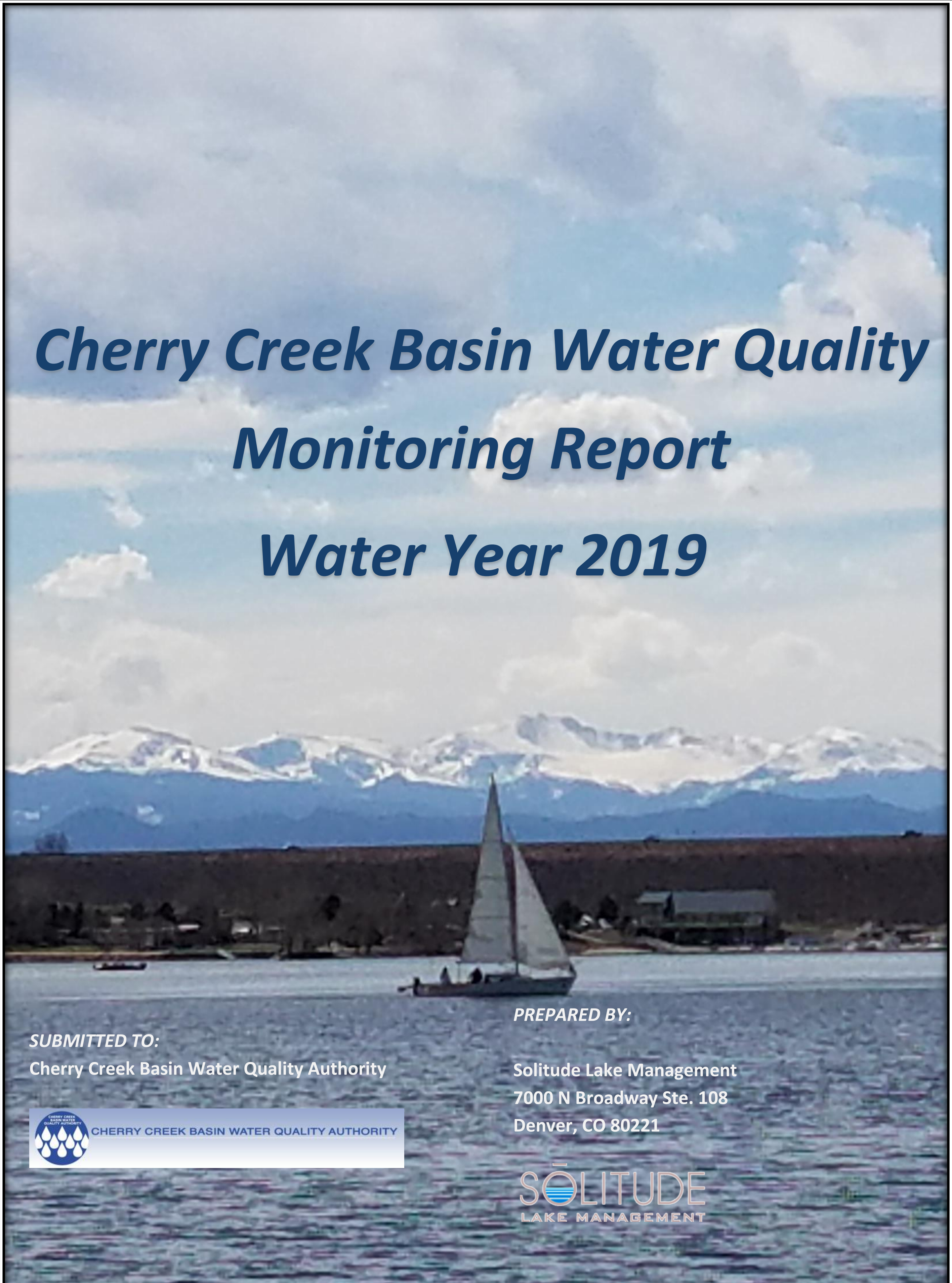

Cherry Creek Basin Water Quality Monitoring Report Water Year 2019

SUBMITTED TO:
Cherry Creek Basin Water Quality Authority

CHERRY CREEK BASIN WATER QUALITY AUTHORITY

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APPENDICES

APPENDIX A – USACE DATA - WY 2019

ACRONYMS/ABBREVIATIONS

Acronyms	Definition
AF	Acre-feet
AOAC	Association of Official Analytical Chemists, now AOAC INTERNATIONAL
ASTM	American Society for Testing and Materials
Authority	Cherry Creek Basin Water Quality Authority
BMPs	Best Management Practices
CCBWQA	Cherry Creek Basin Water Quality Authority
CCR	Code of Colorado Regulations
CDPHE	Colorado Department of Public Health and Environment
CPW	Colorado Parks and Wildlife
CFR	Code of Federal Regulations
cfs	Cubic feet per second
chl α	Chlorophyll α
CR72	Cherry Creek Reservoir Control Regulation 72
DM	Daily Maximum Temperature
DO	Dissolved Oxygen
DOC	Dissolved Organic Carbon
EPA	U. S. Environmental Protection Agency
IEH	IEH Laboratories
HS	High Sierra Water Laboratory
m	Meters
mg/L	Milligrams per liter
mV	Millivolts
µg/L	Micrograms per liter
Mi	Mile
µm	Micrometers
µS/cm	MicroSiemens per centimeter
MWAT	Maximum Weekly Average Temperature
N	Nitrogen
N:P	Nitrogen to Phosphorus Ratio
NOAA	National Ocean and Atmospheric Administration
ND	Non-detect
NH_3-N	Ammonia Nitrogen
NO_3+NO_2-N	Nitrate plus Nitrite Nitrogen
ORP	Oxidation Reduction Potential

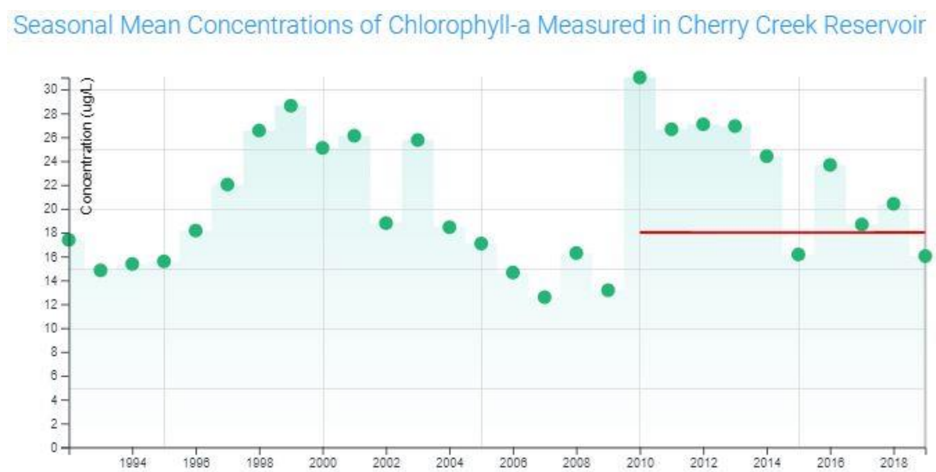
%	Percent
POR	Period of record
PRF	Pollutant Reduction Facility
QA/QC	Quality Assurance/Quality Control
QAPP	Quality Assurance Project Plan
REG 38	Regulation No. 38
SAP	Sampling and Analysis Plan
Reservoir	Cherry Creek Reservoir
SM	Standard Methods
SRP	Soluble Reactive Phosphorus
TDN	Total Dissolved Nitrogen
TOC	Total Organic Carbon
TN	Total Nitrogen
TDP	Total Dissolved Phosphorus
TP	Total Phosphorus
TSI	Trophic State Index
TSS	Total Suspended Solids
TVSS	Total Volatile Suspended Solids
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
VSS	Volatile Suspended Solids
WY	Water Year
WQCC	Water Quality Control Commission

EXECUTIVE SUMMARY

The *Cherry Creek Basin Water Quality Monitoring Report – Water Year 2019* is a comprehensive outline of monitoring completed for the Cherry Creek Basin Water Quality Authority (CCBWQA or Authority) of Cherry Creek Reservoir (Reservoir) and watershed for the 2019 Water Year (WY 2019) between October 1, 2018 and September 30, 2019. The Reservoir and watershed monitoring programs are completed in accordance with the Cherry Creek Sampling and Analysis Plan (SAP), Quality Assurance Program Plan (QAPP), and regulatory requirements. The program includes regular monitoring of biological, physical, and chemical conditions of the reservoir, the streams and tributaries that feed the Reservoir, and precipitation and groundwater in the basin. Highlights of the findings from the monitoring completed during the 2019 Water Year in relation to Water Quality standards, results of Authority efforts, achieving beneficial uses and other notable details are outlined are included in the Executive Summary below.

RESERVIOR HIGHLIGHTS

Chlorophyll α



During each sampling event of WY 2019, chlorophyll *α* (chl α*)* levels were measured from composite samples collected from 0, 1, 2 and 3 m at all three monitoring sites in the reservoir. The chl α measured concentrations ranged between 4.6 µg/L and 72.0 µg/L, with an average annual value of 23.2 mg/L in WY 2019 (Figure A). The highest values were observed in March, and the lowest was observed in June.

The seasonal (July through September) chl α concentration through the WY 2019 growing season concentration was 16.03 µg/L which is in below the 18 µg/L growing season average regulatory standard which allows one exceedance frequency of once in five years. Three of the last five (3/5) and eight of the last ten (8/10) years have exceeded this value. In 2015 the Reservoir last met the chl *α* standard, with a seasonal mean of 16.0 ug/L.

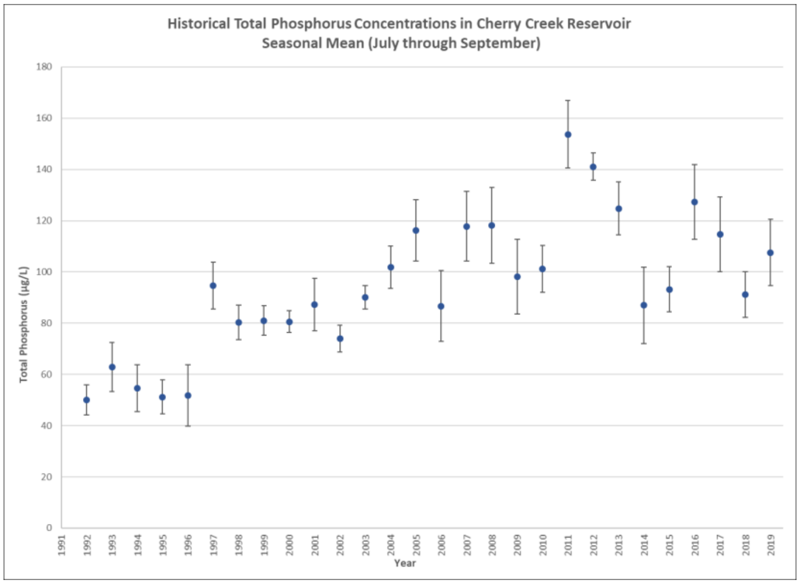
The WY 2019 seasonal mean was lower than the seasonal means of WY 2018 (20.2ug/L), WY 2017 (18.7µg/L) and WY 2016 (23.6 µg/L). Of the six (6) sampling events during the season (July 1-September 30), five of six (5/6) values had a mean chlorophyll α value that met the standard of 18 µg/L. The one monitoring event in the end of September that exceeded the standard had a chlorophyll α concentration of 19.6 µg/L.

Transparency

The mean Secchi depth measurements of the three reservoir monitoring sites during WY 2019 ranged between 0.75 m and 2.6 m, with an average value of 1.16 m for the year. The seasonal mean was 1.04 m during the months of July to September. The Secchi depth measurements were similar for all three sites and followed the same trends when compared to the values collected during the same months in previous years.

The depth of 1% light transmittance into the water column had a strong correlation to the Secchi depth and ranged between 2.1 and 4.8 meters. The depth of 1% light transmittance ranged between 1.5 and 3.5 times the Secchi depth, but on average was approximately 2.8 times the Secchi depth.

Nutrients



The WY 2019 seasonal mean (July-September) Total Phosphorus (TP) of 107.2 µg/L was higher than WY 2018 (91.2 µg/L) but lower than the WY 2017 (114.7 µg/L) and WY 2016 (127.3 µg/L). The WY 2019 seasonal TP mean is also slightly higher than the long-term average of 94.2 µg/L measured from 1992- present. The seasonal mean values for TP appear to be increasing on a long-term scale although the last few years demonstrate more variability.

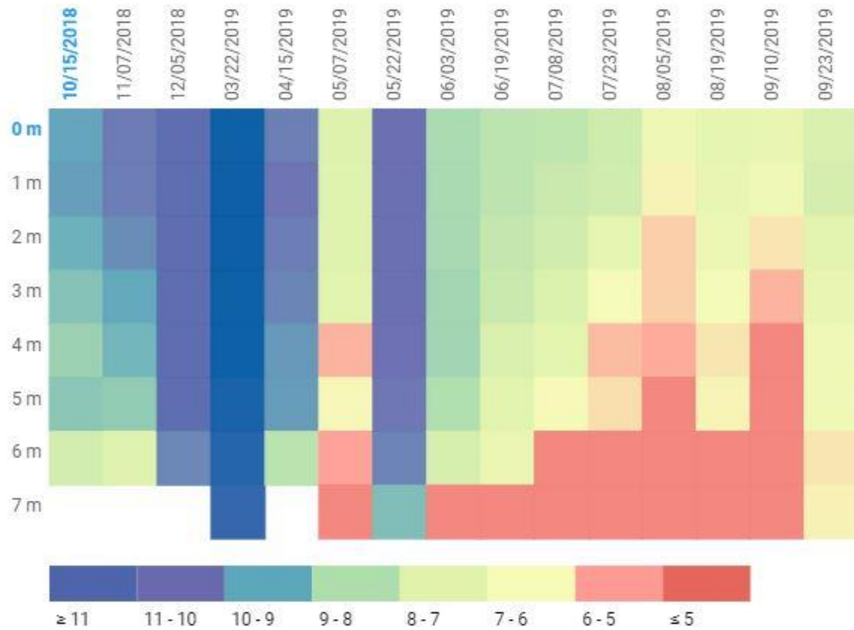
During WY 2019, the monthly mean TP concentrations ranged between 61 µg/L and 170 µg/L with a mean value of 95.3 µg/L.

The lowest values were present in December 2018 and the highest values in July 2019. The WY 2019 data suggests that there are high levels of TP in the Reservoir throughout the year contributing to eutrophic conditions.

Temperature and Dissolved Oxygen

Temperature and dissolved oxygen (DO) profiles were measured in Cherry Creek Reservoir during each sampling event. In addition, 15-minute temperature data was collected at CCR-2 at 1 m intervals from spring through fall 2019. Based on the data collected during WY 2019, the Reservoir met the temperature standards established for the Class I Warm Water Aquatic Life classification established by the Water Quality Control Commission (WQCC) in Regulation No. 31 (REG 31) of 26.2 ˚C Maximum Weekly Average Temperature (MWAT) and 29.3 ˚C Daily Maximum (DM). The maximum temperature measured in the depth profiles was 24.8 ˚C on August 5th, 2019. On these same dates the total change in temperature was minimal from the surface to the bottom of the Reservoir. This data indicated that although there was some variability from the surface to the bottom in the warmer summer months, overall the Reservoir did not develop consistent thermal stratification.

Dissolved Oxygen Concentrations (mg/L) in Cherry Creek Reservoir in 2019.



During WY 2019, DO concentrations in Cherry Creek Reservoir also met the standards established for the Class I Warm Water Aquatic Life classification in WQCC Regulation No. 38, which requires that DO levels are 5.0 mg/L or above near the surface. The DO may be less than 5.0 mg/L near the bottom as long as there is a refuge with DO levels greater than 5.0 mg/L accessible for aquatic life. While DO measurements from 4, 5 or 6m to the bottom of the Reservoir were less than 5.0 mg/L from June to early September, a significant portion of the water column had DO levels that exceeded 5.0 mg/L providing adequate habitat (refuge) for aquatic life. Periods of low dissolved oxygen indicate high microbial activity or decomposition in the sediments which reduces DO concentrations.

pH, ORP and Conductivity

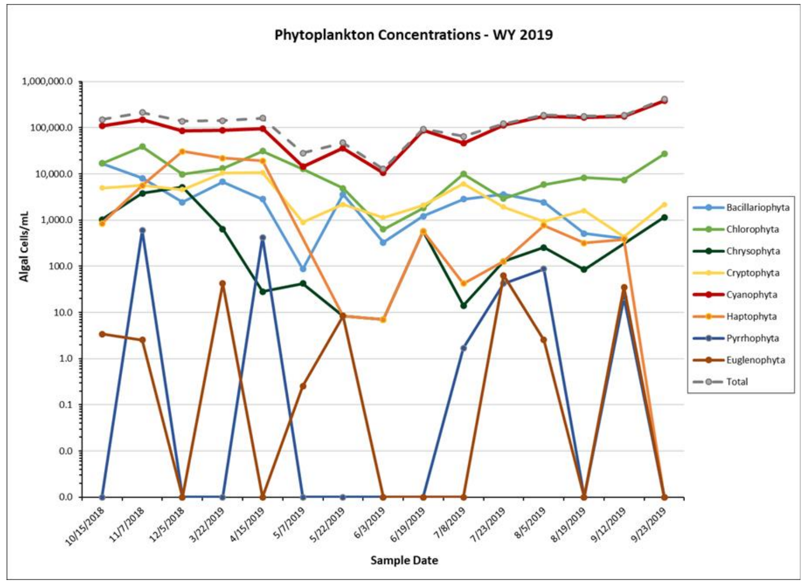
During WY 2019, the pH ranged between 7.7 and 8.6 which meets the instantaneous minimum and maximum standards of 6.5 and 9.0, respectively, set by REG 38. The higher pH values appeared to correlate with higher productivity and elevated chl α in the Reservoir.

The Oxidation Reduction Potential (ORP) in Cherry Creek Reservoir in the photic zone ranged between from 53.1 mV and 218.5 milliVolts (mV). The ORP in the samples near or at the bottom of the Reservoir ranged from -60.2 mV to 194.4 mV. The lower ORP values at the bottom of the Reservoir coincided with the lower DO measurements and the higher ORP values with higher DO levels and colder water temperatures.

The specific conductance (hereafter referred to as “conductivity” in this document) in Cherry Creek Reservoir in WY 2019 ranged from a minimum of 1,043.8 µS/cm to 1,270.9 µS/cm during WY 2019. There was limited variability in conductivity from top to bottom of the Reservoir and between the three monitoring sites.

Phytoplankton

Phytoplankton samples from Cherry Creek Reservoir were collected and analyzed to identify and quantify the populations in detail. The results from WY 2019 indicate high productivity and high species diversity, with an average of 41 phytoplankton species, and a range of 28-60 species present for the 15 sampling dates. The differences in cell concentrations and biomass is based on the relative sizes of each organism. Cell counts were dominated by the Cyanophytes (cyanobacteria or blue-green algae) which were responsible for 50% or more of the total phytoplankton population throughout the year and on four dates a single species made up over 70% of the total biovolume.



In contrast, during WY 2018 cyanobacteria usually made up less than 10% of the biovolume.

While some species of cyanobacteria are capable of producing toxins, those species were not commonly observed during sampling in Cherry Creek Reservoir in WY 2019.

Bacillariophyta (diatoms) and Chlorophyta (green algae) were usually second in concentration to the Cyanophytes throughout most of the season.

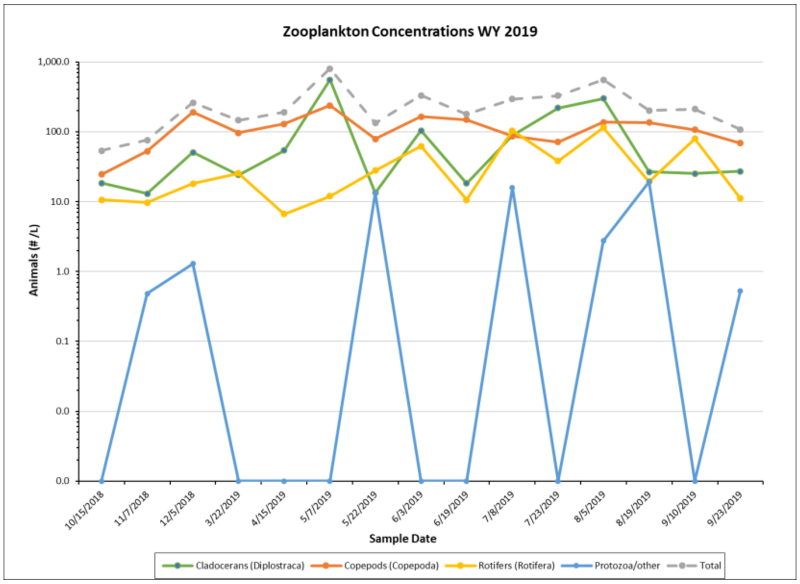
Along with the Cyanophytes, Bacillariophytes, and Chlorophytes, members of the Cryptophyte group (cryptomonads) were often present at levels of 1,000 or more cells/mL, which is a concentration associated with eutrophic conditions. The cryptomonads averaged 14% of the relative biovolume during WY2019 due to their large size.

Haptophytes (golden algae) are widely distributed in brackish or freshwater systems with higher salinities. They are of potential concern because they can produce toxins that are harmful to fish and other aquatic life. Haptophytes, *Chrysochromulina parva*, a known toxin producer, was first noted in Cherry Creek Reservoir in March 2016 and has been present in most samples since that date. *Chrysochromulina parva* was again present in WY 2019 with the exception of the early May and later September samples. In 2019, *Prymnesium parvum*, the golden algae more commonly associated with fish kills, was detected for the first time in Cherry Creek Reservoir in March and April.

Zooplankton

Zooplankton numbers and diversity from samples collected from Cherry Creek Reservoir during WY 2019 were both low compared to phytoplankton.

Most freshwater zooplankton are part of only three phyla: Arthropoda, which include both cladocerans and copepods; Rotifera; and Protozoa. Cladocerans and copepods are microscopic crustaceans that feed primarily on phytoplankton and are an important food source for fish. Rotifers are microscopic animals that feed on detritus and smaller organisms, such as bacteria, and can serve as a food source for larger zooplankton. Protozoans are single-celled organisms that feed on other microorganisms, organic matter, and debris.



Copepods were typically the zooplankton present in the highest numbers, accounting for over 50% of the total population throughout the summer months. For the year, copepods averaged 54% of the zooplankton population and 34% of the biomass.

Cladocerans frequently comprised over half of the zooplankton biomass, averaging 29% of the zooplankton population but 65% of the biomass for WY2019.

The differences in zooplankton concentrations and biomass is a function of the relative sizes of the various organisms. The average cladoceran In Cherry Creek Reservoir had a biomass of 3.0 µg in WY2019, while the biomass of the average copepod was only 0.75 µg, or only about 25% of the weight of the average cladoceran. The rotifers and protozoans were even smaller, with average biomasses of 0.04 and 0.29 µg, respectively.

The cladoceran species present in Cherry Creek Reservoir typically did not include large-bodied Daphnia that are an important source of fish food in many lakes. The most common cladocerans in Cherry Creek Reservoir were *Daphnia ambigua*, *Daphnia rosea*, and *Daphnia lumholtzi*. *Daphnia ambigua* is one of the smaller *Daphnia* and the bosminads, in general, are small cladocerans.

The lack of larger zooplankton may be related to the presence of high populations of gizzard shad (*Dorosoma cepedianum*). Gizzard shad are an important part of the food base for the Cherry Creek Reservoir walleye (*Sander vitreus*) fishery, but they are also effective filter feeders on zooplankton, especially at the larval stage (Johnson, 2014). *Daphnia lumholtzi* is an invasive species that can outcompete native species for food and is an undesirable food source for fish.In WY 2019, *Daphnia lumholtzi* were present in zooplankton samples collected in October and November 2018 and on one sampling date each month from July through September 2019. *Daphnia lumholtzi* comprised over half the total zooplankton biomass on 4 of the 5 dates it was detected.

Trophic State Analysis

The Trophic State Index (TSI) of a lake is a relative expression of the biological productivity of a lake using total phosphorus, chl α and transparency. Elevated values for the Trophic State Index are indicative of higher productivity. Using the Carlson index (1977), a TSI of less than 35 indicates oligotrophic conditions, a TSI between 35 and 50 indicates mesotrophic conditions, and a TSI greater than 50 indicates eutrophic conditions. Hypereutrophic, or excessively productive lakes, have TSI values greater than 70. Higher numbers are associated with increased probabilities of encountering nuisance conditions, such as excessive macrophyte growth and algal scums. Trophic state indices for Cherry Creek Reservoir for phosphorus, chl α and transparency were all above 50, indicating that Cherry Creek Reservoir was eutrophic during WY 2019 (See Table 13).

Table A. Trophic State Characteristics

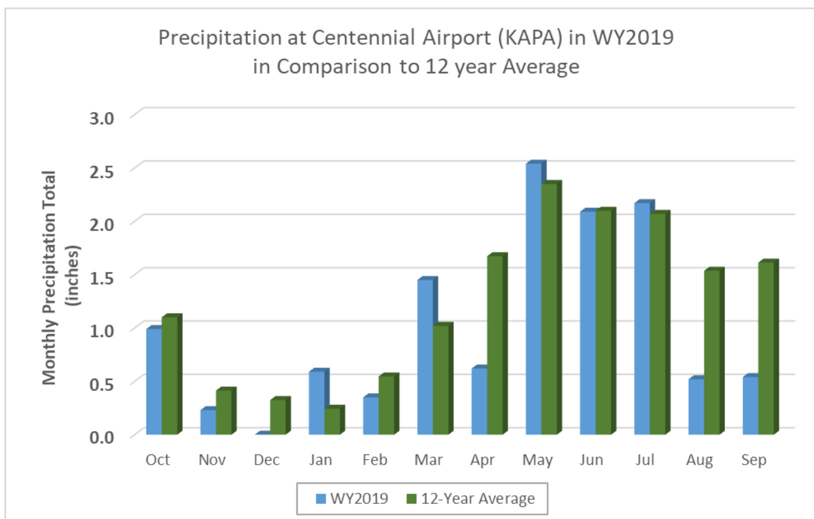
Trophic State	Total P (mg/L)	Characteristic Chlorophyll *a* (µg/L)	Secchi Depth (m)	Relative Productivity
Oligotrophic	< 0.005	< 2.0	> 8	Low
Mesotrophic	0.005 -0.030	2.0 - 6.0	4 – 8	Moderate
Eutrophic	0.030 - 0.100	**6.0 - 40.0**	2 – 4	**High**
Hypereutrophic	**> 0.100**	> 40.0	**< 2**	Excessive
Cherry Creek Reservoir	**0.100**	**14.5**	**1.24**	**High**

Trophic state can also be assessed by comparing monitoring data to trophic state criteria, such as those developed by the U.S. EPA (1980). A comparison of Cherry Creek Reservoir monitoring data from WY 2019 to EPA trophic state criteria (from May through September) also indicates that Cherry Creek Reservoir was eutrophic in WY 2019. Although the Secchi depth indicated excessive productivity, this criterion does not take into account that suspended solids in the water may also affect transparency, such as is the case in Cherry Creek Reservoir.

WATERSHED HIGHLIGHTS

Precipitation

Precipitation measured at the KAPA site was much lower than average during the 2019 Water Year. The historical data from the National Ocean and Atmospheric Administration (NOAA) at the Centennial Airport Station (KAPA), indicated the area received 79% of the average precipitation based on the previous 12 years of data.



However, the watershed as a whole appears to have received above average precipitation, based on the 30-year PRISM average.

Stream Flows

The yearly summary for the U.S. Geological Survey (USGS) gauge “Cherry Creek near Franktown, CO” in the southern area of the watershed listed a provisional total annual flow of 2,369 Acre Feet (AF) with an annual daily mean of 6.9 AF for WY 2019, which is approximately 71.5% of the annual mean discharge of 9.07 AF calculated from WY 1940 -WY 2019.

The provisional yearly summary for the USGS gauge “Cherry Creek near Parker, CO” listed a provisional total annual flow of 4,724 AF and an annual daily mean of 12.94 AF, which is approximately 114% of the annual mean discharge of 11.31 AF calculated from WY 1992- 2019.

It is noteworthy that the headwater flows of Cherry Creek were 28.5% lower than average but flows were 14% above average by the time the stream reached the USGS gauge “Cherry Creek near Parker, CO”. However, the period of record for the Franktown site is much longer than the Parker site which may be responsible for the difference. (Waiting on approved USGS data)

The Authority has automated ISCO samplers at Stations CC-10 on Cherry Creek and CT-2 on Cottonwood Creek to measure water levels. Rating curves have been developed to convert elevation measurements from the ISCO sampler to flows.

At CC-10, while the rating curve is valid for the gage height versus measured flows, changes in the channel since the sampler was installed resulted in an over-estimation of stream flow for the heights measured by the ISCO sampler. Measurements showed that sediment had been deposited over the bottom of the staff gage impacting the accuracy of gage readings. To compensate, the depth of the deposited sediment was subtracted from the average of all ISCO measurements at Station CC-10 for WY 2019. The flow from the resulting corrected ISCO height was subtracted from all calculated ISCO flows. A similar error was probably present for the WY 2018 measurements and would help explain the large negative value of -4,358 AF reported last year (SLM, 2019).

The CT-2 station had a small period of time between December 2018 and January 2019 that had some data loss due to equipment failure. For that period, flows were estimated based on a percentage of flows at CC-10 for the dates when flows were measured at both stations. Flows at CT-2 averaged 25.0% of the flow at CC-10 in WY 2019 which is similar to the percentages of 19.7% reported for WY 2017 (TetraTech, 2018) and 19.8% for WY 2018 (SLM, 2019), indicating this estimation should provide reasonable values for the missing flow data.

