* levels within the reservoir. The overall goal of the monitoring program is to assess attainment of the water quality standards (including beneficial uses and the numeric criteria adopted to protect the uses) and to assess the effectiveness of the Authority's actions.

2.0 Purpose

The Cherry Creek Basin Water Quality Authority (Authority) is required to samples biological, physical, and nutrient parameters in the Cherry Creek Reservoir and its tributaries under Regulation 72, the Cherry Creek Reservoir Control Regulation. Pursuant to this charge, the monitoring program is to meet the following purposes stemming from Regulation 72:

- For the purpose of supporting and calibrating the reservoir water quality model, as anticipated by Regulation 72¹;
- For the purpose of meeting parameter-specific monitoring required of the Authority by Regulation 72 and additional non-specified monitoring determined by the Authority to be supportive of Authority goals;
- For the purpose of meeting nutrient Pollutant Reduction Facility (PRF) monitoring required of the Authority by Regulation 72;

¹ As future special studies are identified, the SAP/QAPP will be reviewed to determine if any modifications need to be made to support the new study. In some instances, a short, stand-alone SAP may be more appropriate. "Special studies" are anticipated by Regulation 72, the Cherry Creek Reservoir Control Regulation, Section 72.8.4: "Special studies may include, but are not limited to, the following areas of investigation: (a) Feasibility study of nutrient removal from point sources; (b) Quantification of effectiveness of nonpoint source concentration-based phosphorus control strategies called PRFs; (c) Quantification of effectiveness of regulated stormwater concentration-based phosphorus control strategies called BMPs; and (d) Quantification of the effectiveness of source control BMPs that include low-impact development techniques." The reservoir model qualifies as a special study. A special study such as a side-by-side comparison of methods for cyanobacteria analysis, e.g., filtering vs. settling, would also require a separate special SAP.

- For the purpose of assessing the effects of the destratification system, as required of the Authority by Regulation 72 as part of its PRF monitoring for nutrients and additional monitoring as may be determined by the Authority;
- For the purpose of determining attainment of applicable water quality standards, as required of the Authority by Regulation 72; and
- For the purpose of evaluating nutrient sources and transport, evaluating fate and transport of phosphorus, and calculating flow-weighted phosphorus concentrations, as required of the Authority by Regulation 72.
- For the purpose of calculating flow-weighted nitrogen concentrations and evaluating the fate and transport of nitrogen, as well as calculating mass balances for both phosphorus and nitrogen inputs and losses from the reservoir, as determined by the Authority to be supportive of its goals, according to the 2010 expansion of Regulation 72 to consider all nutrients, and not just phosphorus.

3.0 Sampling Program Objectives

The Authority's long-term goals serve as assessment end-points for the reservoir and watershed (for example, protection of beneficial uses, and preservation and enhancement of water quality). The sampling program helps the Authority evaluate whether it is attaining its long-term goals. Specific objectives of the sampling program are to:

- Determine biological productivity in the reservoir, as measured by chlorophyll *a* concentrations and collect other data (i.e., phytoplankton) related to the effect of chlorophyll *a* on beneficial uses;
- Determine the concentrations of phosphorus and nitrogen species in the reservoir and streams, and how it changes over time;
- Determine the annual flow-weighted phosphorus concentration and changes to the concentrations entering the reservoir from streams and precipitation and the phosphorus export from the reservoir via the outlet structure;
- Determine the effectiveness of pollutant removal by Pollutant Reduction Facilities; and
- Determine the effectiveness of the destratification system² in protecting the beneficial uses by reducing the algal biomass as measured by chlorophyll *a* and reducing cyanobacteria production as measured by species identification, enumeration, and biovolume.

² Note that the destratification system was originally designed to achieve the following goals: 1) reduce the release of phosphorus and nitrogen nutrients from the bottom sediments into the water column of the reservoir in a typical year by 810 lbs/yr and 1140 lbs/yr, respectively; 2) decrease the seasonal mean (July-Sept) chlorophyll *a* concentrations by approximately 8 ug/L under typical year conditions; 3) decrease annual peak chlorophyll *a* concentrations by up to 30 ug/L; 4) increase dissolved oxygen concentrations in the deepest and most vulnerable zones of the reservoir into the range of 5 mg/L; and 5) reduce the production of blue-green algae by making the habitat of the reservoir less suitable for the production of blue-green algae via vertical mixing. (AMEC Earth & Environmental, Inc., Alex Horne Associates, Hydrosphere Resource Consultants, Inc. (December 5, 2005). *Feasibility Report Cherry Creek Reservoir Destratification.*)

The SAP/QAPP identifies field and laboratory protocols necessary to achieve high quality data. The 2014 SAP/QAPP is intended to build off of the 2008 Sampling and Analysis Plan and Quality Assurance Work Plan (GEI 2008) and includes: quality assurance objectives for the measurement of data in terms of accuracy, representativeness, comparability, and completeness; field sampling and sample preservation procedures, laboratory processing and analytical procedures; and guidelines for data verification and reporting; quality control check; corrective actions; and quality assurance reporting.

4.0 Regulation No. 72 Requirements

Regulation 72 states that the Authority shall develop and implement, in conjunction with local governments, a routine annual water quality monitoring program of the Cherry Creek watershed and Cherry Creek Reservoir. The monitoring program shall include monitoring of the reservoir water quality and inflow volumes, alluvial water quality, and nonpoint source flows. Monitoring shall include, but not be limited to nitrate, nitrite, ammonia, total phosphorus, total soluble phosphorus, and orthophosphate concentrations.

- Routine monitoring of surface water, ground water, and the reservoir shall be implemented to determine the total annual flow-weighted concentration of nutrients to the reservoir; and
- Monitoring of PRFs shall be implemented to determine inflow and outflow nutrient concentrations.

The Authority shall consult with the Colorado Water Quality Control Division (Division) in the development of the monitoring program to ensure that the monitoring plan includes the collection of data to evaluate nutrient sources and transport, to characterize reductions in nutrient concentrations, and to determine attainment of water quality standards in Cherry Creek Reservoir. In addition, the Authority shall consult with the Division and other appropriate entities in development of any water quality investigative special studies.

The monitoring data shall be used by the Authority to determine phosphorus fate and transport, calculate annual flow-weighted phosphorus concentrations, document compliance with the applicable water quality standards, analyze long-term trends in water quality for both the reservoir and the Cherry Creek watershed, and calibrate water quality models (72.8).

Reporting requirements are also required under Regulation 72. The Authority shall submit an annual report on the activities to the Commission and Division by March 31 of each year (72.9).

The SAP/QAPP facilitates the above Regulation 72 requirements, and ensures a high quality, auditable, and well-documented monitoring program.

5.0 Review and Updates

A review of the SAP/QAPP shall be performed by the Technical Advisory Committee (TAC) or Water Quality Committee when there are material changes made to the sampling program (e.g. new

monitoring sites, additional parameters, laboratory changes, changes in personnel, etc.), and any updates shall be made as needed. In addition, a review and update of the SAP/QAPP shall be conducted by the TAC or Water Quality Committee in preparation for Water Quality Control Commission (WQCC) Rule Making Hearings (RMH) and other special studies, as needed. Changes and amendments shall be incorporated into the SAP/QAPP in a timely manner, and shall be well-documented.

6.0 Timeline

Sampling and data collection shall be implemented per Regulation 72. The Cherry Creek Basin is subject to the hearing timelines of the Cherry Creek Reservoir Control Regulation (Regulation 72), statewide water quality standards (Regulation 31), Cherry Creek water quality standards (Regulation 38), statewide water quality standards assessment (Regulation 93), and other regulations (Regulation 22, 43, 61, 85). As these regulations change, the SAP/QAPP may need to be revisited and may change. The next Water Quality Control Commission Triennial Review Informational Hearing for Regulation 72 will be held in May 2015. Figure 1 below shows the timeline of regulation hearings pertaining to the Cherry Creek Basin.

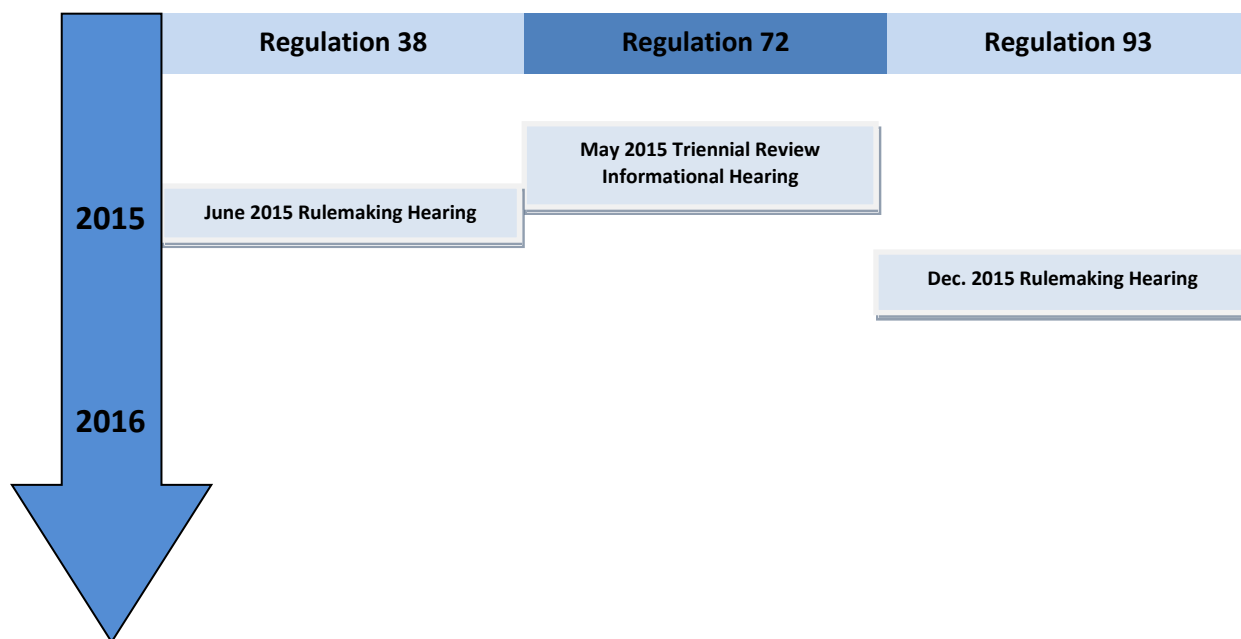


Figure 1: Water Quality Control Commission Regulation Hearing Timeline

7.0 Project Description

The Authority has been collecting water quality data since 1994. The data has provided an extensive site-specific data set for Cherry Creek Reservoir and its tributaries. This SAP/QAPP has been designed to better define water quality conditions and to gain a better understanding of changes of

nutrients in the reservoir and its tributaries and the effectiveness of PRFs. The following includes an overview of sampling site locations, sampling teams and structures, sampling parameters, and frequency of sampling.

7.1 Sample Site Locations

Reservoir, watershed, and PRF sampling shall be routinely conducted at 13 sites, including three sites in Cherry Creek Reservoir, eighteen stream monitoring sites (on Cherry Creek, Cottonwood Creek, Piney Creek, and McMurdo Gulch), and eight alluvial groundwater sites along Cherry Creek mainstem, and one site on Cherry Creek downstream of the Reservoir (Figure 2). Data from many of these monitoring sites are used to assess the effectiveness of several of the Authority's PRFs (Figure 3). In addition to these routine monitoring sites, 10 transect sites (D1 to D10) were established from the approximate mid-point of the dam face extending perpendicular across the destratification zone in the Reservoir, as well as three continuous temperature logging sites near routine reservoir monitoring sites.

All sampling sites are summarized below. Site coordinates for the currently monitored sites can be found in Appendix A. Information on sites that were previously monitored but have been abandoned is found in Appendix B.

7.1.1 Cherry Creek Reservoir Monitoring Sites

CCR-1	This site is also called the Dam site, and was established in 1987. Site CCR-1 corresponds to the northwest area within the reservoir (Knowlton, 1993). Sampling was discontinued at this site in 1996 and 1997 following determination that this site exhibited similar characteristics to the other two sites. Sampling recommenced in July 1998 at the request of consultants for Greenwood Village.
CCR-2	This site is also called the Swim Beach site, and was established in 1987. Site CCR-2 corresponds to the northeast area within the reservoir (Knowlton, 1993).
CCR-3	This site is also called the Inlet site, and was established in 1987. Site CCR-3 corresponds to the south area within the reservoir (Knowlton, 1993).
D-1 to D-10	These sites are a series of transect profile locations that start near the dam face (D1) and continue across the Reservoir to CCR-3. The transect corresponds to Transect D of the Destratification Feasibility Report (AMEC 2005).

7.1.2 Stream Monitoring Sites

7.1.2.1 Cherry Creek

Castlewood	This site has been sampled since 1994, and is located in Castlewood Canyon State Park where the Homestead Trail crosses Cherry Creek. It is located about 0.2 miles north of the USGS gaging station known as "Cherry Creek near Franktown."
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CC-1	This site was established in 2012 on Cherry Creek. This site is located on Cherry Creek approximately 380 m upstream of where Bayou Gulch Road crosses Cherry Creek near Parker Road.
CC-2	This site has been sampled since 1994 and is located on Cherry Creek below the Pinery's wastewater treatment plant. This site is located approximately 0.85 km upstream of Stroh Road.
CC-4	This site has been sampled since 1994, and is located on Cherry Creek below the confluence with Sulphur Gulch and below the outfall for Parker's AWT plant. This site is located approximately 0.50 km downstream of Main Street in Parker.
CC-5	This site has been sampled since 1994, and is located on Cherry Creek immediately downgradient of the confluence with Newlin Gulch. This site is located where Pine Lane crosses Cherry Creek, approximately 0.65 km west of Parker Road.
CC-6	This site has been sampled since 1994, and is located on Cherry Creek downgradient of Parker's North AWT plant. However, the discharge from this AWT plant is transported via pipeline to Sulphur Gulch. This site is located approximately 1.38 km downstream of Cottonwood Drive and 0.41 km west of Parker Road.
CC-7 EcoPark	This site was reestablished in 2013 on Cherry Creek at the downstream boundary of Cherry Creek Valley Ecological Park (EcoPark). This site is approximately 1.7 kilometers (km) upstream (south) of Arapahoe Road, and serves to monitor water quality conditions downstream of the EcoPark Stream Reclamation Project (PRF). This site also provides more accurate flow estimates in this reach of Cherry Creek. (The original CC-7 site, located ¾ mile south of Arapahoe Road, was abandoned in 2000 due to development.)
CC-8	This site has been sampled since 1994, and is located on Cherry Creek, approximately 0.5 miles north of Arapahoe Road.
CC-9	This site was re-established in 2012 on Cherry Creek, and is located in Cherry Creek State Park just upgradient of Cherry Creek Reservoir. This site is located immediately downstream of where East Lake View Drive crosses Cherry Creek in Cherry Creek State Park.
CC-10	This site is on Cherry Creek immediately downstream of the Shop Creek confluence, approximately 0.5 km upstream of Cherry Creek Reservoir. This site provides data to estimate phosphorus loads to the Reservoir from Cherry Creek and includes inputs from upstream tributaries, including Shop Creek.
CC-O	This site was established in 1987, and is located on Cherry Creek downstream of Cherry Creek Reservoir and upstream of the Hampden Avenue-Havana Street junction in the Kennedy Golf Course near the historical USGS gage (06713000).

In 2007, Site CC-O (also identified in the past as Site CC-Out at I225) was relocated immediately downstream of the dam outlet structure and is used to monitor the water quality of the Reservoir outflow.

7.1.2.2 Cottonwood Creek

- CT-P1 This site was established in 2002, and is located on Cottonwood Creek 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 on Cottonwood Creek at the outfall of the PRF, on the west side of Peoria Street. The ISCO® stormwater sampler and pressure transducer is located inside the outlet structure. This site monitors the effectiveness of the PRF on water quality.
- CT-1 This site was established in 1987 where the Cherry Creek Park Perimeter Road crosses Cottonwood Creek. It was chosen to monitor the water quality of Cottonwood Creek before it enters the Reservoir. During the fall/winter of 1996, a PRF, consisting of a water quality/detention pond and wetland system, was constructed downstream of this site. As a result of the back-flow from this pond inundating this site, this site was relocated approximately 250 m upstream near Belleview Avenue in 1997. In 2009, this site was relocated approximately 75 m upstream of the Perimeter Road as it crosses Cottonwood Creek, due to the Cottonwood Creek stream reclamation project. This site is now approximately 200 m upstream of the PRF. It is also used to evaluate the effectiveness of the PRF by documenting the stream concentrations above the PRF.
- CT-2 This site was established in 1996, and was originally located downstream of the Perimeter Pond on Cottonwood Creek. The ISCO pressure transducer and staff gage was located in a section of the stream relatively unobstructed by vegetation, and approximately 50 m downstream of the PRF. However, over the years the growth of vegetation considerably increased along the channel, creating problems with accurately determining stream flow. Eventually, when no accurate and reliable streamflow measurements could be performed in 2003, other locations were evaluated. In August 2004, the pressure transducer and staff gage were relocated inside of the outlet structure for the PRF to mitigate problems associated with streamflow measurements by providing a reliable multilevel weir equation. In 2013, modifications to the PRF overflow elevation and internal weir structure changed the relationship of the multilevel weir equation, resulting in unreliable stream flow estimates. In 2014, the weir elevations were resurveyed and the weir equations were adjusted accordingly. Water quality samples are collected from the outlet structure. This site monitors the effectiveness of the PRF on Cottonwood Creek water quality and provides information on the stream before it enters the Reservoir.

7.1.2.3 Piney Creek

PC-1 This site will be established in 2015 in a reach of Piney Creek upstream of the confluence with Cherry Creek, and downstream of the Piney Creek Stream Reclamation Project.

7.1.2.4 McMurdo Gulch

MCM-1 This site was established in 2012 on McMurdo Gulch, approximately 150 m upstream of the McMurdo Gulch Stream Reclamation Project boundary. This site is also 120 m upstream of the confluence with an unnamed tributary that receives runoff from the Castle Oaks Subdivision. This site serves as the upstream monitoring location for the McMurdo Gulch Stream Reclamation project.

MCM-2 This site was established in 2012 on McMurdo Gulch, approximately 80 m upstream of the Castle Oaks Drive Bridge crossing of McMurdo Gulch, near the North Rocky View Road intersection. This site serves as the downstream monitoring location for the McMurdo Gulch Stream Reclamation Project. This site is located within the project boundary, and consistently maintains base flows, whereas the reach further downstream was often dry due to surface flow becoming subsurface.

7.1.3 Precipitation Sampling Site

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

7.1.4 Alluvial Groundwater Sites

MW-1 This alluvial well monitor has been sampled since 1994, and is located approximately 270 m southeast of where Bayou Gulch Road crosses Cherry Creek near Parker Road.

MW-2 This alluvial well monitor has been sampled since 1994, and is located downstream of the Pinery’s wastewater treatment plant. This site is located approximately 0.85 km upstream of Stroh Road.

MW-3c This alluvial well monitor has been sampled since 2012, and is located near the KOA tower approximately 0.49 km southwest of the Parker Road and Twentymile Road intersection. The original alluvial well MW-3 was abandoned in 2009 and replaced by MW-3b which was then abandoned in 2010.

MW-5	This alluvial well monitor has been sampled since 1994, and is located immediately downgradient of the confluence with Newlin Gulch. This site is located where Pine Lane crosses Cherry Creek, approximately 0.65 km west of Parker Road.
MW-6	This alluvial well monitor has been sampled since 1994, and is located downgradient of Parker's North AWT plant. However, the discharge from this AWT plant is transported via pipeline to Sulphur Gulch. This site is located approximately 1.38 km downstream of Cottonwood Drive and is approximately 0.41 km west of Parker Road.
MW-7a	Site MW-7a was established in 2013 as part of monitoring for the Eco-Park Reclamation Project. This alluvial well monitor has been sampled since 2013, and is located at the downstream boundary of Cherry Creek Valley Ecological Park (EcoPark). This site is approximately 1.7 km upstream of Arapahoe Road. (The original site MW-7 was located adjacent to the Arapahoe Ford #2 production well; it was abandoned as a water quality monitoring site in 2000 due to development.)
MW-9	This alluvial well monitor has been sampled since 1994, and is located in Cherry Creek State Park near the Nature Center. This site is monitored to assess alluvial groundwater that is entering Cherry Creek Reservoir.
Kennedy	This alluvial well monitor has been sampled since 1994, and is located on the Kennedy Golf Course to monitor groundwater quality downgradient from Cherry Creek Reservoir.

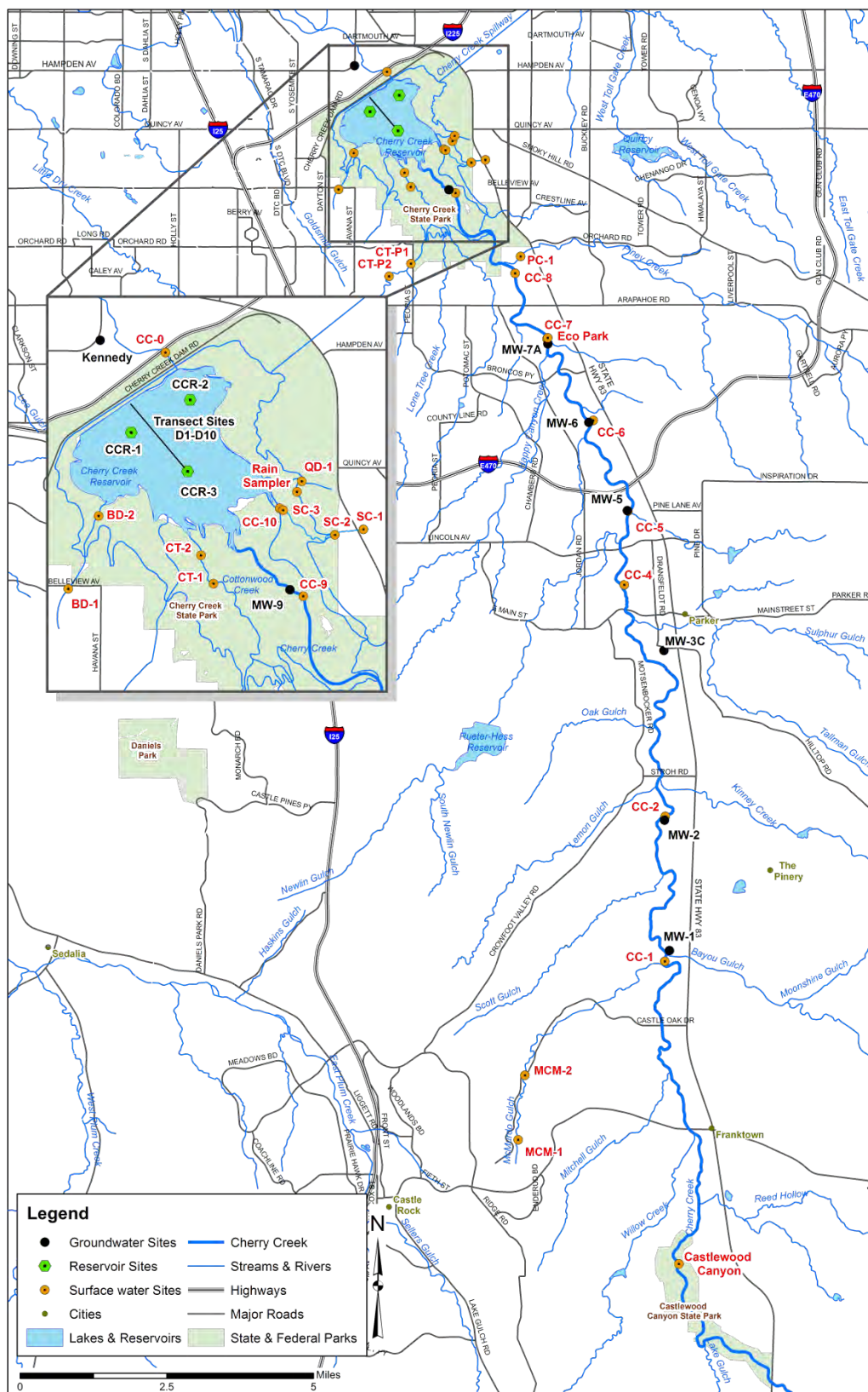


Figure 2: Sample Sites on Cherry Creek Reservoir, Surface Water Monitoring Sites, and Alluvial Groundwater Sites.