Cherry Creek

Water quality data were collected from the USGS Franktown site all the way down Cherry Creek to the Reservoir and below. Conductivity and pH were monitored as surface water moves from the upper basin downstream to the Reservoir during both monitoring events.

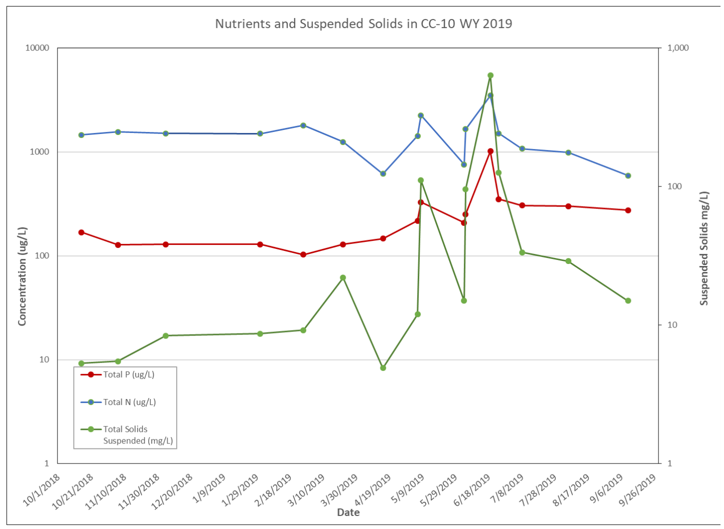
Both upstream to downstream monitoring events indicate limited variability of pH ranging from approximately 7.7 to 8.56 through the basin. However, the data indicate that conductivity increases moving downstream, and appears to be increasing over time when compared to historical data.

During both the November 2018 and May 2019 comprehensive upstream to downstream sampling, the level of TP remained relatively constant. However, total nitrogen (TN) increased from USGS gauge “Cherry Creek near Franktown, CO”, downstream to the CC-2 site through the CC-6 site and then decreased towards and below the Reservoir.

The biologically available forms of phosphorus and nitrogen [soluble reactive phosphorus (SRP), nitrate plus nitrate nitrogen (NO_3+NO_2-N), and ammonia nitrogen (NH_3-N)] followed trends similar to the TP and TN concentrations from the upstream to downstream samples. The TP, SRP, TN and NO_3+NO_2-N levels during these sampling events indicate nutrient retention or utilization within the Reservoir before release from the outlet.

The pH values measured at CC-10 over time appear to have slightly decreased for a few years between 2009 and 2016 but increased again over the last 3 years. Conductivity values measured at CC-10 indicate an increasing trend over the last ten to twelve years, with most values double what they were a few years before.

The median TP concentrations were 161% higher in storm flows than base flow, and median TN concentrations were 84% higher in storm flows. The values of Total Suspended Solids (TSS) ranged between 5 and 637 mg/L and the median values were 1627% higher in storm than base flow conditions sampled.



The relationship between phosphorus and nitrogen and TSS concentrations is also reflected in the difference between the concentrations in samples collected at CC-10 during storm and base flow sampling events. Over time there is variability of both TN and TP during the base and storm flow monitoring. Typically storm flows increase the suspended sediments in the water, represented by higher values of TSS. During WY 2019, there was a distinct correlation of higher nutrient concentrations when the TSS levels were higher. These data suggest that storm events may contribute a larger percentage of the total nutrient loading to the Reservoir.

The WY 2019 flow-weighted phosphorus concentration was 222 µg/L which was lower than WY 2018 (236 µg/L), and recent historical average (2011 – 2018) flow-weighted total phosphorus concentration (254 µg/L). However, the WY 2019 flow-weighted average concentration for Cherry Creek station CC-10 remains much higher than the WY 2019 flow weighted total phosphorus concentration of 49.1 µg/L calculated for station CT-2 in lower Cottonwood Creek.

The WY 2019 flow-weighted nitrogen concentration was 1,557 µg/L, which was lower than WY 2018 (1,833 µg/L) as well as the recent (2011 – 2018) flow-weighted total phosphorus concentration of 1,772 µg/L.

In contrast to phosphorus, the WY 2019 flow-weighted nitrogen concentration for Cherry Creek station CC-10 is much lower than the WY 2019 flow weighted total nitrogen concentration of 2,392 µg/L at site CT-2 just upstream of where Cottonwood Creek enters the Reservoir.

Cottonwood Creek

During WY 2019, the pH of water in Cottonwood Creek before it entered the Reservoir ranged from 7.7 to 8.2. The conductivity, or specific conductance, which represents dissolved solids in the water, at CT-2 ranged between 1,192 µS/cm and 3,407 µS/cm, with a median value of 1,862 µS/ cm. This is higher than the median for Cherry Creek, which was 1,069 µS/cm for WY 2019.

The TP concentrations ranged between 34 and 77 µg/L during the year. The median TP concentrations were 32% higher in storm flows than the base flow conditions. The TN concentrations ranged between 638 and 3,930 µg/L during WY 2019. The median TN concentrations were 12% lower in storm flows. The values of TSS ranged between 5 and 21 mg/L and the median values were 21% lower in storm flow conditions compared to base flows.

A similar relationship between nutrients and TSS is present at CT-2, although it was much less consistent than in Cherry Creek. In addition, the flow weighted TP concentrations were much higher entering the Reservoir at CC-10 than at CT-2 during WY 2019. In contrast the TN concentrations were much higher at CT-2 than CC-10.

POLLUTION REDUCTION FACILITIES (PRF) HIGHLIGHTS

Based upon the data collected in WY 2019, the Cottonwood PRF treatment train (Peoria Pond, Phases 1 and 2 of stream reclamation completed on Cottonwood creek downstream, and the Perimeter Pond) functioned by reducing TP concentrations by approximately 52% under base flow conditions and 69% during storm events. Sediment concentrations, measured as TSS, were reduced by approximately 74% under base flow conditions and 95% during storm flows. Based on the differences in reduction during high and low flow events, these PRFs functioned as designed to reduce phosphorus and sediment loading during WY 2019. (Table 7.)

However, when evaluating the two PRF ponds individually, it appears that the majority of the effectiveness of nutrient and sediment reduction under base flow conditions can be attributed to the Peoria Pond during WY 2019. The TP concentrations were reduced through Peoria Pond by 44% in comparison to only 11% through the Perimeter Pond under base flow conditions. TSS were reduced through Peoria pond by 46% and 23% through the Perimeter pond. Increases were seen from upstream to below the Perimeter Pond for SRP and TDP by 23% and 17% respectively and 9% TN upstream to below the Peoria pond.

In WY 2019, nutrients and suspended solids were all reduced from the upstream to downstream sites on McMurdo Gulch. TP was 29% lower and TN was 30% lower at the downstream site. TSS and VSS concentrations were 74 and 76% lower at the lower McMurdo site.

GROUNDWATER HIGHLIGHTS

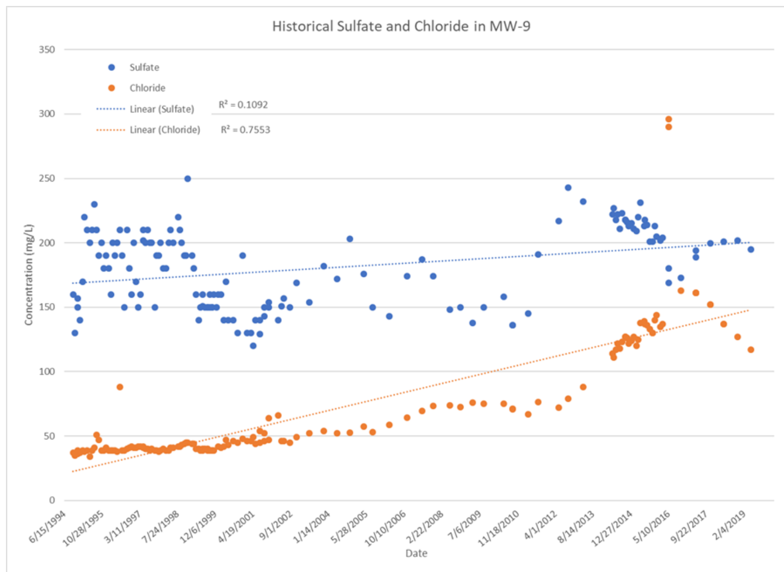
Data from groundwater samples collected from the three monitoring wells upstream of the Reservoir, as well as the one below suggests that the TP concentrations remained relatively consistent during both monitoring dates in WY 2019. In contrast, TN decreased as the wells get closer to the Reservoir, and lower below the dam at the MW- Kennedy site.

The data from the comprehensive basin sampling of all Cherry Creek sites suggests little difference in TP concentrations between surface water and groundwater although slightly higher in groundwater. The mean concentrations of TP in the GW sites were 0.36 and 0.32 mg/ L in both November 2018 and May 2019 respectively. In contrast, the TN concentration was much lower than in the groundwater sites at CC-1 and MW-1 but then was similar or equal to the nearby surface water locations through the rest of the basin with the exception of May 2019 when it was much lower below the Reservoir. Both TN and NO_3+NO_2-N concentrations decreased toward the reservoir and below, but NH_3-N increases in the groundwater site, below the Reservoir at MW- Kennedy.

Both sampling events during WY 2019 indicated groundwater chloride concentrations averaged 124 mg/L and sulfate concentrations averaged 125 mg/L. The pH remained relatively constant and the conductivity seemed to follow the trend of the concentrations of chloride and sulfate. However, during May 2019 sampling event, conductivity was more variable indicating additional dissolved solids were impacting the results.

During WY 2019, the pH values from the monitoring wells ranged between 6.8 and 7.6, with an historical mean value of near neutral at 7.12. The historical pH values from Monitoring Well MW-9 suggest that the pH at site MW-9 may be remaining constant or slightly decreasing over time.

The conductivity values at MW-9 suggest a slightly increasing trend over time, with a mean value of 807 µS/cm between 1995 and 2005 and a mean of 1,103 µS/cm from 2006 to 2019.



Analysis of the historical data for MW-9 from 1994-2019 appears to show that chloride and sulfate may be increasing over time, although chloride may be less variable and increasing slightly more significantly.

Historically, the concentration of SRP in the groundwater upstream of the Reservoir at MW-9 also appears to be slightly increasing.

The long-term TOC (Total Organic Carbon) concentrations in the alluvial groundwater samples collected from well MW-9 range from 2.7 µg/L to 4.3 µg/L, averaging 3.3 µg/L. The TOC concentrations measured in November 2018 were 2.95 mg/L and in May were 2.85 mg/L which are both slightly lower than the long-term averages. Historically, the dissolved fraction (DOC) in well MW-9 ranged between 66% and 100%, with an average of 98% which was slightly higher than the long-term average at 93% of the total.

WATER BALANCE HIGHLIGHTS

The estimated volumes of surface flow entering the Reservoir from these two surface water sources in WY 2019 are:

- Cherry Creek: 14,447 AF
- Cottonwood Creek: 3,754 AF

The estimated evaporative losses from the reservoir were 2,757 ac-ft during WY 2019, or approximately 40.44 inches (3.37 feet) per acre at the median surface area of 819 acres.

The USGS measured outflows for WY 2019 at Station 06713000, Cherry Creek below Cherry Creek Lake, CO totaled 17,799 AF, which were used for nutrient balance calculations.

The Reservoir WY 2019 water balance is summarized in Table B. The net ungauged inflows(+)/outflows(-) was mathematically calculated to result in the Reservoir change in storage to equal the 430 AF reported by the U.S. Army Corps of Engineers (USACE) for WY 2019, which includes ungauged surface water inflows into the reservoir, groundwater seepage from the reservoir through the dam, and measurement uncertainties. Net ungauged outflows for WY 2019 were -294 AF which were apportioned between the Cherry Creek and Cottonwood Creek inflows to calculate nutrient loading. Cherry Creek contributed 75.8% of the combined inflow and Cottonwood Creek contributed 24.2%, based on the 15-minute raw data from the ISCO samplers. The ungauged inflows were calculated and allocated based on the daily values for all inflows and outflows used in the allocation equations, resulting in reductions to surface inflows of 129 AF for Cherry Creek and 165 AF for Cottonwood Creek.

Table B. WY 2019 Water Balance

Water Source	Water Volume (AF)
Inflows	
Cherry Creek (CC-10)	14,349
Cottonwood Creek (CT-2)	3,588
Precipitation	838
Alluvial groundwater	2,200
Total Inflows	**20,095**
Outflows	
Evaporation	-2,757
Reservoir releases	-17,799
Total Outflows	**-20,556**
Net Ungauged Inflows/Outflows	
Calculation *(Included in inflows for CC-10 and CT-2)*	-294
WY 2019 Change in Storage	**430**

NUTRIENT BALANCE HIGHLIGHTS

The WY 2019 flow-weighted TP concentration of all inflows is 188 ug/L, and is lower than WY 2018 (206 µg/L), WY 2017 (197 µg/L), WY 2016 (213 µg/L), and the 2011-2015 median of 200 µg/L. The flow weighted TP concentration is just below the 200 ug/l flow-weighted influent phosphorus goal derived as part of the 2009 Regulation 38 rulemaking process as necessary to achieve the 18 µg/L chl α standard.

The WY 2019 flow weighted TN inflow concentration of 1,609 µg/L is lower than WY 2018 (1,691 µg/L) but higher than WY 2017 (1,284 µg/L), WY 2016 (1,175 µg/L), and the 2011-2015 median of 1,344 µg/L.

Flow-weighted nutrient concentrations for WY 2019 are summarized in Table C[1].

Table C. Flow weighted nutrient loads to Cherry Creek Reservoir WY 2019.

		Source				
	Nutrient	**Cherry Creek**	**Cottonwood Creek**	**Alluvial Groundwater**	**Precipitation**	**Flow-Weighted Total**
Inflow Concentration (µg/L)	Total Phosphorus	222	49.1	228	101	**188**
	Total Nitrogen	1,565	2,427	410	2,009	**1,609**
% of Total Inflow		68.4%	17.1%	10.5%	4.0%	**100%**

The Reservoir inflows (nutrient loads) considered in the WY 2019 nutrient balance are:

- Cherry Creek surface water
- Cottonwood Creek surface water.
- Precipitation (incident to the reservoir's surface)
- Alluvial groundwater

Nutrient balances for total phosphorous and total nitrogen for Cherry Creek Reservoir are calculated for WY 2019 based on the nutrient calculations for inflow and releases. The WY 2019 total phosphorus and nitrogen mass balances are summarized in Table D. The difference between the inflow and the outflow loads indicate that a net 5,499 pounds of phosphorus and 50,460 pounds of nitrogen were retained in the Reservoir in WY 2019.

The total phosphorus inflow load calculation for WY 2019 is lower than WY 2018, WY 2017, WY 2016, and WY 2015 and the historical means from 2011-2015 and the long-term mean from 1995-2015. In contrast, the total nitrogen load calculation for WY 2019 is higher than recent years, 2018, 2017, 2016 and much higher than the historical means of 2011-2015 and 1993-2015.

[1] [1] Flow-weighted concentration = (Cherry Creek concentration X Cherry Creek percent of total flow) + (Cottonwood Creek concentration X Cottonwood Creek percent of total flow) +(Alluvial Groundwater concentration X Alluvial Groundwater percent of total flow) +(Precipitation concentration X Precipitation percent of total flow)

Table D. Nutrient Mass Balance for WY 2019

	Total Phosphorus	Total Nitrogen
Source	**Mass (pounds)**	**Mass (pounds)**
Surface Water		
Cherry Creek (CC-10)	8,662	61,066
Cottonwood Creek (CT-2)	479	23,682
Reservoir Release (CC-Out)	-5,287	-41,319
Alluvial Groundwater		
Inflow	1,364	2,453
Atmospheric		
Precipitation	230	4,579
Evaporation	0	0
WY 2019 Change in Storage	**5,449**	**50,460**

RECOMMENDATIONS AND CONCLUSIONS

During the 2019 monitoring and data analysis efforts, recommendations for improvement and enhancement of the sampling program and analysis were developed. The following recommendations could help facilitate more detailed examination of long-term water quality trends and additional factors impacting water quality within the watershed and sub-basins of Cherry Creek.

- Increasing the accuracy of level and flow gauging on Cherry Creek upstream of the Reservoir is recommended. Additional flow monitoring upstream of the perimeter road to capture information from flows during large storm events that may bypass the current gauging station will be implemented to help quantify these ungauged flows.
- Collecting additional data to analyze the individual Cottonwood PRF ponds (Peoria and Perimeter) using a mass balance approach similar to the Reservoir will provide more information on long term trends and relationships with pond maintenance activities. In 2020, the monitoring sites and frequency will support this effort.
- Comparing data from USACE Tri-Lakes Monitoring Program could be valuable in evaluating trends in Cherry Creek Reservoir based on additional monitoring dates and sites.
- Continuing to analyze nitrogen and phosphorus ratios, limiting nutrient trends, and relationships between chl α and phytoplankton populations will help evaluate the potential for cyanobacteria blooms in Cherry Creek Reservoir throughout the season.
- As development continues, it may be necessary to add additional monitoring sites or equipment to determine potential impacts to changes in water quality.

- The evaluation of additional in-reservoir options to improve water quality will be helpful to determine if increasing oxygen, reducing phosphorus, shifting nutrient ratios, etc. will help reduce chlorophyll α to meet the standard and help maintain the beneficial uses of the Reservoir.

- It is important to continue to monitor the potential negative impacts to beneficial uses that may occur due to the presence of aquatic nuisance organisms (ANS) present in Cherry Creek Reservoir. Golden algae, *Prymnesium parvum* along with the lesser known *Chrysochromulina parva*, present direct risks to the fishery due to their ability to create toxins responsible for fish kills. In addition, the presence of *Daphnia lumholtzi,* known as the spiny water flea, poses indirect threats of an imbalance in high quality forage available to support the fishery.

Continued management of the watershed is vital to maintaining the water quality in Cherry Creek Reservoir in order to preserve the beneficial uses. External loading from the watershed, as well as internal loading from the Reservoir sediments, are contributing to the high nutrient concentrations which drive phytoplankton productivity and higher chl α concentrations.

Precipitation and storm events appear to play a large role in nutrient concentrations in the inflows and nutrient loading of the reservoir. Assessment of the water quality through the PRFs on Cottonwood Creek will help determine scale and frequency of maintenance of the wetlands plants and sediment removal necessary to maintain storage capacity and reduce organic accumulation.

There continues to be a significant difference in water quality between Cherry Creek and Cottonwood Creek. Differences in the stream channel morphology, flow patterns, wetlands, vegetation growth patterns, large variability from storm events differences in the runoff from the watershed affect the nutrients and suspended solids concentrations in the water, as well as PRFs and water quality controls of our partners.

Cherry Creek Reservoir and its tributaries are important assets to all users. Recreational boaters, fishermen, hikers, bikers, wildlife enthusiasts, and others value the many aspects of the watershed that these resources provide. The Cherry Creek Basin Water Quality Authority is very proactive in monitoring effects of development land use, discharges, and other aspects that may impact the water quality within the watershed. The current partnerships with local, state, and federal entities support the Authority's efforts to monitor and maintain watershed improvements to protect all beneficial uses.

1.0 INTRODUCTION

The Cherry Creek Basin Water Quality Authority's (CCBWQA, or Authority) mission and vision are to benefit the public by improving, protecting, and preserving water quality in Cherry Creek and Cherry Creek Reservoir, for recreation, fisheries, water supplies, and other beneficial uses, and achieving and maintaining current water quality standards. The Authority will also provide for effective efforts by counties, municipalities, special districts, and landowners within the basin in the protection of water quality; provide that new developments and construction activities pay their equitable share of costs for water quality preservation and facilities; and promote public health, safety, and welfare.

The CCBWQA was formally created by statute in 1988 by the Colorado State Legislature. The Authority Board consists of representatives from two counties, eight cities, a representative from special districts that provide water and wastewater treatment in the basin, and seven public representatives appointed by the Governor.

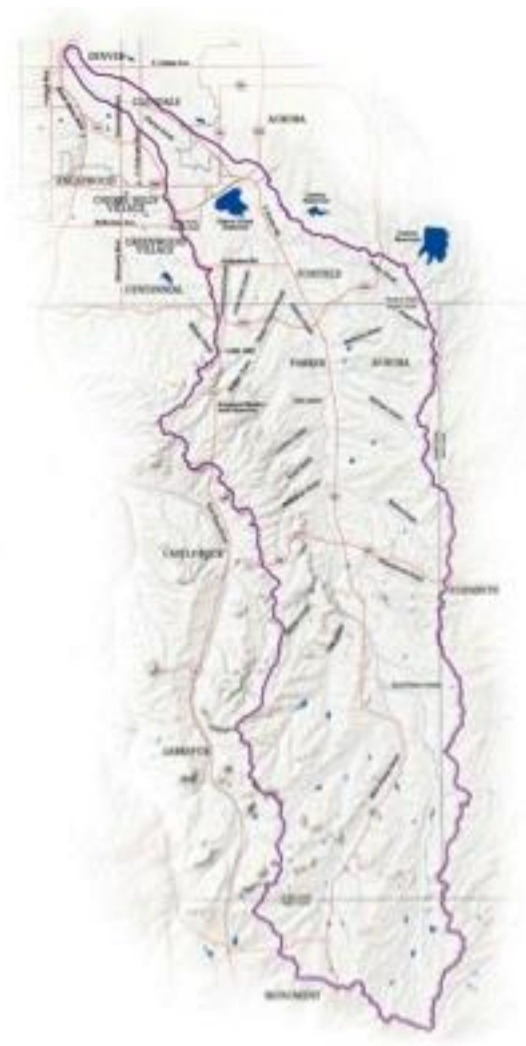


Figure 1. Cherry Creek Basin

The Cherry Creek Basin watershed includes over 386 square miles and 600 miles of creeks and streams. The U.S. Army Corps of Engineers (USACE) states that Cherry Creek Reservoir (Reservoir) has a surface area of 850 surface acres, and is located near the base of the watershed, south of I-225 and west of Parker Rd., in Cherry Creek State Park. Cherry Creek State Park is approximately 4,000 acres and one of the most productive fisheries and widely enjoyed recreational areas in Colorado. The park has miles of trails to view birds and wildlife with scenic views of the Rocky Mountains in the background.

USACE constructed the Reservoir between 1948 and 1950 and it is operated for flood control. Water released from the Reservoir also supports downstream agriculture and water supply uses. Protecting the beneficial uses of the Reservoir is paramount for public safety, water supply, direct recreation, and aquatic habitat.

The Water Quality Control Commission (WQCC) adopted use classifications and water quality standards, most recently effective June 30th, 2017. These numeric standards, as specified in Regulation No. 38 (5 CCR 1002-38) (REG 38), include the mainstem of Cherry Creek to the inlet of the Reservoir and from the outlet to the confluence with the South Platte River, Cherry Creek Reservoir, Cottonwood Creek, and other tributaries, lakes, and reservoirs within the watershed. These standards are set to protect recreation, aquatic life, agriculture, and water supply uses.

2.0 MONITORING PROGRAM

The WQCC's Cherry Creek Reservoir Control Regulation No. 72 (5 CCR 1002-72), (REG72), requires that the Authority execute a water quality monitoring program of the Cherry Creek watershed and Reservoir for water quality, inflow volumes, alluvial water quality, and non-point source flows. The program is implemented to determine total annual flow-weighted concentrations of nutrients to the Reservoir and to monitor the Pollutant Reduction Facilities (PRFs) to determine inflow and outflow nutrient concentrations. The sample collection and analysis provide data required to evaluate the nutrient sources and transport, characterize the reductions in nutrient concentrations, and calculate and document compliance with water quality standards. In addition, these data will be used to update Reservoir and Watershed models.

The *Cherry Creek Basin Water Quality Monitoring Report - Water Year 2019* outlines the Authority monitoring program, data collected during the 2019 water year, and an evaluation of the results.

The WY 2019 monitoring program review is comprised of an assessment of data and results from the Reservoir and watershed, including water quality and quantity of surface water, groundwater, stormwater, and the effectiveness of Pollutant Reduction Facilities (PRFs). The water quality data and results described herein are made available on the Authority's Data Portal, http://www.ccbwqportal.org.

2.1 SAMPLING PROGRAM OBJECTIVES

The Sampling and Analysis Plan/Quality Assurance Project Plan (SAP/QAPP) provides the foundation for the sampling and analysis program activities, including sampling methods, QA/QC (quality assurance/quality control) protocols, etc. All monitoring activities and analytical work are performed in accordance with this document.

The monitoring program was designed to understand and quantify the relationships between nutrient loading (both in-lake and external) and Reservoir productivity. The routine monitoring of surface water and groundwater was implemented to promote the concentration-based management strategy for phosphorus control in the basin, to determine the total annual flow-weighted concentration of nutrients to the Reservoir, to evaluate watershed nutrient sources and transport mechanisms, and to evaluate the effectiveness of PRFs and Best Management Practices (BMPs) in the basin.

The specific objectives of the SAP/QAPP are to determine:

- Attainment of long-term water quality goals and water quality standards (including beneficial uses and the numeric criteria adopted to protect the uses).
- Biological productivity, plankton communities, and chl α concentrations during the growing season in regard to the water quality standard in Cherry Creek Reservoir.
- Relationships between the biological productivity and nutrient concentrations within the Reservoir and total inflows.
- Water quality characterization of Cherry Creek Reservoir and inflows.
- Effectiveness of PRFs within the Cherry Creek basin, as well as those operated and maintained by the CCBWQA within the boundaries of Cherry Creek State Park.
- Measurements of stream flows during base flow and storm conditions.
- Flow-weighted total phosphorus (TP) and total nitrogen (TN) concentrations transported to Reservoir from Cherry Creek and Cottonwood Creek.

- Calculate base flow and storm flow concentrations for nitrogen and phosphorus in tributary inflows, as well as concentrations in the Reservoir and the outflow.
- Long-term water quality trends in the Cherry Creek Basin over time.

The program has also supported other complementary Authority activities over the years, such as calibration of the Reservoir water quality model, determining water quality effectiveness of Authority constructed PRFs, and additional non-specified monitoring determined by the Authority to be supportive of Authority long-term goals for the Reservoir and watershed that promote protection of beneficial uses and preservation and enhancement of water quality.

2.2 SAMPLING PROGRAM DESCRIPTION

The monitoring and sample collection for the 2019 Water Year (WY) was completed by Solitude Lake Management from October 1st, 2018 to September 30, 2019. The 2019 Monitoring Program was conducted in accordance with the 2019 Cherry Creek Basin Water Quality Authority Routine Sampling and Analysis Plan/Quality Assurance Project Plan (SAP/QAPP)[12].

The sampling program uses field sample collection methods and laboratory protocols as identified in the SAP/QAPP to achieve high quality data including:

- Quality assurance for accuracy, representativeness, comparability, and completeness of data collected and reported.
- Quality and reproducible field sampling and sample preservation procedures, laboratory processing, and analytical procedures.
- Data verification and reporting including quality control checks, corrective actions, and quality assurance reporting.

2.2.1 SAMPLING SITE LOCATIONS

Routine sampling is completed at twenty-six (26) sites within the watershed, including three (3) sites in Cherry Creek Reservoir, and one (1) precipitation collection site. There are nineteen (19) stream sites on Cherry Creek, Cottonwood Creek, Piney Creek, and McMurdo Gulch, along with four (4) alluvial groundwater sites along the mainstem of Cherry Creek. All sites are displayed on Figure 2., Cherry Creek Basin Monitoring Site Locations.

Data from many of these sites are used to determine the effectiveness of several of the Authority's PRFs. A map of the Authority's Projects, including these PRFS, is provided in Figure 3, CCBWQA Water Quality Improvement Projects and PRFs.

[2] In addition to Solitude Lake Management, Tetra Tech, GEI and Halepaska have also served as the Authority's SAP/QAPP Consultant.

Figure 2. Cherry Creek Basin Monitoring Site Locations

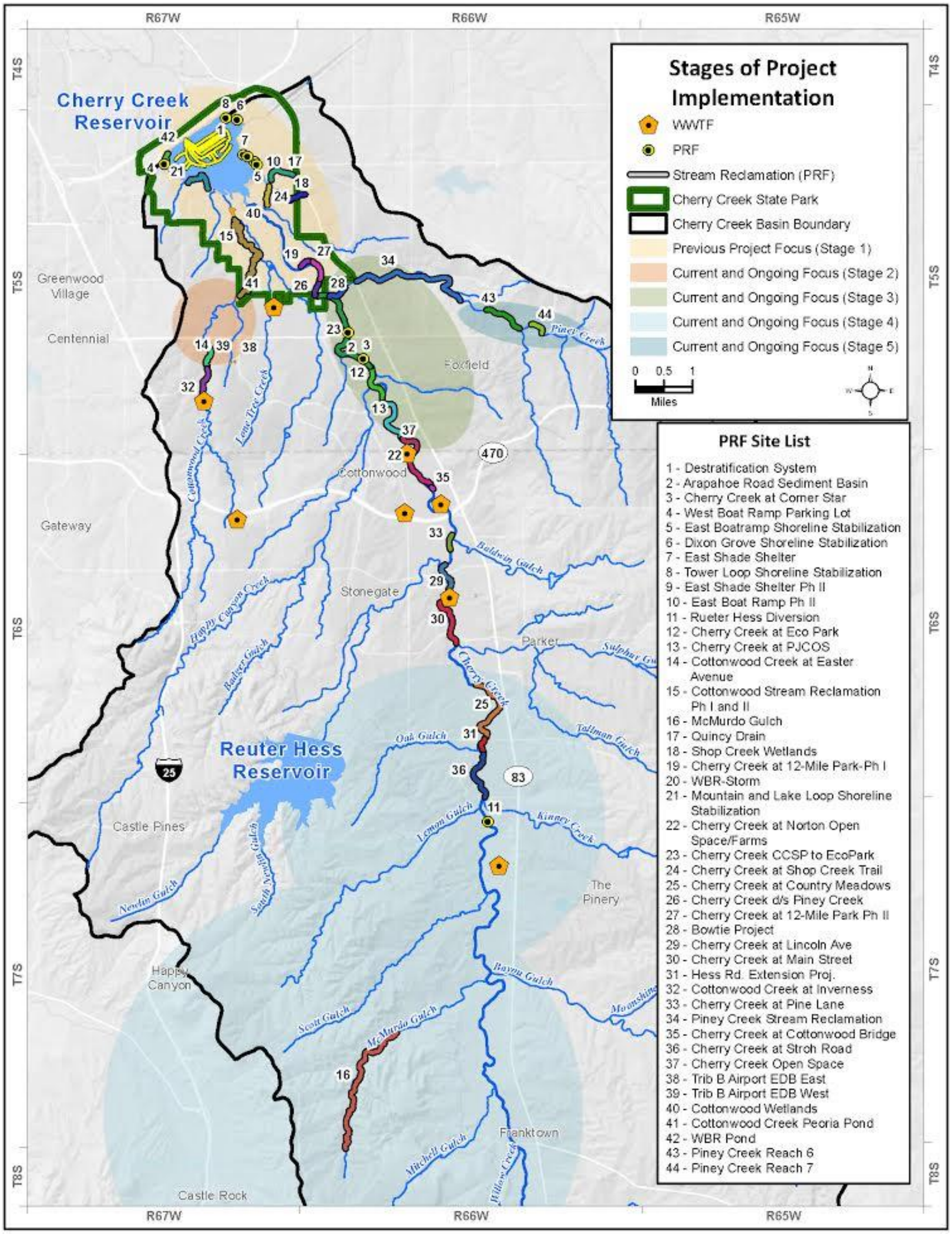


Figure 3. CCBWQA Water Quality Improvement Projects and Pollutant Reduction Facilities

2.2.3 SAMPLING FREQUENCY

In order to ensure high quality, accurate data, all sampling was conducted in accordance with the SAP/QAPP. The physical, chemical, and biological parameters were collected at the frequency specified. Table 1 outlines the Reservoir sampling sites, parameters, and frequency; Table 2 outlines the precipitation site sampling parameters; and Table 3 outlines the stream and groundwater sampling sites, frequency, and parameters.

Table 1. Reservoir Sampling Sites, Parameters, and Frequency

Analyte	**Monthly Nutrient-Biological Samples (Photic Zone)**		**Monthly Nutrient Profile (4m-7m)**	**Bi-monthly Sonde & Nutrient Samples (May- Sept)**
	CCR-1, CCR-3	**CCR-2**	**CCR-2**	**CCR-1, CCR-2, CCR-3**
Total Nitrogen	X	X	X	X
Total Dissolved Nitrogen	X	X	X	X
Ammonia as N	X	X	X	X
Nitrate + Nitrite as N	X	X	X	X
Total Phosphorus	X	X	X	X
Total Dissolved Phosphorus	X	X	X	X
Soluble Reactive Phosphorus	X	X	X	X
Total Organic Carbon		X	X	X
Dissolved Organic Carbon		X	X	X
Total Suspended Solids	X	X		X
Volatile Suspended Solids	X	X		X
Chlorophyll *a*	X	X		X
Phytoplankton		X		X
Zooplankton		X		X

Table 2. Precipitation Site Sampling Parameters

Analyte	**Precipitation Site**
Total Nitrogen	X
Total Phosphorus	X

Table 3. Stream and Groundwater Sampling Sites, Parameters, and Frequency

Analyte	Monthly Surface Water Samples	Every Other Month Surface Water Samples	Storm Event Surface Water ISCO Samples	Bi-annual Surface Water Samples	Bi-annual Groundwater Samples
	5 sites (CC-0, CC-10, CC-7, CT-P1, CT-2, PC-1)	4 Sites (CT-1, CT-P2, MCM-1, MCM-2,)	5 sites (CC-10, CC-7, CT-2, CT-P1, PC-1)	9 sites (USGS Cherry Creek @ Franktown, USGS Cherry Creek @ Parker, CC-1, CC-2, CC-4, CC-5, CC-6, CC-8, CC-9)	4 sites (MW-1, MW-5, MW-9, MW-Kennedy)
Total 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 Phosphorus	X	X	X	X	X
Soluble Reactive Phosphorus	X	X	X	X	X
Chloride					X
Sulfate					X
Total Organic Carbon	X (CC-10, CT-2)				X (MW-9)
Dissolved Organic Carbon	X (CC-10, CT-2				X (MW-9)
Volatile Suspended Solids	X	X	X		
Total Suspended Solids	X	X	X		

2.2.4 LABORATORY ANALYSIS

Analytical services were provided by laboratories in accordance with laboratory QA/QC protocols outlined in the SAP/QAPP.

IEH Laboratories and Consulting Group

IEH Laboratories (IEH) provide a full range of environmental laboratory analytical capabilities for ambient water quality and watershed studies. They work with customers to provide appropriate parameters following EPA, ASTM and AOAC methods to achieve project goals. IEH Laboratories' analytical methods for nitrogen and phosphorus are approved for use in Colorado Nutrients Management Control Regulation 85 nutrient monitoring and all proposed methods are approved under the Clean Water Act (40 CFR Part 136).

Phycotech Inc.

PhycoTech, Inc. is an environmental consulting company specializing in the identification of aquatic organisms. Phycotech's analytical services include identification, enumeration, biovolume (algae), and biomass (zooplankton). Table 4. summarizes the analytical laboratories and laboratory managers used during the monitoring program.

Table 4. Analytical Laboratories

Laboratory/Manager	**Analytical Services**
IEH Analytical, Inc., Damien Gadomski, Ph.D.	Nutrients, inorganics, organics, and chl α.
PhycoTech, Inc., Ann St. Amand, Ph.D.	Phytoplankton and Zooplankton, identification, enumeration, concentration, biovolume and biomass.

2.2.5 WATER QUALITY METHODS AND ANALYTE DESCRIPTION

The parameters analyzed in the monitoring program are useful in determining the suitability of the water for aquatic life recreational use and attaining water quality standards, collectively referred to as "beneficial use." These parameters are also used to define lake trophic state and interactions between the chemical and biological components of lake ecosystems. All analyses were conducted using approved methods described by the U.S. EPA (U.S. EPA 1993; 2014) and/or Standard Methods (Standard Methods, 1998 and other versions). A YSI EXO-3 Multi-parameter sonde was used for all reservoir profiles to measure temperature, pH, conductivity, DO and ORP. A 30 cm (8") black and white disk was used to measure Secchi depth and a LICOR quantum sensor was used to measure light transmittance. All meters were calibrated in the factory for each parameter and with calibration standards prior to each sampling event.

Phytoplankton samples were collected from the photic zone composite sample and preserved with glutaraldehyde for shipment to the lab for identification, enumeration, and biovolume calculations. Zooplankton samples were collected with an 8" diameter 80 µm mesh plankton net from a depth of 6m to the surface and preserved with 70% ethanol for shipment to the lab for identification, enumeration and biomass calculations.

pH

The hydrogen ion activity, indicating the balance of acids and bases in water, determines its pH. A pH of 7 is considered neutral, a pH less than 7 is considered acidic, while a pH greater than 7 is considered basic. Most aquatic organisms survive best in waters with a pH between 6.8 and 8.2. Since pH is expressed on a logarithmic scale, each 1-unit change in pH represents ten-fold increase or decrease in hydrogen ion concentration. Therefore, a pH of 6 would be 10 times more acidic than a pH of 7 and 100 times more acidic than a pH of 8. The pH of normal rainwater (containing no pollutants) is about 5.6. As the rainwater travels over and through rocks and soil, chemical reactions with minerals affect the pH and increase the buffering capacity of the water.

Oxidation Reduction Potential

Oxidation reduction potential measurements are used to quantify the exchange of electrons during chemical reaction in which the oxidation states of atoms are changed, also known as redox or oxidation-reduction 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. 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. Higher ORP values indicate an oxidative environment and high potential to break down organic matter in the water. Low and negative values indicate a reducing environment and usually correlate to lower dissolved oxygen concentrations and higher microbial decomposition activity usually present at deeper sites and in the sediments of lakes.

Conductivity

Conductivity is the ability of water to conduct an electrical current and is based on the dissolved inorganic solids (positive and negative ions) present. High sediment loads do not generally increase conductivity readings since sediment particles are generally considered to be particulate (or suspended) rather than dissolved because of their larger size (greater than 2 microns). The geology of the area, water source, and watershed affect conductivity and 50-1500 µS/cm are typical for surface water. Conductivity also varies in direct proportion with temperature. Thus, to allow direct comparison of samples collected at different temperatures, conductivity is typically corrected to 25^{o}C and reported as specific conductance (µmhos/cm @ 25 ^{o}C). For the sake of simplicity, specific conductance is referred to as "conductivity" in this report.

Dissolved Oxygen

Dissolved oxygen (DO) is the amount of oxygen gas dissolved in the water column. Small amounts of oxygen enter the water column by direct diffusion at the air/water interface and oxygen is produced during photosynthesis. Dissolved oxygen gradients provide an indication of mixing patterns and the effectiveness of mixing processes in a lake. Dissolved oxygen concentrations also have an important bearing on the physical-chemical properties of lakes and the composition of a lake's biota. Lakes impacted by heavy sediment loads may experience low DO levels since the increased turbidity caused by suspended particles can reduce light penetration and limit photosynthesis. The breakdown of organic matter or decomposition can consume large amounts of oxygen from the water column. Fish require oxygen for respiration and become stressed at levels less than 5 mg/L. Dissolved oxygen can be expressed in concentration or mg/L or in percent saturation. Dissolved oxygen saturation is directly related to temperature and the capacity of water to absorb oxygen decreases as temperature increases.

Temperature

Water temperature affects the dissolved oxygen concentration of the water, the rate of photosynthesis, metabolic rates of aquatic organisms, and the sensitivity of organisms to toxins, parasites, and disease. All aquatic organisms are dependent on certain temperature ranges for optimal health. If temperatures are outside of this optimal range for a prolonged period of time, the organisms become stressed and can die. Water temperature generally increases with turbidity; as the particles absorb heat the dissolved oxygen levels are reduced. Temperature is primarily controlled by climatic conditions but can be impacted by human activities.

Secchi Depth

The Secchi depth of a waterbody is a way to quantity turbidity or water clarity and is measured when an 8" black and white disk is no longer visible as it is lowered into the water column. The measurement is based on both light absorption and the amount of light scattered by particles in the water column. The Secchi depth is higher when there are fewer particles in the water and is usually a representation of productivity of the water. Secchi depths of less than 6.6 feet (2.0 meters) have traditionally been considered undesirable for recreational uses in natural lakes; however, lower clarity is usually tolerated in reservoirs.

Light Transmission

Light transmission is a measurement of light absorption in the water column. The depth at which 1% of the surface light penetrates is considered the lower limit of algal growth and is referred to as the photic zone. The measurement of 1% light transmission 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 shady side of the boat. The underwater sensor is lowered until the value displayed on the data logger is 1% of the value of the ambient sensor, and the depth is recorded.

Chlorophyll a

Chlorophyll is the green pigment that allows plants to photosynthesize. The measurement of chl α in water provides an indirect indication of the quantity of photosynthesizing phytoplankton found in the water column. It is found in all algal groups, as well as in the cyanobacteria. More specifically, chl α is a measurement of the portion of the pigment that was still actively respiring and photosynthesizing at the time of sampling and does not include dead biomass. In surface water, lower chl α concentrations correspond to oligotrophic or mesotrophic conditions, where higher concentrations indicate a eutrophic or hypereutrophic state.

Phosphorus

Phosphorus can be found in several forms in freshwater, but the biologically available form for nuisance plant and/ or algal growth is soluble, inorganic orthophosphate or soluble reactive phosphorus. Organic phosphates quickly bind to soil particles and plant roots and, consequently, much of the phosphorus in aquatic systems is bound and moves through the system as sediment particles. This organic form of phosphorus is considered to be biologically unavailable. However, under anoxic (low oxygen) conditions, bound phosphorus can be released from bottom sediments, and the concentration of biologically available orthophosphate can increase dramatically. The erosion of soil particles from steep slopes, disturbed ground, and streambeds is often an important source of phosphorus in aquatic systems. Surface runoff containing phosphorus from fertilizers, wastewater effluent and decaying organic matter will also contribute to biologically available phosphorus enrichment.

> **Total Phosphorus (TP)** is the measure of all phosphorus in a sample as measured by persulfate digestion and includes: inorganic, oxidizable organic and polyphosphates. This includes what is readily available, potential to become available and stable forms. In surface water, concentrations *<12 µg/L are considered oligotrophic; 12-24 µg/L mesotrophic; 25-96 µg/L eutrophic; and >96 µg/L hypereutrophic.*

Soluble Reactive Phosphorus (SRP) is the measure of dissolved inorganic phosphorus (PO_4^{-3}, HPO_4^{-2}, etc.). This form is readily available in the water column for phytoplankton growth.

Dissolved Phosphorus (TDP) is a measure of all phosphorus forms (inorganic, organic, and polyphosphate) that are dissolved in water.

Nitrogen

Nitrogen has a complex cycle and can exist in organic, inorganic, particulate and soluble forms. The soluble, inorganic, oxidized forms are nitrate (NO_3^{-1}), and nitrite (NO_2^{-1}) which are normally found in surface water. The reduced inorganic form is ammonia (NH_3), which is normally found in low oxygen environments. The inorganic forms, NO_3^{-1}, NO_2^{-1}, and NH_3 are the most available for primary productivity. However, atmospheric nitrogen (N_2) can also be used as a nutrient source by some species of algae or cyanobacteria, and various other reduced forms of nitrogen can be produced by decomposition processes. Particulate and dissolved organic forms of nitrogen are not immediately available to drive algal growth but can be converted to ammonia by bacteria and fungi, and can be oxidized to form nitrites and then nitrates. Surface runoff can contain inorganic nitrogen from fertilizers and organic nitrogen from animal waste, wastewater, etc.

Total Nitrogen (TN) is the quantity of all nitrogen in the water and is calculated by adding the measured forms of organic nitrogen, oxidized nitrogen and ammonia.

Nitrates and Nitrites (NO_3+NO_2) are the sum of total oxidized nitrogen, often readily free for algae uptake.

Ammonia (NH_3) is a reduced form of dissolved nitrogen that is readily available for phytoplankton uptake. NH_3 is found where dissolved oxygen is lacking such as in a eutrophic hypolimnion and is produced as a by-product by bacteria during decomposition.

Nitrogen/Phosphorus Levels and Ratios

Phytoplankton require both macronutrients, such as phosphorus, nitrogen, and carbon, and trace nutrients, including iron, manganese, and other minerals, for growth. Biological growth is limited by the substance that is present in the minimum quantity with respect to the needs of the organism. The ratio of total nitrogen to total phosphorus in a waterbody provides insight into nutrient limitation in the waterbody. Since many species of harmful cyanobacteria (blue-green algae) have the ability to fix nitrogen from the atmosphere, they have a competitive advantage over other algae in phosphorus-rich environments when nitrogen is limited and can become dominant over the more beneficial green algae species. Maintaining a molar N:P ratio greater than 16:1, or 7:1 ratio by weight, will favor a balanced phytoplankton diversity and reduce the potential for a cyanobacteria-dominated environment. The ratio of total inorganic nitrogen to soluble reactive phosphorus can sometimes be more indicative of phytoplankton growth potential since these are the forms most available in the water column.

Trophic State

The Trophic state as described by Vollenweider (1970) is used as a guideline for describing water quality as it relates to the trophic state or biological productivity potential.

Oligotrophic - lack of plant nutrients, low productivity, sufficient oxygen at all depths, clear water, deeper lakes can support trout.

Mesotrophic - moderate plant productivity, hypolimnion may lack oxygen in summer, moderately clear water, warm water fisheries only.

Eutrophic - contains excess nutrients, blue-green algae dominate during summer, algae scums are probable at times, hypolimnion lacks oxygen in summer, poor transparency, rooted macrophyte problems may be evident.

Hypereutrophic - algal scums dominate in summer, few macrophytes, no oxygen in hypolimnion, fish kills possible in summer and under winter ice.

Chloride and Sulfate

Chloride and sulfate are major ions that can be indicators of pollutants entering a watershed due to de-icing activities, treated wastewater discharge, stormwater runoff etc. Conductivity is a measure of the ability of water to conduct electricity, which is a function of all the dissolved ions in solution. Since chloride and sulfate are ions in solution, any increase in their concentrations increases conductivity.

Suspended Solids

Total Suspended Solids (TSS) is a quantification of suspended sediment concentrations in water. Suspended solids in lakes include both organic material, such as algal cells and other microorganisms, and inorganic particulate matter, such as silt and clay particles. Algae and other organisms appear to be the main source of TSS in the open waters, while suspended silts and clays appear to be the primary suspended solids in stream or groundwater samples.

Volatile Suspended Solids (VSS) is a measure of the amount particulate organic material that is present in water.

Organic Carbon

Organic carbon provides a measure of all organic compounds in a water body and can provide an assessment of the carbon-based components or pollution of water. Plant material is often a major component of organic carbon and refractory organic compounds from plants can impart a dark color to lake water. Both total and dissolved organic carbon are measured in analytical samples.

3.0 WATERSHED MONITORING RESULTS

The watershed monitoring program includes analysis of the quantity and quality of potential nutrient source inputs to Cherry Creek Reservoir. During WY 2019, nineteen (19) surface and groundwater sites were monitored on a monthly, every other month or bi-annual frequency.

Monthly Base Flow Sampling

When there is sufficient flow, one sample is collected monthly from the following sites; CT-P1, CT-2, CC-10, CC-7 (EcoPark), CC-O (Outlet) and PC-1. Samples are collected midstream from mid-depth and kept cool until shipped to the laboratory for chemical analyses.

Every Other Month Base Flow Sampling

When there is sufficient flow, one sample is collected every other month from the following sites CT-1, CT-P2, MCM-1, and MCM-2. Samples are collected midstream from mid-depth and kept cool until shipped to the laboratory for chemical analysis.

Bi-Annual Base Flow Sampling

The monitoring includes sampling twice a year (e.g. May and November) at nine surface water sites along Cherry Creek (USGS@Franktown, CC-1, CC-2, USGS@Parker, CC-4, CC-5, CC-6, CC-8, and CC-9). Samples are collected midstream from mid-depth and kept cool until shipped to the laboratory for chemical analysis.

Bi-Annual Groundwater Sampling

The monitoring includes sampling twice a year at four alluvial sites along Cherry Creek: MW-1, MW-5, MW-9, and MW-Kennedy.

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 levels associated with storm events. 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. Following the storm event, water collected by the automatic samplers is combined and stored on ice until transferred to the laboratory for analysis. This sampling procedure occurs at CT-P1, CT-2, CC-10, and CC-7 EcoPark. In May of 2019, a new storm monitoring station was also installed at PC-1. Up to seven storm samples are collected from each of the monitoring sites during the April to October storm season.

The watershed monitoring program evaluates surface water and groundwater:

- Routine surface water sampling results from samples collected on a monthly, every other month, or bi-annual frequency.
- Groundwater sampling results on a bi-annual frequency.
- Storm event sampling results.
- Surface water sites abover and below selected PAPs.

3.1 PRECIPITATION

Historically, precipitation in the Cherry Creek watershed has been measured at NOAA's Centennial Airport weather station (KAPA) located at Lat 39.56°N Long 104.85°W and an elevation of 5,869 ft. This station measured a total of 12.9 inches of precipitation in WY 2019, approximately 79% of the 12-year average. January, March, May and July received above average precipitation, and August and September were significantly lower than the 12- year average which is shown in Figure 4. However, when looking at NOAA's annual precipitation map, the watershed as a whole appears to have received slightly above average precipitation during WY 2019 when compared based on the 30-year PRISM normal from 1981-2010. This data is based on "observed" National Weather Service (NWS) precipitation from the CONUS River Forecast Centers (RFCs), and is displayed as a gridded resolution of roughly 4x4 km as shown in Figure 5. The low precipitation in the late summer contributed to not being able to capture samples to characterize the water quality from as many storm events as usual.

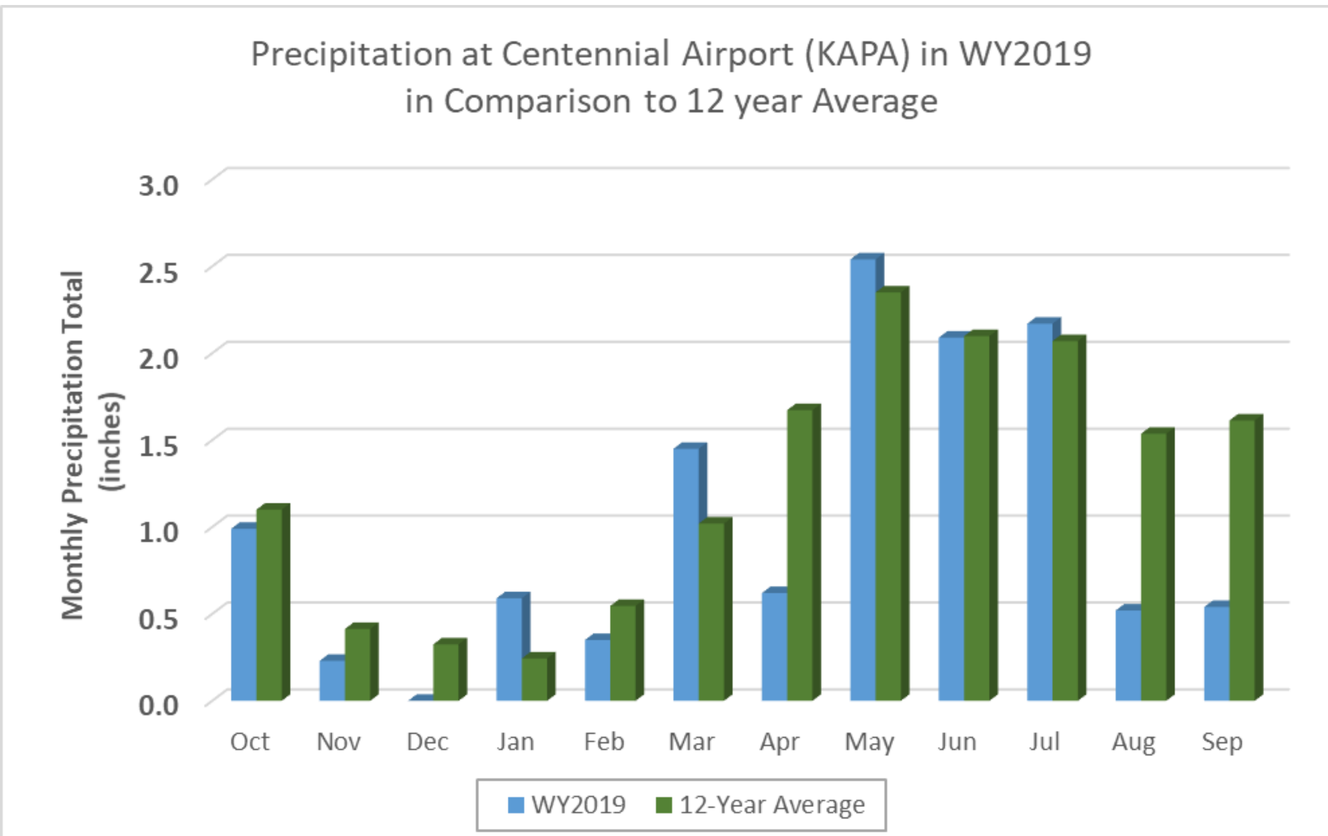


Figure 4. Monthly Precipitation in WY 2019 compared to 12-year average.

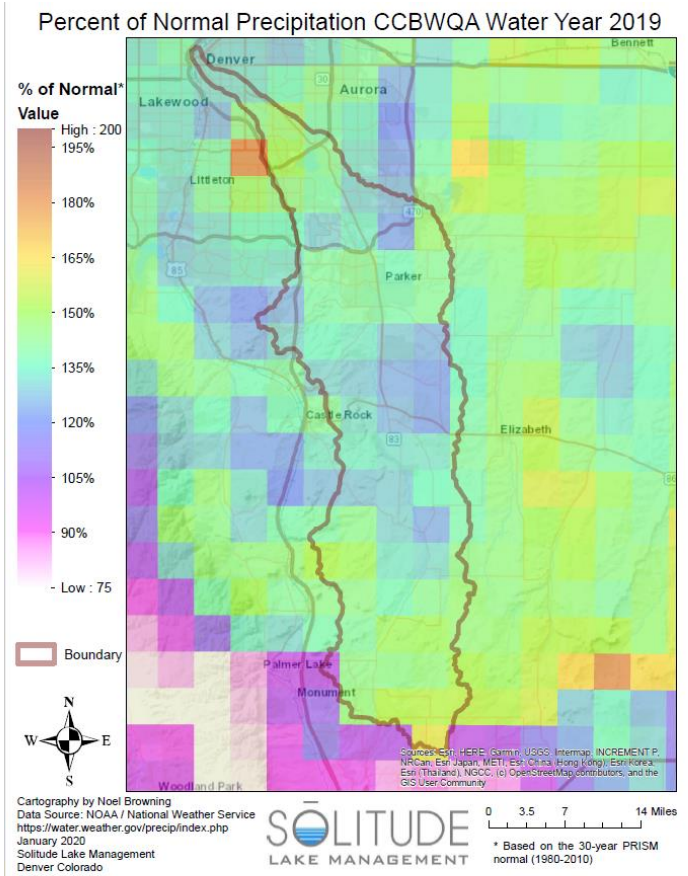


Figure 5. Percent of Normal Precipitation in the Cherry Creek Basin based on 30-year PRISM normal (1981-2010).

3.2 STREAM FLOWS

The U.S. Geological Survey (USGS) operates two gaging stations on Cherry Creek upstream of the Reservoir which are used as monitoring locations for the SAP. The “Cherry Creek near Franktown, CO” station (0671200) has a 76-year period of record (POR) and the “Cherry Creek near Parker, CO” station (393109104464500) has a 25-year POR. The Authority operates two stations upstream of the Reservoir at surface water monitoring sites CC-7 (Eco Park) and CC-10 where pressure transducer level sensors are installed to collect continuous level information.

The USGS Cherry Creek near Franktown station is located in Castlewood Canyon State Park at Lat 39°21'21", Long 104°45'46" referenced to North American Datum of 1927, in NE 1/4 sec.15, T.8 S., R.66 W., Douglas County, CO, Hydrologic Unit 10190003, on right bank. The station is 1.3 mi downstream from Castlewood Dam site, 1.5 mi upstream from Russellville Gulch, and 2.5 mi south of Franktown. This station has a drainage area of 169 mi^2. The USGS WY 2019 provisional summary statistics list a total annual flow of 2,369 AF with an annual daily mean of 6.49 AF. This rate was approximately 71.5% of the annual mean discharge of 9.07 AF calculated from WY1940-WY 2019. Figure 6 shows the estimated daily discharge along with the median daily statistic from the last 79 years.

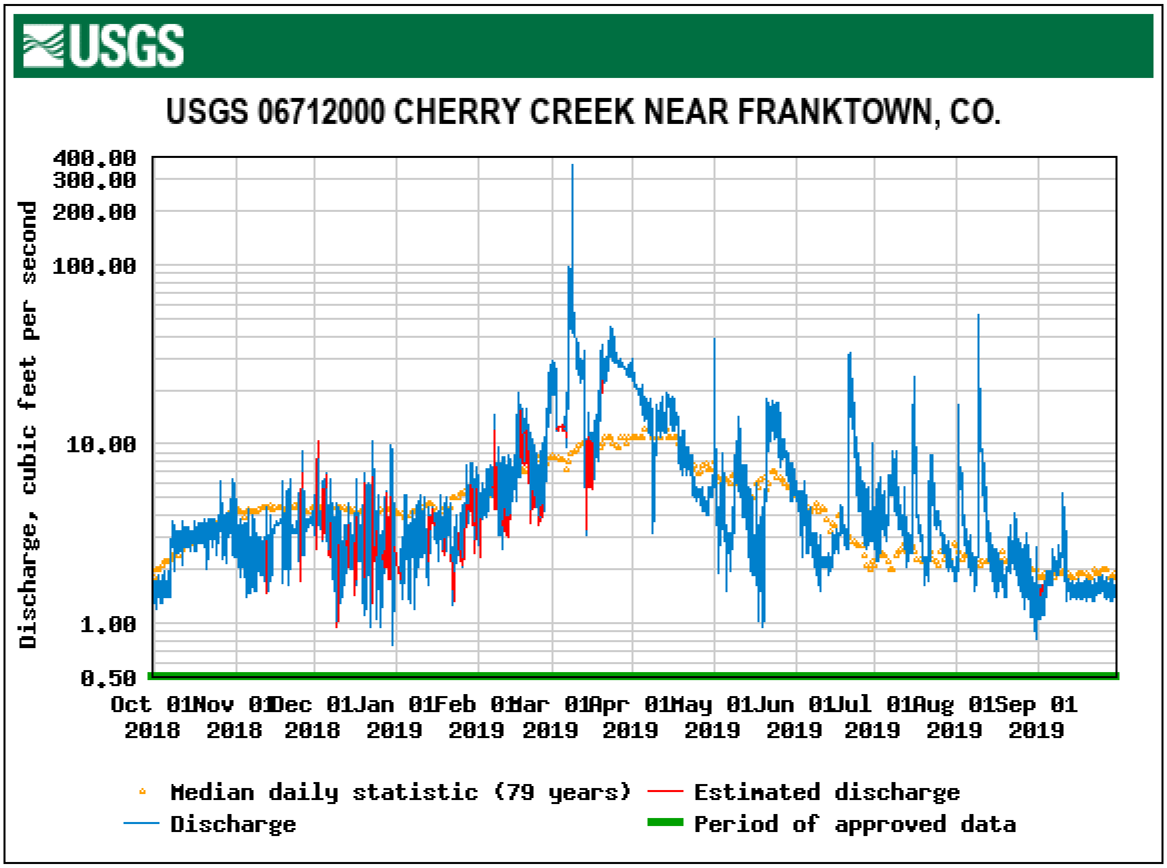


Figure 6. WY 2019 Daily Mean Discharge and Historical Median Flows for USGS Gauge near Franktown (https://nwis.waterdata.usgs.gov/)

The USGS Cherry Creek near Parker station is located at Lat 39°31'09", Long 104°46'45" referenced to North American Datum of 1927, in SE 1/4 NW 1/4 NE 1/4 sec.21, T.6 S., R.67 W., Douglas County, CO, Hydrologic Unit 10190003, on right bank 200 ft upstream from Main Street, 1,100 ft downstream from mouth of Sulphur Gulch, and 0.8 mi west of City of Parker. The station has a drainage area of 287 mi^2.