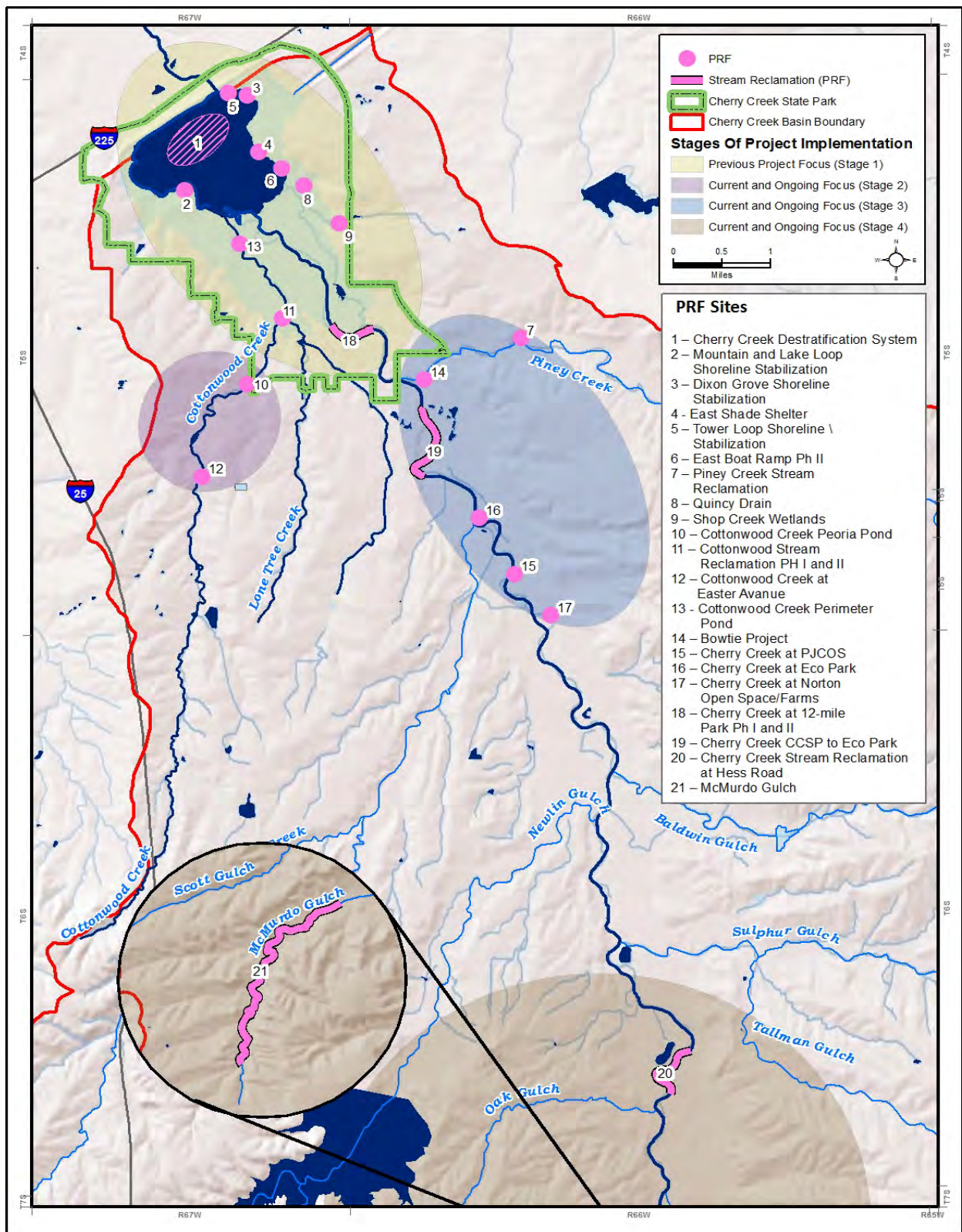


Figure 3: Pollutant Reduction Facility (PRF) Sites Located Throughout the Cherry Creek Watershed.

7.2 Sampling Parameters and Frequency

To ensure a high level of accuracy and precision, sampling and analyses shall be conducted according to the protocols and method and detection limits set forth in this SAP/QAPP. Monitoring parameters include physical, inorganic, organic, and biological parameters. Table 1 summarizes reservoir sampling parameters and sampling frequencies for sites within the reservoir. Table 2 summarizes similar information for stream and alluvial groundwater monitoring.

Table 1. Reservoir Sampling Parameters and Frequency.

ANALYTE	Monthly Vertical Profile WQ Sonde (Oct – April)	Monthly Nutrient-Biological Samples (Photic Zone)		Monthly Nutrient Profile (4m-7m)	Bi-monthly Sonde & Nutrient Samples (May-Sept)	Precipitation	De-stratification Transect Vertical Profile WQ Sonde (Jun-Aug)
	CCR-1, CCR-2, CCR-3	CCR-1, CCR-3	CCR-2	CCR-2	CCR-1, CCR-2, CCR-3	Rain Sampler	11 Sites (D-1, D-2, D-3, D-3.5, D-4, D-5, D-6, D-7, D-8, D-9, D-10)
Physical							
Temperature	X				X		X
Conductivity	X				X		X
pH	X				X		X
Dissolved Oxygen	X				X		X
Oxidation/Reduction Pot'l	X				X		X
1% Transmittance	X				X		
Secchi disk	X				X		
Temperature, Continuous (15-minute interval)	X						
Inorganics							
Total Nitrogen		X	X	X	X	X	
Total Dissolved Nitrogen		X	X	X	X	X	
Ammonia as N		X	X	X	X	X	
Nitrate+Nitrite as N		X	X	X	X	X	
Total Phosphorus		X	X	X	X	X	
Total Dissolved		X	X	X	X	X	
Orthophosphate as P		X	X	X	X		
Organics							
Total Organic Carbon			X	X	X		
Dissolved Organic			X	X	X		
Total Volatile Suspended		X	X		X		
Total Suspended Solids		X	X		X		
Biological							
Chlorophyll a		X	X		X		
Phytoplankton			X		X		
Zooplankton			X		X		

Table 2. Stream and Groundwater Sampling Parameters and Frequency.

ANALYTE	Monthly Surface Water Samples	Storm Event Surface Water ISCO Samples	Bi-annual Surface Water Samples	Bi-annual Groundwater Samples
	10 sites (CC-0, CC-10, CC-7-EcoPark, CT-1, CT-2, CT-P1, CT-P2, MCM-1, MCM-2, PC-1)	7 sites (CC-10, CC-7-EcoPark, CT-1, CT-2, CT-P1, CT-P2, PC-1)	9 sites (Castlewood, CC-1, CC-2, CC-4, CC-5, CC-6, CC-8, CC-9)	8 sites (MW-1, MW-2, MW-3c, MW-5, MW-6, MW-7a, MW-9, Kennedy)
Physical				
Temperature	X		X	X
Conductivity	X		X	X
pH	X		X	X
Dissolved Oxygen	X		X	X
Oxidation/Reduction Pot'l				X
Water Level, Continuous (15-minute interval)		X		X (MW-9 only)
Discharge, Rating Curve		X		
Inorganics				
Total Nitrogen	X	X		
Total Dissolved Nitrogen	X	X		
Ammonia as N	X	X	X	X
Nitrate+Nitrite as N	X	X	X	X
Nitrate as N			X	X
Nitrite as N			X	X
Total Phosphorus	X	X	X	
Total Dissolved Phosphorus	X	X	X	X
Orthophosphate as P	X	X	X	X
Chloride			X	X
Sulfate			X	X
Organics				
Total Organic Carbon				X (MW-9 only)
Dissolved Organic Carbon				X (MW-9 only)
Total Volatile Suspended Solids	X	X		
Total Suspended Solids	X	X		

Note that the Total and Dissolved Organic Carbon samples collected at CCR-1, CCR-2, CCR-3, and MW-9, and the water levels at MW-9, are being collected at the request of the Authority's Reservoir Modeler as input for the model, and should be revisited and perhaps discontinued when this SAP/QAPP is next updated.

7.3 Authority Roles and Participation

The Authority is responsible for the following tasks:

- Manage the water quality monitoring contract
- Prepare the Annual Report to the Colorado Water Quality Control Commission
- Ensure periodic outside Peer Review is solicited at appropriate times
- Coordinate the monitoring program and budgetary needs arising from regulatory changes and new facility monitoring needs (e.g., PRFs)
- Identify and coordinate monitoring needs for any new special studies (see footnote 1 on the bottom of page 3 for more detail re: special studies)
- Periodically review and revise, as needed, the Sampling Program Objectives (see Section 3.0)
- Ensure the monitoring program complies with Regulation 72 requirements (see Section 4.0)
- Provide periodic review and updates to this SAP/QAPP (see Section 5.0)

7.4 Sampling Teams and Structure

The monitoring consultant shall be responsible for implementing sampling requirements per the SAP/QAPP. All personnel involved in the investigation and in the generation of data are a part of the overall project and quality assurance program. The following roles have specifically delegated responsibilities, which is structured to ensure the highest quality of data collection, management, and reporting.

7.4.1 Project Manager

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

- Maintain routine contact with the project's progress;
- Regularly review the project schedule, and review all work products; and
- Evaluate impacts on project objectives and the need for corrective actions based on quality control checks.

7.4.2 Quality Assurance Manager

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

- Ensure data collection is in accordance with the Sampling and Analysis Plan;
- Maintain a repository for all documents relating to this project; and

- Coordinate with the Authority, the WQCD, and the Authority's other consultants to ensure compliance with the Cherry Creek Reservoir Control Regulation 72.

7.4.3 Analytical and Biological Laboratory Managers

The Analytical Laboratory Manager will ensure that all water quality and chlorophyll *a* samples are analyzed in a technically sound and timely manner. The Analytical Laboratory Manager shall be responsible for ensuring all laboratory quality assurance procedures associated with the project are followed, including proper sample entry, sample handling procedures, and quality control records for samples delivered to the laboratory. The Analytical Laboratory Manager will be responsible for all data reduction and verification, and ensure that the data is provided in a format agreed upon between the Project Manager, the Analytical Laboratory Manager, and the Authority. The Biological Laboratory Manager(s) will ensure that phytoplankton and zooplankton identification, enumeration, and biovolume/biomass analyses are analyzed in a technically sound and timely manner, in accordance with the requirements of this SAP/QAPP. The Biological Laboratory Manager(s) 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.

7.4.4 Sampling Crew

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

7.5 Field Methodologies

7.5.1 Reservoir Sampling

7.5.1.1 Transparency

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

Licor quantum sensors provide a quantitative approach to determine the depth at which 1 percent of the light penetrates the water column. This is considered the point at which light no longer can sustain photosynthesis in excess of oxygen consumption from respiration (Goldman and Horne 1983) and represents the deepest portion of the photic zone. This is accomplished by using an ambient and underwater quantum sensor attached to a data logger. The ambient quantum

sensor remains on the surface, while the underwater sensor is lowered into the water on the sunny side of the boat. The underwater sensor is lowered until the value displayed on the data logger is 1 percent of the value of the ambient sensor, and the depth is recorded.

7.5.1.2 Depth Profile Measurements

Measurements for dissolved oxygen, temperature, conductivity, pH, and oxidation/reduction potential (ORP) shall be collected at 1 m intervals, including the surface and near the water/sediment interface, using a multiparameter sonde. The sonde shall be calibrated prior to each sampling episode to ensure accurate readings.

In addition to the monthly/bimonthly profile data, three transect profiles shall be performed, one each in June, July, and August at up to eleven sample locations through the deep-water zone. The sample locations and transect will be consistent with locations previously established by AMEC during its destratification feasibility study. Latitude and longitude coordinates for these locations are shown in Appendix A. Measurements of dissolved oxygen, temperature, conductivity, pH, and ORP shall be collected at 1 m intervals, including the surface and near the water/sediment interface using a multiparameter sonde.

In an effort to minimize probe contamination at the water/sediment interface, a depth sounding line is used to determine maximum depth. The bottom profile measurement is collected approximately 10 cm from the benthos.

7.5.1.3 Continuous Temperature Monitoring

Continuous temperature monitoring to document the water column profiles shall be performed at three locations in the Reservoir (CCR-1, CCR-2, and CCR-3). At each site, Onset HOBO® Water Temp Pro data loggers shall be deployed at 1 m increments, from the 1 m layer to near the sediment/water interface and configured to collect 15-minute interval temperature data.

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

7.5.1.4 Water Samples

A primary task of the monitoring program is to characterize the chemical and biological constituents of the upper 3 m layers of the reservoir. This layer represents the most active layer for algae production (photic zone), and represents approximately 54 percent of the total lake volume given the typical lake level of 5550 ft. At each reservoir site, water from the surface, and 1 m, 2 m, and 3 m depths is sampled individually using a 2-liter vertical Van Dorn water sampler and combined into a clean 5-gallon container to create a composite photic zone sample (Table 3). The vertical Van Dorn sampler is lowered to the appropriate depth, such

that the middle of the sampler is centered on the selected depth. The “messenger” is sent to activate the sampler and the water is retrieved. Four one-liter aliquots are collected from the composite photic zone sample and stored on ice, until transferred to the laboratory for chemical and biological analyses (Table 2). Nutrient analyses shall be performed on all reservoir water samples. Chlorophyll *a* analyses shall be performed on all photic zone composite samples. Phytoplankton analyses shall be performed on all photic zone composite samples. See Table 4 on page 24 for the list of analytes, laboratory methods, and detection limits.

At Site CCR-2, profile water samples are also collected on 1 m increments, starting from 4 m and continuing down to the 7 m depth. The 7 m sample is collected as close to the water/sediment interface as possible, without disturbing the sediment. At times, if the reservoir is unusually full, it may be necessary to collect an additional profile water sample, such as occurred after the September 2013 precipitation events. The sampler and 5-gallon container are rinsed thoroughly with lake water between sites. Based on this sampling scheme, the number of samples collected at each site is shown in Table 3 below:

Table 3. Number of Reservoir Samples Collected.

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

7.5.1.5 Zooplankton Samples

Zooplankton samples shall be collected at each reservoir site (CCR-1, CCR-2, and CCR-3) and composited to create one sample per sampling event. The zooplankton sample should always be collected following the collection of water samples, so as not to compromise the integrity of the water samples. Collection of a vertical water column zooplankton sample is performed using an eight inch mouth, 80 µm mesh Turtox Student Net. The zooplankton net is rinsed with reservoir water and lowered to the 6 m depth at sites CCR-1 and CCR-2 and 4 m at Site CCR-3. At each site, the net is slowly retrieved and the concentrated sample is drained into the sample container with all organic matter being rinsed from the net and into the sample container. Each site tow is composited into the same sample container and preserved with 70% alcohol. The diameter of the tow net and combined length of each tow is recorded to provide an estimate of the water volume sampled. The zooplankton are identified, enumerated, and estimates of biomass are performed.

7.5.2 Stream Sampling

7.5.2.1 Monthly Base Flow Sampling

One sample shall be collected from each stream site on a monthly basis, when there is sufficient flow (CT-1, CT-2, CT-P1, CT-P2, CC-10, EcoPark, Piney Creek, MCM-1, and MCM-2). Samples shall be collected as mid-stream mid-depth grab samples using a 5-gallon container. Two one-liter aliquots are collected from this grab sample and stored on ice, until transferred to the laboratory for chemical analyses.

7.5.2.2 Storm Event Sampling

Samples from storm flow events are collected using ISCO automatic samplers, which are programmed to collect samples when the flow reaches a threshold level. The threshold level is determined by analyzing annual hydrographs from each stream and determining storm levels. When the threshold is reached, the ISCO collects a sample every 15 minutes for approximately 2.5 hours (i.e., a timed composite) or until the water recedes below the threshold level. This sampling procedure occurs at CT-1, CT-2, CT-P1, CT-P2, CC-10, EcoPark, and Piney Creek. Following the storm event, water collected by the automatic samplers is combined (timed composite) into a clean 5-gallon container, with two 1 liter (L) aliquots collected from the composited sample and stored on ice until transferred to the laboratory for analysis. Approximately 4 L would be collected from the 24 bottles, with each bottle contributing a sample amount representative of the flow at which it was collected. Up to seven storm samples shall be collected from each of the monitoring sites during the April to October storm season.

7.5.2.3 Continuous Water Level Monitoring

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

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

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

7.5.3 Watershed Surface Water Sampling

The Cherry Creek mainstem monitoring was initiated in 1994. The monitoring includes semiannual sampling at seven surface water sites along Cherry Creek (Castlewood, CC-1, CC-2, CC-4, CC-5, CC-6, CC-8, and CC-9). Other sites are included on the Cherry Creek mainstem (e.g. CC-7 (EcoPark), CC-10, and CC-0) which are monitoring on a more frequent basis as part of the Reservoir and PRF efforts. The following constituents are monitored on a semi-annual basis at the seven Cherry Creek mainstem sites:

- Nitrite + Nitrate
- Nitrite
- Nitrate
- Ammonia
- Total dissolved phosphorus
- Total phosphorus
- Soluble reactive phosphorus (AKA Orthophosphate)
- Chloride
- Sulfate

Historically, the sampling frequency was on a monthly basis, but was reduced to semiannual monitoring (May and November) in 2003.

7.5.4 Alluvial Groundwater Sampling

Cherry Creek alluvial groundwater sites are generally paired with mainstem surface water sites to provide corresponding data. Groundwater sampling was initiated in 1994, and includes semiannual sampling at eight alluvial sites along Cherry Creek

(MW-1, MW-2, MW-3c, MW-5, MW-6, MW-7a, MW-9, and Kennedy) for the following constituents:

- Nitrite + Nitrate
- Nitrite
- Nitrate
- Ammonia
- Total dissolved phosphorus
- Soluble reactive phosphorus (AKA Orthophosphate)
- Chloride
- Sulfate

The sampling frequency was reduced from monthly monitoring to semiannual monitoring (May and November) in 2003.

7.5.5 Precipitation Sampling

After each monitored storm, the sample bottle shall be removed, stored on ice, and transferred to the laboratory for analysis of phosphorus and nitrogen fractions. The sampler shall be inspected and cleaned of any accumulations of unimportant precipitation on a weekly basis. This will minimize extraneous “dry fall” from being washed into the sampler between monitored storm events. A precipitation event of greater than 0.25 inches at the Centennial Airport KAPA weather station is generally a sufficient storm event that activates ISCO samplers and storm event monitoring.

8.0 Laboratory Procedures

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

The turnaround time is variable and generally ranges from 30 days for most routine chemical analyses up to 120 days for biological (i.e., phytoplankton and zooplankton) analyses, but the turnaround time will depend on the analyses to be performed, the number of samples, and the laboratory backlog. Rapid turnaround time is generally available for an additional fee by most laboratories. In the case of cyanotoxin analyses, the turnaround time is generally 2-3 days, but rapid turnaround times (i.e., 12 hours) are generally available for an additional fee by most laboratories.

Table 4. List of Analytes, Abbreviations, Analytical Methods, Recommended Hold Times, and Detection Limits for Chemical Laboratory Analyses.

Parameter	Abbreviation	Analytical Method	Recommended Hold Times	Detection Limit
Physicochemical				
Total Nitrogen	TN	10-107-04-4-B*	< 24 hrs before digestion; < 7 days after digestion	2 µg/L
Total Dissolved Nitrogen	TDN	10-107-04-4-B	48 hrs	2 µg/L
Nitrate/Nitrite Nitrogen	NO ₃ +NO ₂	10-107-04-1-C	48 hrs	2 µg/L
Ammonium Ion Nitrogen	NH ₄	10-107-06-2-A	24 hrs	3 µg/L
Total Phosphorus	TP	10-115-01-4-B*	< 24 hrs before digestion	2 µg/L
Total Dissolved Phosphorus	TDP	10-115-01-4-B	48 hrs	2 µg/L
Soluble Reactive Phosphorus	SRP	10-115-01-1-T	48 hrs	2 µg/L
Total Suspended Solids	TSS	SM 2540D	7 days	4 mg/L
Total Volatile Suspended Solids	TVSS	SM 2540 E	7 days	4 mg/L
Total Organic Carbon	TOC	SM 5310 B	28 days	0.16 mg/L
Dissolved Organic Carbon	DOC	SM 5310 B	28 days	
Chloride	Cl	EPA 300.0/SW846 9056	28 days	0.1 mg/L
Sulfate	SO ₄	EPA 300.0/SW846 9056	28 days	0.1 mg/L
Biological				
Chlorophyll a	Chl	SM 10200 H (modified)**	< 24 hrs before filtration	0.1 µg/L
Phytoplankton	--	SM 10200 B.2.a SM 10200 C.2 SM 10200 .D.2 SM 10200 E.4 SM 10200 F.2.c	NA	NA
Zooplankton	--	SM 10200 B.2.B SM 10200 C.4 SM 10200 D.4 SM 10200 E.4 SM 10200 .G	NA	NA

* TP and TN can be measured from same digest.

** "modified" means the ethanol is heated to reduce the time necessary for extraction

Method References:

American Public Health Association, American Water Works Association, and Water Environment Federation. (2005). *Standard Methods for Examination of Water and Wastewater*. (21st Edition). Washington DC 1985.

Lachat Instruments. Methods List - Methods List for Automated Ion Analyzers Flow Injection Analyses-Ion Chromatography. (September 2013). <http://www.lachatinstruments.com/download/LL022-Rev-7.pdf>

Pfaff, John D. August 1993. Method 300.0 - Determination of Inorganic Anions by Ion Chromatography, Inorganic Chemistry Branch, Chemistry Research Division, Revision 2.1. Environmental Monitoring Systems Laboratory, Office Of Research and Development, U.S. Environmental Protection Agency. Cincinnati, Ohio 45268

http://water.epa.gov/scitech/methods/cwa/bioindicators/upload/2007_07_10_methods_method_300_0.pdf

<http://www.epa.gov/wstew/hazard/testmethods/sw846/online/index.htm>

8.1 Biological Laboratory Analysis

Biological analyses for the samples collected in the study, include chlorophyll a, phytoplankton (identification, enumeration, and biovolume), and zooplankton (identification, enumeration, and biomass). The methods of these analyses, with appropriate QA/QC procedures shall be in accordance with the methods provided in Table 1.