The USGS WY 2019 provisional summary statistics list a total annual flow of 4,724 AF with an annual daily mean of 12.94 AF. This rate was approximately 114% of the annual mean discharge of 11.3 AF calculated from WY 1992 -WY 2019. Figure 7 shows the estimated daily discharge along with the median daily statistic from the last 28 years.

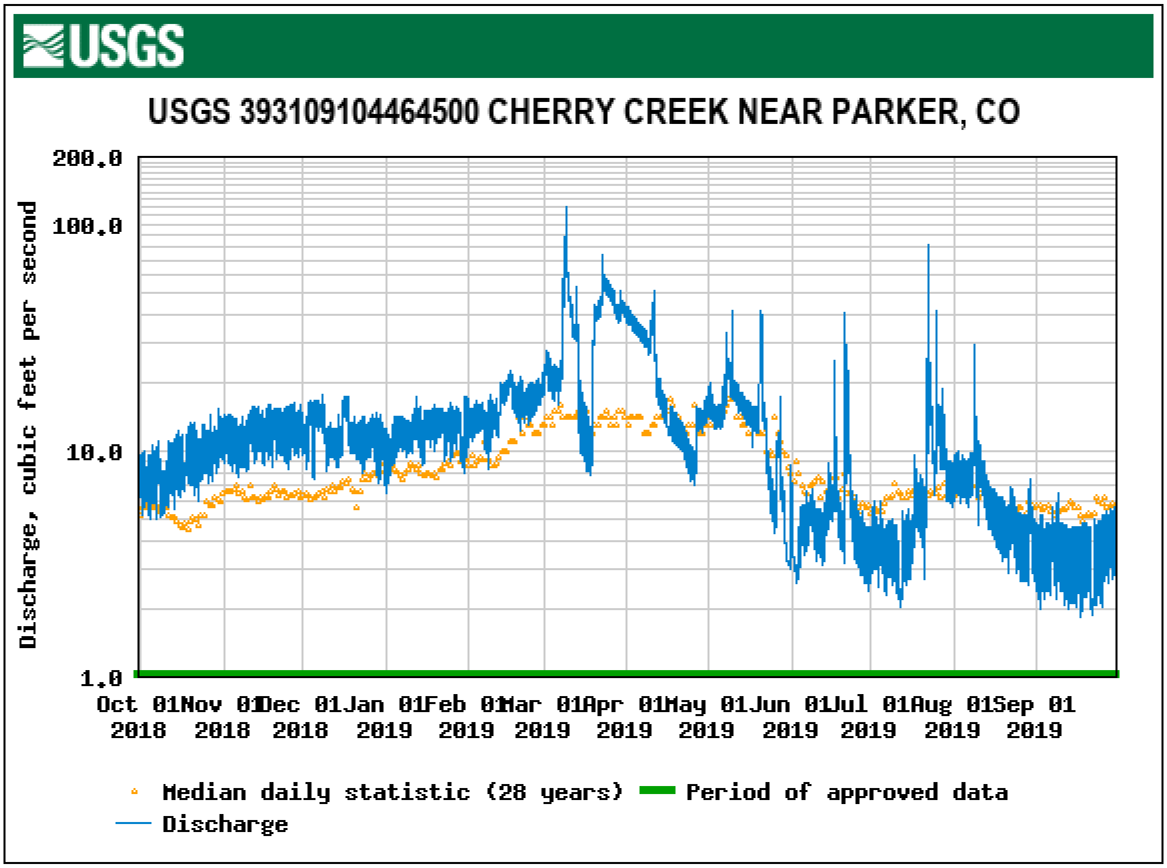


Figure 7. WY 2019 Daily Mean Discharge and Historical Median Flows for USGS Gage near Parker

CCBWQA owns and operates equipment that continuously monitors water levels so annual flows can be calculated at multiple sites along Cherry Creek and Cottonwood Creek. The two recording stations on Cherry Creek are CC-7 (Eco Park) and CC-10, and the two main recording stations on Cottonwood Creek are CT-P1 and CT-2 which are included in the SAP. The CCBWQA provides Arapahoe County Water & Wastewater Authority flow data for site CT-1 for Regulation 85 compliance so level is recorded, and flows are also calculated for the CT-1 site. CC-10 is located just upstream of the Reservoir on Cherry Creek and CT-2 monitoring site is located at the outflow of “Perimeter Pond” on Cottonwood Creek also upstream of the Reservoir. These two sites are used to calculate inflows and nutrient loading into the reservoir. (Figure 8 and Figure 9). The raw data for the levels and flows are available on the CCBWQA data portal.

The estimated WY 2019 flow at the CC-10 monitoring site totals 14,447 AF with an average daily discharge of 39.7 AF. The estimated WY 2019 flow at the CT-2 monitoring site total 3,754 AF with an average daily discharge of 10.3 AF.

The USACE calculates net daily inflow into the Cherry Creek Reservoir by estimating the change in reservoir storage and accounting for loss from outlet release and estimated evaporation and gains from precipitation based on surface area of the Reservoir. The USACE’s net daily inflow calculation includes flows from Cherry Creek, Cottonwood Creek, other minor tributaries, and alluvial groundwater. The USACE’s WY 2019 daily inflow estimates are included in Appendix A.

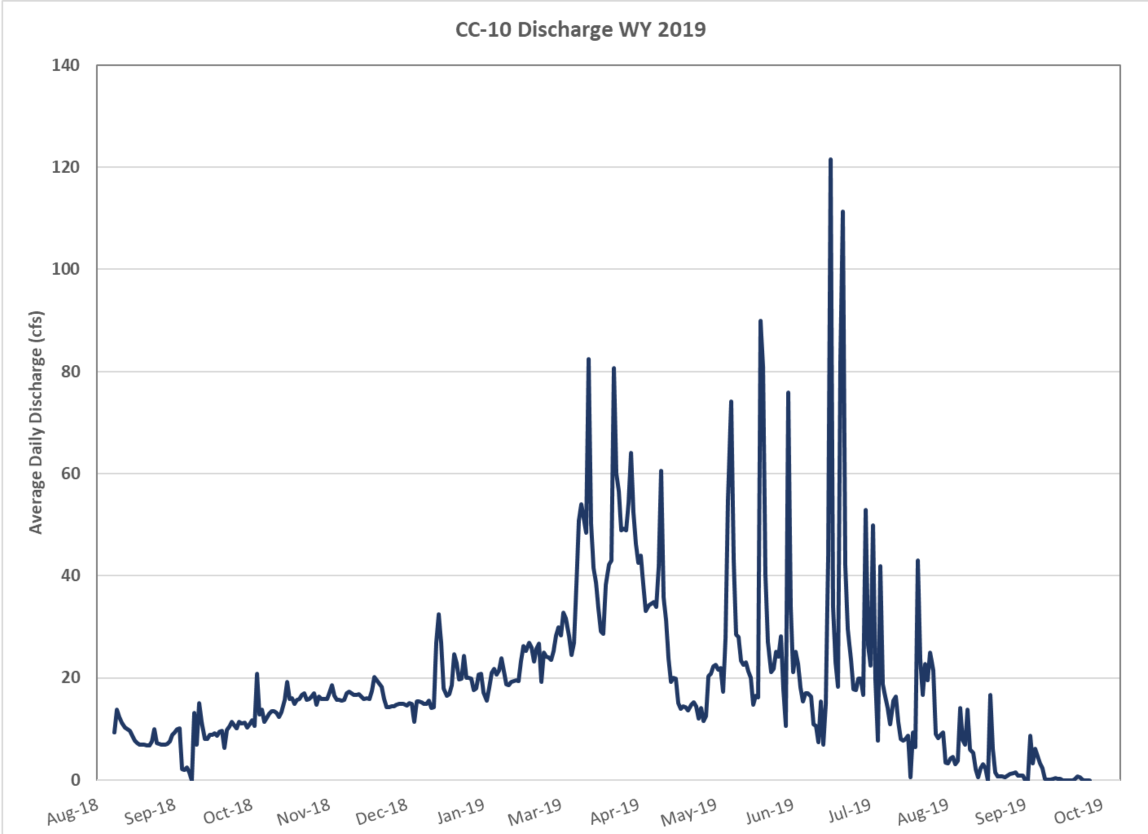


Figure 8. Daily Discharge Rates at CC-10 during WY 2019.

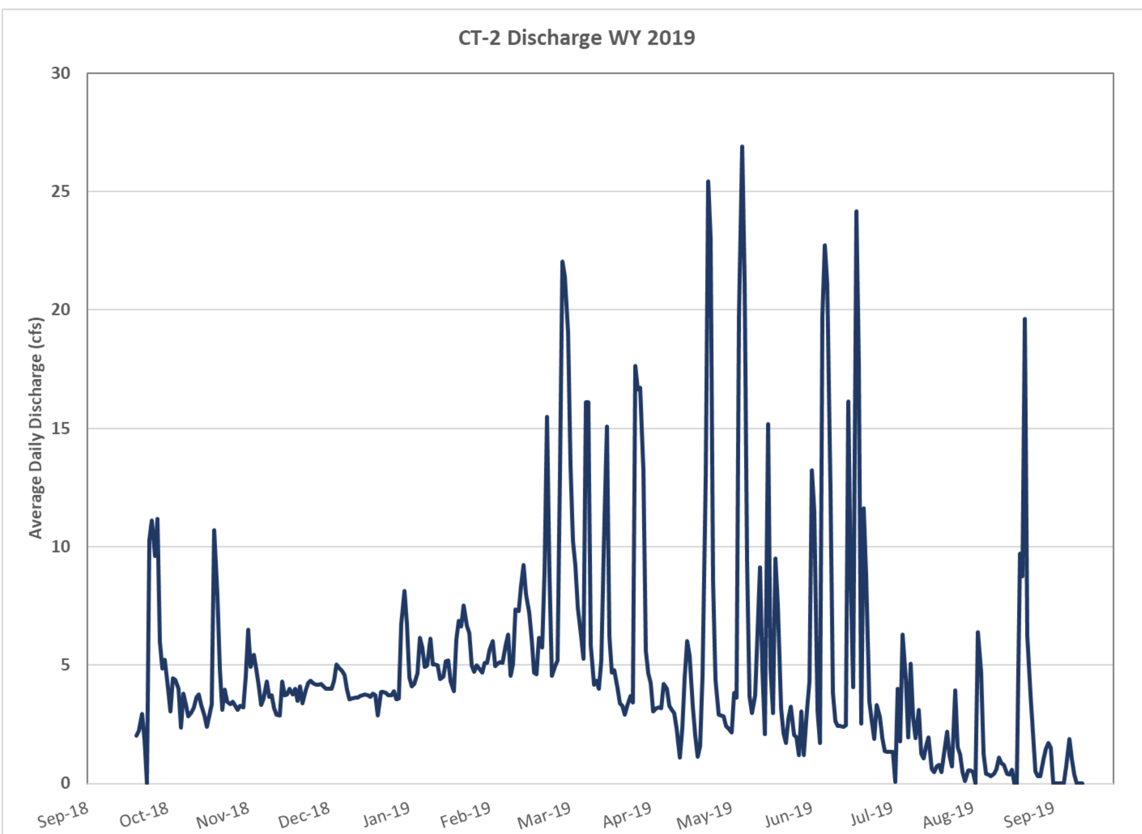


Figure 9. Average Daily Discharge at CT-2 during WY 2019.

3.3 CHERRY CREEK WATER QUALITY

Chery Creek flows from south to north to the Reservoir through a 245,000-acre drainage basin. The basin includes various types of land use, including agriculture in the upper basin and heavy development closer to the Reservoir, as well as permitted discharges in and around Cherry Creek. The SAP includes monitoring of all the sites along Cherry Creek from upstream to downstream two times per year in the spring and fall. Water samples and field measurements are taken at each site starting in Castlewood Canyon (USGS near Franktown) site and moving downstream towards the Reservoir.

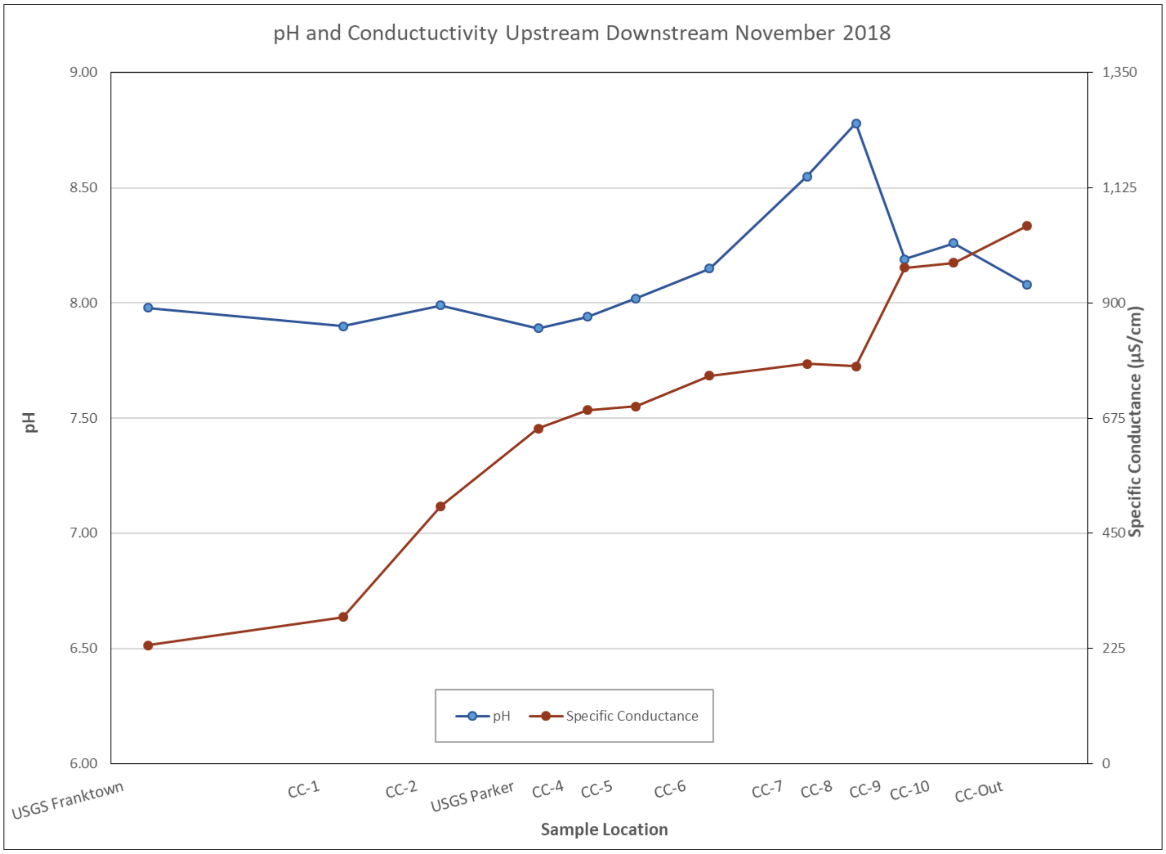


Figure 10. pH and Conductivity Upstream to Downstream on Cherry Creek, November 2018.

The specific conductance (conductivity) and pH were monitored from the surface water sites from the upper basin downstream to the Reservoir in November 2018 and May 2019 ((Figure 10 and Figure 11). Conductivity values were 4.5 times higher from the furthest upstream (USGS Franktown) to lowest downstream site (CC-O below the Reservoir) in both November 2018 and in May 2019. The increasing conductivity in the upstream to downstream samples indicates increased dissolved solids, such as salts, in the water, as it moves towards and out of the Reservoir. In addition, evaporation could play a role in increasing these values as well, especially in the Reservoir and below. The pH has some minimal variability but remained within the same range on both sampling events, ranging from approximately 7.7 to 8.5 throughout the basin.

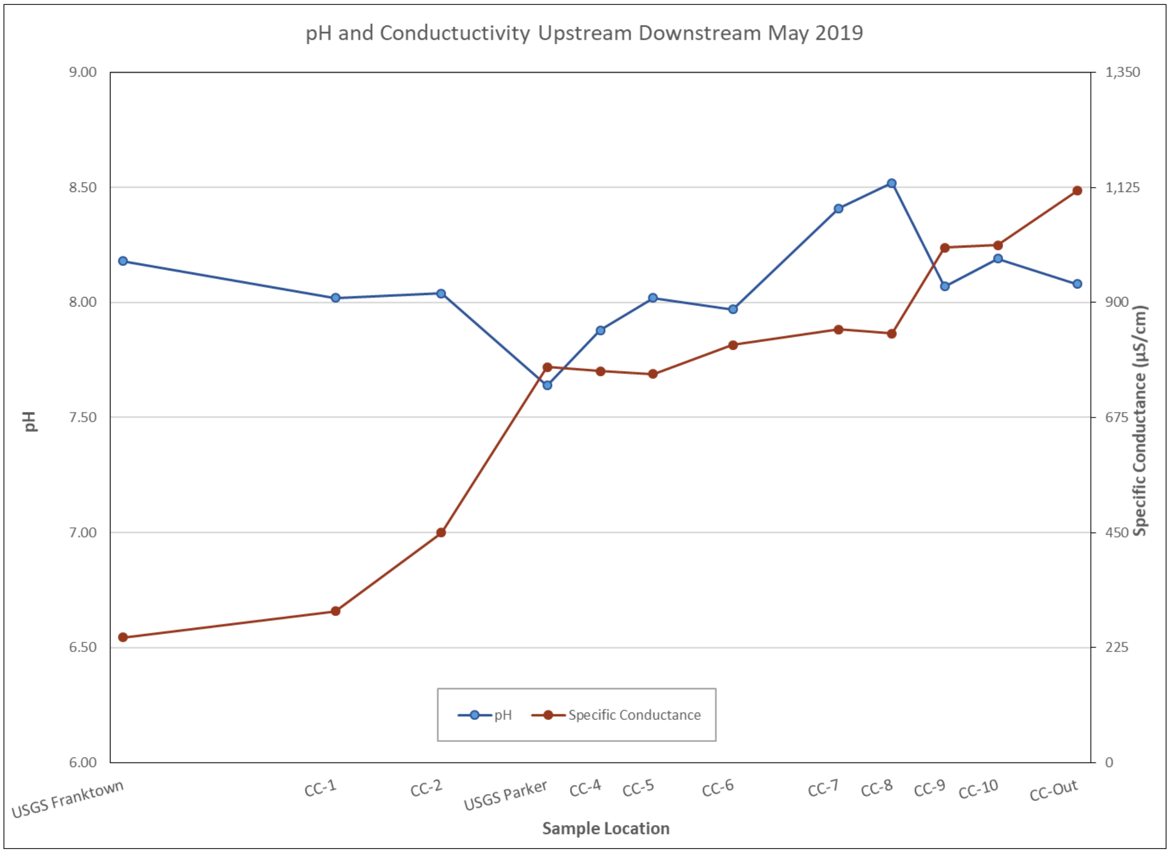


Figure 11. pH and Conductivity Upstream to Downstream on Cherry Creek, May 2019.

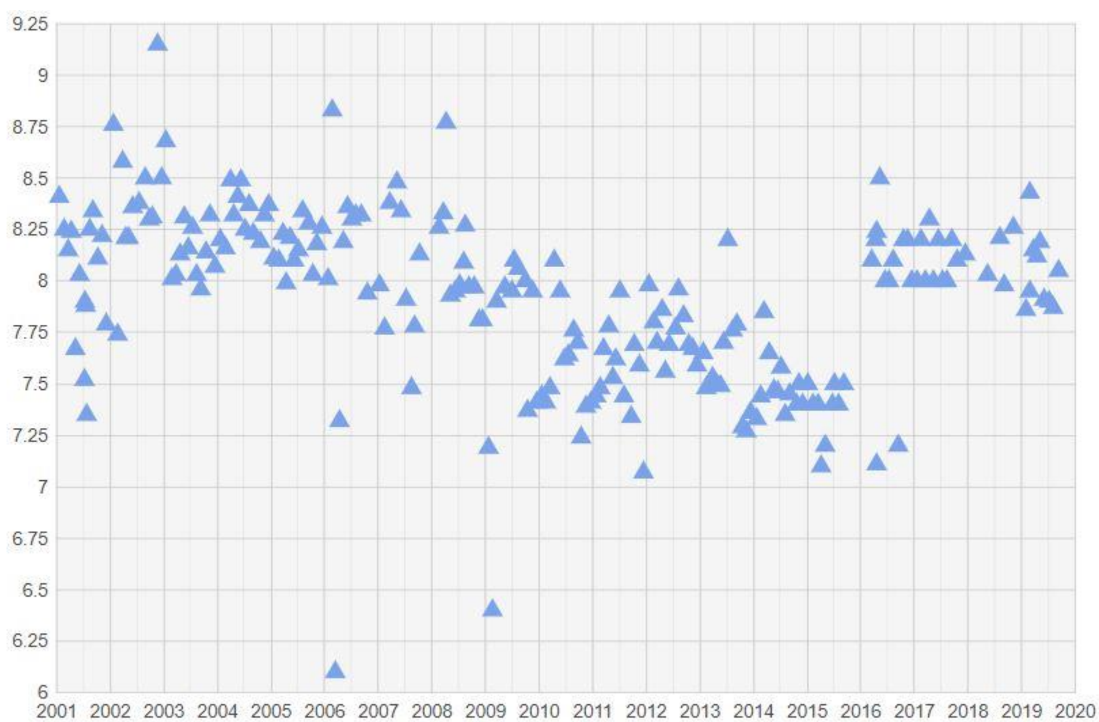


Figure 12. Historical pH Values at CC-10 through WY2019 (X-axis) and pH (Y-axis)

The historical pH values measured at CC-10 appear to have slightly decreased for a few years between 2009 and 2016 but have shown higher values over the last 3 years (Figure 12). In WY 2019, the pH values sampled at CC-10 ranged from 7.9 to 8.4.

The specific conductance values measured at CC-10 indicate an increasing trend over the last ten to twelve years, with most values double what they were when the monitoring program started (Figure 13). In WY 2019, the specific conductance values sampled at CC-10 ranged from 610 to 1,307 µS/cm. The mean specific conductance on Cherry Creek was 1,069 µS/cm which was significantly lower than the mean on Cottonwood Creek during WY 2019 which was 1,862 µS/cm.

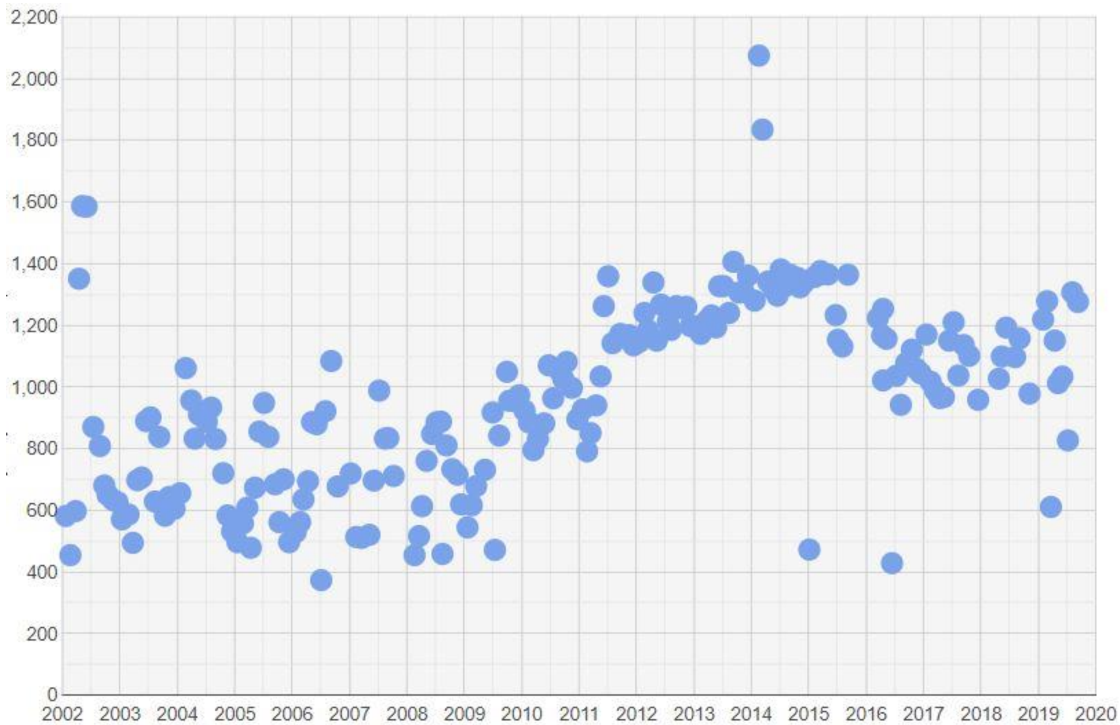


Figure 13. Historic Conductivity at CC-10 through WY 2019. Specific Conductance µS/cm (Y-axis)

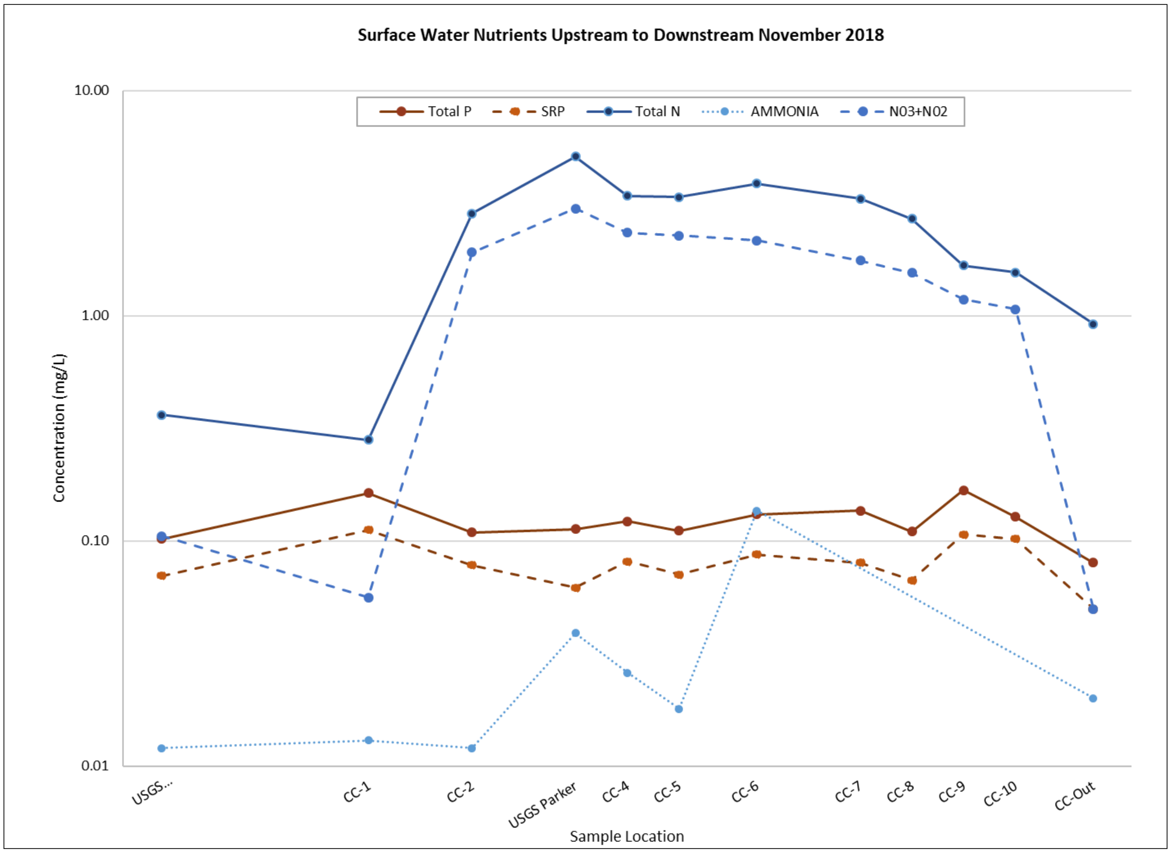


Figure 14. Surface Water Nutrient Sampling of Cherry Creek, November 2018 .

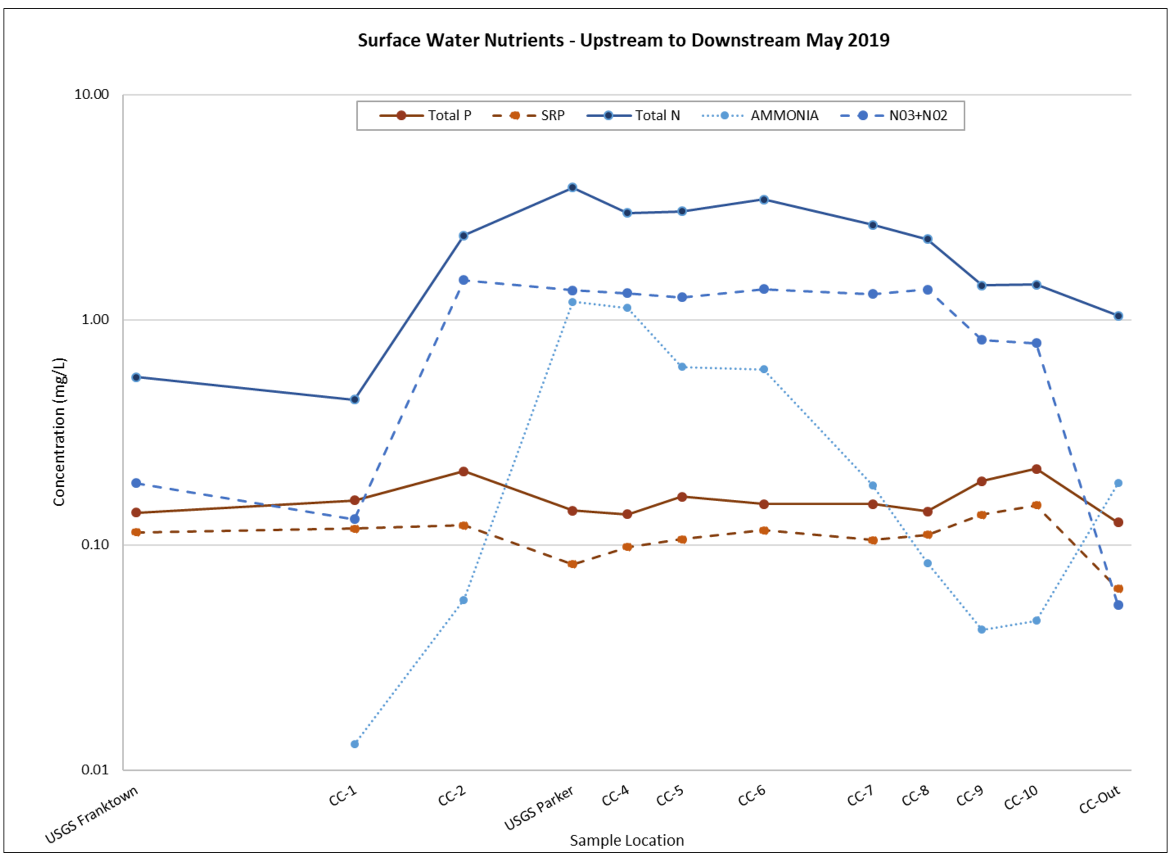


Figure 15. Surface Water Nutrient Sampling of Cherry Creek, May 2019.

During both comprehensive upstream to downstream sampling events, the level of TP remained relatively constant. However, the TN increased from the USGS near Franktown site downstream to the CC-2 site, then leveled out till around CC-6 where the value then decreased all the way to the Reservoir and outflow (Figure 14 and 15). During both events the TP levels from the outlet site (CC-O) were less than those entering the Reservoir.

In the May 2019 sample, the NH_3-N concentration at CC-0 was higher below the lake. In contrast during both sampling events, all other nutrient concentrations were lower below the lake than the sites on Cherry Creek just above the Reservoir. The concentrations from these sampling events indicate nutrient retention or utilization within the Reservoir before release from the outlet. The increase in NH_3-N concentrations below the lake may have been the result of anoxic conditions in the hypolimnion of the reservoir.

Summary statistics for total phosphorus, total nitrogen, and TSS concentrations at CC-10 during base and storm flows during WY 2019 are provided in Table 5. The TP concentrations ranged between 103 and 1,020 µg/L during the year. The mean TP concentrations were more than double in storm flow than base flow. The TN concentrations ranged between 595 and 3,500 µg/L during WY 2019. The mean TN concentrations were 84% higher in storm flows. The values of TSS ranged between 5 and 637 mg/L and the mean values were more than ten times higher in storm flow than base flow conditions sampled.

Table 5. Total Phosphorus and Total Nitrogen at CC-10 during Base Flow and Storm Events, WY 2019.

Statistic	Total Phosphorus (µg/L)			Total Nitrogen (µg/L)			Total Suspended Solids (mg/L)		
	Base Flow	Storm Flow	Percent Difference	Base Flow	Storm Flow	Percent Difference	Base Flow	Storm Flow	Percent Difference
Count	12	4		12	4		12	4	
Minimum	103	252	145%	595	1,510	154%	5	96	1,859%
Maximum	307	1,020	232%	1810	3,500	93%	34	637	1,801%
Mean	187	488	161%	1213	2,230	84%	14	243	1,627%
Median	158	341	116%	1340	1,955	46%	11	119	1,018%

The relationship between phosphorus and nitrogen and TSS concentrations is also reflected in the difference in concentrations from samples collected at CC-10 during storm and base flow sampling events. Figure 16 illustrates the relationship between TP and TN and both nutrients in relation to TSS in the water. Over time there is variability of both TN and TP during the base and storm flow monitoring. Typically storm flows increase the suspended sediments in the water, represented by higher values of TSS. During WY 2019, there was a distinct correlation of higher nutrient concentrations when the TSS levels were higher. These data suggest that storm events may contribute a large percentage of the total nutrient and sediment loading to the Reservoir.

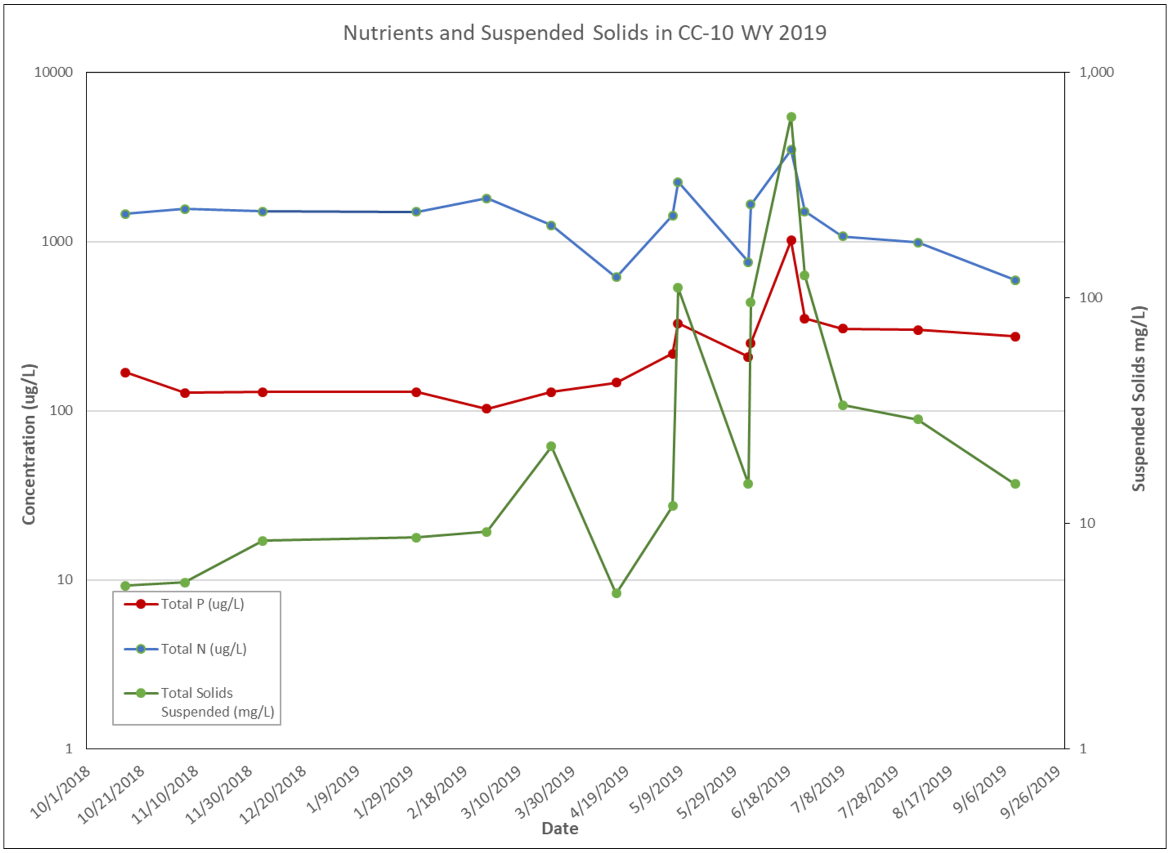


Figure 16. Comparison of Total Phosphorus and Nitrogen to Total Suspended Solids at CC-10, WY 2019.

3.3.1 PINEY CREEK

Piney Creek is one of the primary tributaries which feeds Cherry Creek. In 2018, a sampling site was added on this creek in order to determine water quality from this sub-basin and potential influence on the water quality in Cherry Creek. This site was sampled every other month during 2018 and changed to monthly during 2019 after the site was relocated to a permanent site and storm monitoring equipment was installed. The mean values for each of the analytes from the samples collected during WY 2019 are listed in the table below. As a reference the mean values for the same parameters from Cherry Creek at CC-10 and Cottonwood Creek at CT-2 from the same dates during base flow conditions are listed in the table for comparison. Due to equipment difficulty detecting low levels at this site, only one grab storm sample was collected in WY 2019 and was not included in the analysis.

During WY 2019 all nutrient and suspended solids mean concentrations were significantly lower in Piney Creek than just below the confluence with Cherry Creek during the same time period. In future years, additional storm sampling will be completed at this site to further evaluate the water quality in storm flows in addition to base flow conditions.

In comparison, in base flow conditions, all forms of phosphorus (TP, SRP and TDP) concentrations were higher in Piney Creek than on Cottonwood just upstream of the reservoir at CT-2. However, all forms of nitrogen (TN, NO_3+NO_2-N, and NH_3-N) and suspended solids were lower in Piney Creek than at the CT-2 site.

Table 6. Water Quality in Piney Creek Compared to Cherry Creek and Cottonwood Creek, WY 2019.

Base Flow	**Mean Concentration**		
N=	**9**	**12**	**12**
	Site		
Analyte	**PC-1**	**CC-10**	**CT-2**
TP, µg/L	92.1	187.1	47.6
SRP, µg/L	62.5	126.9	7.75
TDP, µg/L	68.5	148.6	18
TN, µg/L	1,009.5	1,213.2	2,323.5
NO_3+NO_2-N, µg/L	438.4	730.3	1,220.9
NH_3-N, µg/L	18.4	35.7	101
TSS, mg/L	8.2	14.04	11.1
VSS, mg/L	2.3	3.5	3.01

3.4 COTTONWOOD CREEK WATER QUALITY

Cottonwood Creek is the second largest surface water input to Cherry Creek Reservoir. Cottonwood Creek has a smaller watershed, more developed land use, and fewer permitted wastewater discharges than Cherry Creek. There are four monitoring sites on Cottonwood Creek. There are two sites upstream on Cottonwood Creek off Peoria St. and two sites in Cherry Creek State Park. These sites are monitored regularly and CT-P1 and CT-2 are equipped with equipment to monitor stream levels and collect storm samples.

CT-2 is the site upstream on Cottonwood Creek just before it enters the Reservoir and it is representative of inflow water quality. The other Cottonwood Creek sites are discussed in regard to the evaluation of the effects of the PRFs in Section 3.5 below.

During WY 2019, the pH of water in Cottonwood Creek before it entered the Reservoir ranged from 7.7 to 8.2. Conductivity at CT-2 ranged between 1,192 µS/cm and 3,507 µS/cm with a mean value of 1,862 µS/cm. This is higher than the mean for Cherry Creek, which was 1,069 µS/cm for WY 2019.

Summary statistics for total phosphorus, total nitrogen, and TSS concentrations at CT-2 during base and storm flows during WY 2019 are provided in Table 7. The TP concentrations ranged between 34 and 77 µg/L during the year. The median TP concentrations were 32% higher in storm flows than the base flow conditions measured. The TN concentrations ranged between 638 and 3,930 µg/L during WY 2019. The median TN concentrations were 12% lower in storm flows. The values of TSS ranged between 5 and 21 mg/L and the median values were 32% lower in storm than base flow conditions sampled. Some of the variability may be due to the fact that water quality from only 4 storm events were able to be captured in WY 2019.

Table 7. TN and TP at CT-2 During Base Flow and Storm Events, WY 2019.

Statistic	Total Phosphorus (µg/L)			Total Nitrogen (µg/L)			TSS (mg/L)		
	Base Flow	Storm Flow	Percent Difference	Base Flow	Storm Flow	Percent Difference	Base Flow	Storm Flow	Percent Difference
Count	12	4		12	4		12	4	
Minimum	34	56	65%	638	1,220	91%	5	6	6%
Maximum	72	77	7%	3,930	2,660	-32%	21	11	-48%
Mean	48	67	41%	2,324	1,850	-20%	11	8	-26%
Median	46	60	32%	1,935	1,700	-12%	10	7	-32%

The concentrations of TP and TN measured at CT-2 in WY 2019 are shown in Figure 17 with the TSS values on the second axis as a comparison. As pictured, a similar relationship between nutrients and TSS is present on Cottonwood Creek at CT-2, although it is much less significant than seen Cherry Creek. In addition, the TP concentrations are much higher entering the Reservoir at CC-10 than at CT-2 during WY 2019.

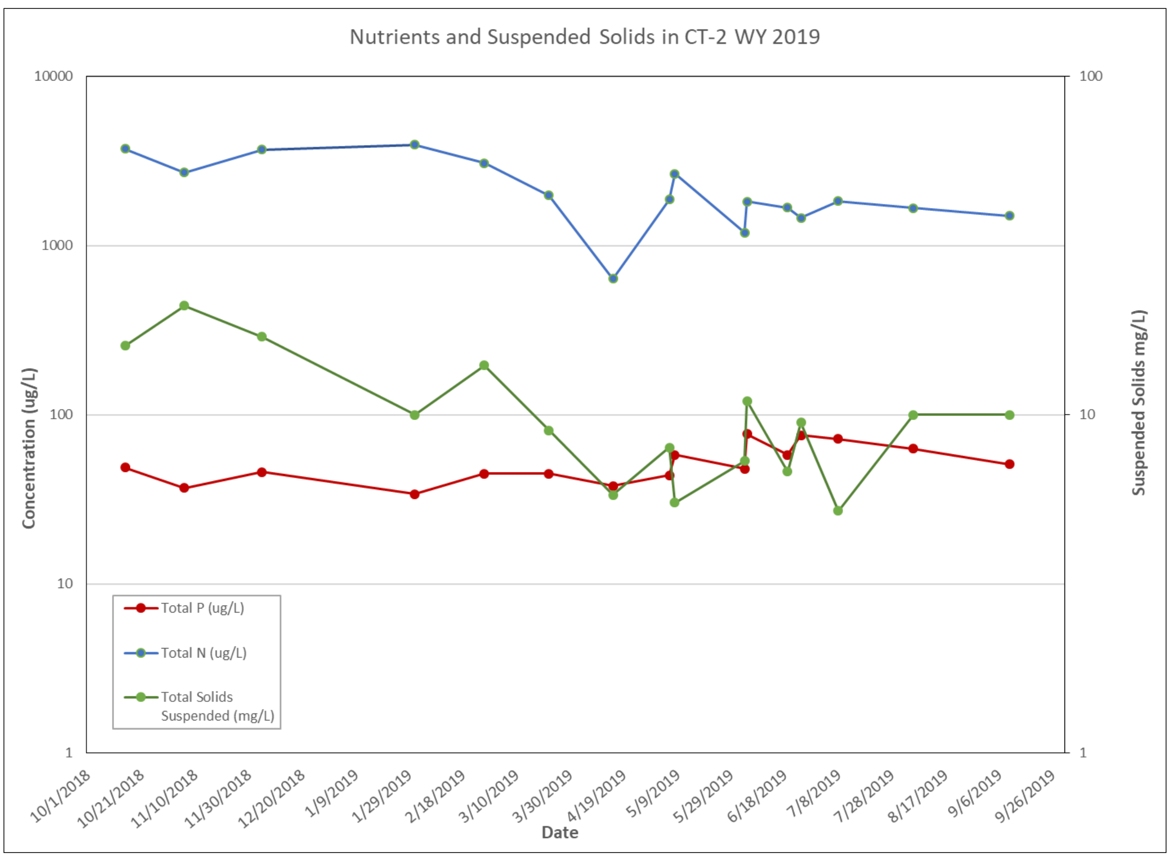


Figure 17. Comparison of Nutrients and Suspended Solids at CT-2 during WY 2019.

3.5 POLLUTANT REDUCTION FACILITIES

The Cherry Creek Basin Water Quality Authority has completed multiple pollutant abatement projects (PAPs) which include pollution reduction facilities (PRFs) in various locations through the watershed. WQCC Control Regulation No. 72 states:

"Pollutant Reduction Facility (PRF) means projects that reduce nonpoint source pollutants in stormwater runoff that may also contain regulated stormwater. PRFs are structural measures that include, but are not limited to, detention, wetlands, filtration, infiltration, and other technologies with the primary purpose of reducing pollutant concentrations entering the Reservoir or that protect the beneficial uses of the Reservoir."

The SAP includes assessment of the effectiveness of selected PRF projects in relation to nutrients and sediment concentrations as water moves downstream. The current monitoring program includes assessment of the PRFs on Cottonwood Creek and McMurdo Gulch.

The Cottonwood Creek PRF is a series of wetland detention systems along with an area where stream reclamation has been completed, collectively referred to as the Cottonwood Treatment Train. The monitoring program includes water quality samples during routine sampling as well as storm conditions above and below these sites.

Samples are collected during base flow and/or storm events at four monitoring sites on Cottonwood Creek (Table 3). Monitoring sites CT-P1 and CT-P2 monitor the inflow and outflow of the PRF located west of Peoria Street (Peoria Pond) and sites CT-1 and CT-2 monitor the inflow and outflow of the PRF located just upstream of the Reservoir in the park (Perimeter Pond).

During WY 2019, during base flow conditions in the Cottonwood Treatment Train, mean concentrations of TP, SRP, TDP, TSS and VSS upstream to downstream between CT-P1 and CT-2 all decreased (Table 8.) During those same conditions, TN, NO_3+NO_2-N and NH_3-N mean concentrations increased. During storm flow conditions, all nutrients and suspended solid concentrations decreased from the upstream to downstream site. In all the PRF data analysis, the increased concentrations from upstream to downstream are highlighted in light red and the decreased concentrations are highlighted in light green.

Table 8. Pollutant Reduction Analysis of the Cottonwood PRFs in WY 2019

	Base Flow				Storm Flow			
	Mean Concentration		Upstream to Downstream		Mean Concentration		Upstream to Downstream	
Site	CT-P1	CT-2	Net	Percent	CT-P1	CT-2	Net	Percent
Events	12	12	Difference	Difference	4	4	Difference	Difference
Analyte								
TP, µg/L	98.8	47.7	-51.1	-51.7	209.2	65.4	-143.8	-68.7
SRP, µg/L	13	7.8	-5.3	-40.4	13.7	12.2	-1.5	-10.7
TDP, µg/L	20.8	18	-2.8	-13.6	27	25	-2	-7.4
TN, µg/L	1255.9	2323.5	1067.6	85	2074	1818	-256	-12.3
NO2+NO3,µg/L	397.1	1176.5	779.4	196.3	551.8	403.6	-148.2	-26.9
NH4, µg/L	71.1	102.0	30.8	43.4	81.2	60.6	-20.6	-25.4
TSS, mg/L	43	11.1	-31.9	-74.2	166	7.9	-158.1	-95.2
TVSS, mg/L	7.9	3	-4.9	-62	31.9	3.1	-28.8	-90.3

Based upon the data collected in WY 2019, the Cottonwood Treatment Train as a whole (between Peoria Pond and Perimeter Pond), combined with water quality controls by others, such as nutrient reductions at WWTPs and water quality detention ponds required by MS4s and other land use agencies, reduced TP concentrations by approximately 52% under base flow conditions and 69% during storm events. Sediment concentrations, measured as TSS, were reduced by approximately 74% under base flow conditions and 95% during storm flows. Based on the concentrations in base and storm flow events, the PRFs reduced phosphorus and suspended sediment concentrations in downstream flows during WY 2019.

However, when evaluating the two sections individually (Peoria Pond and Perimeter Wetland System), (Table 9 and Table 10) it appears that the majority of the effectiveness of nutrient and sediment reduction in base flows can be attributed to the Peoria Pond PRF during WY19. The TP concentrations from site above the Peoria Pond to site below were reduced by 44% in comparison to 11% upstream to downstream of the Perimeter pond. Concentrations of SRP and TDP increased through the Perimeter pond and TN increased through the Peoria Pond, but all other parameters displayed lower concentrations in the downstream samples. The increases seen downstream could be due to resuspension of sediments or breakdown of organic matter in the pond. The difference could also indicate sediment removal and plant harvesting may be beneficial to remove organic material and to restore capacity and function.

In 2017 the Authority stopped collecting comprehensive water quality and flow data at CT-P2 and CT-1 due to the belief that the whole Cottonwood Treatment Train could be evaluated as a whole. However, for WY 2020, the two sites are being brought back into the SAP to continue monthly data and flow collection at all sites.

Table 9. Pollutant Reduction Analysis of the Cottonwood Creek "Perimeter Pond" Wetland PRF in WY 2019.

	Base Flow			
	Mean Concentration		Upstream to Downstream	
Site	CT-1	CT-2	Net Difference	Percent Difference
Events	6	12		
Analyte				
TP, µg/L	53.7	47.7	-6	-11.3
SRP, µg/L	6.3	7.8	1.5	23.3
TDP, µg/L	15.4	18	2.6	16.7
TN, µg/L	2,568.3	2,323.5	-244.8	-9.5
NO2+NO3, µg/L	1,362.7	1,176.5	-186.2	-13.7
NH4, µg/L	107.5	102	-5.5	-5.2
TSS, mg/L	17.3	11.1	-6.2	-35.9
TVSS, mg/L	3.9	3	-0.9	-23.3

Table 10. Pollutant Reduction Analysis of the Peoria St. Wetland PRF in WY 2019.

	Base Flow			
	Mean Concentration		Upstream to Downstream	
Site	CT-P1	CT-P2	Net Difference	Percent Difference
Events	12	6		
Analyte				
TP, µg/L	98.8	55.2	-43.6	-44.1
SRP, µg/L	13	8.7	-4.3	-33.3
TDP, µg/L	20.8	15.3	-5.5	-26.4
TN, µg/L	1,255.9	1368.2	112.3	8.9
NO2+NO3, µg/L	1,362.7	1176.5	-186.2	-13.7
NH4, µg/L	71.1	53.6	-17.5	-24.7
TSS, mg/L	43	14.6	-28.4	-66
TVSS, mg/L	7.9	4.3	-3.6	-45.8

One of the upper tributaries of Cherry Creek is McMurdo Gulch, which had a reclamation project completed early in the areas' urbanization, a proactive PRF designed to protect the gulch and reduce sediment and nutrient loading into Cherry Creek. Routine water quality samples only under base flow conditions were collected every other month from monitoring site MCM-1, upstream of the stream reclamation project area, and MCM-2, downstream.

Table 11. Pollutant Reduction Analysis of the McMurdo Gulch in WY 2019.

Mean Concentration			Upstream to Downstream	
Flow	Base			
Site	MCM-1	MCM-2	Mean Difference	Percent Change
Events	5	5		
Analyte				
TP, µg/L	315.7	225.0	-90.1	-29%
SRP, µg/L	277.7	206.0	-71.7	-26%
TDP, µg/L	297.3	216.0	-81.3	-27%
TN, µg/L	532.2	373.0	-159.2	-30%
NO2+NO3, µg/L	248.7	87.5	-161.2	-65%
NH_3-N, µg/L	18.7	5.8	-12.9	-69%
TSS, mg/L	5.8	1.5	-4.3	-74%
VSS, mg/L	1.7	0.4	-1.3	-76%

In WY 2019, TP, TDP, SRP, and NO_3+NO_2-N were all reduced upstream to downstream of the McMurdo stream reclamation project (Table 11). During the sampling period, measured values of both TSS and VSS were higher downstream of the PRF. Although the percent increases were high, 544% and 151% respectively, the overall increase in TSS and VSS values were not that significant since the levels upstream were so low. The water level in McMurdo Gulch was also very low as the season progressed, which could have affected sampling results for these parameters.

3.6 GROUNDWATER

Four well sites are included in the alluvial groundwater monitoring, which is completed twice per year in the spring and fall (Table 3). The wells are located throughout the basin, including the top of the basin (MW-1), the middle of the basin (MW-5), and just upstream (MW-9) and just downstream of the Reservoir (MW- Kennedy) (Figure 2).

3.6.1 LEVEL AND TEMPERATURE

The groundwater level in well MW-9 is measured with a continuous water level and temperature monitoring device which was installed in April 14, 2016. This equipment records pressure transducer levels and temperature every 15 minutes. The daily mean water level and temperature values measured in well MW-9 can be found in Figure 12.

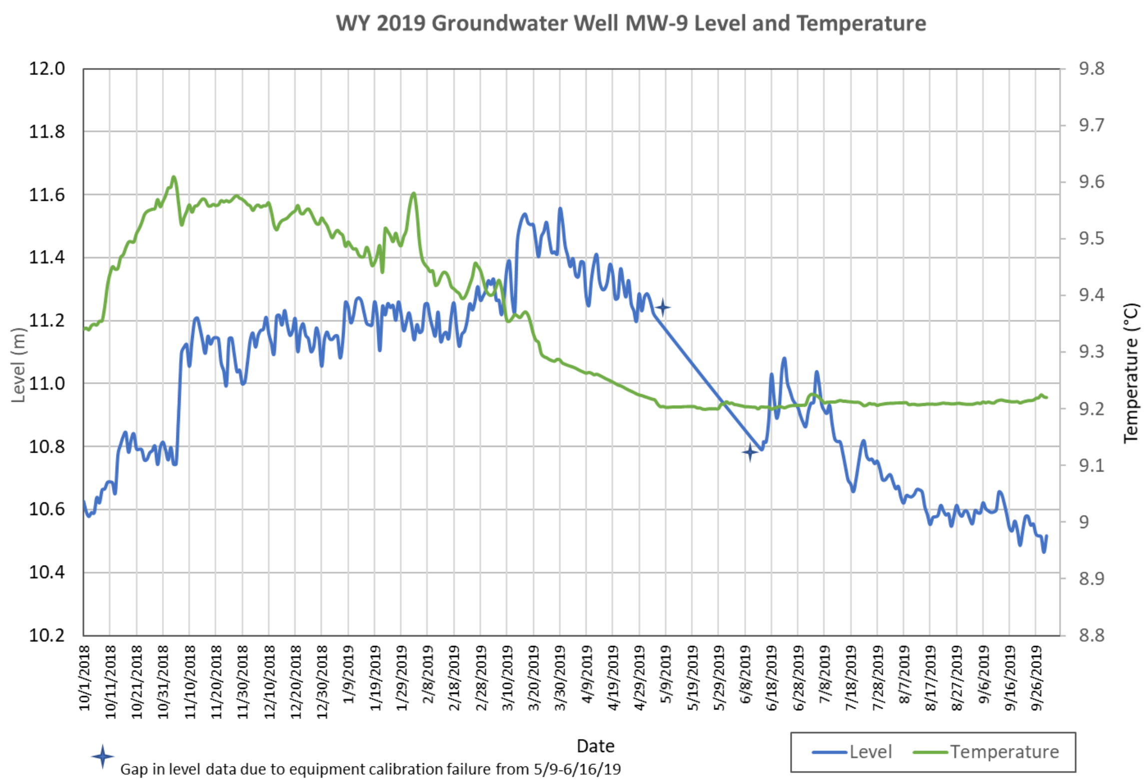


Figure 18. Daily Mean Level and Temperature in Groundwater Well MW-9.

The level and temperature in groundwater well MW-9 has some seasonal fluctuation. The highest temperatures were observed in late October through early January of 2019 and the lowest were observed in May through September 2019. The water levels in MW-9 fluctuated daily but a decreasing trend was observed as the year progressed, with the lowest values observed in September 2019. Due to a problem with sensor calibration, there was a minimal amount of data loss between May 9 and June 16, 2019.

3.6.2 GROUNDWATER WATER QUALITY

Alluvial well MW-1 has been sampled since 1994 and is located approximately halfway between Parker and Franktown, 270 meters southeast of where Bayou Gulch Road crosses Cherry Creek near Parker Road.

Well MW-5, in the Town of Parker, 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 650 meters west of Parker Road.

The MW-9 alluvial well monitoring site has been sampled since 1994 and is located in Cherry Creek State Park near the State Park office and is the basis for evaluating groundwater entering Cherry Creek Reservoir.

The MW-Kennedy well has been sampled since 1994 and is located on the Kennedy Golf Course to monitor groundwater quality downgradient from Cherry Creek Reservoir.

The data suggest that the TP concentrations remain relatively consistent between the wells in November 2018 and May 2019. In contrast, TN decreases as the wells get closer to the Reservoir, and slightly lower below the dam. The TP concentrations were also at the lowest levels below the outlet.

Data from November 2018 and May 2019 mirrors the comprehensive basin sampling of all Cherry Creek sites, showing little difference in TP concentrations between surface water and groundwater. The mean concentration of TP in the GW sites was 0.29 mg/L, with concentrations of 0.26 mg/L in November 2018 and 0.32 mg/L in May 2019. In contrast, the TN concentrations in the GW decrease toward the Reservoir during both monitoring events. There is a slight increase in TN, NO_3+NO_2-N, and more of an increase in NH_3-N below the Reservoir at MW-Kennedy. The combined values of nitrate+nitrite (NO_3+NO_2-N) did not exceed the state drinking water standard for nitrate of 10 mg/L (5 CCR 1002-41.8) in any of the GW samples.

As shown in Figure 21 and Figure 22, data from both sampling events during WY 2019 indicated groundwater concentrations of chloride averaged 124 mg/L and sulfate averaged 125 mg/L. Although these are not drinking water wells, these values did not exceed the state water supply standard for sulfate of 250 mg/L (5 CCR 1002-41.8). The pH remains relatively constant but is slightly higher in the wells closer to the Reservoir. The conductivity seems to follow the trend of increasing concentrations of chloride and sulfate during both monitoring events.