8.2 Laboratory Quality Assurance/Quality Control Protocols

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

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

9.0 Program Quality Assurance/Quality Control Protocols

Field Sampling

All field team members will be responsible for visually inspecting and monitoring for contamination and should a bottle be contaminated it will be replaced with a clean one. To provide Quality Control/Quality Assurance (QC/QA) information on the field samples, both field blanks and field duplicates shall be collected and will comprise approximately 10 percent of the total number of samples analyzed for the project. The field blank and duplicate samples will be labeled and stored with the field collected samples and analyzed using the same laboratory methods. The QC/QA samples will provide information on sampling and analytical error.

Laboratory

The analytical and biological laboratories will follow their in-house Quality Assurance Plans (QAP), which will be consistent with specific state requirements. These documents will be available to the Authority upon request.

10.0 Data Validation and Usability

All field data and chain-of-custody (COC) forms will be reviewed the Field Team Leader for correctness. The QA Manager will be responsible for data validation, and will review the field book, laboratory's results and reports for accuracy and will report any issues to the Project Manager. Laboratory data will be reviewed to ensure that appropriate methods were used and that data are qualified with method detection limits. Any problems that arise will be brought to the attention of the Project Manager and it is this person's responsibility to accept or reject the data.

11.0 Data Verification, Reduction, and Reporting

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

12.0 References

AMEC Earth & Environmental, Inc., Alex Horne Associates, Hydrosphere Resource Consultants, Inc.
(December 5, 2005). *Feasibility Report Cherry Creek Reservoir Destratification*.

American Public Health Association. (20th Edition American Public Health Association). *Standard Methods for Examination of Water and Wastewater*. Washington DC: 1985.

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

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. a. (1983). *Limnology*. NY: McGraw-Hill Company.

Knowlton, M. a. (1993). *Limnological Investigations of Cherry Creek Lake*. Final report to Cherry Creek
Basin Water Quality Authority.

U.S. Environmental Protection Agency (EPA). (August 1999). *Site-Specific Sampling and Analysis Plan
Template*.

U.S. Environmental Protection Agency. (December 2000). *Peer Review Handbook, 2nd Edition*.
Washington, DC 20460: Science Policy Council.

APPENDIX A – Sampling Site Locations

Waterbody	ID	Latitude	Longitude
Cherry Creek Reservoir	CCR-1	39°38'34.68"N	104°51'41.88"W
Cherry Creek Reservoir	CCR-2	39°38'49.09"N	104°51'08.15"W
Cherry Creek Reservoir	CCR-3	39°38'17.46"N	104°51'09.69"W
Cherry Creek Reservoir	D-1	39°38'47.04"N	104°51'34.27"W
Cherry Creek Reservoir	D-2	39°38'43.13"N	104°51'31.93"W
Cherry Creek Reservoir	D-3	39°38'39.66"N	104°51'29.20"W
Cherry Creek Reservoir	D-3.5	39°38'36.42"N	104°51'26.95"W
Cherry Creek Reservoir	D-4	39°38'33.91"N	104°51'24.64"W
Cherry Creek Reservoir	D-5	39°38'30.57"N	104°51'22.50"W
Cherry Creek Reservoir	D-6	39°38'27.78"N	104°51'20.76"W
Cherry Creek Reservoir	D-7	39°38'25.01"N	104°51'18.02"W
Cherry Creek Reservoir	D-8	39°38'22.46"N	104°51'15.87"W
Cherry Creek Reservoir	D-9	39°38'19.75"N	104°51'13.29"W
Cherry Creek Reservoir	D-10	39°38'17.52"N	104°51'10.12"W
Cherry Creek	Castlewood	39°21'28.58"N	104°45'49.69"W
Cherry Creek	CC-1	39°25'57.80"N	104°46'05.10"W
Cherry Creek	CC-2	39°28'6.90"N	104°46'04.20"W
Cherry Creek	CC-4	39°31'33.10"N	104°46'50.50"W
Cherry Creek	CC-5	39°32'38.70"N	104°46'46.00"W
Cherry Creek	CC-6	39°33'59.40"N	104°47'25.70"W
Cherry Creek	CC-7	39°35'12.06"N	104°48'18.63"W
Cherry Creek	CC-8	39°36'10.40"N	104°48'55.10"W
Cherry Creek	CC-9	39°37'28.10"N	104°50'03.60"W
Cherry Creek	CC-10	39°38'00.46"N	104°50'17.22"W
Cherry Creek	CC-O	39°39'10.60"N	104°51'22.52"W
Cottonwood Creek	CT-P1	39°36'07.96"N	104°51'20.03"W
Cottonwood Creek	CT-P2	39°36'19.23"N	104°50'55.01"W
Cottonwood Creek	CT-1	39°37'27.73"N	104°50'54.95"W
Cottonwood Creek	CT-2	39°37'40.27"N	104°51'00.94"W
Piney Creek	PC-1	39°36'23.21"N	104°48'52.02"W
McMurdo Gulch	MCM-1	39°23'19.54"N	104°48'53.63"W
McMurdo Gulch	MCM-2	39°24'16.60"N	104°48'46.01"W
Precipitation	PRECIP	39°38'12.40"N	104°50'8.47"W
Groundwater	MW-1	39°26'07.50"N	104°45'59.80"W
Groundwater	MW-2	39°28'03.50"N	104°46'4.90"W
Groundwater	MW-3c	39°30'34.57"N	104°46'05.07"W
Groundwater	MW-5	39°32'39.10"N	104°46'46.88"W
Groundwater	MW-6	39°33'57.70"N	104°47'30.90"W
Groundwater	MW-7a	39°35'07.55"N	104°48'17.63"W
Groundwater	MW-9	39°37'25.00"N	104°50'11.20"W
Groundwater	Kennedy	39°39'15.80"N	104°52'0.20"W

APPENDIX B –Abandoned Sampling Sites

Historical Surface Water Sites (Abandoned)

CC-3	This site was located 1 mile south of West Parker Road. It is no longer used as a water quality sampling location.
CC-7	This was the original CC-7 site, located ¾ mile south of Arapahoe Road. It was abandoned in 2000 due to development.
CC-10A	This site was established in 1999 on an intermittent channel of Cherry Creek. CC-10A is active during spring runoff and some precipitation events. Flow measurements at this site were used to provide additional data on total inflows into the Reservoir. This site has not been monitored since 2001.
SC-1	This site was established in 1987, immediately east of Parker Road on Shop Creek. Originally, SC-1 monitored phosphorous levels prior to the confluence with Cherry Creek. From 1990 through 2001, this site monitored water quality upstream of the Shop Creek detention pond/wetland PRF. This site has not been monitored since 2001.
SC-2	This site was established in 1990, and was located west of Parker Road at the outlet from the Shop Creek detention pond. This site monitored the water quality as it left the detention pond. This site has not been monitored since 2001.
SC-3	This site is located 35 m upstream of its confluence with Cherry Creek, and was used to monitor the water quality of Shop Creek before it joins Cherry Creek. Sampling ceased at this site in 2013 because flow and total phosphorus loads were less than one percent of the total annual flow-weighted load entering the reservoir.
QD-1	This site was established in 1996 on Quincy Drainage, above of the Perimeter Road wetlands, which were constructed in 1990 just downstream of the outlet for the Quincy Road/Parker Road stormwater drain. This site monitored water quality of the Quincy Drainage upstream of the wetlands and a new PRF, consisting of a water quality/berm system, established in late 1995, downstream of the Perimeter Road. This site has not been monitored since 2001.
BD-1	This site was established in mid-1996 at the suggestion of State Parks personnel, and is used to monitor the inflow to an old stock pond on this drainage near Belleview Avenue. This site has not been monitored since 2001.
BD-2	This site was established in mid-1996 at the suggestion of State Parks personnel, and is used to monitor this drainage as it crosses the Perimeter Road before entering the Reservoir. This site monitors the nutrient removal abilities of the

historic stock pond and natural wetland system. This sites has not been monitored since 2001.

Historical Groundwater Sites (Abandoned)

MW-4b	This site was located downstream of Sulphur Gulch, and was abandoned in 2002 due to development.
MW-7	This site was located south of Arapahoe Road near EcoPark, and it was abandoned in 2000 due to development.
MW-8	This site was the Arapahoe Deem production well, located north of Arapahoe Road. It was abandoned as a sampling site in 2000 due to development.

Appendix B 2015 WY Reservoir Water Quality Data

CCR-1 GEI Water Chemistry Data											
Analytical Detection Limits		2	2	2	6	6	2	5	0.1	4	4
Sample Date	Sample Name/ Location	Total Phosphorous (µg/L)	Total Dissolved Phosphorous (µg/L)	Ortho- phosphate (µg/L)	Total Nitrogen (µg/L)	Total Dissolved Nitrogen (µg/L)	Nitrate+ Nitrite (µg/L)	Ammonia (µg/L)	Average Chlorophyll a (mg/m³)	TSS (mg/L)	TVSS (mg/L)
10/14/2014	CCR-1 Photic	57	8	6	1,166	689	2	30	39.3	10.9	5.4
11/4/2014	CCR-1 Photic	68	24	6	928	522	2	19	34.5	11.1	5.2
3/18/2015	CCR-1 Photic	64	23	8	1,174	510	6	9	20.0	12.0	7.0
4/8/2015	CCR-1 Photic	49	9	13	763	401	4	20	15.0	8.7	4.8
5/12/2015	CCR-1 Photic	70	35	9	783	657	2	32	11.2	10.2	ND
5/27/2015	CCR-1 Photic	73	31	28	988	629	3	21	24.2	6.2	4.2
6/9/2015	CCR-1 Photic	37	9	24	718	451	2	32	10.3	7.4	ND
6/23/2015	CCR-1 Photic	110	69	63	881	596	3	16	15.6	7.0	4.4
7/7/2015	CCR-1 Photic	111	70	66	627	364	ND	13	13.9	9.0	4.2
7/21/2015	CCR-1 Photic	94	62	52	869	595	ND	19	12.0	6.2	ND
8/4/2015	CCR-1 Photic	90	50	56	819	553	ND	18	8.4	6.8	ND
8/18/2015	CCR-1 Photic	97	32	27	733	502	ND	20	17.3	9.2	4.2
9/9/2015	CCR-1 Photic	80	19	14	741	492	ND	73	21.0	8.0	4.0
9/22/2015	CCR-1 Photic	59	11	12	584	385	47	70	21.9	12.4	5.0

Note:

ND = below detection limit.

CCR-2 GEI Water Chemistry Data											
Analytical Detection Limits		2	2	2	6	6	2	5	0.1	4	4
Sample Date	Sample Name/ Location	Total Phosphorous (µg/L)	Total Dissolved Phosphorous (µg/L)	Ortho- phosphate (µg/L)	Total Nitrogen (µg/L)	Total Dissolved Nitrogen (µg/L)	Nitrate+ Nitrite (µg/L)	Ammonia (µg/L)	Average Chlorophyll a (mg/m ³)	TSS (mg/L)	TVSS (mg/L)
10/14/2014	CCR-2 Photic	71	22	7	920	536	2	23	32.1	7.8	4.4
10/14/2014	CCR-2 4m	69	6	6	812	550	7	25	--	--	--
10/14/2014	CCR-2 5m	49	25	6	732	654	3	24	--	--	--
10/14/2014	CCR-2 6m	64	24	7	874	624	8	24	--	--	--
10/14/2014	CCR-2 7m	76	24	6	876	633	8	29	--	--	--
11/4/2014	CCR-2 Photic	64	21	6	837	658	2	11	33.2	10.4	4.8
11/4/2014	CCR-2 4m	66	23	6	860	564	3	10	--	--	--
11/4/2014	CCR-2 5m	61	19	6	874	476	2	8	--	--	--
11/4/2014	CCR-2 6m	74	18	7	849	537	6	14	--	--	--
11/4/2014	CCR-2 7m	87	18	7	907	609	2	6	--	--	--
3/18/2015	CCR-2 Photic	66	18	14	1,224	603	4	31	20.6	11.8	6.6
3/18/2015	CCR-2 4m	55	22	18	897	497	3	24	--	--	--
3/18/2015	CCR-2 5m	71	10	18	1,180	704	4	26	--	--	--
3/18/2015	CCR-2 6m	75	11	17	1,001	451	4	28	--	--	--
3/18/2015	CCR-2 7m	76	12	19	1,006	459	2	25	--	--	--
4/8/2015	CCR-2 Photic	55	11	10	747	480	ND	59	13.0	8.5	4.8
4/8/2015	CCR-2 4m	57	12	10	781	401	3	30	--	--	--
4/8/2015	CCR-2 5m	57	9	10	920	710	ND	28	--	--	--
4/8/2015	CCR-2 6m	59	10	10	745	386	ND	61	--	--	--
4/8/2015	CCR-2 7m	62	12	13	716	486	ND	59	--	--	--
5/12/2015	CCR-2 Photic	52	25	21	787	505	76	109	8.7	5.8	ND
5/12/2015	CCR-2 4m	70	33	36	676	602	ND	72	--	--	--
5/12/2015	CCR-2 5m	62	43	42	796	591	ND	52	--	--	--
5/12/2015	CCR-2 6m	73	42	39	717	587	64	85	--	--	--
5/12/2015	CCR-2 7m	90	48	47	689	627	73	92	--	--	--
5/12/2015	CCR-2 8m	131	53	54	846	661	65	100	--	--	--
5/27/2015	CCR-2 Photic	66	23	24	864	519	3	28	19.3	6.0	4.2
5/27/2015	CCR-2 4m	66	45	27	792	562	4	30	--	--	--

CCR-2 GEI Water Chemistry Data											
Analytical Detection Limits		2	2	2	6	6	2	5	0.1	4	4
Sample Date	Sample Name/ Location	Total Phosphorous (µg/L)	Total Dissolved Phosphorous (µg/L)	Ortho- phosphate (µg/L)	Total Nitrogen (µg/L)	Total Dissolved Nitrogen (µg/L)	Nitrate+ Nitrite (µg/L)	Ammonia (µg/L)	Average Chlorophyll a (mg/m³)	TSS (mg/L)	TVSS (mg/L)
5/27/2015	CCR-2 5m	97	59	56	785	552	52	38	--	--	--
5/27/2015	CCR-2 6m	95	61	57	764	703	52	94	--	--	--
5/27/2015	CCR-2 7m	112	66	63	915	820	60	153	--	--	--
5/27/2015	CCR-2 7.6m	113	69	68	874	771	59	187	--	--	--
6/9/2015	CCR-2 Photic	47	11	8	701	511	ND	26	10.5	7.8	ND
6/9/2015	CCR-2 4m	80	35	32	751	535	9	32	--	--	--
6/9/2015	CCR-2 5m	125	83	76	741	515	30	43	--	--	--
6/9/2015	CCR-2 6m	146	109	112	702	521	7	113	--	--	--
6/9/2015	CCR-2 7m	174	136	141	684	511	7	158	--	--	--
6/9/2015	CCR-2 7.4m	169	126	134	648	488	7	142	--	--	--
6/23/2015	CCR-2 Photic	101	68	67	794	600	3	34	12.0	7.2	ND
6/23/2015	CCR-2 4m	122	81	81	750	532	4	39	--	--	--
6/23/2015	CCR-2 5m	124	86	85	705	533	5	43	--	--	--
6/23/2015	CCR-2 6m	135	97	97	752	582	10	62	--	--	--
6/23/2015	CCR-2 7m	143	101	102	649	527	17	65	--	--	--
6/23/2015	CCR-2 8m	270	215	217	813	745	10	250	--	--	--
6/23/2015	CCR-2 8.5m	327	265	265	918	795	6	339	--	--	--
7/7/2015	CCR-2 Photic	112	63	63	689	439	3	17	12.4	12.4	4.8
7/7/2015	CCR-2 4m	115	62	64	679	365	2	16	--	--	--
7/7/2015	CCR-2 5m	121	65	62	604	417	2	15	--	--	--
7/7/2015	CCR-2 6m	119	61	64	660	449	2	21	--	--	--
7/7/2015	CCR-2 7m	129	58	67	683	421	2	29	--	--	--
7/21/2015	CCR-2 Photic	97	49	49	963	657	ND	8	14.2	7.8	4.6
7/21/2015	CCR-2 4m	95	53	51	810	583	ND	ND	--	--	--
7/21/2015	CCR-2 5m	129	81	78	997	642	4	78	--	--	--
7/21/2015	CCR-2 6m	139	96	91	938	631	4	115	--	--	--
7/21/2015	CCR-2 7m	254	114	105	1,132	790	ND	245	--	--	--
8/4/2015	CCR-2 Photic	99	58	55	873	606	6	68	7.55	6.0	ND

CCR-2 GEI Water Chemistry Data											
Analytical Detection Limits		2	2	2	6	6	2	5	0.1	4	4
Sample Date	Sample Name/ Location	Total Phosphorous (µg/L)	Total Dissolved Phosphorous (µg/L)	Ortho- phosphate (µg/L)	Total Nitrogen (µg/L)	Total Dissolved Nitrogen (µg/L)	Nitrate+ Nitrite (µg/L)	Ammonia (µg/L)	Average Chlorophyll a (mg/m³)	TSS (mg/L)	TVSS (mg/L)
8/4/2015	CCR-2 4m	83	52	54	662	497	3	64	--	--	--
8/4/2015	CCR-2 5m	90	47	55	683	510	5	60	--	--	--
8/4/2015	CCR-2 6m	86	48	56	645	492	3	69	--	--	--
8/4/2015	CCR-2 7m	123	65	70	775	580	10	153	--	--	--
8/18/2015	CCR-2 Photic	102	38	34	836	432	2	22	18.8	9.0	4.6
8/18/2015	CCR-2 4m	107	36	32	696	450	3	25	--	--	--
8/18/2015	CCR-2 5m	109	35	32	740	462	4	25	--	--	--
8/18/2015	CCR-2 6m	102	34	33	784	454	5	24	--	--	--
8/18/2015	CCR-2 7m	107	35	33	834	449	5	30	--	--	--
9/9/2015	CCR-2 Photic	78	19	13	762	564	6	17	18.8	8.0	ND
9/9/2015	CCR-2 4m	78	17	13	675	477	ND	15	--	--	--
9/9/2015	CCR-2 5m	94	24	18	719	462	ND	23	--	--	--
9/9/2015	CCR-2 6m	114	29	24	708	440	ND	29	--	--	--
9/9/2015	CCR-2 7m	139	31	27	824	430	ND	33	--	--	--
9/22/2015	CCR-2 Photic	71	11	12	715	421	ND	25	22.7	12.2	6.2
9/22/2015	CCR-2 4m	59	10	9	576	385	ND	19	--	--	--
9/22/2015	CCR-2 5m	71	12	13	624	381	ND	27	--	--	--
9/22/2015	CCR-2 6m	71	18	16	556	404	ND	22	--	--	--
9/22/2015	CCR-2 7m	95	22	23	467	391	3	24	--	--	--

Note:

ND = below detection limit

CCR-3 GEI Water Chemistry Data											
Analytical Detection Limits		2	2	2	6	6	2	5	0.1	4	4
Sample Date	Sample Name/ Location	Total Phosphorous (µg/L)	Total Dissolved Phosphorous (µg/L)	Ortho- phosphate (µg/L)	Total Nitrogen (µg/L)	Total Dissolved Nitrogen (µg/L)	Nitrate+ Nitrite (µg/L)	Ammonia (µg/L)	Average Chlorophyll a (mg/m³)	TSS (mg/L)	TVSS (mg/L)
10/14/2014	CCR-3 Photic	78	25	6	996	684	4	26	34.3	10.9	ND
11/4/2014	CCR-3 Photic	78	20	6	931	643	4	19	32.7	13.4	ND
3/18/2015	CCR-3 Photic	63	28	8	894	637	2	11	22.9	11.0	ND
4/8/2015	CCR-3 Photic	53	9	12	765	431	3	23	13.0	7.0	5.3
5/12/2015	CCR-3 Photic	61	31	9	719	540	2	31	7.3	8.8	5.8
5/27/2015	CCR-3 Photic	78	34	29	751	506	3	28	24.1	8.4	6.4
6/9/2015	CCR-3 Photic	54	12	29	813	482	7	33	17.0	9.0	4.8
6/23/2015	CCR-3 Photic	126	74	10	846	589	ND	28	14.6	7.2	4.6
7/7/2015	CCR-3 Photic	141	73	68	700	424	ND	8	11.4	13.0	4.6
7/21/2015	CCR-3 Photic	96	62	80	870	612	ND	23	13.5	7.4	4.0
8/4/2015	CCR-3 Photic	92	51	56	758	580	ND	18	8.5	7.4	4.6
8/18/2015	CCR-3 Photic	106	38	54	716	411	ND	22	20.1	12.4	4.6
9/9/2015	CCR-3 Photic	87	18	31	766	424	ND	69	22.3	11.4	4.4
9/22/2015	CCR-3 Photic	66	13	14	646	417	ND	72	26.6	14.0	6.6

Note:

ND = below detection limit

Site CCR-1

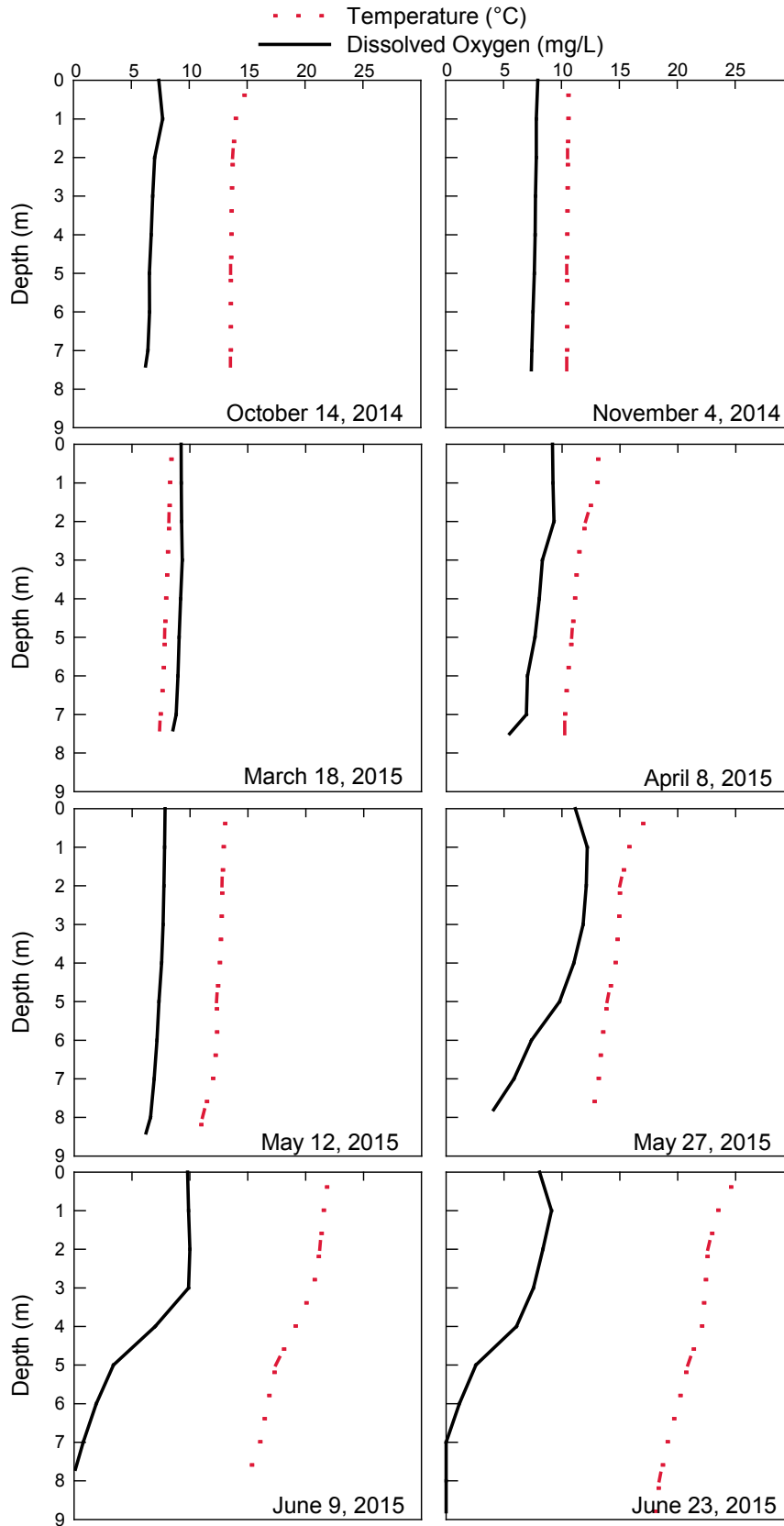
Sample Date	Depth (m)	Temperature (°C)	Conductivity (µS/cm)	Dissolved Oxygen (mg/L)	pH	ORP (mV)	1% Transmittance (m)	Secchi Disk (m)
10/14/2014	0	15.2	1,406	7.4	8.2	203	--	0.74
	1	14.0	1,401	7.7	8.1	201		
	2	13.7	1,401	7.0	8.0	202		
	3	13.6	1,401	6.8	8.0	203		
	4	13.6	1,401	6.7	8.0	203		
	5	13.6	1,400	6.6	8.0	203		
	6	13.6	1,401	6.6	8.0	203		
	7	13.5	1,401	6.4	8.0	204		
	7.4	13.6	1,401	6.2	8.0	200		
	--							
11/4/2014	0	10.6	1,157	8.0	8.1	255	--	0.85
	1	10.6	1,157	7.8	8.1	255		
	2	10.5	1,158	7.8	8.1	255		
	3	10.5	1,157	7.8	8.1	255		
	4	10.5	1,157	7.7	8.1	254		
	5	10.5	1,157	7.7	8.1	254		
	6	10.5	1,158	7.6	8.1	254		
	7.0	10.5	1,158	7.5	8.1	254		
	7.5	10.5	1,159	7.4	8.0	176		
	--							
3/18/2015	0	8.4	1,334	9.2	8.1	270	--	0.73
	1	8.2	1,334	9.3	8.1	270		
	2	8.2	1,334	9.3	8.1	269		
	3	8.0	1,332	9.3	8.1	269		
	4	7.9	1,332	9.2	8.1	269		
	5	7.8	1,332	9.1	8.0	269		
	6	7.7	1,332	9.0	8.0	269		
	7	7.4	1,332	8.8	8.0	269		
	7.4	7.4	1,333	8.5	8.0	269		
	--							
4/8/2015	0	13.1	1,357	9.2	8.0	273	--	--
	1	13.0	1,357	9.2	8.0	272		
	2	12.0	1,355	9.3	8.0	271		
	3	11.3	1,352	8.3	7.9	271		
	4	11.1	1,353	8.0	7.8	271		
	5	10.8	1,353	7.7	7.8	271		
	6	10.5	1,354	7.0	7.7	272		
	7	10.2	1,352	6.9	7.6	273		
	7.5	10.3	1,352	5.5	7.6	273		
	--							

Sample Date	Depth (m)	Temperature (°C)	Conductivity (µS/cm)	Dissolved Oxygen (mg/L)	pH	ORP (mV)	1% Transmittance (m)	Secchi Disk (m)
5/12/2015	0	13.1	1,247	7.8	7.6	319	2.75	1.00
	1	12.9	1,230	7.8	7.6	313		
	2	12.7	1,222	7.7	7.6	310		
	3	12.7	1,213	7.7	7.6	308		
	4	12.5	1,189	7.5	7.5	305		
	5	12.3	1,182	7.3	7.5	304		
	6	12.3	1,235	7.1	7.5	302		
	7	11.9	1,199	6.9	7.5	301		
	8	11.1	1,154	6.6	7.4	301		
	8.4	10.8	1,137	6.2	7.3	302		
	--							
5/27/2015	0	17.8	1,153	11.2	8.3	209	3.25	1.75
	1	15.8	1,147	12.2	8.2	208		
	2	15.0	1,143	12.1	8.2	209		
	3	14.9	1,143	11.8	8.1	210		
	4	14.6	1,141	11.0	8.0	211		
	5	13.9	1,142	9.8	7.9	213		
	6	13.5	1,151	7.4	7.7	215		
	7	13.2	1,153	5.9	7.6	218		
	7.8	12.7	1,157	4.1	7.5	178		
	--							
6/9/2015	0	22.0	1,118	9.8	8.2	230	3.30	1.80
	1	21.5	1,115	9.9	8.1	230		
	2	21.2	1,112	10.0	8.1	229		
	3	20.6	1,117	9.9	8.1	229		
	4	19.1	1,098	7.0	7.7	235		
	5	17.4	1,109	3.4	7.3	242		
	6	16.7	1,130	1.9	7.2	243		
	7	16.0	1,145	0.8	7.2	244		
	7.7	15.2	1,151	0.1	7.1	194		
	--							
6/23/2015	0	25.3	963	8.1	8.2	150	3.75	1.50
	1	23.5	956	9.1	8.3	148		
	2	22.6	955	8.4	8.2	150		
	3	22.4	955	7.6	8.1	152		
	4	22.1	955	6.1	7.9	156		
	5	20.9	955	2.6	7.5	166		
	6	20.0	951	1.1	7.3	169		
	7	19.1	951	0.0	7.2	171		
	8	18.4	963	0.0	7.2	171		
	8.8	18.1	973	0.0	7.2	-100		
	--							

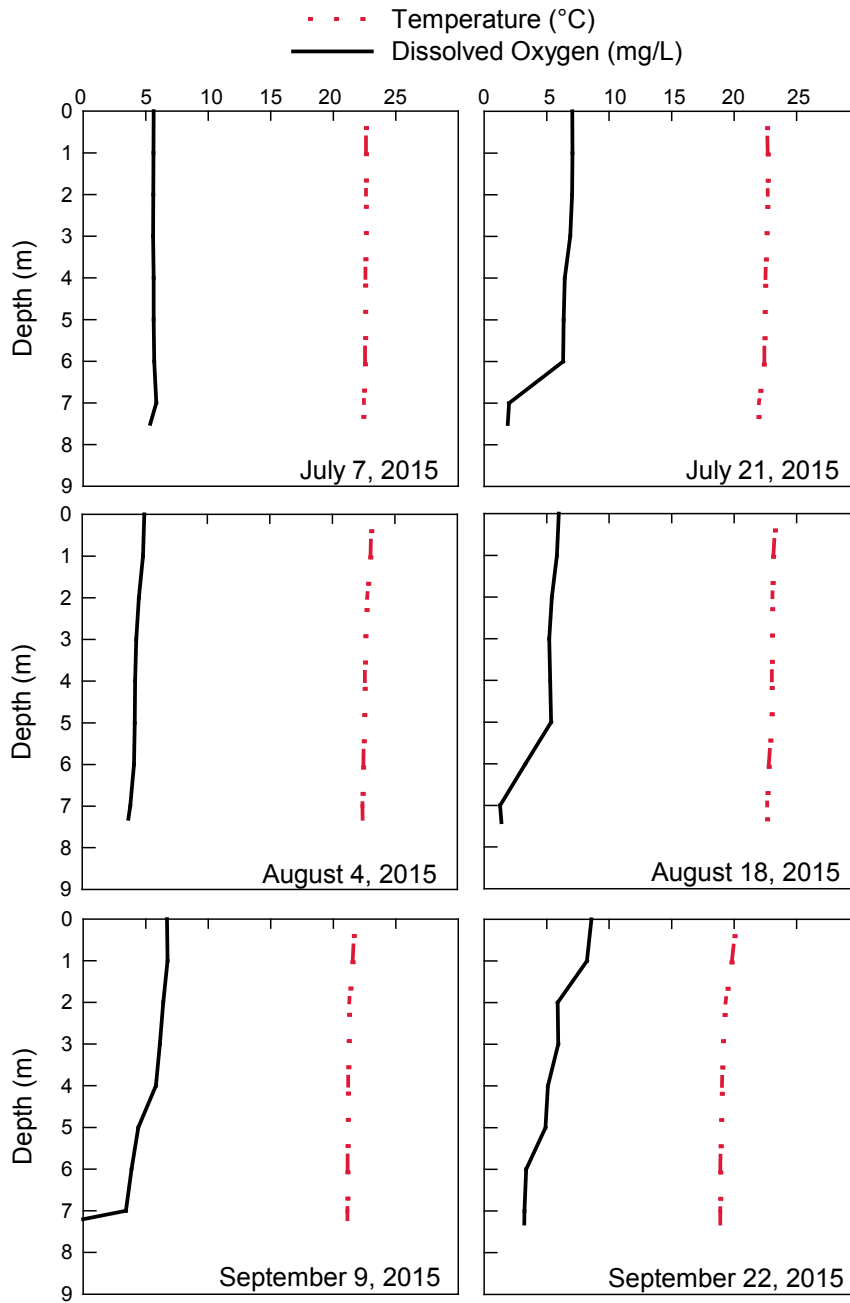
Sample Date	Depth (m)	Temperature (°C)	Conductivity (µS/cm)	Dissolved Oxygen (mg/L)	pH	ORP (mV)	1% Transmittance (m)	Secchi Disk (m)
7/7/2015	0	22.6	997	5.6	7.9	227	2.50	0.90
	1	22.6	996	5.6	7.8	227		
	2	22.6	997	5.6	7.8	227		
	3	22.6	996	5.6	7.8	227		
	4	22.6	997	5.6	7.8	226		
	5	22.6	996	5.6	7.8	226		
	6	22.5	995	5.7	7.9	226		
	7	22.4	996	5.8	7.9	224		
	7.5	22.4	998	5.4	7.8	27		
	--							
7/21/2015	0	22.6	1,018	7.1	8.0	115	3.50	1.12
	1	22.7	1,019	7.1	8.0	121		
	2	22.7	1,019	7.0	8.0	125		
	3	22.6	1,019	6.9	8.0	128		
	4	22.5	1,019	6.4	7.9	132		
	5	22.5	1,020	6.4	7.9	135		
	6	22.4	1,020	6.3	7.9	137		
	7	22.0	1,022	2.0	7.5	149		
	7.5	22.0	1,023	1.9	7.4	151		
	--							
8/4/2015	0	23.2	1,047	5.0	8.1	236	3.25	1.10
	1	23.0	1,045	4.9	8.0	236		
	2	22.8	1,046	4.5	7.9	237		
	3	22.6	1,045	4.3	7.9	238		
	4	22.6	1,045	4.2	7.9	238		
	5	22.5	1,046	4.2	7.9	238		
	6	22.5	1,044	4.1	7.9	238		
	7	22.4	1,046	3.8	7.8	238		
	7.3	22.4	1,046	3.7	7.8	185		
	--							
8/18/2015	0	23.3	1,024	6.0	7.8	230	2.35	0.95
	1	23.1	1,024	5.8	7.8	229		
	2	23.1	1,024	5.4	7.8	228		
	3	23.0	1,024	5.2	7.8	227		
	4	23.0	1,023	5.3	7.8	226		
	5	23.0	1,024	5.4	7.8	226		
	6	22.8	1,023	3.3	7.6	228		
	7	22.6	1,021	1.3	7.4	227		
	7.4	22.6	1,021	1.4	7.4	224		
	--							

Sample Date	Depth (m)	Temperature (°C)	Conductivity (µS/cm)	Dissolved Oxygen (mg/L)	pH	ORP (mV)	1% Transmittance (m)	Secchi Disk (m)
9/9/2015	0	21.7	1,063	6.7	7.9	127	2.90	0.90
	1	21.5	1,062	6.7	8.0	126		
	2	21.3	1,062	6.4	7.9	127		
	3	21.2	1,063	6.1	7.9	127		
	4	21.2	1,063	5.8	7.9	128		
	5	21.1	1,063	4.4	7.8	130		
	6	21.1	1,063	3.9	7.7	133		
	7	21.1	1,065	3.4	7.6	134		
	7.2	21.1	1,065	0.0	7.3	-61		
	--							
9/22/2015	0	20.2	1,046	8.6	8.0	258	2.25	0.73
	1	19.8	1,046	8.2	7.9	257		
	2	19.3	1,049	5.9	7.7	260		
	3	19.1	1,050	5.9	7.8	259		
	4	19.0	1,052	5.1	7.7	261		
	5	19.0	1,053	4.9	7.7	260		
	6	18.9	1,055	3.4	7.5	263		
	7	18.9	1,055	3.2	7.5	263		
	7.3	18.9	1,055	3.2	7.5	260		
	--							

CCR-1



CCR-1



CCR-2

Sample Date	Depth (m)	Temperature (°C)	Conductivity (µS/cm)	Dissolved Oxygen (mg/L)	pH	ORP (mV)	1% Transmittance (m)	Secchi Disk (m)
10/14/2014	0	15.9	1,408	7.0	8.1	197	--	0.77
	1	14.0	1,401	7.7	8.1	195		
	2	13.6	1,402	6.8	8.0	197		
	3	13.5	1,402	6.1	7.9	199		
	4	13.4	1,402	5.7	7.9	200		
	5	13.3	1,403	5.5	7.9	200		
	6	13.2	1,402	5.6	7.9	200		
	7	13.1	1,403	5.4	7.9	200		
	7.3	13.1	1,403	5.2	7.9	196		
	--							
11/4/2014	0	10.8	1,153	7.8	8.0	261	--	0.85
	1	10.8	1,154	7.7	8.1	260		
	2	10.7	1,154	7.6	8.1	258		
	3	10.7	1,154	7.5	8.1	257		
	4	10.7	1,155	7.5	8.1	257		
	5	10.6	1,155	7.5	8.1	257		
	6	10.6	1,155	7.4	8.1	257		
	7.0	10.6	1,157	7.2	8.1	257		
	7.3	10.6	1,156	6.3	8.0	228		
	--							
3/18/2015	0	8.5	1,334	9.4	8.1	287	--	0.74
	1	8.3	1,332	9.4	8.0	288		
	2	7.9	1,333	9.1	8.0	290		
	3	7.7	1,332	9.0	8.0	290		
	4	7.7	1,332	9.0	8.0	290		
	5	7.6	1,332	8.9	8.0	290		
	6	7.6	1,334	8.7	7.9	290		
	7	7.5	1,332	8.6	7.9	290		
	7.3	7.4	1,331	8.4	7.9	287		
	--							
4/8/2015	0	12.9	1,357	9.0	7.9	293	--	0.89
	1	12.6	1,356	9.0	7.9	291		
	2	11.8	1,354	8.9	7.9	290		
	3	11.5	1,354	8.7	7.9	289		
	4	11.4	1,353	8.5	7.9	288		
	5	11.0	1,353	7.6	7.7	288		
	6	10.8	1,353	7.3	7.7	288		
	7	10.6	1,353	6.6	7.6	288		
	7.3	10.3	1,354	5.4	7.5	278		
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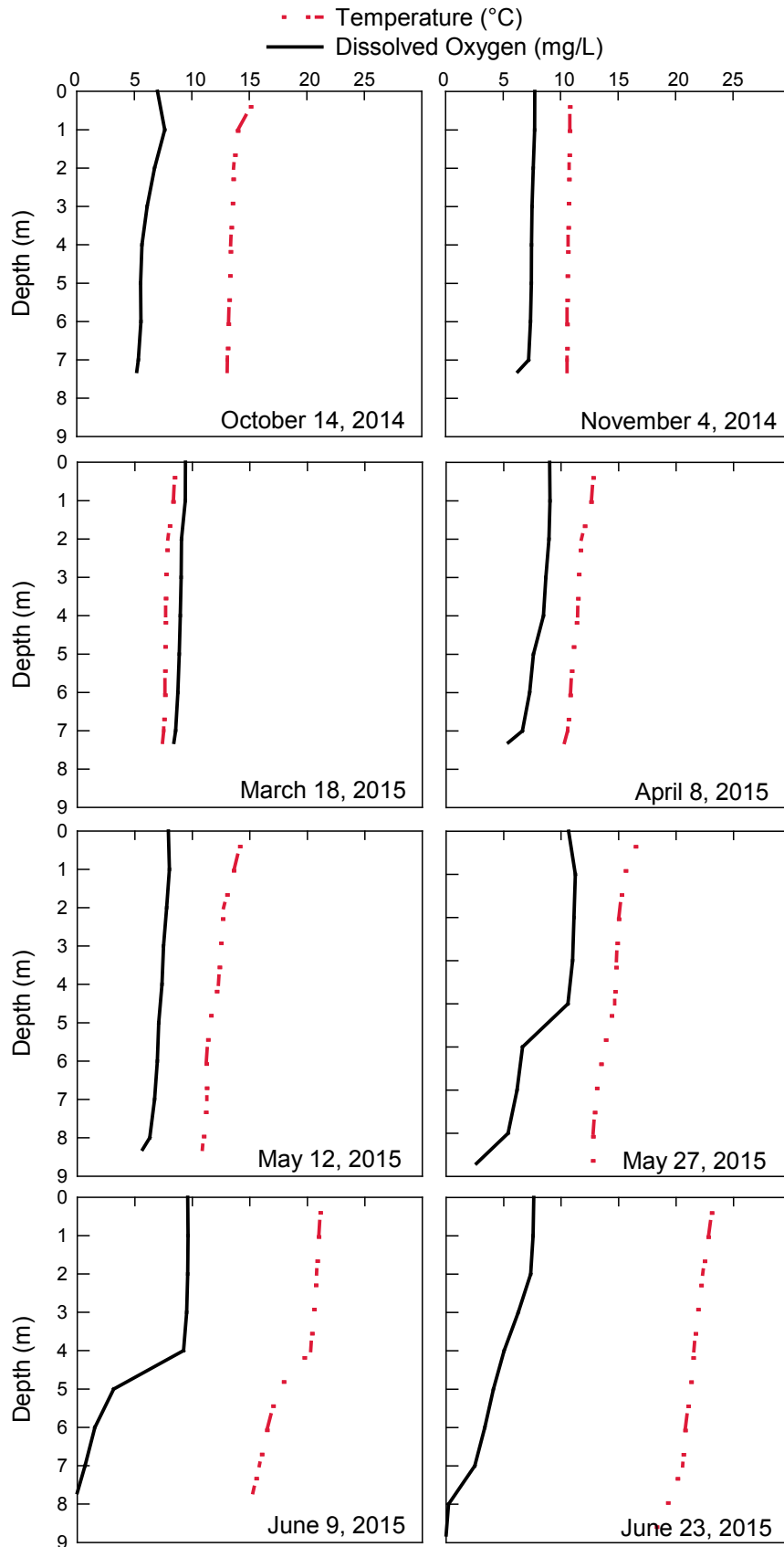
Sample Date	Depth (m)	Temperature (°C)	Conductivity (µS/cm)	Dissolved Oxygen (mg/L)	pH	ORP (mV)	1% Transmittance (m)	Secchi Disk (m)
5/12/2015	0	14.5	1,292	7.9	7.6	255	3.40	1.80
	1	13.6	1,290	8.0	7.6	256		
	2	12.7	1,252	7.8	7.6	256		
	3	12.5	1,246	7.5	7.6	257		
	4	12.3	1,222	7.4	7.6	257		
	5	11.5	1,128	7.1	7.5	258		
	6	11.2	1,090	7.0	7.4	258		
	7	11.3	1,149	6.7	7.4	258		
	8	11.0	1,144	6.3	7.4	259		
	8.3	10.9	1,144	5.7	7.4	260		
	--							
5/27/2015	0	17.1	1,158	10.7	8.2	139	4.30	1.90
	1	15.5	1,156	11.2	8.2	139		
	2	15.0	1,151	11.1	8.1	139		
	3	14.8	1,154	11.0	8.1	140		
	4	14.7	1,152	10.6	8.0	141		
	5	13.7	1,145	6.6	7.7	150		
	6	13.1	1,140	6.2	7.6	152		
	7	12.8	1,148	5.4	7.6	153		
	7.7	12.8	1,153	2.6	7.5	153		
	--							
6/9/2015	0	21.2	1,114	9.6	8.1	216	3.95	1.35
	1	21.0	1,112	9.6	8.1	215		
	2	20.8	1,112	9.6	8.1	215		
	3	20.5	1,109	9.5	8.1	215		
	4	20.3	1,102	9.2	8.0	215		
	5	17.4	1,082	3.2	7.4	228		
	6	16.5	1,139	1.5	7.2	230		
	7	15.8	1,147	0.7	7.2	231		
	7.7	15.3	1,151	0.0	7.1	171		
	--							
6/23/2015	0	23.3	957	7.6	8.1	204	4.00	1.55
	1	22.8	957	7.6	8.1	204		
	2	22.3	956	7.4	8.1	204		
	3	21.9	956	6.3	7.9	207		
	4	21.6	958	5.0	7.8	211		
	5	21.3	958	4.1	7.7	213		
	6	20.8	959	3.4	7.6	213		
	7	20.6	958	2.5	7.5	215		
	8	19.3	954	0.2	7.3	217		
	8.8	18.0	973	0.0	7.2	-95		
	--							