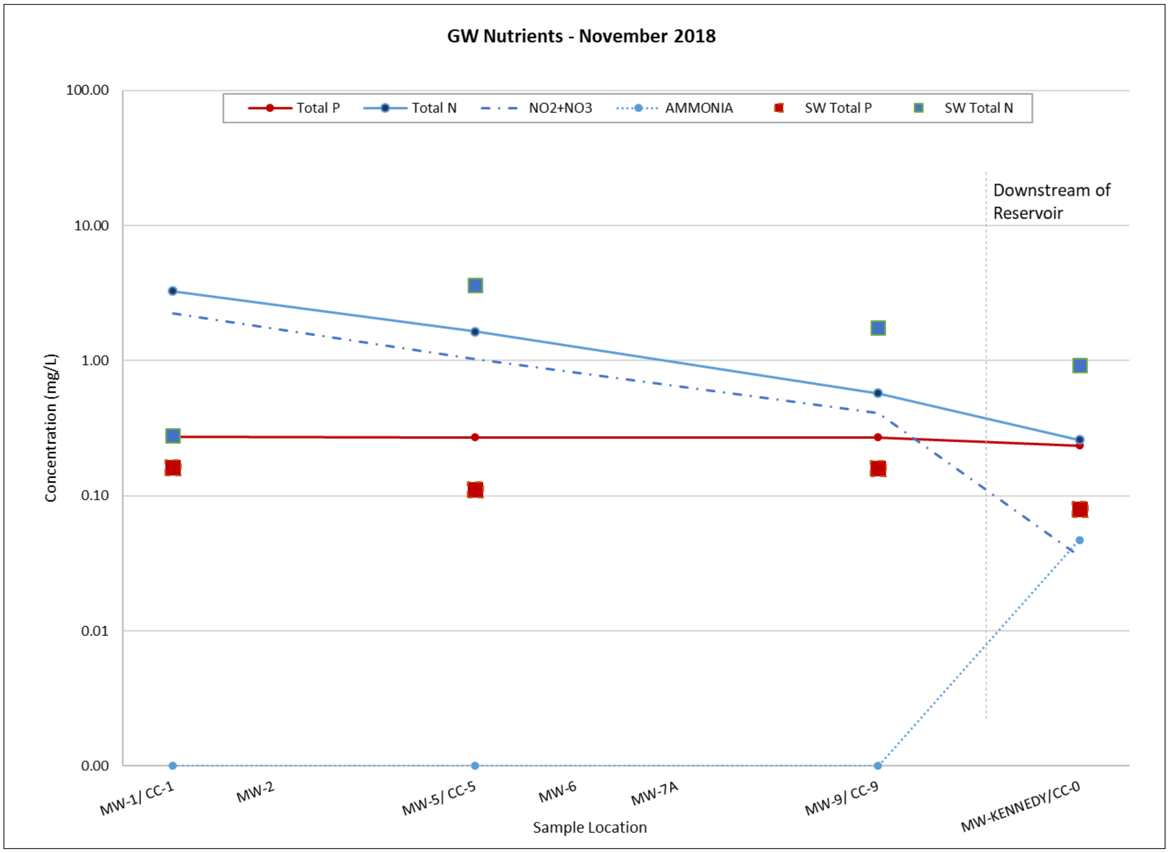


Figure 19. Groundwater Water Quality of Monitoring Wells in November 2018.

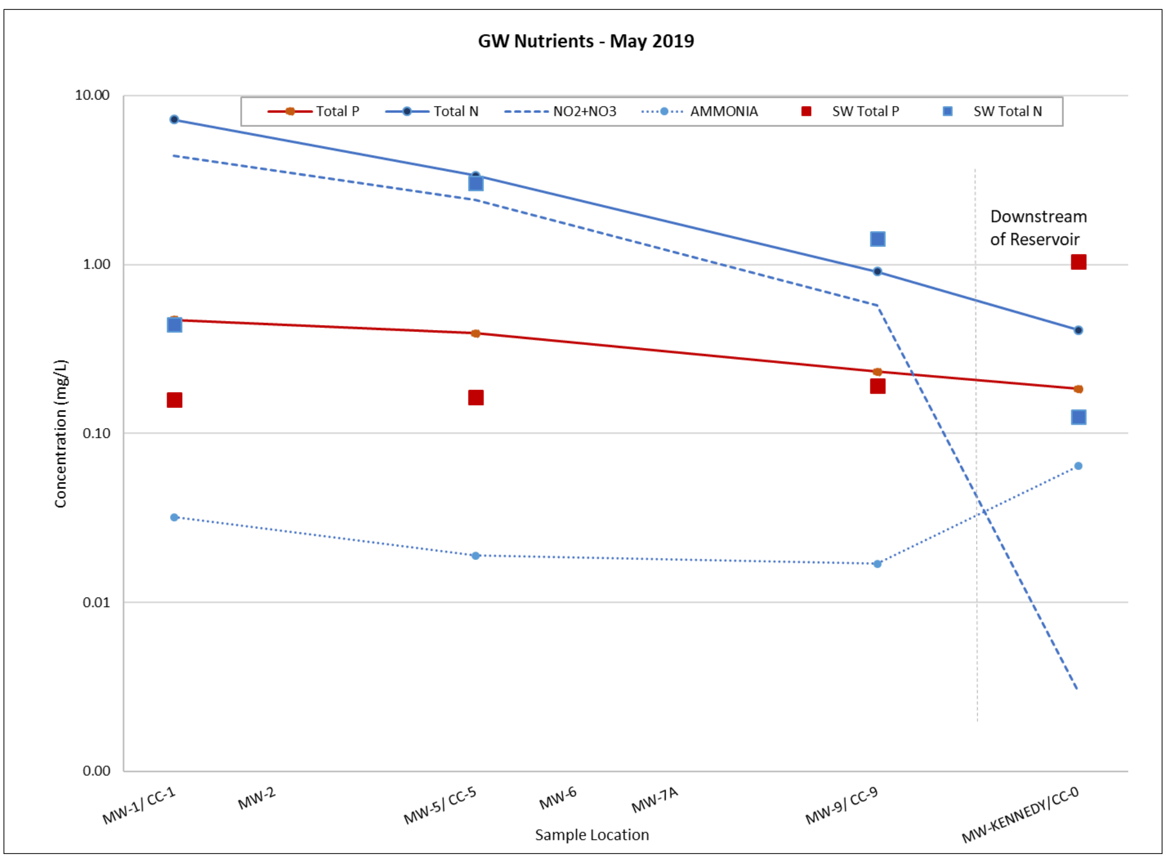


Figure 20. Groundwater nutrients from monitoring wells in May 2019.

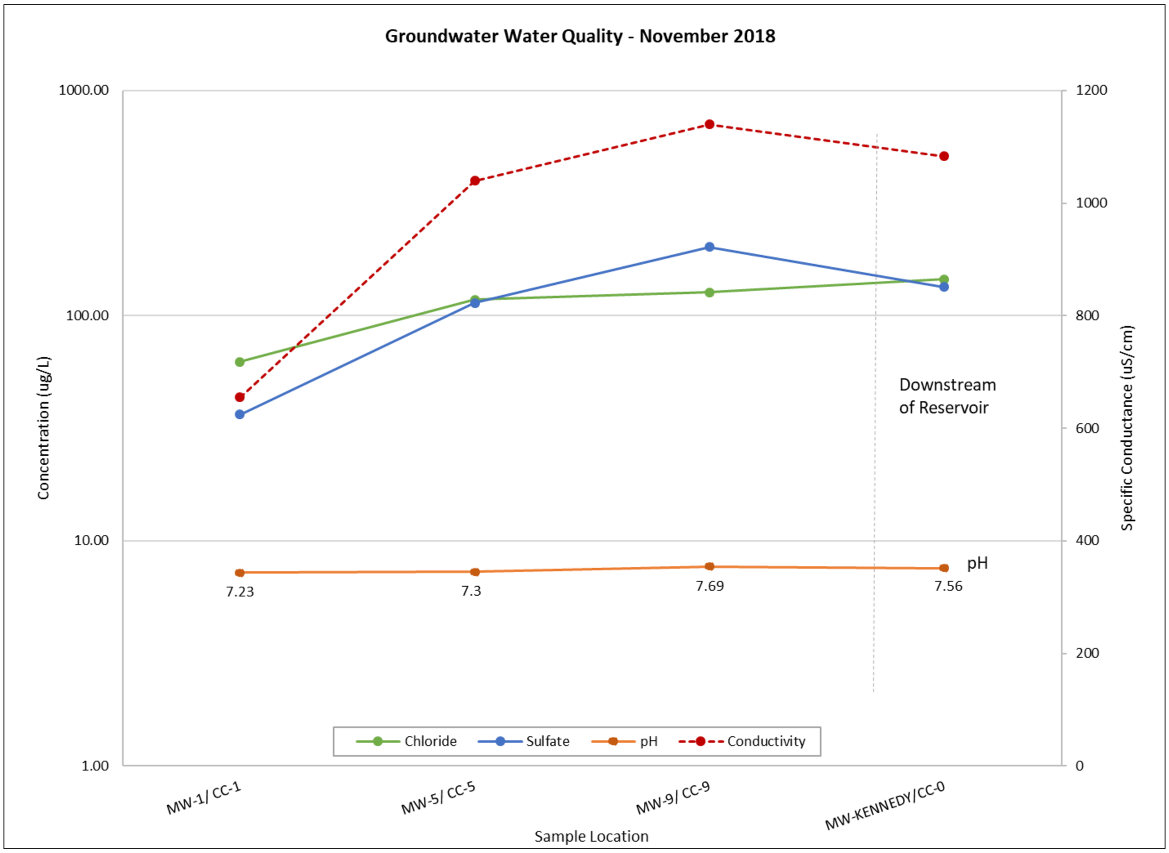


Figure 21. Groundwater Levels of Sulfate, Chloride, Specific Conductance, and pH, November 2018.

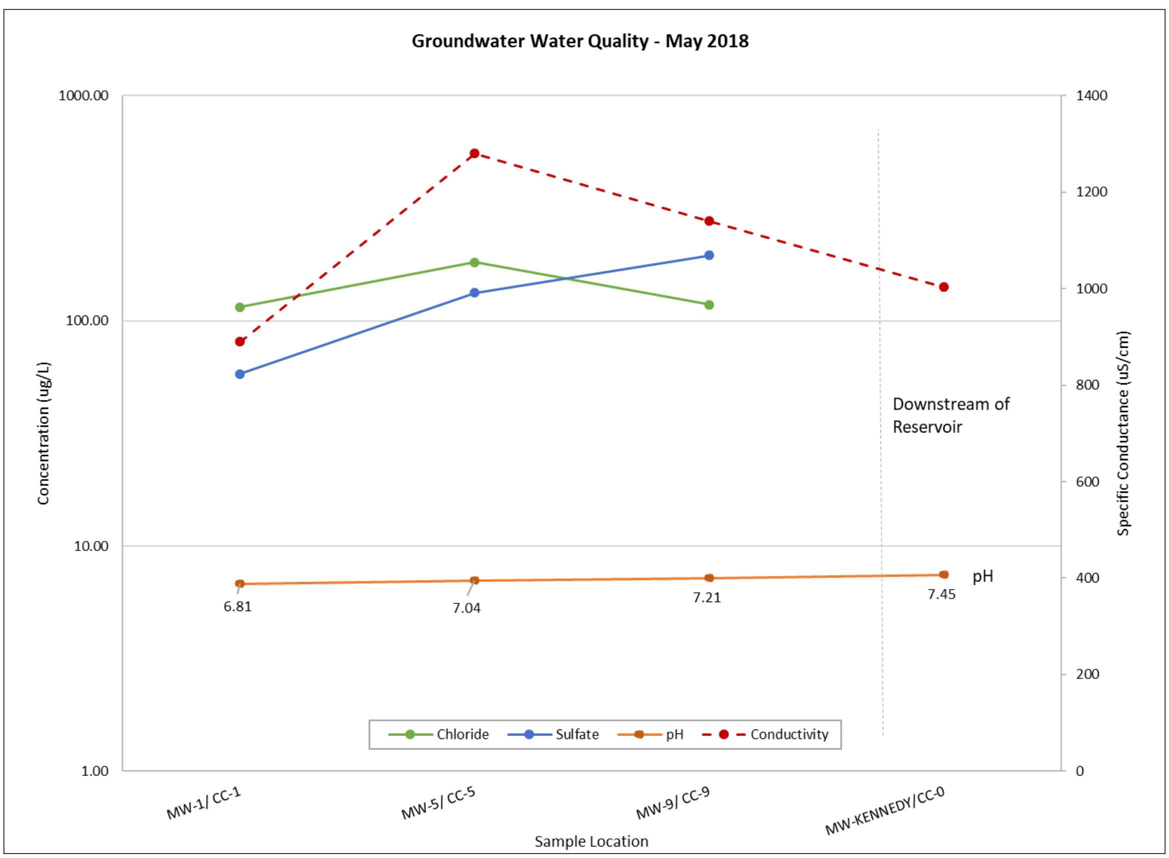


Figure 22. Groundwater Levels of Sulfate, Chloride, Specific Conductance, and pH, May 2019.

3.6.3 GROUNDWATER UPSTREAM OF RESERVOIR AT MONITORING WELL MW-9

The pH and specific conductance (conductivity) were monitored at all wells included in the SAP during both monitoring events. The pH at MW-9 was 7.69 in November 2018 and 7.21 in May 2019. With the exception of a few outliers, pH values have ranged between 6.5 and 7.5. The historical pH values from Monitoring Well MW-9 1994-2019 are plotted in Figure 23. The data suggest that the pH at site MW-9 is somewhat variable but remains near neutral, around 7.0.

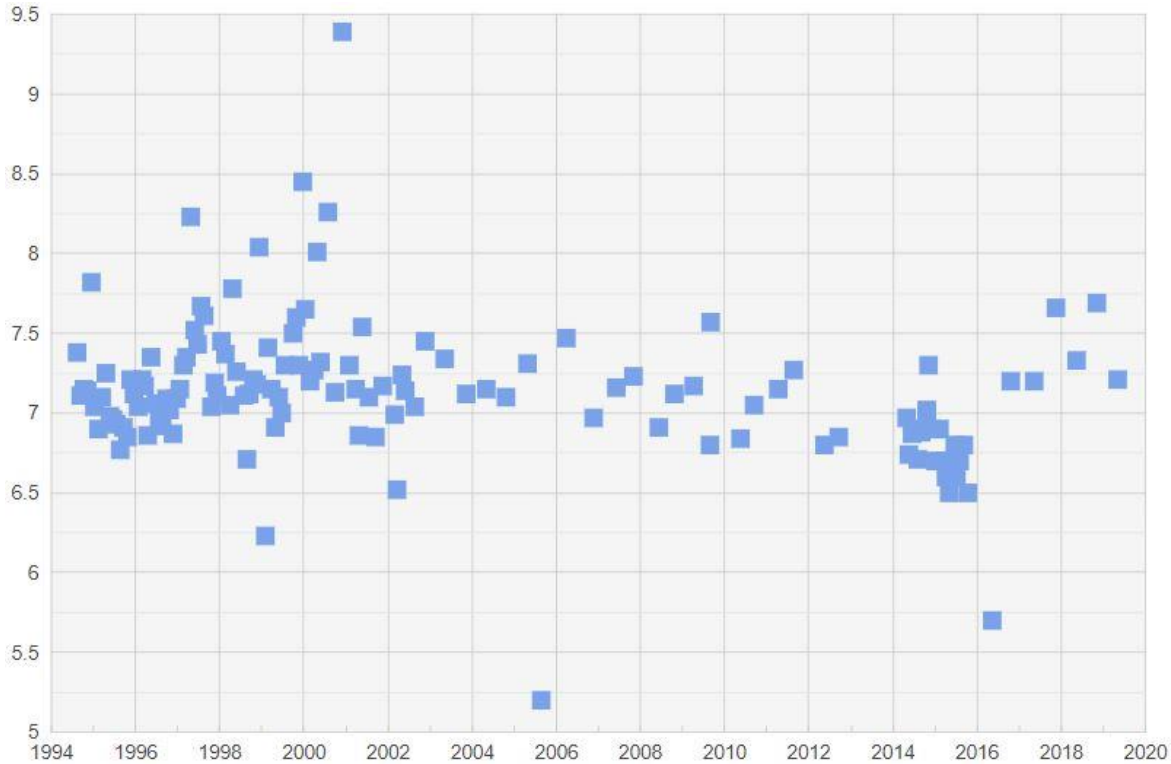


Figure 23. Historic pH Values in Well MW-9, 1994-2019. (http://ccbwqportal.org/)

The conductivity at MW-9 was 1140 µS/cm in both November 2018 and May 2019. The historical conductivity values at MW-9 suggest a slightly increasing trend over time with a mean value of 807 µS/cm between 1995 and 2005 and a mean value of 1,105 µS/cm from 2006 to 2019. (Figure 24.)

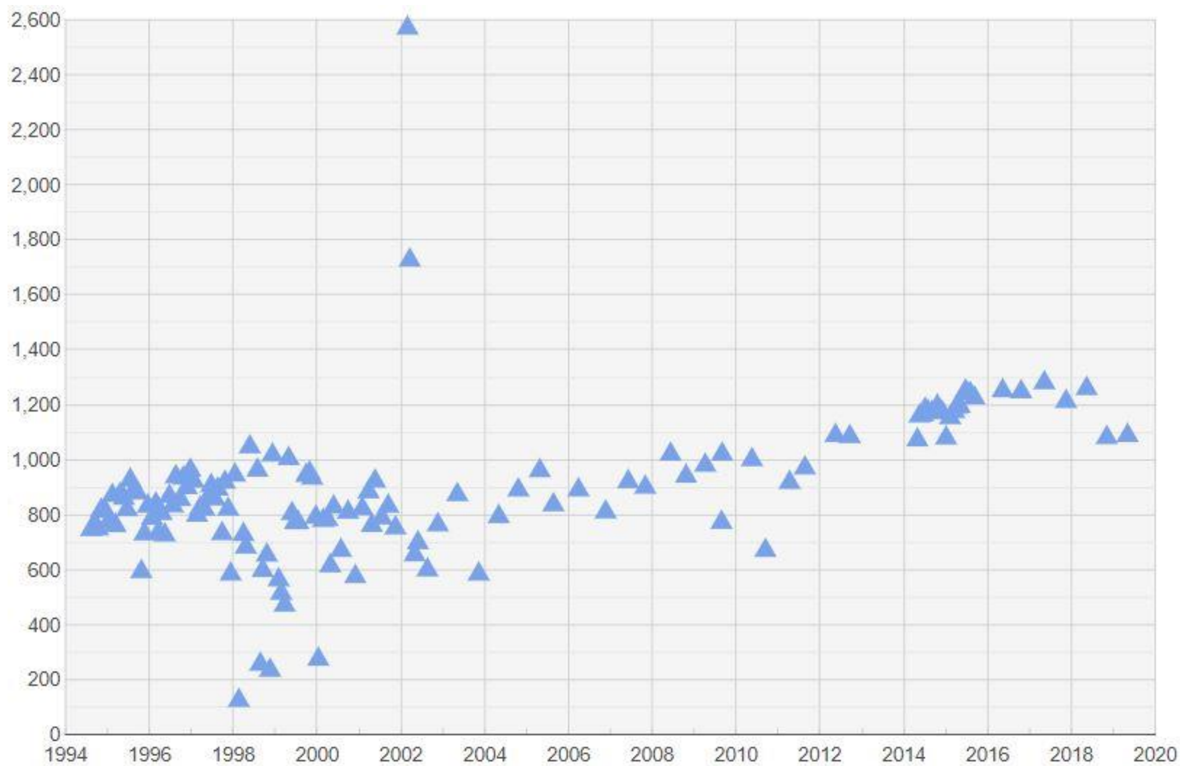


Figure 24. Historic Specific Conductance (µS/cm) Concentration in Well MW-9, 1994-2019. (http://ccbwqportal.org/)

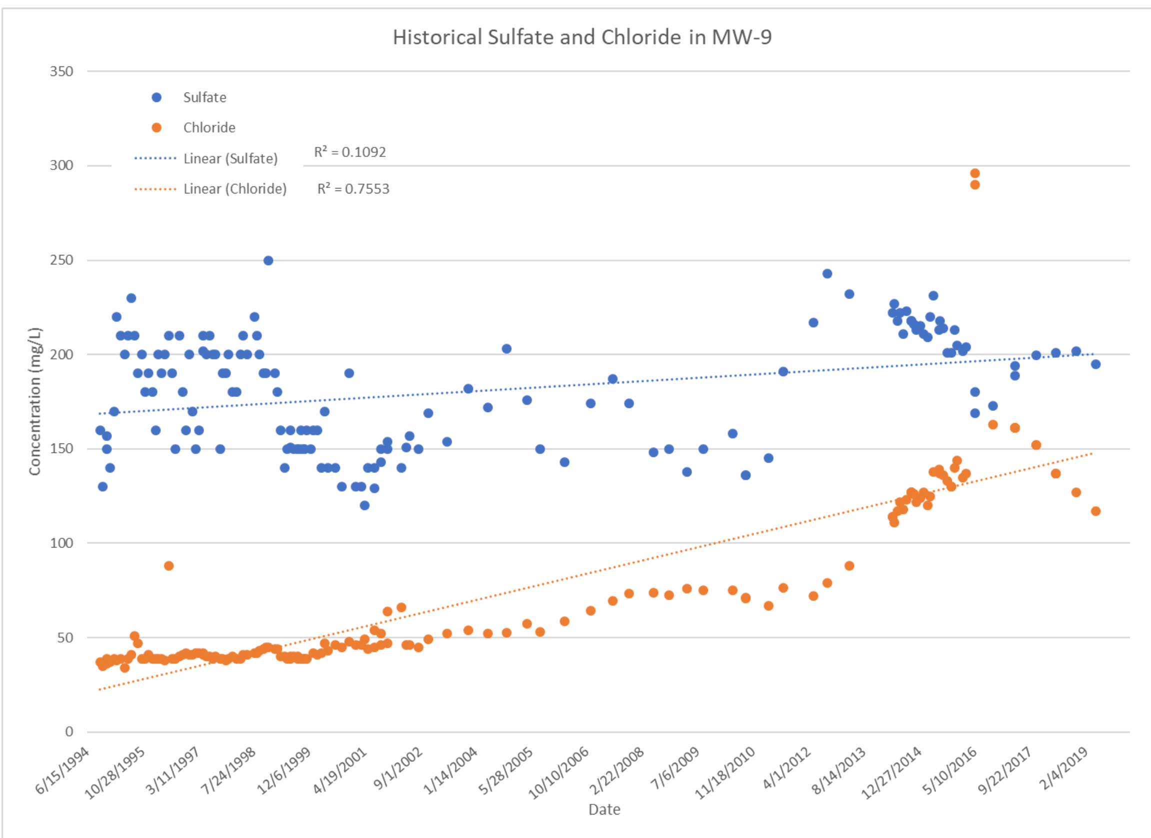


Figure 25. Historical Sulfate and Chloride (mg/L) at MW-9, 1994-2019.

Figure 25 illustrates the historical chloride and sulfate concentrations from 1994-2019. It appears that both may be increasing over time although chloride may be less variable and increasing slightly more significantly. However, there may be is a slight decreasing trend in the recent history, from 2017 to present.

Figure 26. Historic SRP (µg/L) Concentrations in Groundwater Monitoring Well MW-9 (1994–2019).
(http://ccbwqportal.org/)

Historically, the concentration of SRP in the groundwater upstream of the Reservoir at MW-9 also appears to be slightly increasing (Figure 26).

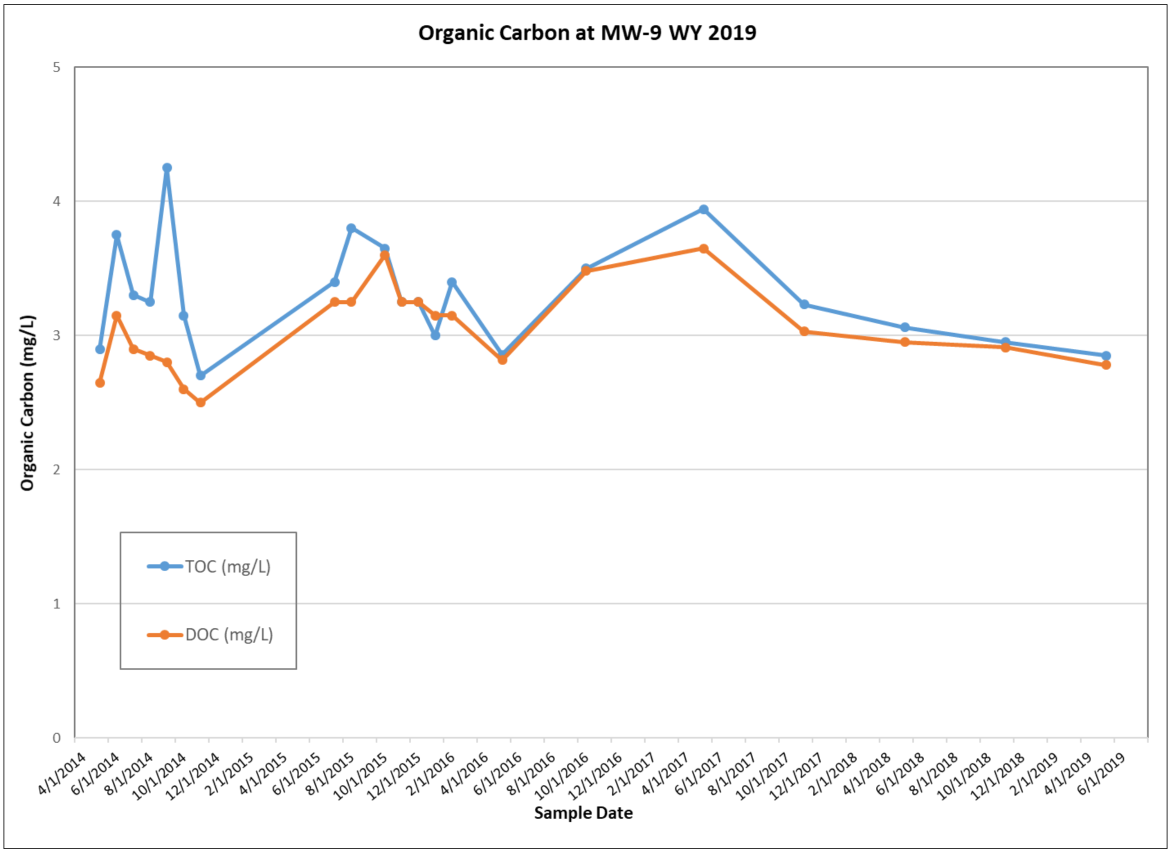


Figure 27. Total and Dissolved Organic Carbon Data from MW-9, 2014-2019.

The long-term TOC concentrations in the alluvial groundwater samples collected from well MW-9 range from 2.7 µg/L to 4.3 µg/L, averaging 3.3 µg/L (Figure 27). The TOC concentrations measured in November 2018 were 2.95 mg/L and in May 2019 were 2.85 mg/L, which are both slightly lower than the long-term average of 3.31 mg/L from 2014-2019. Historically, the dissolved fraction of the TOC in well MW-9 ranged between 66% and 105%, with an average of 98%, which was higher than the long-term average of at 93% of the total.

4.0 RESERVOIR MONITORING RESULTS

Reservoir monitoring focuses on data collection to support regulatory requirements and maintaining the beneficial uses of aquatic life, recreation, water supply and agriculture. The primary concerns are nutrients, including all species of phosphorus and nitrogen, and chl α.

Three sites in the Reservoir are included in the monitoring program: CCR-1, CCR-2 and CCR-3. CCR-1, also called the Dam site, is located in the northwest area within the Reservoir. CCR-2, called the Swim Beach site, located in the northeast area within the Reservoir nearest the swim beach. CCR-3 is referred to as the Inlet site and corresponds to the south area within the Reservoir closer to the inlets.

Each site is sampled monthly though the year when ice free conditions allow and twice a month from May through September. Transparency, dissolved oxygen, temperature, and pH are included in the regular monitoring to support regulations protecting aquatic life and beneficial uses.

Analysis of reservoir plankton concentrations also helps determine overall health of Cherry Creek Reservoir, potential for environmental risks, as well as impacts of water quality. Plankton growth trends and population diversity through the seasons are analyzed through sample collection on a monthly basis throughout the year and twice a month through the summer months. Identification and enumeration are completed on all samples with biovolumes calculated on all phytoplankton samples and biomass calculated on all zooplankton samples.

4.1 USACE RESERVOIR FLUSHING EXERCISE

Beginning on May 21, 2019, at 9:00 am and continuing through 12:30 am on May 22, the USACE performed the annual flushing exercise to verify the operation of the outlet gates. The USACE individually operated gates 1-5 with various flows ranging from 50 cfs to 250 cfs for durations of 10-60 minutes each. During this event, approximately 16,157,900 gallons of water (49.6 AF) were released from the Reservoir. However, the Reservoir level increased on those dates since a recent storm had increased inflows significantly just prior to the event.

4.2 TRANSPARENCY

Transparency is used an indicator for primary productivity and turbidity of the water column and can be a good reference point of the overall health of an aquatic ecosystem. In order to determine transparency, Secchi depths and the depth of 99% light attenuation, or 1% light transmittance, were measured with a Secchi disk and a LI-COR quantum sensor at all three sites in the Reservoir during each monitoring event.

The Secchi depth was measured as the depth at which the Secchi disk disappears as lowered into the water on the shady side of the boat. Depth was measured twice at each location to verify measurement accuracy.

The LI-COR sensor provides a quantitative approach to determine the depth at which ninety-nine percent (99%) of the ambient light is attenuated. This is considered the depth of the photic zone.