Sample Date	Depth (m)	Temperature (°C)	Conductivity (µS/cm)	Dissolved Oxygen (mg/L)	pH	ORP (mV)	1% Transmittance (m)	Secchi Disk (m)
7/7/2015	0	22.5	993	5.6	7.7	229	2.70	0.95
	1	22.5	993	5.7	7.8	228		
	2	22.5	993	5.6	7.8	227		
	3	22.5	993	5.6	7.8	227		
	4	22.5	993	5.6	7.8	227		
	5	22.5	993	5.7	7.8	227		
	6	22.4	993	5.7	7.8	227		
	7	22.3	993	5.3	7.8	228		
	7.5	22.2	993	5.1	7.8	183		
--	--	--	--	--	--	--	--	--
7/21/2015	0	23.0	1,018	7.9	8.0	307	--	1.00
	1	22.9	1,018	7.6	8.0	305		
	2	22.9	1,019	7.3	7.9	303		
	3	22.8	1,018	7.1	8.0	302		
	4	22.8	1,018	7.0	7.9	287		
	5	22.8	1,019	6.6	7.9	288		
	6	21.9	1,029	0.9	7.3	298		
	7	21.7	1,028	0.0	7.3	300		
	7.4	21.5	1,032	0.0	7.2	279		
--	--	--	--	--	--	--	--	--
8/4/2015	0	23.0	1,046	4.8	7.8	321	3.30	1.14
	1	22.9	1,044	4.8	7.8	319		
	2	22.8	1,045	4.7	7.8	318		
	3	22.8	1,045	4.7	7.8	318		
	4	22.8	1,045	4.7	7.8	318		
	5	22.8	1,045	4.7	7.8	318		
	6	22.7	1,046	4.4	7.8	318		
	7	22.4	1,049	2.7	7.7	232		
	7.4	22.4	1,050	2.3	7.7	227		
--	--	--	--	--	--	--	--	--
8/18/2015	0	22.9	1,023	4.7	7.6	257	2.50	0.85
	1	22.9	1,022	4.7	7.7	256		
	2	22.8	1,023	4.5	7.7	255		
	3	22.7	1,024	4.4	7.7	254		
	4	22.7	1,024	4.4	7.7	253		
	5	22.6	1,025	4.6	7.7	251		
	6	22.6	1,027	4.6	7.7	250		
	7	22.5	1,027	4.6	7.7	250		
	7.6	22.4	1,029	4.1	7.6	48		
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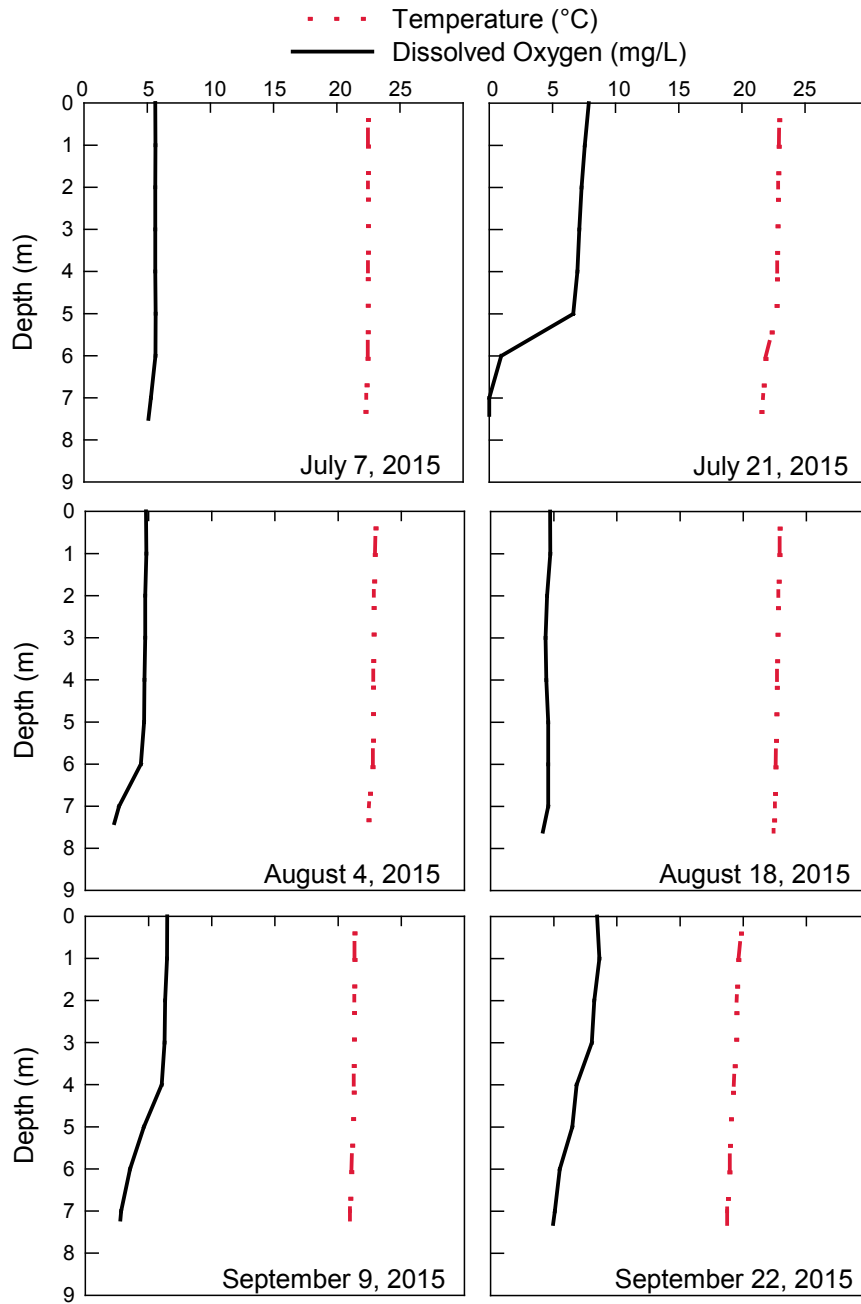
2015 CHERRY CREEK MONITORING REPORT
FEBRUARY 2016

Sample Date	Depth (m)	Temperature (°C)	Conductivity (µS/cm)	Dissolved Oxygen (mg/L)	pH	ORP (mV)	1% Transmittance (m)	Secchi Disk (m)
9/9/2015	0	21.3	1,062	6.5	7.8	205	2.80	0.85
	1	21.3	1,062	6.5	7.9	205		
	2	21.3	1,063	6.3	7.9	205		
	3	21.2	1,062	6.3	7.9	205		
	4	21.2	1,061	6.0	7.9	206		
	5	21.2	1,064	4.6	7.8	208		
	6	21.0	1,064	3.5	7.6	212		
	7	20.9	1,065	2.8	7.6	213		
	7.2	20.9	1,067	2.8	7.6	213		
	--							
9/22/2015	0	20.0	1,047	8.4	7.8	286	2.50	0.78
	1	19.6	1,047	8.6	7.9	284		
	2	19.5	1,046	8.2	7.9	283		
	3	19.4	1,046	8.0	7.9	282		
	4	19.3	1,048	6.8	7.8	284		
	5	19.0	1,053	6.5	7.8	283		
	6	18.9	1,053	5.5	7.7	284		
	7	18.7	1,055	5.1	7.6	285		
	7.3	18.7	1,055	4.9	7.5	284		
	--							

CCR-2



CCR-2



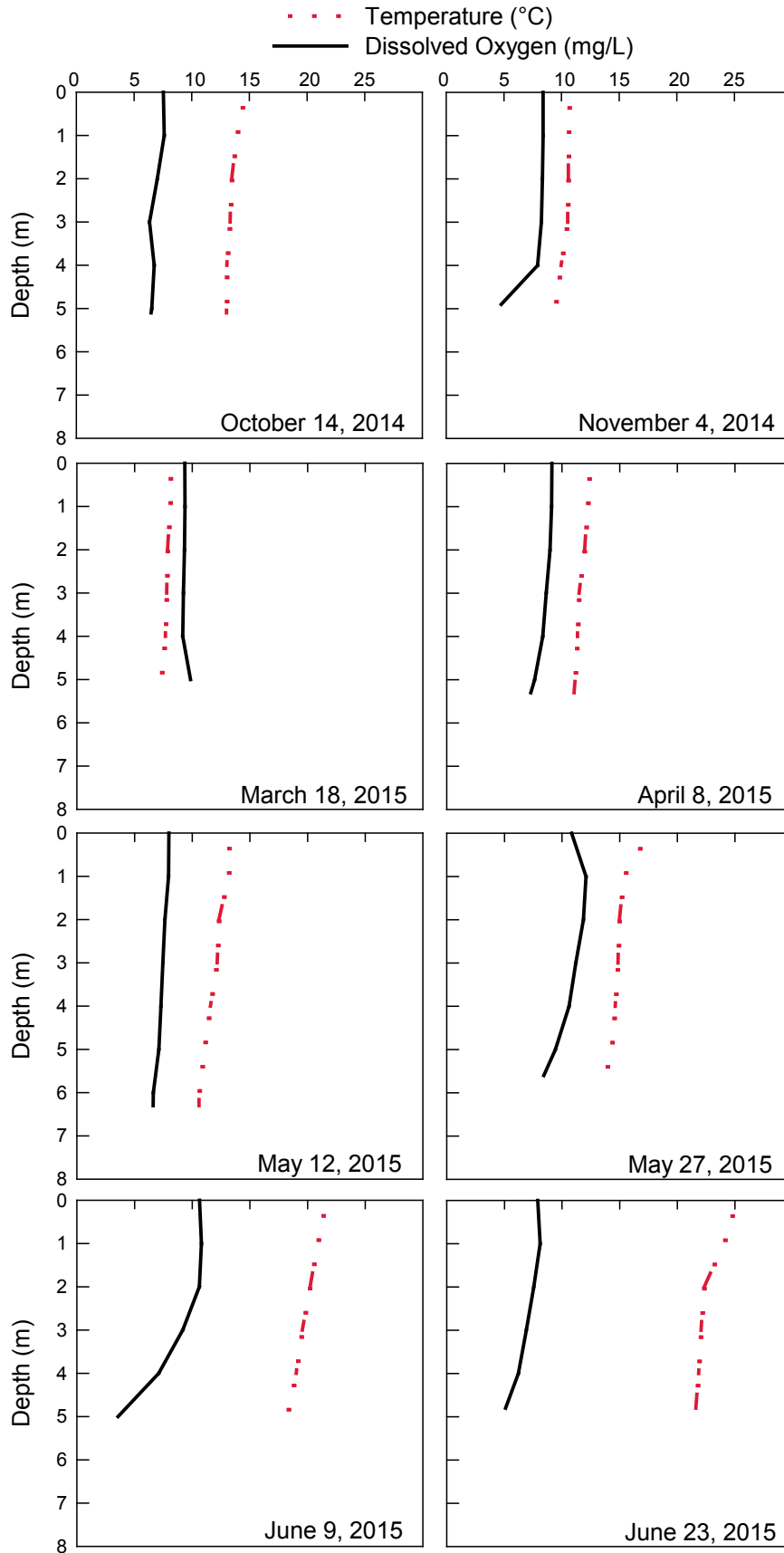
CCR-3

Sample Date	Depth (m)	Temperature (°C)	Conductivity (µS/cm)	Dissolved Oxygen (mg/L)	pH	ORP (mV)	1% Transmittance (m)	Secchi Disk (m)
10/14/2014	0	14.7	1,766	7.5	8.1	216	--	0.78
	1	13.9	1,761	7.6	8.1	215		
	2	13.5	1,762	7.0	8.0	216		
	3	13.3	1,762	6.3	7.9	217		
	4	13.0	1,761	6.8	8.0	216		
	5	13.0	1,761	6.5	8.0	216		
	5.1	13.0	1,759	6.5	8.0	216		
	--							
11/4/2014	0	10.7	1,156	8.4	8.1	255	--	0.75
	1	10.6	1,159	8.4	8.1	253		
	2	10.6	1,157	8.3	8.1	253		
	3	10.5	1,156	8.3	8.1	253		
	4	10.0	1,156	7.9	8.1	252		
	4.9	9.5	1,159	4.8	8.1	252		
	--							
3/18/2015	0	8.1	1,331	9.4	8.1	268	--	0.74
	1	8.1	1,330	9.4	8.1	268		
	2	7.8	1,330	9.3	8.1	268		
	3	7.8	1,332	9.2	8.1	268		
	4	7.7	1,330	9.2	8.1	268		
	5	7.3	1,333	9.9	8.0	268		
	--							
4/8/2015	0	12.4	1,356	9.1	7.9	268	--	0.98
	1	12.2	1,354	9.1	7.9	268		
	2	12.0	1,354	9.0	7.9	266		
	3	11.5	1,353	8.6	7.9	266		
	4	11.3	1,353	8.3	7.9	266		
	5	11.1	1,352	7.6	7.7	267		
	5.3	11.1	1,353	7.3	7.7	266		
	--							
5/12/2015	0	13.2	1,267	8.0	7.7	272	2.80	1.30
	1	13.2	1,263	7.9	7.7	271		
	2	12.3	1,215	7.6	7.6	272		
	3	12.2	1,185	7.5	7.6	272		
	4	11.6	1,102	7.3	7.5	272		
	5	11.0	1,034	7.1	7.5	272		
	6	10.6	1,006	6.6	7.4	266		
	6.3	10.6	1,008	6.6	7.4	267		
	--							

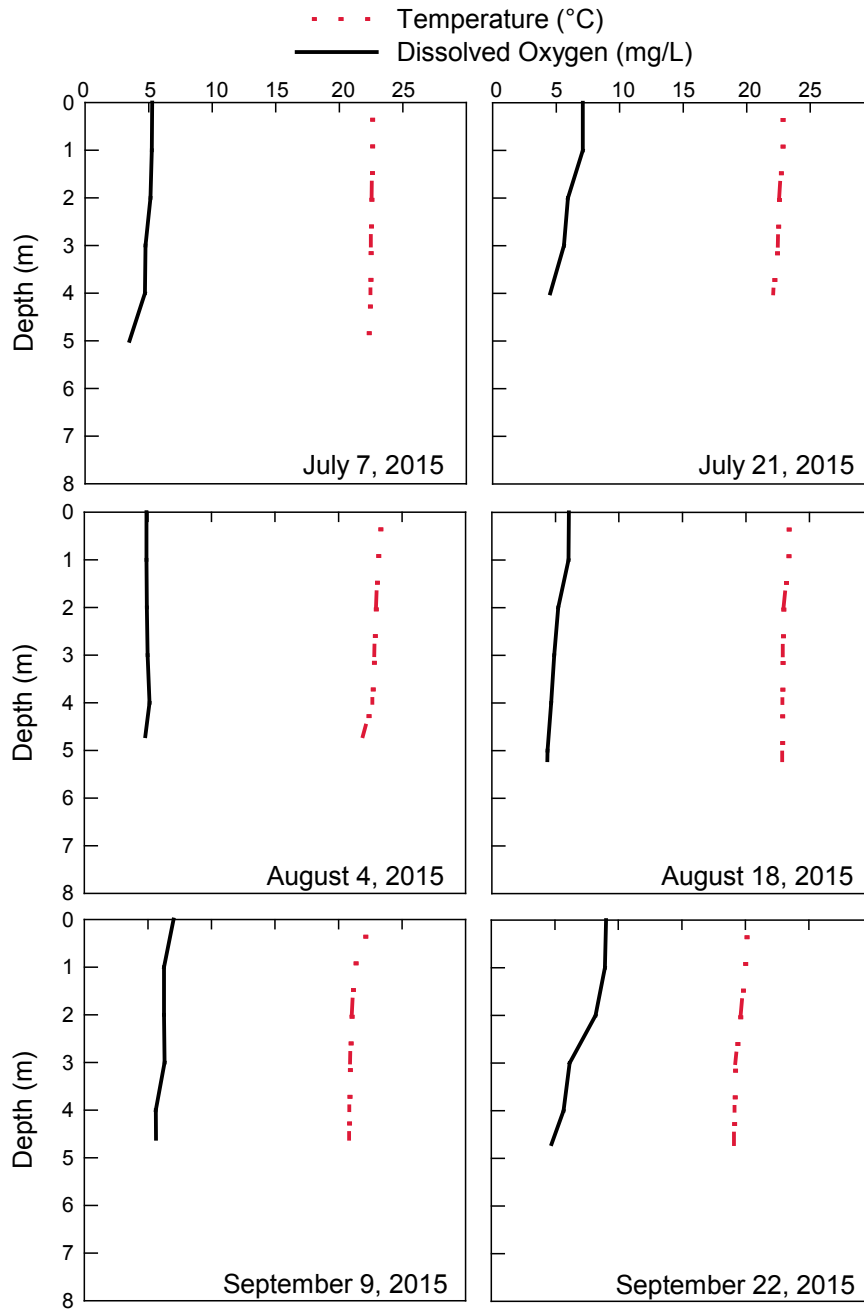
Sample Date	Depth (m)	Temperature (°C)	Conductivity (µS/cm)	Dissolved Oxygen (mg/L)	pH	ORP (mV)	1% Transmittance (m)	Secchi Disk (m)
5/27/2015	0	17.5	1,137	10.8	8.0	222	3.50	1.40
	1	15.4	1,137	12.1	8.1	219		
	2	15.0	1,138	11.9	8.1	219		
	3	14.9	1,146	11.2	8.1	219		
	4	14.6	1,143	10.6	8.0	220		
	5	14.3	1,144	9.4	7.9	222		
	5.6	13.8	1,149	8.4	7.8	220		
	--							
6/9/2015	0	21.6	1,124	10.6	8.2	229	3.25	1.60
	1	20.9	1,117	10.8	8.2	229		
	2	20.2	1,104	10.6	8.1	229		
	3	19.5	1,096	9.2	8.0	231		
	4	19.0	1,078	7.1	7.7	234		
	5	18.2	1,088	3.6	7.4	239		
	--							
6/23/2015	0	25.2	961	7.9	8.2	128	3.25	1.55
	1	24.0	960	8.1	8.1	128		
	2	22.3	956	7.5	8.1	130		
	3	22.1	957	6.9	8.0	132		
	4	21.8	958	6.2	7.9	135		
	4.8	21.6	958	5.1	7.8	130		
	--							
7/7/2015	0	22.6	1,002	5.3	7.8	206	2.00	0.70
	1	22.6	1,001	5.2	7.8	203		
	2	22.5	1,001	5.1	7.7	202		
	3	22.5	1,000	4.8	7.7	203		
	4	22.4	999	4.7	7.7	202		
	5	22.3	998	3.5	7.6	204		
	--							
7/21/2015	0	22.8	1,019	7.1	8.0	135	3.00	1.10
	1	22.8	1,019	7.1	8.0	136		
	2	22.6	1,021	5.9	7.8	139		
	3	22.4	1,023	5.6	7.8	141		
	4	22.1	1,029	4.5	7.7	145		
	--							
8/4/2015	0	23.4	1,046	4.9	7.9	213	3.25	1.20
	1	23.1	1,047	4.9	7.9	213		
	2	22.9	1,046	4.9	7.9	213		
	3	22.8	1,047	5.0	7.9	213		
	4	22.6	1,053	5.1	8.0	213		
	4.7	21.9	1,082	4.8	7.9	213		
	--							

Sample Date	Depth (m)	Temperature (°C)	Conductivity (µS/cm)	Dissolved Oxygen (mg/L)	pH	ORP (mV)	1% Transmittance (m)	Secchi Disk (m)
8/18/2015	0	23.4	1,028	6.1	7.8	240	2.40	0.80
	1	23.4	1,028	6.0	7.8	239		
	2	23.0	1,027	5.2	7.8	239		
	3	22.9	1,027	4.9	7.7	239		
	4	22.9	1,027	4.7	7.7	238		
	5	22.9	1,027	4.4	7.7	238		
	5.2	22.9	1,028	4.4	7.7	236		
	--							
9/9/2015	0	22.6	1,065	7.0	8.1	88	2.70	0.80
	1	21.2	1,062	6.3	8.0	91		
	2	21.0	1,063	6.3	8.0	93		
	3	20.9	1,064	6.3	8.0	96		
	4	20.8	1,064	5.6	7.9	99		
	4.6	20.8	1,064	5.6	7.9	99		
	--							
9/22/2015	0	20.2	1,049	9.0	8.0	265	2.25	0.70
	1	20.0	1,049	8.9	8.0	263		
	2	19.6	1,050	8.2	8.0	262		
	3	19.2	1,052	6.2	7.8	265		
	4	19.2	1,055	5.7	7.7	265		
	4.7	19.1	1,056	4.7	7.6	267		
	--							

CCR-3



CCR-3



Cherry Creek Transect ORP Data

Sample Date	Depth	Transect ORP (mV)										
		D1	D2	D3	D3.5	D4	D5	D6	D7	D8	D9	D10
6/23/2015	0	150	81	75	66	56	73	65	88	70	73	128
	1	150	84	81	75	57	76	68	61	73	78	128
	2	151	88	86	77	65	79	70	66	74	80	130
	3	153	90	89	80	80	81	73	69	78	83	132
	4	156	94	94	84	83	86	79	74	82	87	135
	5	162	101	97	88	88	91	84	79	87	90	130
	6	167	105	101	94	93	95	87	81	91	99	--
	7	170	104	102	94	92	90	88	85	93	90	--
	8	172	94	25	-174	-163	-116	-132	-169	-137	-139	--
	Bottom	-183	-177	-187	-192	-195	-194	-168	-191	-172	--	--

Sample Date	Depth	Transect ORP (mV)										
		D1	D2	D3	D3.5	D4	D5	D6	D7	D8	D9	D10
7/21/2015	0	90	84	111	119	112	96	92	86	127	109	135
	1	93	88	112	120	113	98	94	91	127	111	136
	2	95	93	115	121	116	102	99	97	131	117	139
	3	98	96	118	123	119	106	101	101	133	123	141
	4	104	98	120	125	121	111	104	107	137	127	145
	5	106	101	122	130	124	114	110	108	137	128	--
	6	113	108	127	132	127	117	111	112	139	130	--
	7	119	113	133	139	133	121	117	115	141	119	--
	Bottom	103	21	-34	58	137	125	114	33	0	--	--

Sample Date	Depth	Transect ORP (mV)										
		D1	D2	D3	D3.5	D4	D5	D6	D7	D8	D9	D10
8/18/2015	0	176	173	167	157	140	152	127	142	111	228	240
	1	175	173	166	157	140	153	129	143	115	228	239
	2	175	173	166	158	142	155	132	145	120	229	239
	3	176	173	167	159	144	155	134	146	123	229	239
	4	177	175	167	159	145	156	135	147	126	229	238
	5	179	175	167	159	145	156	136	148	128	229	238
	6	178	175	167	159	146	156	138	149	130	230	236
	7	177	176	168	159	146	159	142	154	135	230	--
	Bottom	155	178	171	161	149	114	145	155	137	102	--

Cherry Creek Transect DO Data

Sample Date	Depth	Dissolved Oxygen (mg/L)										
		D1	D2	D3	D3.5	D4	D5	D6	D7	D8	D9	D10
6/23/2015	0	8.2	8.2	8.2	7.8	7.4	7.5	7.7	7.9	7.8	8.4	7.9
	1	8.3	8.3	8.3	7.6	7.3	7.5	7.7	7.9	7.8	8.4	8.1
	2	7.9	8.1	7.0	7.5	7.3	7.3	8.2	8.2	8.1	8.3	7.5
	3	7.2	7.6	6.9	7.0	6.1	7.2	7.9	7.6	7.3	7.3	6.9
	4	6.3	6.7	5.0	5.9	5.7	5.8	6.2	6.1	6.2	6.1	6.2
	5	3.7	4.0	4.2	4.6	3.5	5.3	4.5	4.1	3.8	4.9	5.1
	6	1.7	1.6	1.4	1.3	1.6	2.2	2.3	1.8	1.3	0.7	--
	7	0.7	0.8	0.5	0.6	0.7	0.8	0.9	0.3	0.2	0.0	--
	8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	--
	Bottom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	--	--

Sample Date	Depth	Dissolved Oxygen (mg/L)										
		D1	D2	D3	D3.5	D4	D5	D6	D7	D8	D9	D10
7/21/2015	0	7.9	8.1	8.2	7.7	7.6	7.4	7.4	7.4	7.4	7.5	7.1
	1	7.8	8.3	8.2	7.4	7.6	7.4	7.4	7.4	7.4	7.4	7.1
	2	7.3	6.7	6.9	6.9	7.0	6.4	6.1	6.6	6.7	6.8	5.9
	3	6.6	6.3	6.3	6.4	6.4	6.3	6.3	6.2	5.9	5.1	5.6
	4	6.0	6.2	6.0	5.9	6.2	5.0	5.3	4.5	4.8	4.6	4.5
	5	4.9	4.1	5.7	4.2	5.3	3.9	3.6	5.6	4.9	4.8	--
	6	1.4	2.1	2.9	3.3	3.9	2.8	3.8	4.9	4.7	4.8	--
	7	0.0	0.0	0.8	0.3	1.8	1.6	1.5	2.3	2.4	0.4	--
	Bottom	0.0	0.0	0.0	0.0	0.0	0.0	0.7	1.8	2.1	--	--

Sample Date	Depth	Dissolved Oxygen (mg/L)										
		D1	D2	D3	D3.5	D4	D5	D6	D7	D8	D9	D10
8/18/2015	0	6.4	6.2	6.3	6.3	6.2	6.2	6.1	6.2	6.2	6.2	6.1
	1	6.4	6.2	6.2	6.3	6.2	6.2	6.0	6.1	6.1	6.2	6.0
	2	6.3	5.9	6.1	5.9	5.4	5.0	5.1	5.1	5.2	5.4	5.2
	3	5.8	5.3	5.0	4.8	4.6	5.0	4.7	4.8	4.9	4.9	4.9
	4	4.6	4.5	4.5	4.6	4.6	4.8	4.6	4.7	4.8	4.6	4.7
	5	3.5	4.5	4.6	4.5	4.7	4.7	4.6	4.6	4.6	4.1	4.4
	6	4.1	4.3	4.5	4.5	4.5	4.5	4.4	4.3	4.0	3.6	4.4
	7	4.4	3.5	3.2	4.4	4.2	2.5	1.3	1.3	2.3	3.7	
	Bottom	3.9	1.8	1.9	3.0	2.7	1.2	1.1	1.2	2.2	1.9	--

Appendix C 2015 WY Stream Water Quality and Precipitation Data

Table C-1: 2015 Stream WQ Data

GEI Water Chemistry Data									
Analytical Detection Limits	2	2	2	6	6	2	5	4	4
Site/Sample Date	Total Phosphorus (µg/L)	Total Dissolved Phosphorus (µg/L)	Ortho- phosphate (µg/L)	Total Nitrogen (µg/L)	Total Dissolved Nitrogen (µg/L)	Nitrate+ Nitrite (µg/L)	Ammonia (µg/L)	Total Suspended Solids (mg/L)	Total Volatile Suspended Solids (mg/L)
EcoPark									
10/21/2014	95	64	75	925	807	571	--	--	--
11/6/2014	79	56	58	696	586	285	25	--	--
12/1/2014	103	63	61	1,741	1,560	1,189	13	15.4	--
1/5/2015	230	71	69	2,651	2,425	1,865	172	55.1	6.7
2/9/2015	92	69	64	1,502	1,585	1,203	22	6.2	--
3/17/2015	69	40	38	1,502	1,356	926	27	7.6	--
4/6/2015	63	36	39	979	886	559	19	--	--
5/4/2015	114	111	115	1,550	1,435	1,082	101	8.4	--
6/22/2015	196	139	144	1,609	1,595	1,113	28	18.8	4.0
7/6/2015	183	120	126	1,186	976	543	47	18.6	--
8/3/2015	202	133	138	1,677	1,404	936	22	16.0	4.0
9/8/2015	158	113	105	1,709	1,505	932	39	6.8	--
EcoPark Storm									
4/17/2015	131	64	51	1,706	1,507	1,009	59	26.4	5.4
6/12/2015	211	111	126	1,086	1,010	758	51	53.0	9.5
10/21/2015	197	97	96	1,740	1,568	1,154	22	26.5	7.5
CC-10									
10/21/2014	213	204	249	653	632	461	30	7.6	--
11/6/2014	191	155	152	645	670	324	26	4.7	--
12/1/2014	155	147	136	847	733	454	41	5.7	--
1/5/2015	190	146	141	1,044	1,011	611	99	8.8	--
2/9/2015	163	126	135	725	674	413	36	7.5	--
3/17/2015	132	101	106	794	769	406	38	15.4	--
4/6/2015	160	124	140	542	627	216	23	8.4	--
5/4/2015	224	193	187	780	766	406	47	7.6	--
6/22/2015	395	336	328	833	834	386	49	12.2	--
7/6/2015	436	336	353	806	710	227	27	38.4	6.4
8/3/2015	373	263	282	930	715	229	21	32.2	5.6
9/8/2015	328	273	266	621	553	218	23	9.4	--

Table C-1 (Cont.)