The Secchi depth measurements represent reduced clarity and eutrophic conditions through most of the year, with the exception of a few dates. The Secchi depths were very similar between CCR-1, 2, and 3, with the highest variance of 2.3% but an average of less than 1% variance between the sites. The measured Secchi depth ranged between 0.75 and 2.6 m, with an annual mean of 1.16 m. Figure 28 depicts the Secchi depth measurements from the three sites during each sampling event in WY 2019.

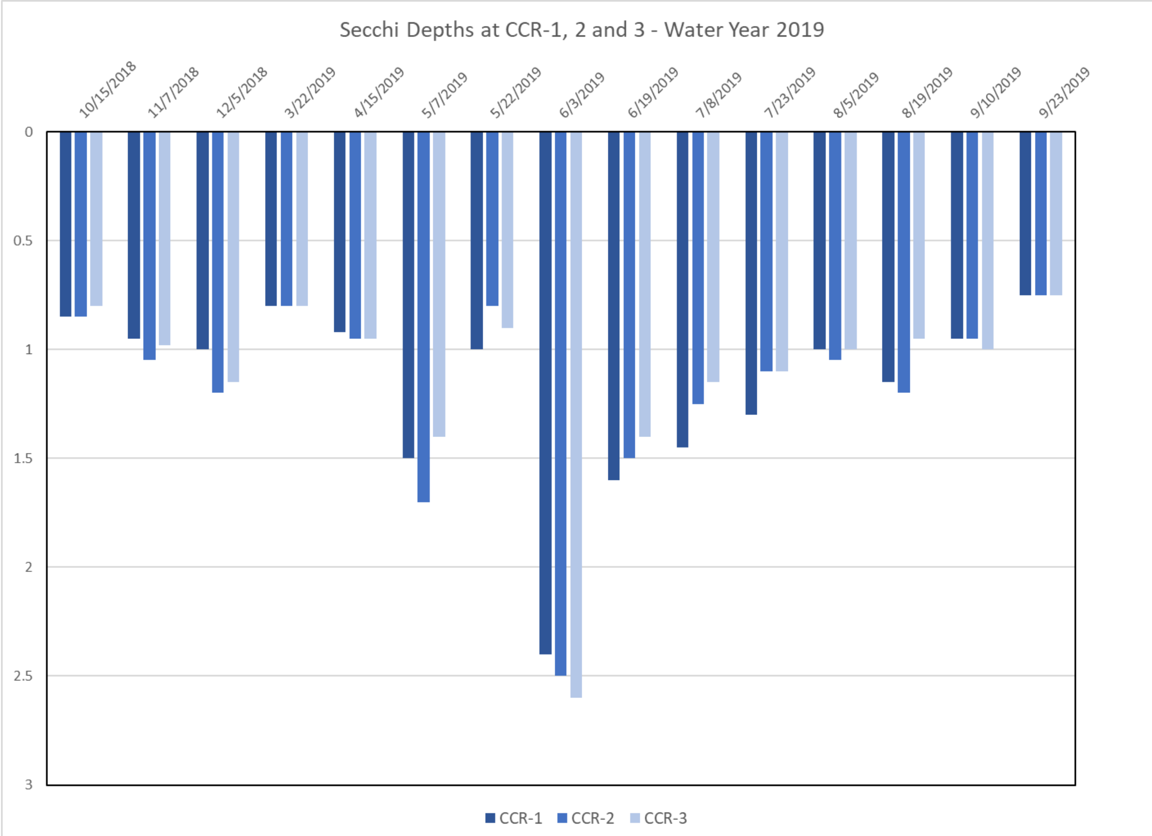


Figure 28. Secchi Depths in Cherry Creek Reservoir, Stations CCR-1, CCR-2 and CCR-3 during WY 2019.

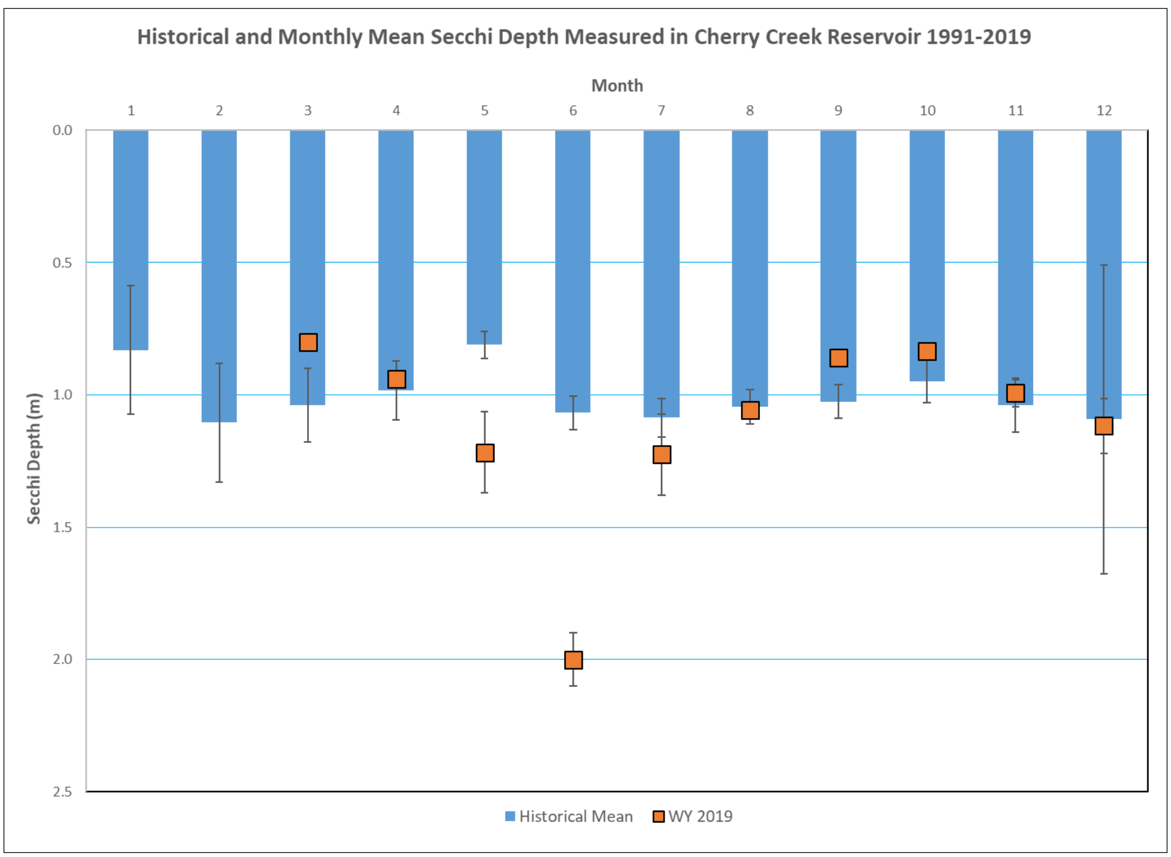


Figure 29. Historical and Monthly Mean Secchi Depth in Cherry Creek Reservoir from 1992- 2019.

Figure 29 shows the historical monthly mean Secchi depth as well as the values from WY 2019. The seasonal mean was 1.04 m during the months of July to September. The Secchi depth measurements were similar for all three sites and followed the same trends when compared to the values collected during the same months in previous years. The average Secchi depths are very similar to the previous year measurements at similar dates. The long-term monthly means seems to show less of a seasonal trend but increased variability during the colder months of January-March and December. The historical data shows the least variability during May through September. In WY 2019 the values in May and June were much higher than the historical average during that time period; this means higher clarity, which is good.

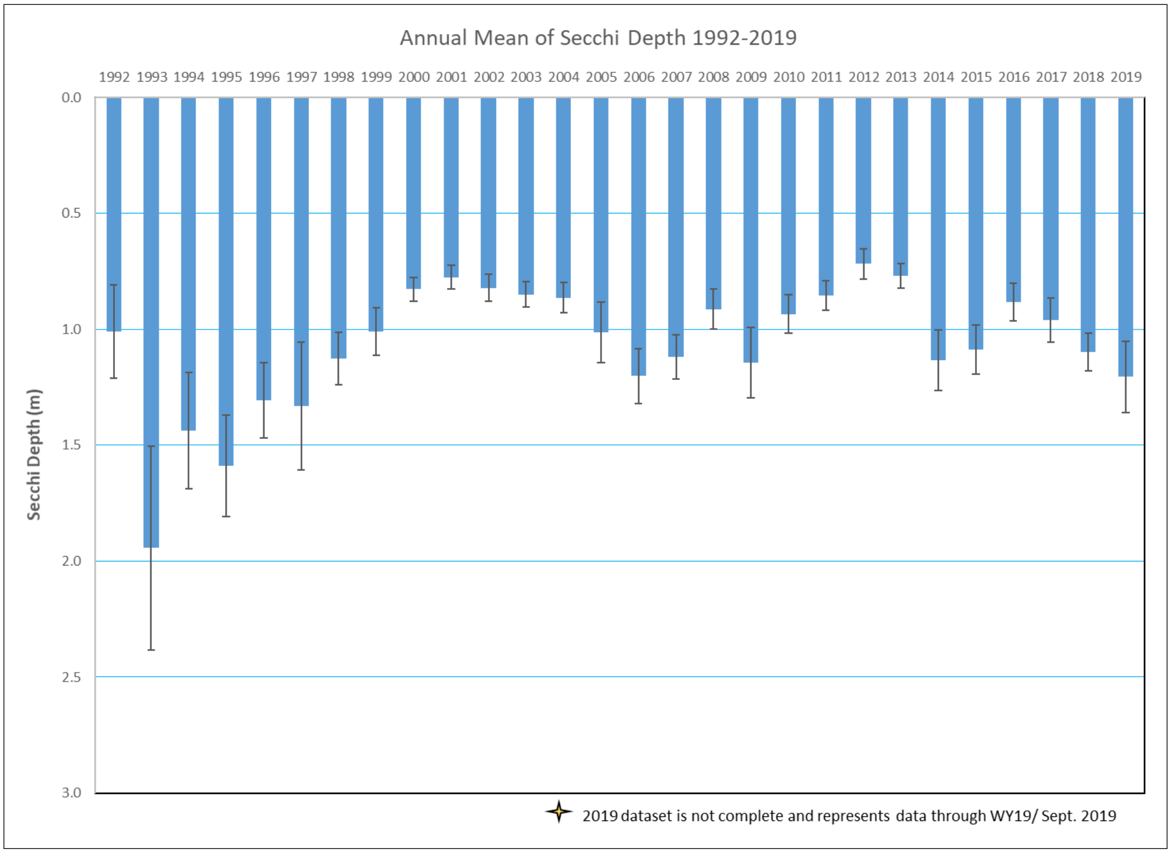


Figure 30. Annual Mean of Secchi Depth in Cherry Creek Reservoir from 1992- 2019.

The historical annual mean Secchi depth values for Cherry Creek Reservoir are pictured in Figure 30. From approximately 1998 to present, the annual mean Secchi depth has been in the eutrophic range, varying between approximately 0.75 m to 1.25 m. The lowest values were observed in 2000-2004 and again in 2011-2013.

Due to the similarity of the values between the three Reservoir sites, the data and values from CCR-2 are shown below to illustrate the Secchi depths during each monitoring event. The depth of 99% light attenuation or 1% light transmittance at site CCR-2 ranged from 2.1 m to 4.8 m during WY 2019. The lowest values were observed in the late summer and the maximum depths of 4.8 m occurred in June. There is a clear relationship between Secchi depth and depth of 99% light attenuation (Figure 31).

The depth of 1% light transmittance ranged between 1.5 and 3.5 times the Secchi depth, but on average was approximately 2.8 times the Secchi depth.

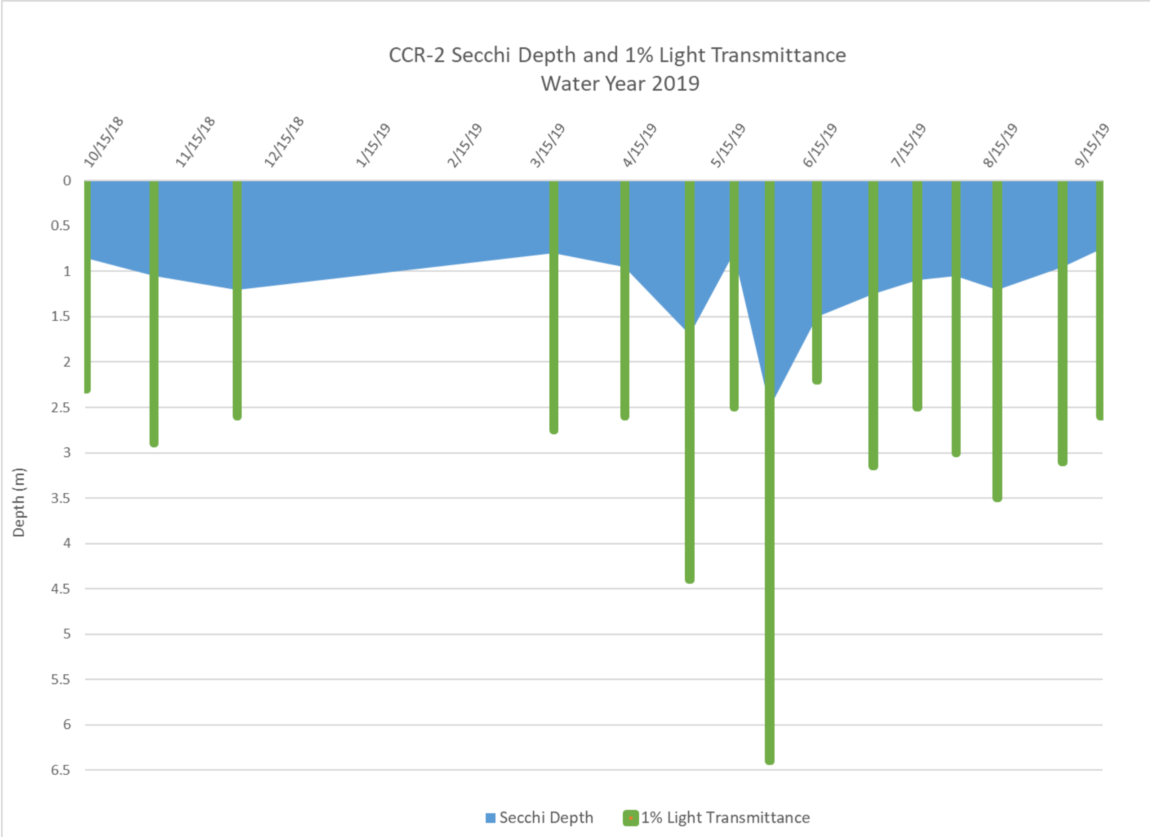


Figure 31. Secchi Depth and Depth of 1% Light Transmittance at CCR-2 during WY 2019.

The historical data from site CCR-2 in the Reservoir were then analyzed to determine the mathematic correlation between the Secchi depth and depth of 99% light attenuation. Figure 32 illustrates the relationship calculated on the data portal. The trendline equation is Y = 1.84x +1.18 with a Pearson correlation coefficient of 0.86.

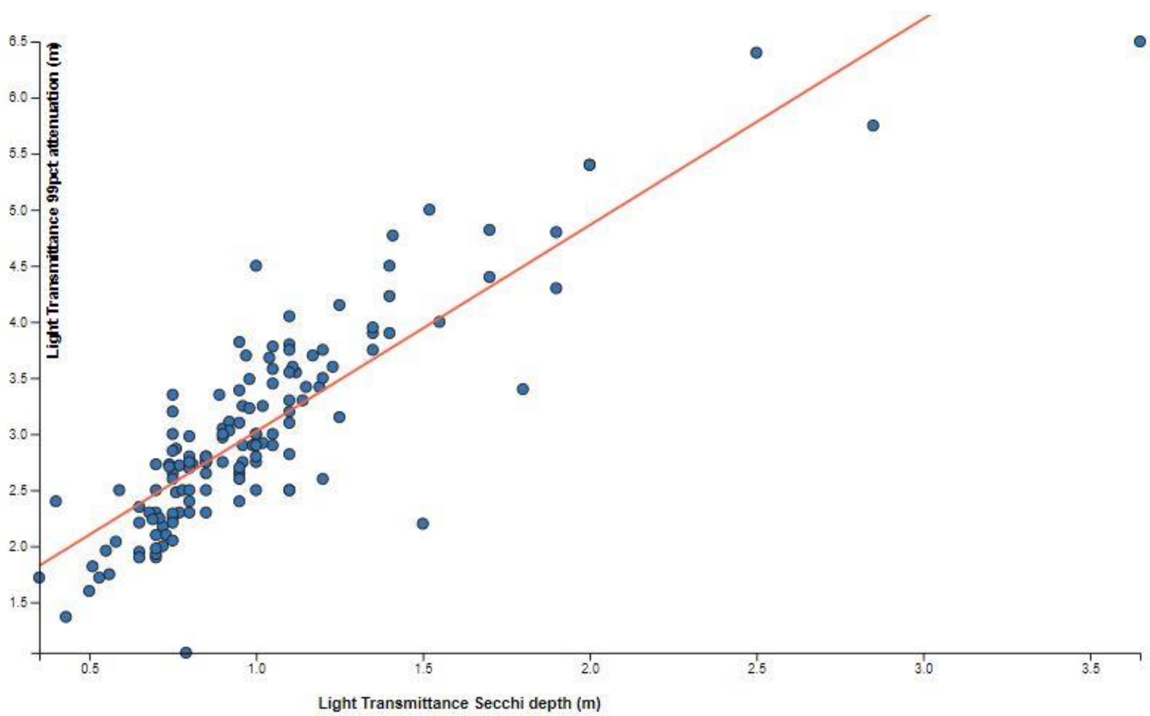


Figure 32. Relationship between Secchi Depth and Depth of 1% Light Transmittance. (http://ccbwqportal.org/)

4.3 CHLOROPHYLL A

During each sampling event of WY 2019, chl α levels were measured from composite samples collected from 0, 1, 2, and 3 meters at all three monitoring sites in the Reservoir. The chl α concentrations ranged between 4.6 µg/L and 72.0 µg/L, with an average annual value of 23.2 µg/L in WY 2019 (Figure 33). The highest values were observed in March, and the lowest in June and July.

The seasonal chl α concentration for WY19 through the growing season (July through September) concentration was 16.03 µg/L, which was lower than 20.2 µg/L in WY 2018, 18.7 µg/L in WY 2017, and 23.6 µg/L in WY 2016 (Figure 34). Of the six sampling events during the season (July 1-September 30), five had a mean value that were below the standard of 18 µg/L and only one that was higher.

The seasonal mean for WY 2019 met the 18 µg/L growing season average regulatory standard value; however, the standard only allows an exceedance frequency of once in five years. Three of the last five (3/5) and eight of the last ten (8/10) years have exceeded this value. The Reservoir is not meeting the chl α water quality standard.

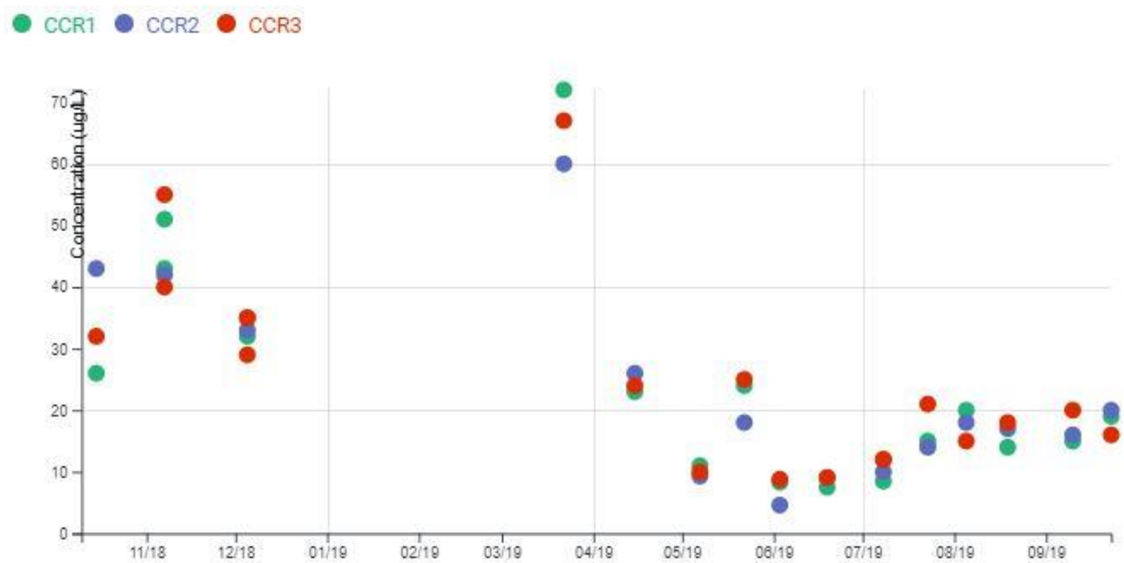


Figure 33. Monthly Chlorophyll *a* (µg/L) Concentrations in Cherry Creek Reservoir During WY 2019. (http://ccbwqportal.org/)

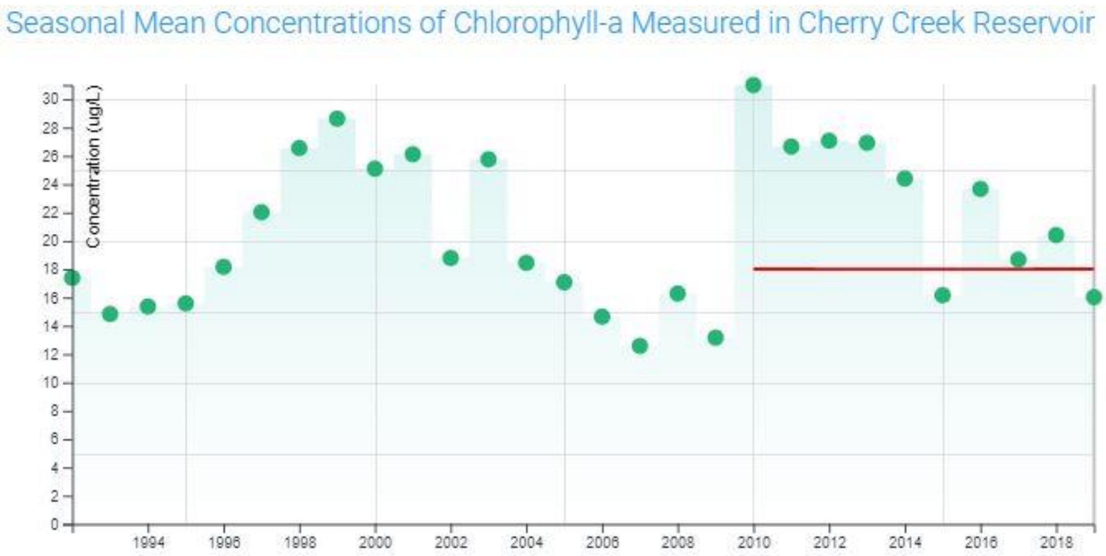


Figure 34. Historical Seasonal Mean of Chlorophyll *a* in Cherry Creek Reservoir 1991-2019.

(Red line --- indicates the 18.0 ug/L chl α standard. (http://ccbwqportal.org/)

Translating the impacts of chl α concentrations on water quality into terms that are meaningful to most recreational lake users is a complex task. Walmsley and Butty (1979) proposed some typical relationships between maximum chl α concentrations and observed impacts (Table 12) to describe perceptions of water quality by typical lake users. The maximum monthly mean chl α concentration in Cherry Creek Reservoir in WY 2019 was 66.3 µg/L in March, which was collected right after ice-off. The lowest was in June when the mean concentration was 7.9 µg/L. The average of all readings during the summer months (seasonal mean) was 16.03 µg/L. This would indicate that lake users could notice some algal scums but would not perceive nuisance conditions on most days.

Table 12. Impact of Chlorophyll *a* Concentrations on Perceived Water Quality

Chlorophyll *a* Concentration	Nuisance Value
0 to 10 µg/L	No problems evident
10 to 20 µg/L	Some algal scums evident
20 to 30 µg/L	Nuisance conditions encountered
Greater than 30 µg/L	Severe nuisance conditions encountered

4.4 TEMPERATURE

Continuous temperature monitoring is completed at site CCR-2 in Cherry Creek Reservoir during the late spring, summer and early fall. The HOBO temperature loggers are placed in even increments from one (1) meter of depth to the bottom of the Reservoir and are mounted on a State Parks buoy. The continuous temperature data from 2019 is plotted in Figure 35 which represents the thermal stratification throughout the period of time the thermistors are installed. Some thermistor data from depths below 4 meters were lost from June to September 2019 due to the thermistor chain wrapping around the buoy chain and dislodging or resetting the equipment. Modifications to the hardware connecting the equipment will be completed in 2020 to reduce the potential of lost data.

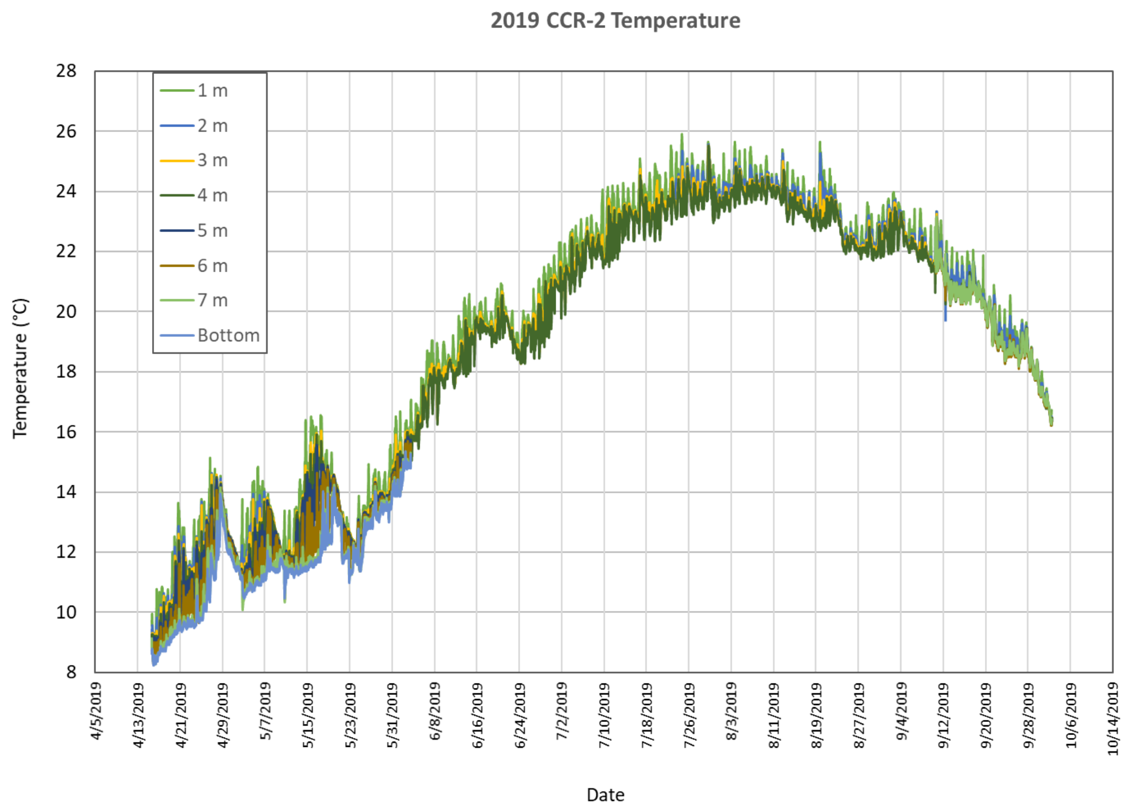


Figure 35. 2019 Temperature Profile of CCR-2 in Cherry Creek Reservoir.

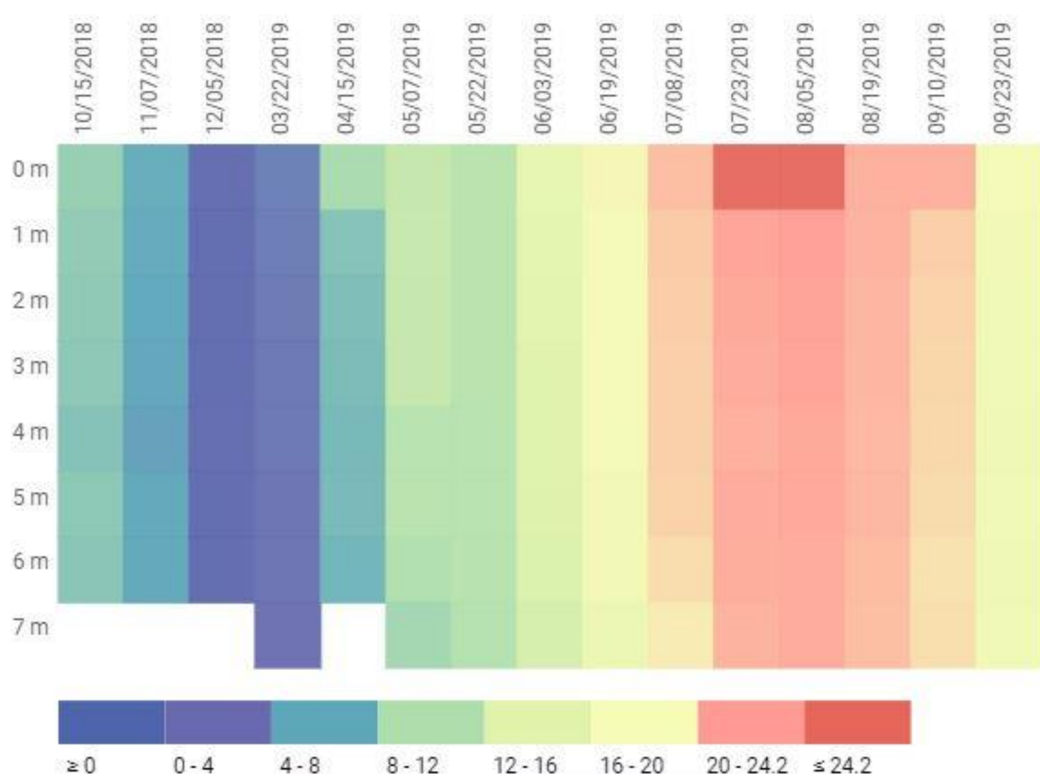


Figure 36. WY 2019 Temperature (˚C) Profile in Cherry Creek Reservoir. (http://ccbwqportal.org/)

In addition to the continuous temperature loggers installed at CCR-2, temperature profiles were also collected during each monitoring event. Figure 36 illustrates the temperature profiles collected at Reservoir station CCR-2 during the routine monitoring events in WY 2019. The Reservoir met the temperature standards established for the Class I Warm Water Aquatic Life classification (WQCC Regulation No. 31) of 26.3 ˚C (79.2 ºF) Maximum Weekly Average Temperature (MWAT) and 29.3˚C (84.6 ºF) Daily Maximum (DM). The maximum temperature measured in the surface during the reservoir monitoring events was 24.8 ˚C (76.6 ºF) on August 5, 2019, and the highest temperature recorded by the continuous monitoring thermistors was 25.9 ˚C (78.6 ºF) on July 24, 2019. The largest temperature range seen was 2.9 ˚C (37.2 ºF) on April 14, 2019, from 11.7 ˚C (53.1 ºF) to 8.8˚C (47.8 ºF) from top to bottom.