GEI Water Chemistry Data									
Analytical Detection Limits	2	2	2	6	6	2	5	4	4
Site/Sample Date	Total Phosphorus (µg/L)	Total Dissolved Phosphorus (µg/L)	Ortho- phosphate (µg/L)	Total Nitrogen (µg/L)	Total Dissolved Nitrogen (µg/L)	Nitrate+ Nitrite (µg/L)	Ammonia (µg/L)	Total Suspended Solids (mg/L)	Total Volatile Suspended Solids (mg/L)
CC-10 Storm									
4/17/2015	258	77	122	1,054	971	395	73	63.5	7.3
5/5/2015	207	101	170	880	914	409	53	26.8	--
5/19/2015	301	179	167	821	755	380	63	110.4	7.0
6/12/2015	572	173	195	1,100	621	324	213	388.0	44.0
8/11/2015	545	268	276	1,367	1,071	294	74	135.0	18.0
10/21/2015	302	218	214	562	402	141	13	42.5	10.0
CC-Out @ I225									
10/21/2014	77	11	10	888	544	3	13	15.6	6.0
11/4/2014	73	23	12	1,034	860	10	56	15.6	6.0
12/2/2014	45	12	5	802	533	9	25	5.1	--
1/6/2015	63	31	23	922	723	61	118	--	--
2/10/2015	60	20	19	967	666	33	36	6.6	--
3/19/2015	73	12	7	1,099	579	3	29	20	7.4
4/6/2015	65	12	9	887	654	4	20	14.0	5.0
5/4/2015	62	37	33	697	610	11	40	5.4	--
6/23/2015	213	172	170	751	569	22	142	7.8	--
7/7/2015	142	73	73	947	691	2	16	23.7	8.0
8/3/2015	202	69	72	1,297	777	72	22	30.8	10.8
9/8/2015	220	51	35	1,939	1,160	230	182	23.0	9.8

Table C-1 (Cont.)

GEI Water Chemistry Data									
Analytical Detection Limits	2	2	2	6	6	2	5	4	4
Site/Sample Date	Total Phosphorus (µg/L)	Total Dissolved Phosphorus (µg/L)	Ortho- phosphate (µg/L)	Total Nitrogen (µg/L)	Total Dissolved Nitrogen (µg/L)	Nitrate+ Nitrite (µg/L)	Ammonia (µg/L)	Total Suspended Solids (mg/L)	Total Volatile Suspended Solids (mg/L)
CT-P1									
10/21/2014	44	10	14	926	897	387	--	23	4.4
11/7/2014	28	3	9	955	830	381	51	6.8	--
12/1/2014	10	2	7	1,014	884	546	28	4.0	--
1/5/2015	31	22	10	1,806	1,676	941	190	9.7	--
2/9/2015	33	17	15	980	756	336	33	5.6	--
3/17/2015	34	5	6	1,099	740	225	51	11.4	4.2
4/6/2015	61	4	7	1,140	833	274	26	17.0	5.3
5/4/2015	50	4	8	1,302	888	426	46	17.8	5.4
6/22/2015	55	21	4	1,191	951	333	29	12.4	--
7/6/2015	64	23	23	1,269	1,164	471	63	15.4	4.8
8/3/2015	68	14	19	1,363	1,089	360	21	48.4	5.0
9/8/2015	57	15	19	1,060	931	439	32	17.0	--
CT-P1 Storm									
4/17/2015	219	19	15	1,838	1,451	537	311	107.0	22.0
5/5/2015	314	3	6	1,295	1,014	474	142	262.0	35.0
5/19/2015	125	--	3	1,015	742	455	59	58.0	9.4
6/12/2015	114	11	13	1,265	894	386	33	37.5	8.5
6/25/2015	198	14	--	2,096	1,462	626	57	124.0	18.0
8/11/2015	668	13	16	1,982	915	393	142	442.0	58.0
10/21/2015	189	44	42	2,104	1,748	783	304	81.5	12.5

Table C-1 (Cont.)

GEI Water Chemistry Data									
Analytical Detection Limits	2	2	2	6	6	2	5	4	4
Site/Sample Date	Total Phosphorus (µg/L)	Total Dissolved Phosphorus (µg/L)	Ortho- phosphate (µg/L)	Total Nitrogen (µg/L)	Total Dissolved Nitrogen (µg/L)	Nitrate+ Nitrite (µg/L)	Ammonia (µg/L)	Total Suspended Solids (mg/L)	Total Volatile Suspended Solids (mg/L)
CT-P2									
10/21/2014	62	15	15	1,136	1,170	659	18	21.4	--
11/7/2014	27	5	10	1,120	1,057	603	59	16.1	--
12/1/2014	35	7	8	1,332	1,196	807	39	25.0	--
1/5/2015	52	29	12	2,040	1,870	1,111	213	23.1	--
2/9/2015	43	16	9	1,011	897	480	29	14.5	--
3/17/2015	50	9	7	1,101	872	405	60	12.0	5.4
4/6/2015	43	4	7	1,151	978	462	26	9.3	--
5/4/2015	50	5	7	1,473	1,163	678	71	11.2	--
6/22/2015	68	18	16	1,406	1,231	634	53	20.8	4.2
7/6/2015	102	30	23	1,677	1,316	527	104	20.8	6.4
8/3/2015	68	3	12	1,653	1,398	482	20	17.8	6.2
9/8/2015	61	8	12	1,340	1,125	591	45	20.6	4.6
CT-P2 Storm									
4/17/2015	115	26	20	1,833	1,428	549	268	45.7	11.0
5/5/2015	189	4	11	1,273	1,097	488	165	93.0	15.0
5/19/2015	100	25	24	1,043	870	514	122	27.6	6.0
6/12/2015	100	26	27	1,328	1,090	475	92	27.0	8.5
6/25/2015	673	11	5	2,608	1,971	628	142	45.5	11.0
8/11/2015	520	29	30	1,807	1,075	445	265	326.0	38.0
10/21/2015	122	39	39	2,173	1,825	766	256	39.0	8.0

Table C-1 (Cont.)

GEI Water Chemistry Data									
Analytical Detection Limits	2	2	2	6	6	2	5	4	4
Site/Sample Date	Total Phosphorus (µg/L)	Total Dissolved Phosphorus (µg/L)	Ortho- phosphate (µg/L)	Total Nitrogen (µg/L)	Total Dissolved Nitrogen (µg/L)	Nitrate+ Nitrite (µg/L)	Ammonia (µg/L)	Total Suspended Solids (mg/L)	Total Volatile Suspended Solids (mg/L)
CT-1									
10/21/2014	52	18	18	1,604	1,463	872	73	29.6	--
11/6/2014	84	10	9	2,224	2,086	1,498	76	54.5	5.9
12/1/2014	62	17	14	2,600	2,434	1,575	315	29.8	--
1/5/2015	70	22	12	3,327	3,245	2,272	310	24.6	--
2/9/2015	93	20	12	2,183	2,099	1,358	70	44.6	5.2
3/17/2015	62	11	6	1,891	1,687	951	87	28.2	5.4
4/6/2015	76	12	11	1,632	1,474	866	77	30.1	6.0
5/4/2015	90	15	10	1,565	1,309	666	187	30.8	6.6
6/22/2015	89	15	15	1,424	1,006	376	117	37.6	5.4
7/6/2015	103	14	12	1,809	1,334	466	109	47.4	8.6
8/3/2015	88	--	8	2,146	1,796	834	109	36.2	7.0
9/8/2015	91	14	13	1,362	1,200	560	102	41.0	6.4
CT-1 Storm									
4/17/2015	60	37	30	1,425	1,259	606	164	32.5	6.5
6/12/2015	241	55	59	1,057	877	433	154	95.0	13.5
6/25/2015	167	14	11	1,944	1,722	924	195	96.5	12.5
8/11/2015	539	165	166	2,042	1,385	668	228	165.0	28.0
10/21/2015	133	28	26	2,090	1,841	1,143	105	60.5	8.0

Table C-1 (Cont.)

GEI Water Chemistry Data									
Analytical Detection Limits	2	2	2	6	6	2	5	4	4
Site/Sample Date	Total Phosphorus (µg/L)	Total Dissolved Phosphorus (µg/L)	Ortho- phosphate (µg/L)	Total Nitrogen (µg/L)	Total Dissolved Nitrogen (µg/L)	Nitrate+ Nitrite (µg/L)	Ammonia (µg/L)	Total Suspended Solids (mg/L)	Total Volatile Suspended Solids (mg/L)
CT-2									
10/21/2014	40	11	11	1,408	1,383	741	74	12.6	--
11/6/2014	67	6	8	1,947	1,808	1,171	91	25.8	4.0
12/1/2014	45	18	11	1,764	2,345	1,388	226	29.6	4.4
1/5/2015	58	27	14	3,253	3,201	2,022	312	16.3	--
2/9/2015	64	15	7	2,187	2,012	1,256	56	22.8	4.4
3/17/2015	45	7	4	1,529	1,259	663	97	19.8	4.2
4/6/2015	62	8	6	2,146	1,949	819	138	22	4
5/4/2015	66	8	7	1,332	1,110	324	175	15.8	5.0
6/22/2015	83	19	18	1,155	831	167	135	12.8	--
7/6/2015	74	17	12	1,272	1,132	231	210	24.2	6.2
8/3/2015	57	--	7	1,295	1,004	298	135	25.2	6.8
9/8/2015	82	9	9	1,208	989	306	125	32.6	6.4
CT-2 Storm									
4/17/2015	57	29	12	2,187	1,933	1,124	135	11.5	--
5/5/2015	101	10	11	1,452	1,176	603	154	41.0	7.5
5/19/2015	48	22	7	1,577	1,550	847	135	16.0	--
6/12/2015	127	29	36	996	870	427	148	37.5	7.5
6/25/2015	93	9	2	1,392	1,200	417	101	28.5	8.5
8/11/2015	436	102	100	1,826	1,337	632	180	143.0	22.0
10/21/2015	65	11	8	1,584	1,511	834	105	18.5	4.5

Note:

-- Denotes result less than MDL.

Table C-2: CC-10 mean daily temperatures (°C).

Day of Month	April	May	June	July	August	September
1	'--	12.97	15.54	17.74	16.62	15.38
2	'--	12.67	16.21	17.05	16.54	15.62
3	'--	12.57	15.41	18.44	17.73	15.16
4	'--	12.28	16.33	18.59	16.96	14.55
5	'--	11.92	16.26	18.41	16.68	15.54
6	'--	12.80	17.08	16.93	16.58	15.26
7	'--	12.35	17.55	15.98	15.86	14.28
8	'--	11.79	17.18	15.77	16.40	14.30
9	'--	10.14	17.79	16.48	16.79	14.12
10	11.81	5.67	17.40	17.09	15.54	13.68
11	10.53	9.74	17.01	17.07	17.77	14.59
12	10.27	11.89	16.81	16.59	18.41	14.02
13	10.31	12.59	18.37	16.21	18.47	13.75
14	11.06	13.09	19.20	16.19	18.63	13.61
15	11.07	13.16	18.19	16.31	17.96	14.43
16	6.01	12.75	17.68	16.49	17.94	13.94
17	5.06	11.95	18.52	16.66	17.43	13.42
18	8.84	11.45	18.59	15.95	15.81	12.52
19	8.72	10.54	20.10	17.09	15.07	12.10
20	9.45	9.51	19.11	16.62	15.62	12.08
21	10.58	10.15	18.82	15.87	15.84	12.91
22	11.19	11.92	17.77	16.26	15.57	13.24
23	11.63	12.69	18.50	16.62	14.49	15.08
24	10.91	11.70	18.78	15.74	14.84	13.71
25	10.64	13.13	18.80	16.42	15.32	13.14
26	9.54	14.44	18.50	16.35	15.78	13.68
27	8.43	15.77	18.29	16.70	15.49	14.50
28	10.58	15.31	17.94	15.80	15.45	13.86
29	12.43	14.71	18.01	16.04	15.18	14.67
30	13.16	15.03	17.89	16.48	15.64	14.29
31	'--	16.10	'--	16.56	15.30	'--

Table C-3: CT-2 mean daily temperatures (°C).

Day of Month	April	May	June	July	August	September
1	'--	16.47	20.15	23.89	23.69	20.94
2	'--	15.26	20.82	22.79	22.73	21.33
3	'--	15.94	20.46	23.67	20.71	20.60
4	'--	15.15	20.73	23.92	21.22	19.42
5	'--	14.07	19.59	22.94	22.61	20.66
6	'--	14.12	18.82	20.61	23.16	20.99
7	'--	14.50	20.14	18.90	22.64	20.01
8	'--	13.75	21.09	18.48	23.22	19.86
9	'--	11.65	22.08	20.21	24.03	19.84
10	'--	6.89	21.52	22.27	22.18	19.64
11	'--	9.93	20.77	23.08	17.55	20.21
12	'--	12.28	17.82	23.03	20.16	19.15
13	'--	13.45	18.86	22.73	22.19	19.55
14	12.75	14.69	20.62	22.24	22.08	18.20
15	12.75	15.34	20.45	22.90	22.93	18.63
16	7.98	15.20	19.46	22.69	23.56	18.96
17	4.57	14.15	20.47	22.59	22.14	18.63
18	8.21	13.88	21.05	21.96	20.74	17.92
19	9.27	11.76	22.02	20.79	19.78	17.05
20	10.76	10.66	22.54	21.73	19.65	17.35
21	12.65	10.92	22.41	21.47	20.86	17.60
22	13.84	13.04	21.07	22.52	20.99	18.01
23	13.64	14.19	21.71	23.98	19.96	19.17
24	13.56	13.47	23.24	22.92	20.33	19.17
25	13.09	14.81	21.95	23.16	21.50	18.50
26	11.51	16.44	21.75	24.26	21.38	18.46
27	9.16	17.53	22.66	24.27	20.85	18.79
28	10.70	18.26	23.09	22.72	21.20	18.06
29	14.41	18.00	23.55	22.12	21.13	18.40
30	16.51	18.83	24.18	23.26	21.42	18.22
31	'--	20.37	'--	23.74	21.64	'--

Appendix D 2015 WY Streamflow, Rainfall, Phosphorous and Nitrogen Loading Calculations and Final Inflow and Load Data Normalized to the U.S. Army Corps of Engineers Inflow Data

D.1 Streamflow Determination

Water levels (stage) were monitored at all sites on 15-minute intervals using ISCO Model 6700 and 6712 flowmeters. Each unit was calibrated on a monthly basis using *in-situ* staff gage measurements. Stage-discharge relationships were developed for sites without weirs (CC-10, CT-P1, CT-1) and daily mean water levels were translated to stream discharge. Multi-level orifice and weir equations that have been previously developed for the sites with weirs (EcoPark, CT-P2, and CT-2) were used to translate daily mean water levels to stream discharge.

Rating curves were developed by first establishing a stage-discharge relationship. Data for this relationship were collected by measuring stream discharge (ft^3/sec) with a Marsh McBirney Model 2000 flowmeter and recording the water level at the staff gage and ISCO flowmeter (Table D-1). Stage-discharge data collected in the 2015 WY were combined with data collected during previous years. Historical data was not used if major changes to the streambed morphology, transducer, or staff gage had occurred. For example, if the transducer or staff gage was relocated or reset, then only the data collected post-change would be used. Rating curves were then developed by fitting a nonlinear regression model to the data (Table D-2). A two-stage rating curve was developed for CC-10 to more accurately estimate low flows at this site.

Weirs at sites CT-P2 and CT-2 are located in the outlet structure of each pond. The CT-P2 weir equations were provided by Muller Engineering (Unpublished data, 2004; Table D-2), and the CT-2 weir equations were provided by Bill Ruzzo (Unpublished data, 2014). The weir at EcoPark is located directly in the main channel of the creek and the equation was developed by GEI (Unpublished data, 2013). ISCO measured water level data (daily mean) were used in these equations to calculate daily stream discharge.

While water levels for Cherry Creek and Cottonwood Creek are monitored on a continuous basis, there were periods of time when daily mean flows were estimated due to a dead battery, pressure transducer malfunction, ice, 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).

Table D-1: Stage-discharge data used to develop rating curves for sites CC-10, CT-P1, CT-P2, and CT-1 in 2015.

Site	Year	Date	Staff Gage Level (ft)	Transducer Level (ft)	Discharge (cfs)
CC-10	2004	27-May-04	1.09	1.463	3.10
CC-10	2004	22-Jun-04	2.50	2.493	24.45
CC-10	2004	23-Jun-04	1.54	1.530	8.65
CC-10	2004	24-Aug-04	2.47	2.472	23.93
CC-10	2005	01-Apr-05	2.39	2.531	20.11
CC-10	2005	14-Apr-05	4.84	4.890	142.89
CC-10	2005	25-Apr-05	4.05	4.093	91.76
CC-10	2005	02-May-05	2.63	2.630	40.14
CC-10	2005	19-May-05	1.68	1.612	14.27
CC-10	2005	26-May-05	1.40	1.422	8.79
CC-10	2005	01-Jun-05	1.47	1.469	17.86
CC-10	2005	16-Aug-05	0.81	0.808	3.60
CC-10	2005	13-Oct-05	2.41	2.418	29.81
CC-10	2006	20-Apr-06	1.40	1.391	10.92
CC-10	2006	13-Jun-06	0.56	0.567	2.05
CC-10	2006	12-Jul-06	1.56	1.482	23.62
CC-10	2006	08-Aug-06	0.55	0.550	5.18
CC-10	2006	27-Dec-06	1.27	1.230	20.51
CC-10	2007	13-Mar-07	4.27	4.317	93.87
CC-10	2007	10-May-07	3.10	3.100	62.15
CC-10	2007	26-Jul-07	0.61	0.621	1.63
CC-10	2007	9-Aug-07	1.32	1.306	11.11
CC-10	2007	13-Nov-07	1.70	1.692	6.27
CC-10	2008	19-Feb-08	2.50	2.470	31.14
CC-10	2008	27-Mar-08	1.98	1.980	25.65
CC-10	2008	26-Jun-08	0.64	0.617	2.79
CC-10	2008	15-Aug-08	0.87	0.864	5.92
CC-10	2008	11-Dec-08	1.36	1.387	21.28
CC-10	2009	22-Jan-09	1.27	--	21.53
CC-10	2009	24-Mar-09	1.18	1.126	17.98
CC-10	2009	23-Jun-09	1.80	1.767	19.25
CC-10	2009	08-Dec-09	1.79	1.802	11.11
CC-10	2009	18-Aug-09	2.48	2.470	38.79
CC-10	2009	20-Nov-09	2.12	2.081	27.89
CC-10	2010	26-Jan-10	1.76	1.733	21.03
CC-10	2010	15-Apr-10	2.15	2.136	28.03
CC-10	2010	29-Jun-10	0.91	0.889	6.10
CC-10	2010	10-Aug-10	1.58	1.566	21.51
CC-10	2010	8-Sep-10	0.42	0.468	1.77
CC-10	2011	1-Mar-11	1.76	1.767	21.17

Site	Year	Date	Staff Gage Level (ft)	Transducer Level (ft)	Discharge (cfs)
CC-10	2011	31-Mar-11	1.52	1.656	22.81
CC-10	2011	27-Apr-11	1.48	1.414	18.63
CC-10	2011	11-May-11	2.35	2.485	29.56
CC-10	2011	4-Aug-11	1.15	1.153	5.36
CC-10	2011	27-Sep-11	0.78	0.662	1.88
CC-10	2012	6-Jan-12	1.35	1.344	12.05
CC-10	2012	24-Jan-12	1.60	1.542	18.59
CC-10	2012	8-Mar-12	1.58	1.584	12.82
CC-10	2012	18-Apr-12	2.02	2.016	20.40
CC-10	2012	24-May-12	2.31	2.320	24.74
CC-10	2012	16-Jun-12	1.74	1.650	8.29
CC-10	2012	1-Jul-12	0.98	0.973	2.24
CC-10	2012	17-Aug-12	0.40	0.424	1.20
CC-10	2013	2-Mar-13	1.17	1.168	11.81
CC-10	2013	26-Mar-13	2.04	2.069	29.63
CC-10	2013	28-Apr-13	1.60	1.613	17.61
CC-10	2013	25-May-13	1.44	1.440	11.29
CC-10	2013	11-Aug-13	1.15	1.130	4.61
CC-10	2013	13-Sep-13	1.90	1.900	25.87
CC-10	2014	24-Apr-14	2.40	2.411	35.88
CC-10	2014	5-Jun-14	1.90	1.900	16.66
CC-10	2014	9-Jun-14	3.89	3.892	89.59
CC-10	2014	15-Jul-14	3.28	3.249	80.69
CC-10	2015	29-Sept-15	0.88	0.852	3.92
CC-10	2015	22-Oct-15	2.20	2.155	44.71
CT-P1	2014	22-Jan-14	1.41	1.413	1.24
CT-P1	2014	24-Apr-14	2.05	2.054	7.74
CT-P1	2014	9-Jun-14	1.87	1.871	6.37
CT-P1	2014	15-Jul-14	2.42	2.415	31.20
CT-P1	2015	19-May-15	2.62	2.590	29.54
CT-P1	2015	28-May-15	1.78	1.793	2.71
CT-P1	2015	29-Sept-15	1.48	1.500	0.91
CT-P1	2015	22-Oct-15	3.00	3.003	55.39
CT-1	2011	20-Jun-11	1.80	2.237	119.77
CT-1	2015	19-May-15	2.20	0.454	101.24
CT-1	2015	20-May-15	1.82	--	19.76
CT-1	2015	28-May-15	1.62	1.840	6.44
CT-1	2015	29-Sept-15	1.44	1.463	1.47
CT-1	2015	08-Oct-15	1.53	--	4.33
CT-1	2015	22-Oct-15	2.02	1.992	37.06

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

Site	Stage Interval	Discharge Equations	R ²
EcoPark	≤ 0.78	$Q = 3.33*(H^{1.5})*(6-0.2*H)$	
	> 0.78	$Q = 3.33*(H-0.78)^{1.5}*(6+(H-0.78)*(13.06)*(2)) + 13.406$	
CC-10	< 0.99	$Q = \text{EXP}((H+0.2103)/0.7425)$	0.77
	> 0.99	$Q = \text{EXP}((H+9.2305)/2.6960)-39.1077$	0.90
CT-P1	All	$Q = \text{EXP}((H-0.6822)/0.5442)-3.3117$	0.96
CT-P2	< 0.60	$Q = (3.3)*(1)*(H)^{1.5}$	
	0.61 - 1.09	$Q = (0.60)*(0.50)*((2*32.2*(\text{Hadj}))^{0.5})$	
	1.10 - 1.99	$Q = (0.60)*(0.50)*((2*32.2*(\text{Hadj}))^{0.5})+((3.33)*(1)*(H-1.0)^{1.5})$	
	2.00 - 2.59	$Q = (0.60)*(0.50)*(2*32.2*(\text{Hadj}))^{0.5}+((0.60)*(0.50)*((2*32.2*(\text{Hadj}-1.0))^{0.5})+((3.33)*(1)*(H-2.0)^{1.5})$	
	2.60 - 2.99	$Q = (0.60)*(0.50)*(2*32.2*(\text{Hadj}))^{0.5}+((0.60)*(0.50)*((2*32.2*(\text{Hadj}-1.0))^{0.5})+((0.60)*(0.50)*(Hadj-2.0)^{0.5})$	
	3.00 - 3.59	$Q = (0.60)*(0.50)*(2*32.2*(\text{Hadj}))^{0.5}+((0.60)*(0.50)*((2*32.2*(\text{Hadj}-1.0))^{0.5})+((0.60)*(0.50)*(Hadj-2.0)^{0.5})+((3.3)*(1)*(H-3.0)^{1.5})$	
	3.60 - 3.99	$Q = (0.60)*(0.50)*(2*32.2*(\text{Hadj}))^{0.5}+((0.60)*(0.50)*((2*32.2*(\text{Hadj}-1.0))^{0.5})+((0.60)*(0.50)*(Hadj-2.0)^{0.5})+((0.60)*(0.50)*(2*32.2*(\text{Hadj}-3.0))^{0.5})$	
	4.00 - 4.49	$Q = (0.60)*(0.50)*(2*32.2*(\text{Hadj}))^{0.5}+((0.60)*(0.50)*((2*32.2*(\text{Hadj}-1.0))^{0.5})+((0.60)*(0.50)*(Hadj-2.0)^{0.5})+((0.60)*(0.50)*(2*32.2*(\text{Hadj}-3.0))^{0.5})+((3.3)*(1)*(H-4.0))^{1.5})$	
	4.50 - 5.19	$Q = (0.60)*(0.50)*(2*32.2*(\text{Hadj}))^{0.5}+((0.60)*(0.50)*((2*32.2*(\text{Hadj}-1.0))^{0.5})+((0.60)*(0.50)*(Hadj-2.0)^{0.5})+((0.60)*(0.50)*(2*32.2*(\text{Hadj}-3.0))^{0.5})+((0.60)*(0.50)*(2*32.2*(\text{Hadj}-4.0))^{0.5})$	
	5.20 - 6.80	$Q = (0.60)*(0.50)*(2*32.2*(\text{Hadj}))^{0.5}+((0.60)*(0.50)*((2*32.2*(\text{Hadj}-1.0))^{0.5})+((0.60)*(0.50)*(Hadj-2.0)^{0.5})+((0.60)*(0.50)*(2*32.2*(\text{Hadj}-3.0))^{0.5})+((0.60)*(0.50)*(2*32.2*(\text{Hadj}-4.0))^{0.5})+((3.3)*(1)*(H-5.2))^{1.5})$	
CT-1	All	$Q = \text{EXP}((H-1.0528)/0.2507)-3.0061$	0.99
CT-2 ^a	0.50 – 1.09	$Q = 4.2198*(H_3) + 15.437*(H_2) - 8.9773*(H)$	
	1.10 – 2.59	$Q = 7.5895*(H_2) - 7.7255*(H) + 13.727$	
	2.60 – 3.69	$Q = 0.8954*(H_3) - 8.9145*(H_2) + 32.481*(H) + 4.8161$	
	≥3.70	$Q = 2642.5*(H_2) - 18781*(H) + 33360$	

H_{adj} = Mean daily level - 0.25 ft

^a = CT-2 without blockage

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

Site	Equations	R2	Percent of Annual Data Estimated
EcoPark, Oct - Nov	EcoPark Level = $0.5873 \times (\text{CT-P1 Level}) - 0.3755$	0.75	2%
EcoPark, Jan - May	EcoPark Level = $0.513 \times (\text{CC-10 Level}) - 0.5075$	0.77	5%
CC-10, Nov - June	CC-10 Level = $7.3186 \times \text{LN}(\text{Parker Level}) -$	0.69	8%
CT-P1, Oct - May	CT-P1 Level = $0.2055 \times (\text{CT-P2 Level}) + 1.3958$	0.91	14%
CT-P1, June - Sept	CT-P1 Level = $0.4918 \times (\text{Parker Level}) - 0.2483$	0.76	7%
CT-P2, Oct	CT-P2 Level = $4.4346 \times (\text{CT-P1 Level}) - 6.0771$	0.91	5%
CT-P2, July - Sept	CT-P2 Level = $1.8983 \times (\text{CT-2 Level}) - 0.3616$	0.72	10%
CT-P2, Sept	CT-P2 Level = $4.2393 \times (\text{CT-P1 Level}) - 5.7558$	0.70	4%
CT-2, Dec - May	CT-2 Level = $0.3176 \times (\text{CT-P2 Level}) + 0.566$	0.84	5%
CT-2, Aug - Sept	CT-2 Level = $2.2352 \times (\text{CT-1 Level}) - 2.7336$	0.71	2%

D.2 Phosphorus Loading

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

In an effort to maintain a seasonality component in phosphorus and nitrogen loads and exports for the reservoir, the normalization process was performed on monthly data. Loads attributed to stream inflow, reservoir outflow, precipitation and the alluvium were still calculated on a daily basis, using the daily inflow records and respective concentration data, but summed to create a monthly inflow value. In the case of the alluvial inflow constant, the annual value was divided by the number of days in the year to create a daily value, and then summed to create a monthly value, with no seasonal dynamics. The monthly precipitation and alluvial inflow values are subtracted from the monthly USACE inflow value to create an Adjusted USACE Inflow. The monthly GEI stream flow (sites CC-10 and CT-1 flow) is subtracted from the Adjusted USACE Inflow to determine the quantity of flow that needs to be redistributed proportionally among the two primary surface inflow streams (Cherry Creek and Cottonwood Creek). If the monthly Redistributed Inflow is greater than 1,000 ac-ft, then the first 1,000 ac-ft is redistributed proportionally to the stream sites, with the remainder being placed in an Ungaged Flow category. This category represents unmonitored flow that may be attributed to wetland seepage, stream bank storage, or ungaged surface flows during the respective month. Once the redistributed inflows are apportioned to the stream sites, monthly loads are computed using their respective flow-weighted total phosphorus and total

nitrogen concentrations and identified as “Normalized” to the USACE inflow. The alluvial load is based on the long-term (1994 to 2015) median TDP and TIN concentrations for Site MW-9 (190 and 430 µg/L, respectively). Notably, flow and loads for sites upstream of Site CT-2 are not normalized. Only the unadjusted flow and load data was used to evaluate the effectiveness of the PRFs on Cottonwood Creek.

D.3 Tributary Streams

Once the water year flow record for each stream site was finalized, the mean daily flows were categorized as either base flow or storm flow events. If the mean daily flow was greater than the 90th percentile of the annual value (Table D-4), then the flow was categorized as storm flow. Flows less than the 90th percentile were categorized as base flows.

Table D-4: Threshold flow value used to categorize base flows and storm flows in 2015.

Site	90 th Percentile (cfs)
CC-7-EcoPark	15.53
CC-10	44.78
CT-P1	5.61
CT-P2	6.95
CT-1	21.36
CT-2	18.49

For all streams, TP and TN concentrations were determined for base flow samples collected on a monthly basis and for storm flow samples collected at irregular intervals throughout the year (Appendix C). For each monitoring site, the monthly base flow TP and TN concentrations (Table D-5) were applied to their respective daily base flows during that month, while the annual median storm flow TP and TN concentrations were applied to their respective storm flows (Equation D-1).

Daily loadings were then summed to obtain estimates of monthly and water year phosphorus and nitrogen loading for each stream site (Table D-6).

Equation D-1: Nutrient loading.

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

where:

L_{day} = pounds per day phosphorus / nitrogen loading,

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

Q_{in} = mean daily flow in ft³/sec.

Table D-5: Monthly base flow and median annual storm flow TP and TN concentrations (µg/L) applied to respective flows in 2015.

Month	CC-O		EcoPark		CC-10		CT-P1		CT-P2		CT-1		CT-2	
	TP	TN	TP	TN	TP	TN	TP	TN	TP	TN	TP	TN	TP	TN
October 2014	77	888	95	925	213	653	44	926	62	1,136	52	1,604	40	1,408
November 2014	73	1,034	79	696	191	645	28	955	27	1,120	84	2,224	67	1,947
December 2014	45	802	103	1,741	155	847	10	1,014	35	1,332	62	2,600	45	1,764
January 2015	63	922	230	2,651	190	1,044	31	1,806	52	2,040	70	3,327	58	3,253
February 2015	60	967	92	1,502	163	725	33	980	43	1,011	93	2,183	64	2,187
March 2015	73	1,099	69	1,502	132	794	34	1,099	50	1,101	62	1,891	45	1,529
April 2015	65	887	63	979	160	542	61	1,140	43	1,151	76	1,632	62	2,146
May 2015	62	697	114	1,550	224	780	50	1,302	50	1,473	90	1,565	66	1,332
June 2015	213	751	196	1,609	395	833	55	1,191	68	1,406	89	1,424	83	1,155
July 2015	142	947	183	1,186	436	806	64	1,269	102	1,677	103	1,809	74	1,272
August 2015	202	1,297	202	1,677	373	930	68	1,363	68	1,653	88	2,146	57	1,295
September 2015	220	1,939	158	1,709	328	621	57	1,060	61	1,340	91	1,362	82	1,208
Water Year Storm Flow Median	--	--	131	1,396	280	1,054	198	1,567	115	1,568	167	1,685	93	1,515

D.4 Reservoir Outflow

The USACE monitors flows through the outlets gates on a regular interval and provides GEI with estimates of daily outflow for the reservoir. GEI monitors water quality of the outflow at a site located approximately 75 m downstream of the concrete outflow structure at the base of the dam (CC-O @ I-225). The monthly TP and TN concentrations collected from this site were applied to the USACE outflow to estimate the 2015 WY export load (Equation D-1).

D.5 Precipitation

Precipitation data collected at the KAPA was used to estimate TP and TN loading due to precipitation in 2015, 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 TP and TN loads into Cherry Creek Reservoir from precipitation were based on the long-term median phosphorus and nitrogen concentrations of 124 and 2,013 µg/L, respectively (1992 to 2015) and Equation D-2.

Equation D-2: Pounds of nutrients from precipitation.

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

where:

L_{precip} = pounds of phosphorus/ nitrogen from precipitation,

PR = rainfall precipitation in inches,

A_{res} = surface area of the reservoir (875 ac), and

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

D.6 Alluvium

The alluvial water component remains one of the unmonitored sources of inflow to the reservoir. The annual flow is relatively constant given the boundaries of the alluvium in relation to the reservoir. The majority of the alluvial water monitored at Site 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 and nitrogen 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 ac 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 2015 alluvial component was defined as a constant source of water to the reservoir that accounted for 2,000 ac-ft/yr with no seasonal fluctuations. The long-term (1994-2015) median TDP and TIN concentrations for Site MW-9 (190 and 430 µg/L, respectively) was used to estimate the alluvial load component (Equation D-3).

Equation D-3: Alluvial nutrient loading.

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

where:

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

$\mu\text{g/L}$ = 190 µg/L and 430 µg/L, long-term median TDP and TIN concentration, respectively

Q_{alluvium} = alluvial inflow in ac-ft

D.7 Redistributed Inflows

During the 2015 WY, the repartitioning of the alluvial inflow component created a “Redistributed Inflow” category that is comprised of flows that are currently unaccounted for given the current monitoring regime. The majority of these flows are likely the result of bank full flooding that occurs along Cherry Creek, upstream of Site CC-10, which eventually enters the reservoir as seepage from the wetland area. Other flows in this category include unmonitored inflows from the Belleview and Quincy drainages, and surface inflows around the margin of the reservoir. The monthly “Redistributed Inflow” is calculated as presented below (Equation D-4, Table D-6; Table D-7), and is either a positive or negative value depending on the monthly balance.

Equation D-4: Redistributed Inflow.

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

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

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

Additionally, when the redistributed inflow is greater than 1,000 ac-ft/month, the first 1,000 ac-ft will be redistributed among the two streams, and the remainder will be placed into an “Ungaged Inflow” category. The reasoning behind this category is that if the redistributed inflow is truly this great, then the current inflow monitoring regime should be reevaluated to address such occurrences.

Table D-6: Monthly unadjusted and final normalized flow.

Month	Unadjusted Flow (ac-ft/mo)									Normalized Flow (ac-ft/mo)	
	USACE Inflow	USACE Outflow	CC-10	CT-P1	CT-P2	CT-1	CT-2	Precip	Alluvium	CC-10	CT-2
October 2014	1,400	1,316	989	223	280	*--	406	105	170	798	328
November 2014	982	756	1,081	102	113	*--	300	34	164	614	170
December 2014	922	653	1,063	90	94	*--	284	35	170	566	151
January 2015	1,029	1,135	1,154	92	113	*--	325	28	170	649	183
February 2015	1,172	1,017	1,165	125	150	*--	417	90	153	684	245
March 2015	1,517	1,309	1,583	173	196	*--	556	59	170	954	335
April 2015	2,025	1,480	1,932	322	389	*--	575	199	164	1,280	381
May 2015	6,849	6,975	4,347	771	721	*--	1,089	319	170	5,087	1,274
June 2015	7,934	6,831	4,665	1,334	451	1,784	744	384	164	5,528	882
July 2015	1,381	1,722	1,202	135	201	*--	283	71	170	922	217
August 2015	1,991	1,739	1,412	142	216	*--	394	210	170	1,260	352
September 2015	458	135	310	85	94	191	132	28	164	187	80
Water Year Total	27,662	25,070	20,903	3,594	3,018	799--	5,506	1,561	2,000	18,528	4,597

* Influenced by beaver dam.

Table D-7: Monthly unadjusted and final normalized loads.

Month	Unadjusted Load (lbs/mo)																Normalized Load (lbs/mo)			
	USACE Outflow (CC-O)		CC-10		CT-P1		CT-P2		CT-1		CT-2		Precip		Alluvium		CC-10		CT-2	
	TP	TN	TP	TN	TP	TN	TP	TN	TP	TN	TP	TN	TP	TN	TP	TN	TP	TN	TP	TN
October 2014	276	3,178	573	1,755	65	720	69	1,042	*--	*--	57	1,580	35	575	88	199	462	1,417	46	1,275
November 2014	150	2,126	561	1,895	8	266	8	344	*--	*--	55	1,588	11	184	85	192	319	1,076	31	901
December 2014	80	1,425	448	2,447	8	265	9	342	*--	*--	35	1,361	12	192	88	199	239	1,304	19	725
January 2015	195	2,847	596	3,276	13	444	16	627	*--	*--	51	2,876	9	152	88	199	335	1,843	29	1,617
February 2015	166	2,675	517	2,298	11	333	18	413	*--	*--	73	2,480	30	495	79	179	303	1,348	43	1,455
March 2015	260	3,912	568	3,418	32	561	34	642	*--	*--	81	2,308	20	323	88	199	342	2,059	49	1,390
April 2015	262	3,571	1,043	3,714	138	1,263	101	1,538	*--	*--	124	2,805	67	1,090	85	192	691	2,462	82	1,859
May 2015	1,176	13,220	3,154	11,720	362	3,190	198	3,032	*--	*--	250	4,314	107	1,744	88	199	3,691	13,715	293	5,048
June 2015	3,957	13,950	3,916	12,664	662	5,535	120	1,849	752	7,978	180	2,762	130	2,104	85	192	4,640	15,005	213	3,273
July 2015	665	4,435	1,425	2,635	24	467	57	903	*--	*--	59	1,005	24	387	88	199	1,094	2,022	45	771
August 2015	955	6,133	1,366	3,660	26	526	49	956	*--	*--	77	1,482	71	1,150	88	199	1,219	3,265	68	1,322
September 2015	81	714	277	524	13	246	16	341	47	709	30	435	9	152	85	192	166	315	18	261
Water Year Total	8,222	58,186	14,444	50,008	1,362	13,816	694	12,029	*--	*--	1,070	24,995	526	8,546	1,033	2,339	13,501	45,830	935	19,899

* Influenced by beaver dam.

Table D-8: 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)	Redistributed Inflow (ac-ft/mo)	Percent of GEI Inflow (%)		Redistributed Flow (ac-ft/mo)			Redistributed Load (lbs/mo)						Ungaged Residual Load (lbs/mo)	
									Total		CC-10		CT-2			
				CC-10	CT-2	CC-10	CT-2	Ungaged	TP	TN	TP	TN	TP	TN	TP	TN
October 2014	1,125	1,395	-269	71	29	-191	-78	0	121	644	-111	-339	-11	-305	0	0
November 2014	784	1,381	-597	78	22	-467	-130	0	266	1,505	-243	-819	-24	-686	0	0
December 2015	717	1,346	-629	79	21	-496	-133	0	225	1,779	-209	-1,143	-16	-636	0	0
January 2015	832	1,479	-647	78	22	-505	-142	0	283	2,692	-261	-1,434	-22	-1,258	0	0
February 2015	928	1,582	-654	74	26	-482	-172	0	244	1,975	-214	-950	-30	-1,025	0	0
March 2015	1,288	2,139	-851	74	26	-630	-221	0	258	2,277	-226	-1,359	-32	-918	0	0
April 2015	1,662	2,507	-845	77	23	-651	-194	0	393	2,198	-352	-1,252	-42	-946	0	0
May 2015	6,360	5,436	925	80	20	740	185	0	-579	-2,728	537	1,994	43	734	0	0
June 2015	7,385	5,410	1,976	86	14	1,704	272	976	-757	-2,852	724	2,341	33	511	706	2,902
July 2015	1,140	1,485	-345	81	19	-280	-66	0	345	846	-331	-613	-14	-234	0	0
August 2015	1,612	1,807	-195	78	22	-152	-43	0	156	555	-148	-395	-8	-160	0	0
September 2015	266	443	-177	70	30	-124	-53	0	-122	-383	-110	-209	-12	-174	0	0
Water Year Total	24,101	26,409	-2,309	77	23	-1,534	-774	976	834	8,509	-943	-4,178	-135	-5,096	706	2,902

Note:

Water year mean and not water year total.

Appendix E 2015 Biological Data

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

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

Table E-1 (Cont.)

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

Table E-1 (Cont.)

	2007	2008	2009	2010	2011	2012	2013	2014
Black crappie								
Size (inches)	--	--	1.4	--	1.1 to 1.2	0.7 to 1.8	1.6	0.9
Number	--	--	5,000	--	97,399	41,541	5,000	6,500
Channel catfish								
Size (inches)	3	--	3.3	2.7	3.4	2.5 to 6.6	4	3
Number	9,360	--	3,780	13,500	9,450	11,750	4,050	3,375
Cutthroat trout								
Size (inches)	--	--	--	12.5 to 14.7	15.1	--	--	--
Number	--	--	--	1,562	200	--	--	--
Rainbow × cutthroat trout								
Size (inches)	--	9.7	--	--	--	--	--	--
Number	--	4,001	--	--	--	--	--	--
Rainbow trout								
Size (inches)	10	10.1	4.8	9.6 to 17.7	10.1 to 10.9	10.1 to 17.0	9.6 to 9.9	9.6 to 10.3
Number	37,709	11,588	12,287	11,038	28,029	29,872	8,261	6,881
Size (inches)	12	--	10.2	9.8 to 10.2	10.6	--	9.7 to 16.7	10.3
Number	4,800	--	29,759	39,200	1,737	--	11,275	2,538
Size (inches)	--	--	14	--	--	--	10.1 to 10.7	10.3
Number	--	--	109	--	--	--	10,296	7,296
Walleye								
Size (inches)	0.3	0.2	0.2	0.2 to 1.1	0.2	0.23	0.2 to 1.2	0.2 to 1.2
Number	4,300,000	3,992,572	4,012,800	4,264,512	4,001,400	4,001,400	4,008,182	4,215,301
Size (inches)	1	--	1.3	--	--	1	--	--
Number	7,998	--	14,998	--	--	15,000	--	--
Wiper								
Size (inches)	1.5	--	--	1.6	--	--	--	2
Number	4,600	--	--	8,000	--	--	--	4,000

Table E-2: 2015 Cherry Creek Reservoir phytoplankton density (#/mL).

	2015													
	18-Mar	8-Apr	12-May	27-May	9-Jun	23-Jun	7-Jul	21-Jul	4-Aug	18-Aug	9-Sep	22-Sep	13-Oct	10-Nov
Bacillariophyta														
Centrales														
Cocconeis placentula	44	--	--	--	--	--	--	--	--	--	--	--	--	--
Cyclotella meneghiniana	44	--	--	--	--	--	29	--	--	38	--	--	--	--
Cyclotella stelligera	--	--	--	--	--	24	--	61	--	345	176	317	195	1,451
Melosira ambigua	--	--	27	--	62	--	--	--	--	--	--	--	--	--
Melosira granulata	--	--	--	--	3,005	--	--	--	11	--	--	63	--	132
Melosira granulata angustissima	44	--	--	--	--	--	--	--	--	--	--	--	--	--
Stephanodiscus astraea minutula	177	37	27	--	--	--	--	61	11	38	35	--	98	132
Stephanodiscus hantzschii	--	--	--	152	--	72	--	--	44	3,030	423	760	586	1,978
Coscinodiscophyceae														
Melosira italica	--	--	--	--	--	--	--	--	--	--	--	63	--	--
Pennate														
Achnanthes lanceolata	--	--	27	--	--	--	--	--	11	38	35	--	--	--
Asterionella formosa	--	110	--	425	31	191	--	--	--	--	--	--	--	132
Fragilaria crotonensis	--	--	--	--	--	24	6,443	61	--	--	35	--	--	--
Fragilaria construens	177	37	--	--	--	--	37	30	11	--	35	--	98	--
Fragilaria construens venter	--	--	--	--	--	--	--	--	11	38	--	--	--	--
Gomphoneis herculeana	--	--	--	--	--	--	--	--	--	--	63	--	--	--
Navicula anglica	--	--	--	--	--	--	--	--	--	--	35	--	--	--
Navicula capitata	44	--	--	--	--	--	--	--	--	--	--	--	--	--
Navicula cascadenis	--	--	--	--	--	--	--	--	--	--	63	--	--	--
Navicula cryptocephala veneta	--	--	--	--	--	24	--	--	--	--	--	--	--	--
Navicula gregaria	--	--	--	30	--	--	--	--	--	--	--	--	--	--
Navicula minima	--	--	--	--	--	--	--	30	--	--	--	--	--	--
Navicula tripunctata	--	--	--	--	--	--	--	--	11	--	--	--	--	--
Nitzschia acicularis	1,545	805	--	30	--	--	--	30	--	77	35	63	--	--
Nitzschia capitellata	--	110	--	--	31	--	--	61	--	77	--	--	--	--
Nitzschia frustulum	--	--	--	--	--	--	--	--	--	--	--	63	--	--
Nitzschia palea	--	--	--	30	--	--	--	--	--	38	--	63	--	132
Nitzschia paleacea	221	--	--	--	--	--	--	--	--	--	--	--	--	132
Synedra radians	--	403	--	--	--	--	--	--	--	--	--	63	--	--
Synedra ulna	--	37	--	--	--	--	--	--	--	--	38	--	--	--
Chlorophyta														
Ankistrodesmus falcatus	177	110	54	243	248	72	37	515	55	268	141	380	1,074	527
Chlamydomonas sp.	--	73	--	--	62	--	--	182	143	153	599	950	1,367	527
Chodatella wratislawiensis	44	37	--	--	--	--	--	--	--	--	--	--	--	--
Closteriopsis longissima	--	--	--	--	--	24	--	--	--	--	--	63	--	--
Crucigenia crucifera	--	--	--	--	--	--	--	--	--	--	141	127	--	--
Crucigenia quadrata	--	73	--	--	93	167	110	61	--	--	--	63	98	132
Crucigenia tetrapedia	--	--	--	--	93	24	--	--	--	--	70	63	488	396
Oocystis lacustris	--	--	--	--	--	48	--	--	--	--	--	--	--	--
Oocystis pusilla	88	146	27	122	434	215	220	61	11	38	--	127	488	264

Table E-2 (Cont.)

	2015													
	18-Mar	8-Apr	12-May	27-May	9-Jun	23-Jun	7-Jul	21-Jul	4-Aug	18-Aug	9-Sep	22-Sep	13-Oct	10-Nov
Chlorophyta (cont.)														
Pediastrum boryanum	44	--	--	61	62	--	--	--	--	--	--	--	--	--
Pediastrum tetras	--	--	--	--	--	--	--	--	--	--	106	63	--	--
Scenedesmus abundans	44	37	--	--	--	24	--	--	11	--	70	--	488	1,582
Scenedesmus acuminatus	88	--	--	--	--	--	--	121	--	--	35	--	98	132
Scenedesmus bijuga	--	--	--	--	31	72	73	--	--	--	--	--	--	--
Scenedesmus quadricauda	265	293	54	30	31	48	110	212	110	192	317	507	781	396
Selenastrum minutum	1,191	476	--	--	31	24	37	394	--	--	--	127	98	132
Sphaerocystis Schroeteri	--	--	--	30	31	72	--	--	--	--	--	--	98	264
Tetraedron minimum	--	329	108	30	31	--	37	91	33	38	423	1,140	1,464	264
Tetraedron regulare	--	--	--	--	--	--	--	--	22	--	--	63	98	--
Tetrastrum staurogeniaforme	44	--	--	--	--	--	37	--	--	--	--	--	98	--
Chrysophyta														
Chromulina sp.	--	--	--	--	--	--	--	--	--	--	--	--	195	--
Chrysococcus rufescens	485	73	--	--	--	--	--	--	--	--	--	--	--	132
Kephyrion sp.	44	--	27	--	--	--	--	--	--	--	--	--	--	--
Kephyrion littorale	177	--	--	--	31	--	73	91	--	38	35	--	--	--
Rhodomonas minuta	485	2,196	1,947	1,823	186	1,647	1,062	2,213	739	1,112	352	823	2,245	3,824
Cyanobacteria														
Anabaena flos-aquae	--	--	--	425	62	--	--	--	--	--	106	253	--	--
Euglenophycota														
Euglena sp.	--	--	--	--	--	--	--	--	--	38	35	--	--	--
Trachelomonas crebea	--	--	--	--	--	--	--	--	--	--	--	63	--	--
Trachelomonas hispida	--	37	--	--	--	--	--	--	--	--	--	--	--	--
Trachelomonas scabra	44	--	--	--	--	--	--	--	33	--	--	63	--	--
Pyrrophyphyta														
Ceratium hirundinella	--	--	--	--	--	--	37	--	11	38	--	--	--	--
Glenodinium sp.	--	--	--	--	--	24	--	152	11	38	--	63	--	264
Peridinium cinctum	--	--	--	30	--	--	--	30	--	--	--	--	--	--
Cryptophyta														
Cryptomonas erosa	88	403	514	2,674	465	859	37	61	44	384	388	950	1,464	2,769
Unidentified Flagellate														
Unidentified flagellate	--	--	--	--	--	--	--	61	11	--	--	--	--	--
Total Density (cells/mL)	5,604	5,821	2,812	6,139	5,018	3,651	8,346	4,577	1,346	6,098	3,629	7,474	11,617	15,693
Total Taxa	23	20	10	15	19	19	14	20	19	21	22	28	20	22

Table E-3: Total reservoir phytoplankton density (#/mL) and number of taxa in Cherry Creek Reservoir, 1984 to 2014.

	1984	1985	1986	1987	1988	1989	1991	1992	1993	1994	1995	1996
Blue-Green Algae												
Density	71,780	66,496	99,316	168,259	155,180	273,175	307,691	77,516	15,708	10,015	18,194	16,599
Taxa	7	7	6	18	24	24	14	16	7	3	7	9
Green Algae												
Density	5,864	11,760	25,595	11,985	19,177	55,415	18,688	41,899	1,198	314	355	738
Taxa	11	10	13	58	76	66	46	48	16	2	11	11
Diatoms												
Density	1,776	3,863	5,428	10,677	12,880	9,311	4,160	1,243	946	194	2,189	2,354
Taxa	6	4	7	34	30	31	21	11	15	2	15	13
Golden-Brown Algae												
Density	--	7	125	469	56	505	821	93	158	3	63	249
Taxa	--	1	1	6	4	7	5	4	1	1	2	4
Euglenoids												
Density	514	135	208	251	276	108	89	23	231	196	304	409
Taxa	2	1	1	9	9	6	3	5	2	1	2	3
Dinoflagellates												
Density	--	13	19	19	83	28	23	54	--	31	5	21
Taxa	--	1	1	2	4	3	2	2	--	1	2	4
Cryptomonads												
Density	1,513	718	1,113	1,090	2,689	1,689	628	529	332	450	919	1,104
Taxa	2	3	3	6	4	5	2	3	1	1	1	1
Miscellaneous												
Density	--	--	--	--	--	--	--	--	--	--	--	--
Taxa	--	--	--	--	--	--	--	--	--	--	--	--
Total Density (#/mL)	81,447	82,992	131,804	192,750	190,341	340,231	329,773	121,357	18,573	11,203	22,029	21,474
Total Number of Taxa	28	27	32	133	151	142	93	89	42	11	40	45

Table E-3 (Cont.)

	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Blue-Green Algae												
Density	19,716	44,951	15,263	164,290	148,691	941	54,114	165,677	79,154	665,696	1,266,765	1,124,197
Taxa	10	11	8	19	12	3	21	27	19	19	21	19
Green Algae												
Density	2,461	1,809	898	43,881	33,217	1,973	55,190	56,236	189,777	1,358,248	563,344	1,531,579
Taxa	18	18	18	71	56	27	70	75	66	63	63	67
Diatoms												
Density	1,109	628	838	12,019	5,256	978	2,026	1,720	3,610	32,036	60,127	27,681
Taxa	8	18	16	34	22	24	22	26	24	21	21	17
Golden-Brown Algae												
Density	227	56	--	391	1,346	34	44	57	335	542	2,380	6,270
Taxa	2	2	--	14	13	3	5	5	4	5	3	3
Euglenoids												
Density	838	698	1,252	126	91	22	308	24	39	1,549	1,303	259
Taxa	3	3	1	6	4	3	9	11	8	10	10	11
Dinoflagellates												
Density	--	18	45	80	157	193	20	57	60	330	595	722
Taxa	--	2	2	8	6	5	3	5	6	5	5	3
Cryptomonads												
Density	1,487	1,393	559	2,472	2,851	355	3,282	3,158	3,293	40,511	61,037	35,962
Taxa	1	1	1	4	6	4	8	8	9	12	9	11
Miscellaneous												
Density	--	--	--	1,923	5,714	15	1,294	164	2,014	4,855	73,435	53,330
Taxa	--	--	--	1	1	1	3	6	6	6	7	8
Total Density (#/mL)	25,838	49,553	18,855	225,182	197,323	4,511	116,278	227,093	278,282	2,103,767	2,028,986	2,780,000
Total Number of Taxa	39	55	46	157	120	70	141	164	142	141	139	139

Table E-3 (Cont.)

	2009	2010	2011	2012	2013	2014	2015	Long-term
Blue-Green Algae								
Density	332	4,177	1,136	2,648	731	1,776	846	54,114
Taxa	3	6	3	2	2	3	1	9
Green Algae								
Density	10,733	19,202	26,055	23,851	21,270	32,506	26,556	21,270
Taxa	20	22	23	20	21	23	20	23
Diatoms								
Density	11,609	13,975	39,654	24,186	16,380	12,669	26,213	5,256
Taxa	25	30	21	34	22	30	29	21
Golden-Brown Algae								
Density	246	587	1895	1,304	6,371	16,363	22,055	335
Taxa	4	3	4	3	5	6	5	4
Euglenoids								
Density	83	272	570	1,802	1,308	474	313	272
Taxa	3	4	4	5	7	5	4	4
Dinoflagellates								
Density	4,497	2,556	6,253	1,158	326	1,857	698	70
Taxa	4	3	1	2	3	4	3	3
Cryptomonads								
Density	22,277	16,794	14,850	12,130	7,930	9,787	11,100	2,472
Taxa	2	2	2	2	2	1	1	2
Miscellaneous								
Density	--	--	--	94	--	323	72	1,609
Taxa	--	--	--	1	--	1	1	2
Total Density (#/mL)	49,777	57,563	90,413	67,173	54,316	75,755	87,825	87,825
Total Number of Taxa	61	70	58	68	62	73	63	70

Table E-4: 2015 Cherry Creek Reservoir zooplankton (#/L).

	2015													
	18-Mar	8-Apr	12-May	27-May	9-Jun	23-Jun	7-Jul	21-Jul	4-Aug	18-Aug	9-Sep	22-Sep	13-Oct	10-Nov
Cladocera														
<i>Alona guttata</i>	--	0.5	--	--	0.4	--	--	--	--	--	--	--	--	--
<i>Bosmina longirostris</i>	25.5	54.1	48.1	6.4	22.1	15.9	26.0	0.2	65.0	22.0	66.2	22.4	32.6	8.9
<i>Daphnia ambigua</i>	1.0	1.6	23.7	20.5	21.7	32.9	--	--	2.9	0.3	--	--	--	--
<i>Daphnia lumholtzi</i>	--	--	--	--	--	--	--	0.2	31.1	1.2	9.1	1.8	10.6	6.0
<i>Daphnia parvula</i>	--	--	11.0	2.5	2.7	6.4	--	--	--	--	4.0	1.6	1.3	0.1
<i>Daphnia</i> sp.	--	2.1	--	--	--	--	2.5	--	--	--	--	--	--	--
<i>Skistodiaptomus pallidus</i>	7.0	3.2	1.1	1.8	7.1	3.7	7.3	0.2	0.7	0.3	8.1	0.5	7.2	4.2
Copepod														
<i>Diacyclops thomasi</i>	88.5	90.8	3.9	24.1	10.2	2.7	--	0.1	0.7	0.2	1.3	0.30	4.9	2.5
Immature instar (copepodid)	109.5	82.3	64.4	30.8	22.6	16.5	4.8	0.2	17.4	5.3	36.5	12.1	13.7	8.0
<i>Mesocyclops edax</i>	--	5.8	1.8	1.1	11.5	6.4	--	0.1	1.2	0.1	--	0.10	1.4	--
Nauplius	62.8	35.4	69.0	72.1	95.1	41.1	97.3	4.4	190.6	94.5	167.2	93.4	46.4	33.3
Rotifer														
<i>Asplanchna</i> sp.	--	--	--	--	1.8	63.3	46.0	--	20.2	6.4	6.4	5.8	--	12.0
<i>Brachionus angularis</i>	--	--	--	--	--	--	15.9	10.0	--	1.1	27.1	35.0	13.1	2.1
<i>Brachionus calyciflorus</i>	22.1	--	--	--	--	--	--	--	--	--	--	--	--	--
<i>Conochiloides</i> sp.	149.5	--	--	--	--	--	--	--	--	--	--	--	--	--
<i>Keratella cochlearis</i>	4.0	7.5	51.3	14.6	196.4	249.5	4.0	0.6	1.6	0.5	--	2.7	5.3	13.8
<i>Polyarthra</i> sp.	0.9	--	--	--	--	--	0.4	0.6	--	5.8	--	22.8	0.4	--
<i>Pompholyx</i> sp.	--	--	--	--	0.9	--	--	--	--	--	--	--	--	--
Total Concentration (#/mL)	470.8	283.3	274.3	173.9	392.5	438.4	204.2	16.6	331.4	137.7	325.9	198.5	136.9	90.9
Total Number of Taxa	9	9	8	8	11	9	8	9	9	11	8	11	10	9

Table E-5: 2015 Routine cyanotoxin sampling events (µg/L, result and detection limit)

Anatoxin-A							Cylindrospermopsin						
Date	CCR 1,2,3 Comp			Swim Beach			Date	CCR 1,2,3 Comp			Swim Beach		
	Result	D.L.	Method	Result	D.L.	Method		Result	D.L.	Method	Result	D.L.	Method
5/27	ND	0.05	LC-MS/MS	ND	0.05	LC-MS/MS	5/27	ND	0.10	ELISA	ND	0.10	ELISA
Mycrocystin							Saxitoxin						
Date	CCR 1,2,3 Comp			Swim Beach			Date	CCR 1,2,3 Comp			Swim Beach		
	Result	D.L.	Method	Result	D.L.	Method		Result	D.L.	Method	Result	D.L.	Method
5/27	ND	0.15	ELISA	ND	0.15	LC-MS/MS	5/27	ND	0.05	ELISA	ND	0.05	ELISA
6/9	ND	0.15	ELISA	ND	0.15	ELISA							
6/23	ND	0.15	ELISA	ND	0.15	ELISA							
7/7	ND	0.15	ELISA	ND	0.15	ELISA							
7/21	ND	0.15	ELISA	ND	0.15	ELISA							
8/4	ND	0.15	ELISA	ND	0.15	ELISA							
8/18	ND	0.15	ELISA	ND	0.15	ELISA							
9/9	0.18	0.15	ELISA	ND	0.15	ELISA							
9/22	ND	0.15	ELISA	ND	0.15	ELISA							

Table E-6: 2014 Opportunistic cyanotoxin sampling events (µg/L, result and detection limit).

Anatoxin-a						
Date	Opportunistic #1			Opportunistic #2		
	Result	D.L.	Method	Result	D.L.	Method
5/27	ND	0.05	LC-MS/MS	--	--	--
9/22	--	--	--	--	--	--
Cylindrospermopsin						
Date	Opportunistic #1			Opportunistic #2		
	Result	D.L.	Method	Result	D.L.	Method
5/27	ND	0.1	ELISA	--	--	--
9/22	--	--	--	--	--	--
Microcystin						
Date	Opportunistic #1			Opportunistic #2		
	Result	D.L.	Method	Result	D.L.	Method
5/27	ND	0.15	ELISA	--	--	--
9/22	--	--	--	ND	0.15	ELISA
Saxitoxin						
Date	Opportunistic #1			Opportunistic #2		
	Result	D.L.	Method	Result	D.L.	Method
5/27	ND	0.05	ELISA	--	--	--
9/22	--	--	--	--	--	--

Appendix F MW-9 Data

Table F-1: MW-9 mean daily temperatures (°C).

Day of Month	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June
1	10.39	10.30	9.46	8.84	9.19	8.96	8.88	8.86	8.84
2	10.53	10.30	9.53	8.86	9.19	8.94	8.87	8.87	8.86
3	10.81	10.30	9.53	8.82	9.22	8.92	8.88	8.87	8.88
4	10.83	10.25	9.49	8.89	9.22	8.92	8.89	8.92	8.85
5	10.77	10.26	9.46	9.06	9.20	8.90	8.87	8.88	8.84
6	10.71	10.18	9.46	9.34	9.18	8.88	8.86	8.84	8.76
7	10.64	10.15	9.43	9.30	9.17	8.89	8.86	8.84	8.78
8	10.59	10.15	9.44	9.31	9.15	8.89	8.85	8.85	8.80
9	10.56	10.13	9.37	9.32	9.14	8.88	8.85	8.78	8.82
10	10.49	10.14	9.32	9.32	9.10	8.88	8.86	8.74	8.84
11	10.81	10.14	9.32	9.31	9.11	8.90	8.86	8.73	8.85
12	10.77	10.14	9.31	9.32	9.13	8.88	8.85	8.73	8.75
13	10.56	10.11	9.32	9.29	9.11	8.89	8.85	8.74	8.75
14	10.60	10.11	9.29	9.29	9.08	8.89	8.85	8.75	8.75
15	10.61	10.09	9.25	9.28	9.05	8.90	8.85	8.77	8.77
16	10.60	10.09	9.17	9.26	9.04	8.90	8.85	8.77	8.78
17	10.57	10.07	9.13	9.27	9.05	8.90	8.87	8.78	8.80
18	10.54	10.04	9.09	9.27	9.08	8.89	8.82	8.79	8.81
19	10.50	10.00	9.09	9.26	9.07	8.91	8.83	8.78	8.83
20	10.47	9.94	9.06	9.27	9.06	8.89	8.84	8.77	8.86
21	10.36	9.91	9.06	9.26	9.05	8.89	8.85	8.78	'--
22	10.35	9.88	9.01	9.24	9.05	8.90	8.85	8.79	'--
23	10.33	9.86	8.99	9.22	9.04	8.89	8.86	8.78	'--
24	10.32	9.79	8.97	9.23	9.03	8.90	8.86	8.77	'--
25	10.31	9.67	8.95	9.22	9.01	8.91	8.86	8.78	'--
26	10.31	9.61	8.92	9.23	8.99	8.91	8.86	8.78	'--
27	10.31	9.62	8.90	9.24	8.98	8.90	8.82	8.78	'--
28	10.31	9.62	8.91	9.24	8.98	8.90	8.83	8.80	'--
29	10.30	9.62	8.91	9.22	'--	8.90	8.84	8.80	'--
30	10.29	9.62	8.90	9.20	'--	8.89	8.85	8.81	'--
31	10.29	'--	8.88	9.17	'--	8.89	'--	8.83	'--

Table F-2: MW-9 mean water level (ft).

Day of Month	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June
1	10.54	10.48	10.52	10.50	10.60	10.69	10.55	10.76	10.77
2	10.70	10.45	10.52	10.49	10.59	10.60	10.60	10.72	10.72
3	10.72	10.52	10.54	10.49	10.62	10.58	10.69	10.69	10.73
4	10.62	10.59	10.51	10.57	10.67	10.65	10.62	10.66	10.77
5	10.57	10.60	10.57	10.55	10.65	10.68	10.53	10.71	10.84
6	10.53	10.61	10.60	10.67	10.64	10.72	10.49	10.72	10.95
7	10.54	10.56	10.58	10.77	10.59	10.76	10.54	10.76	10.91
8	10.53	10.62	10.60	10.65	10.63	10.76	10.50	10.79	10.89
9	10.56	10.51	10.57	10.67	10.62	10.73	10.61	10.89	10.82
10	10.71	10.46	10.55	10.58	10.61	10.73	10.62	11.04	10.78
11	10.64	10.57	10.53	10.59	10.71	10.74	10.56	11.09	10.80
12	10.58	10.62	10.52	10.66	10.68	10.72	10.55	11.00	11.17
13	10.68	10.58	10.47	10.63	10.68	10.77	10.61	10.92	11.02
14	10.65	10.49	10.45	10.63	10.63	10.74	10.55	10.88	11.00
15	10.58	10.51	10.53	10.64	10.61	10.69	10.48	10.79	11.00
16	10.57	10.55	10.56	10.57	10.62	10.66	10.62	10.77	10.95
17	10.59	10.57	10.52	10.60	10.63	10.69	10.77	10.82	10.92
18	10.57	10.56	10.54	10.59	10.65	10.60	10.82	10.90	10.91
19	10.56	10.56	10.54	10.60	10.64	10.76	10.82	10.93	10.84
20	10.56	10.55	10.51	10.62	10.59	10.81	10.76	10.94	10.81
21	10.52	10.55	10.44	10.64	10.63	10.75	10.71	10.89	'--
22	10.54	10.48	10.48	10.64	10.72	10.71	10.68	10.84	'--
23	10.56	10.49	10.56	10.63	10.70	10.66	10.65	10.86	'--
24	10.56	10.55	10.48	10.60	10.67	10.63	10.60	10.86	'--
25	10.55	10.55	10.41	10.62	10.64	10.71	10.58	10.83	'--
26	10.46	10.60	10.52	10.65	10.70	10.75	10.71	10.85	'--
27	10.49	10.60	10.55	10.62	10.65	10.72	10.90	10.85	'--
28	10.55	10.52	10.50	10.62	10.64	10.67	10.88	10.83	'--
29	10.55	10.46	10.56	10.70	'--	10.69	10.77	10.86	'--
30	10.60	10.52	10.63	10.63	'--	10.66	10.72	10.86	'--
31	10.57	'--	10.56	10.55	'--	10.62	'--	10.80	'--