Although there was some variability from the surface to the bottom in the warmer summer months, overall the Reservoir did not develop significant thermal stratification.

4.5 DISSOLVED OXYGEN

During WY 2019, Cherry Creek Reservoir had DO concentrations that met REG 38 requirements calling for levels of 5.0 mg/L or above near the surface. The DO may be less than 5.0 mg/L near the bottom as long as there is adequate refuge with DO levels greater than 5.0mg/L available for aquatic life.

Figure 37 illustrates the DO levels in the Reservoir at Station CCR-2 over time from the surface (0 m) to the bottom (depth varies). During June through early September 2019 sampling events, DO levels from 5 meters to the bottom were less than 5.0 mg/L. However, during those times, the majority of the Reservoir had DO levels that exceeded 5.0 mg/L to provide adequate habitat (refuge) for aquatic life. Periods of low dissolved oxygen indicate high microbial activity or decomposition in the hypolimnion and sediments which reduces DO concentrations.

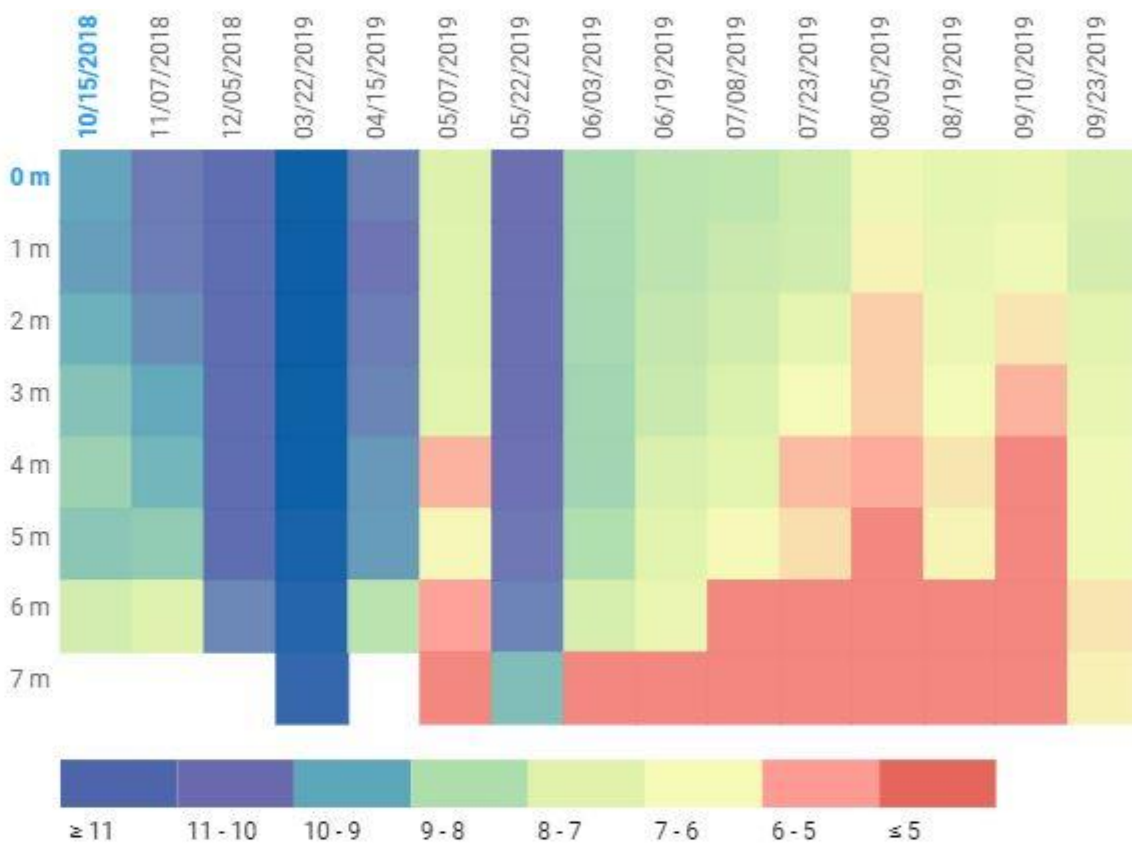


Figure 37. WY 2019 Dissolved Oxygen (mg/L) Profile in Cherry Creek Reservoir. (http://ccbwqportal.org/)

4.6 PH

The pH in Cherry Creek Reservoir during WY 2019 ranged from 7.5 at the bottom of the Reservoir on August 5, 2019 to 8.8 at the Reservoir surface on March 22, 2018. The composite values from all three monitoring sites are displayed (Figure 38). The pH levels in the Reservoir met the instantaneous minimum and maximum standards of 6.5 and 9.0, respectively, during each of the monitoring events during WY 2019. The chl α concentration on March 22, 2019 was the highest concentration observed in WY 2019 which corresponded to the highest pH value. Higher pH values usually correlated with higher productivity and elevated chl α concentrations in the Reservoir.

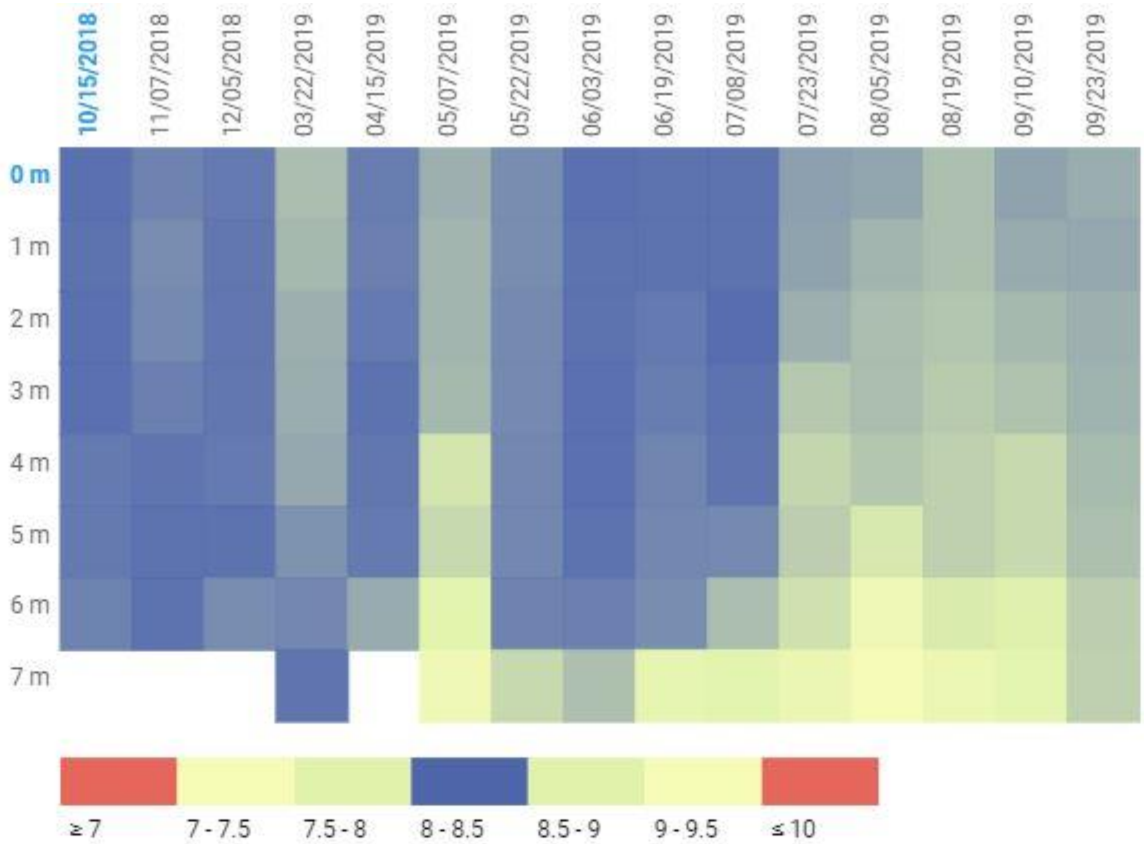


Figure 38. WY 2019 pH Profile in Cherry Creek Reservoir. (http://ccbwqportal.org/)

4.7 OXIDATION REDUCTION POTENTIAL

The Oxidation Reduction Potential (ORP) in Cherry Creek Reservoir was measured during each monitoring event and the composite values from all three monitoring sites are displayed (Figure 39). The ORP in the photic zone ranged from 66.5 mV in May 22, 2019 to 196 mV in April 2019.). The ORP in the samples near or at the bottom of the reservoir ranged from -62.5 mV on August 5, 2019 to 195.5 mV on September 23, 2019. The lower ORP values measured in May and August coincided with monitoring events when the DO measurements were much lower at the bottom of the Reservoir than the rest of the water column. In addition, the pH values during the low ORP values were also lower in the deeper samples. Low pH values are also an indication of decomposition processes.

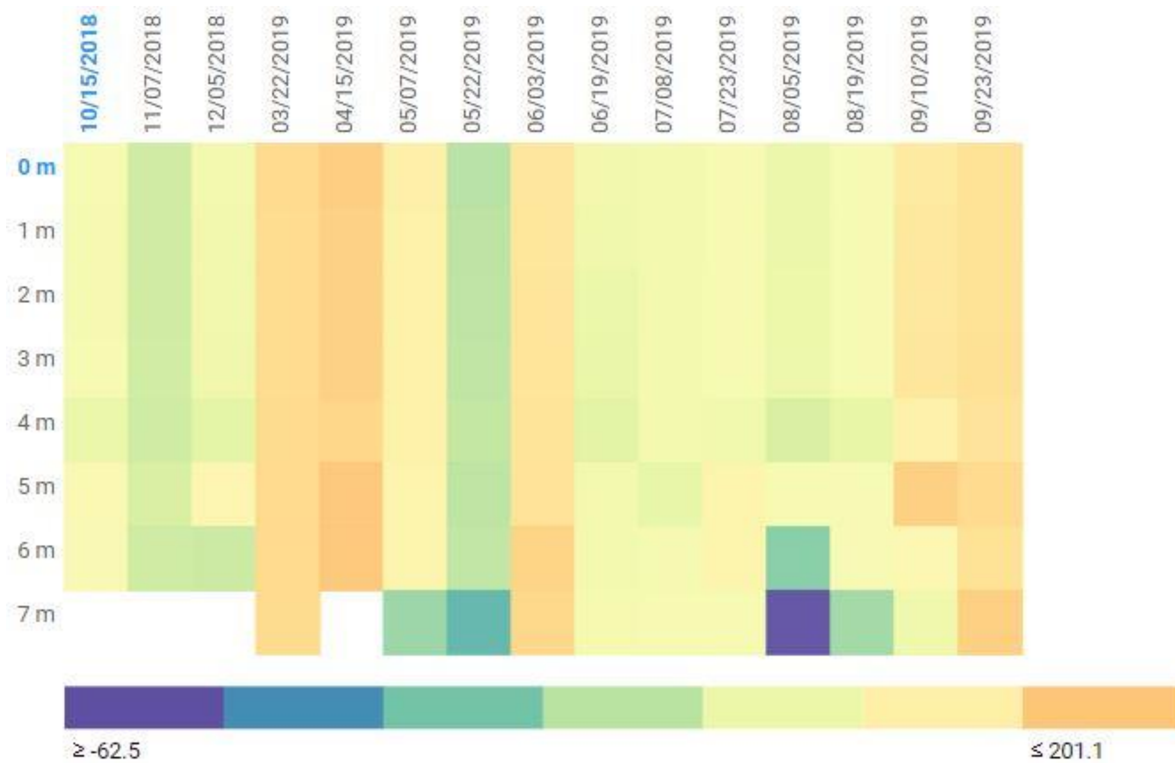


Figure 39. WY 2019 Oxidation Reduction Potential (mV) Profile in Cherry Creek Reservoir. (http://ccbwqportal.org/)

4.8 CONDUCTIVITY

The specific conductance, or conductivity, in Cherry Creek Reservoir in WY 2019 ranged from a minimum of 1,043.8 µS/cm from October 2018 to 1,270.9 µS/cm during September WY 2019 (Figure 40). There was limited variability in conductivity from top to bottom of the Reservoir and between the three monitoring sites. The concentrations increased as the season progressed with the highest concentrations in September 2019.

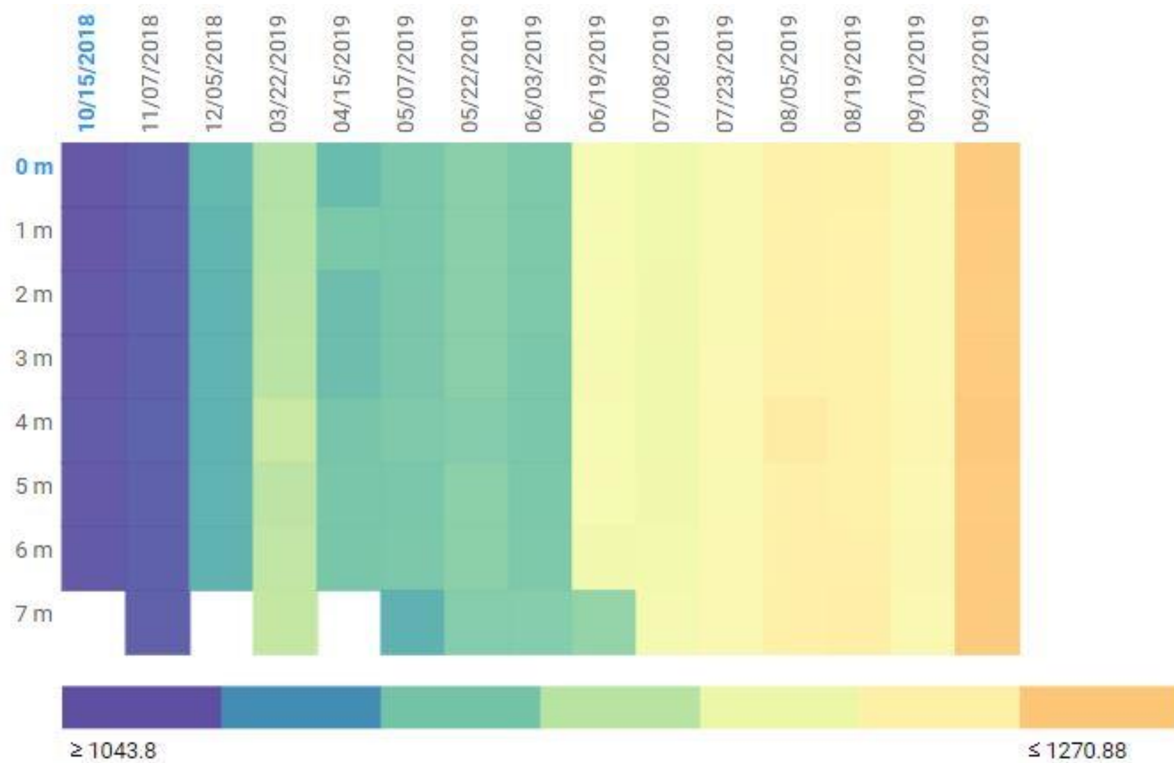


Figure 40. Conductivity (Specific Conductance µS/cm) Profile in Cherry Creek Reservoir, WY 2019. (http://ccbwqportal.org/)

4.9 TOTAL PHOSPHORUS

The SAP includes TP sampling at all three sites in the Reservoir. Figure 41 shows the historical seasonal mean (July to September) TP concentration from the three sites in the photic zone. The 2019 seasonal mean of 107.2 was higher than WY 2018 (91.2 µg/L) and lower than both the WY 2017 (114.7 µg/L) and WY 2016 values (127.3 µg/L). The WY 2019 seasonal TP mean is also higher than the long-term average of 94.2 µg/L measured from 1992- present.

Although there are no site-specific standards for TP and TN in Cherry Creek Reservoir, CDPHE Regulation 31 includes interim nutrient values for warm water reservoirs greater than twenty-five (>25) acres. These are criteria only, and do not become standards unless they are adopted as waterbody-specific standards during a basin-specific water quality standards rulemaking hearing. The warm water total phosphorus criterion for large reservoirs is 83 µg/L TP as a summer (July 1-September 30) average in the mixed layer (median of multiple depths), with an allowable exceedance frequency of one-in-five years.

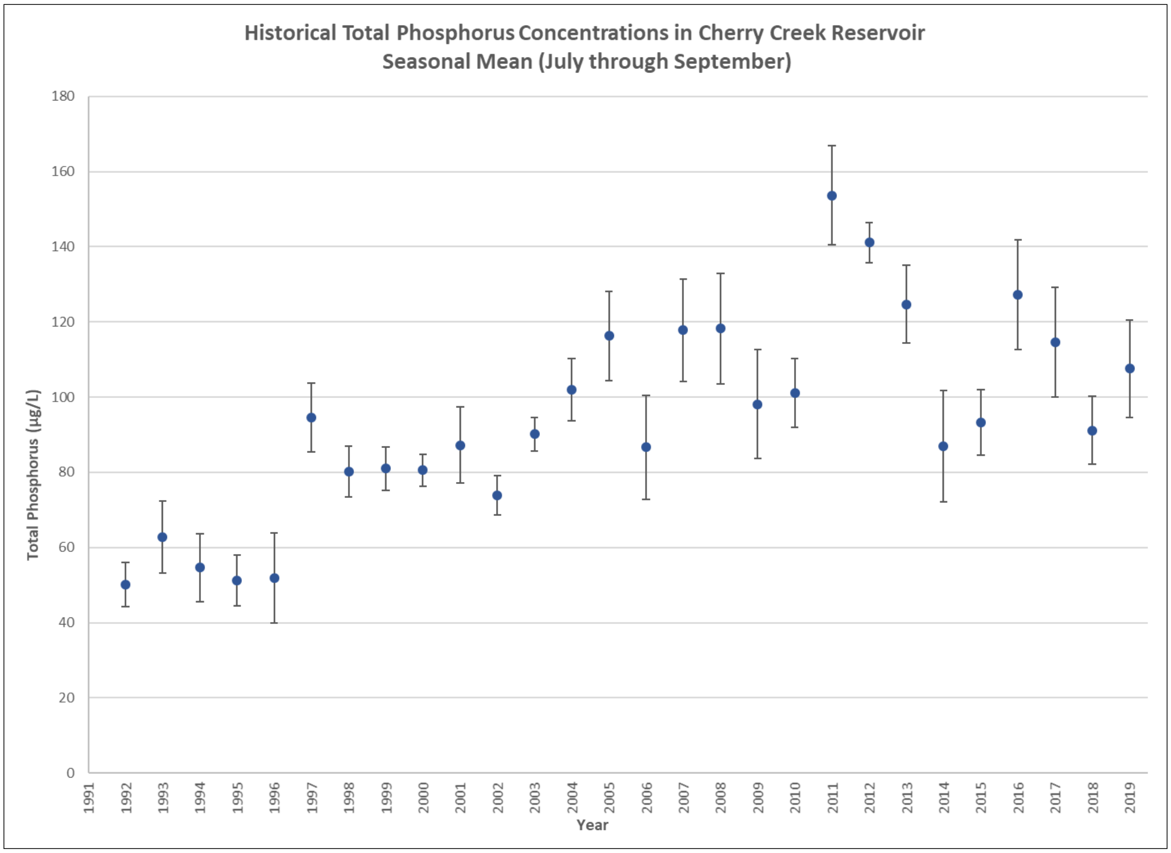


Figure 41. Historical Seasonal Mean TP Concentrations in Photic Zone of Cherry Creek Reservoir 1992-2019.

During WY 2019 as a whole, the monthly mean TP concentrations ranged between 61 µg/L and 170 µg/L, with a mean value of 95.3 µg/L (Figure 43). The lowest values were present in December 2018 and the highest values in July 2019. The WY 2019 data suggests that there are high levels of TP in the Reservoir throughout the year contributing to eutrophic conditions.

The data illustrated in Figure 42 indicate that overall levels of TP in the Reservoir were above 60 µg/L during all of WY 2019, with most levels at or above 75 µg/L, only 6 of the 15 samples had mean TP levels above 100 µg/L.

In addition to the Photic Zone composite of 0, 1, 2, and 3 meters, individual samples were also collected through the water column at 1-m increments from 4-7m at CCR-2. These samples usually had TP concentrations that generally increased with depth. Average WY 2019 TP concentrations at station CCR-2 ranged from 66 µg/L to 330 µg/L in samples collected in the water column at 4 m, 5 m, 6 m, and 7 m. Figure 43 illustrates the TP profiles with depth at Reservoir monitoring station CCR-2, with the composite Photic zone samples from all 3 sites.

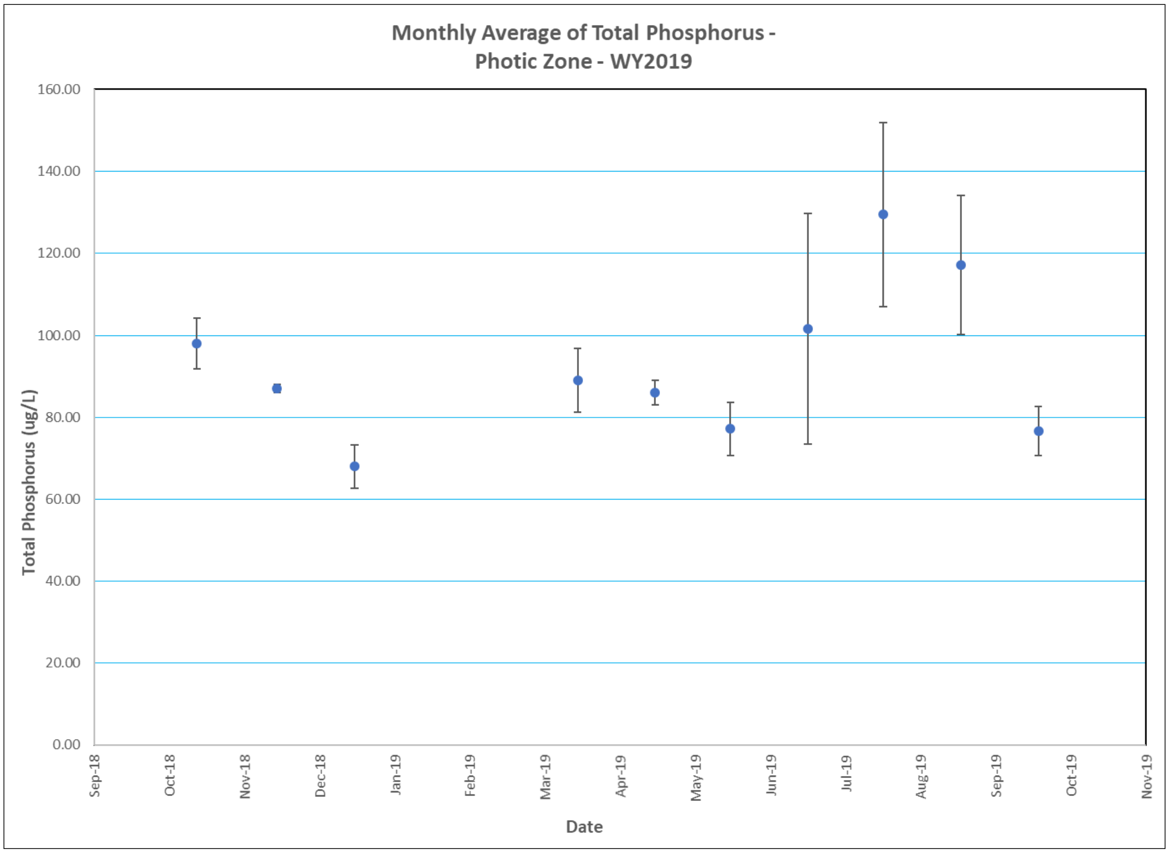


Figure 42. Monthly Average of Total Phosphorus in the Photic Zone, Cherry Creek Reservoir, WY 2019.

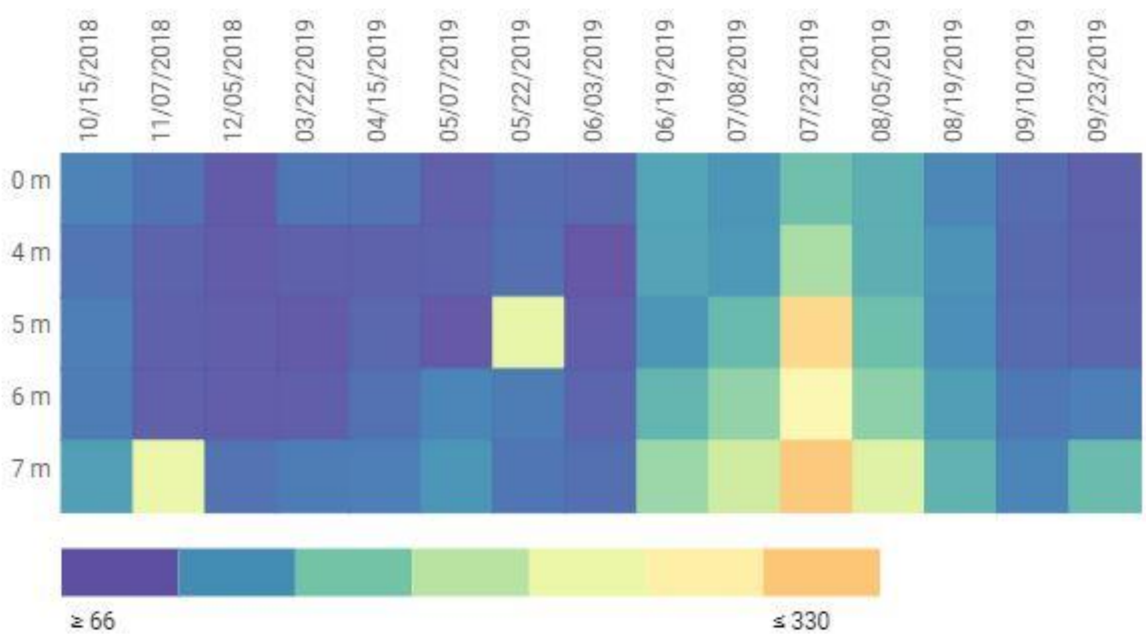


Figure 43. Total Phosphorus (ug/L) Profile in Cherry Creek Reservoir, WY 2019. (http://ccbwqportal.org/)

Elevated TP concentrations in the hypolimnion were noted from early spring through summer, with three notable increases from the deeper samples. Phosphorus increases in the hypolimnion can be caused by internal loading or result from the decomposition of algal cells and other organic matter settling from higher levels in the water column. Inflows of cold runoff water, which has a higher density than warmer, surface waters and sinks to the bottom as it enters a lake, can also directly increase hypolimnetic nutrient concentrations, especially in reservoirs.

The three monitoring events on July 8th, July 23rd and August 5th, 2019 demonstrated significantly elevated TP above 200 µg/L at the 7 m depth and at the 5 and 6 m samples on July 23rd as well. Theses samples were all collected after the de-stratification system had been shut down for the season on July 4th.

4.10 DISSOLVED AND SOLUBLE REACTIVE PHOSPHORUS

Total Phosphorus is made up of both particulate and dissolved phosphorus. Particulate phosphorus is what remains suspended in the water column instead of settling to the bottom of a lake or reservoir. It includes both inorganic material, such as soil particles and clay minerals, and organic phosphorus, which includes particulate forms such as algal cells and plant fragments. Total dissolved phosphorus (TDP) includes dissolved organic and inorganic material. Dissolved inorganic phosphorus is usually reported as soluble reactive phosphorus (SRP), which represents the bioavailable form of phosphorus. Figures 44 and 45 depict the profiles of TDP and SRP from site CCR-2 during WY 2019.

During WY 2019 it appeared that both TDP and SRP remained relatively constant through late fall and winter 2018-19, but levels in the photic zone began to increase in early May (Figure 44 and 45). At the same time, TDP and SRP levels at depths of 6 and 7 m increased from May through early August. Since SRP is the bioavailable form of phosphorus, it is typical to see decreases in SRP concentrations in the Photic zone through the summer months as productivity increases and phytoplankton and other organisms incorporate SRP into cell material. The trends of increased TDP and SRP were similar to those of TP although there was a strong correlation of lower levels of TDP and SRP in the photic zone during the events when levels were elevated at depth. On June 26th and July 8th, concentrations of TDP and SRP from the samples collected at 7 m were 161 µg/L and 145 µg/L respectively. However, the photic zone levels were the lowest in the water column; TDP was 68.7 µg/L and SRP was 54.3 µg/L. This trend indicates that the primary productivity in the photic zone was utilizing the available forms of phosphorus as they were released and mixed through the water column.

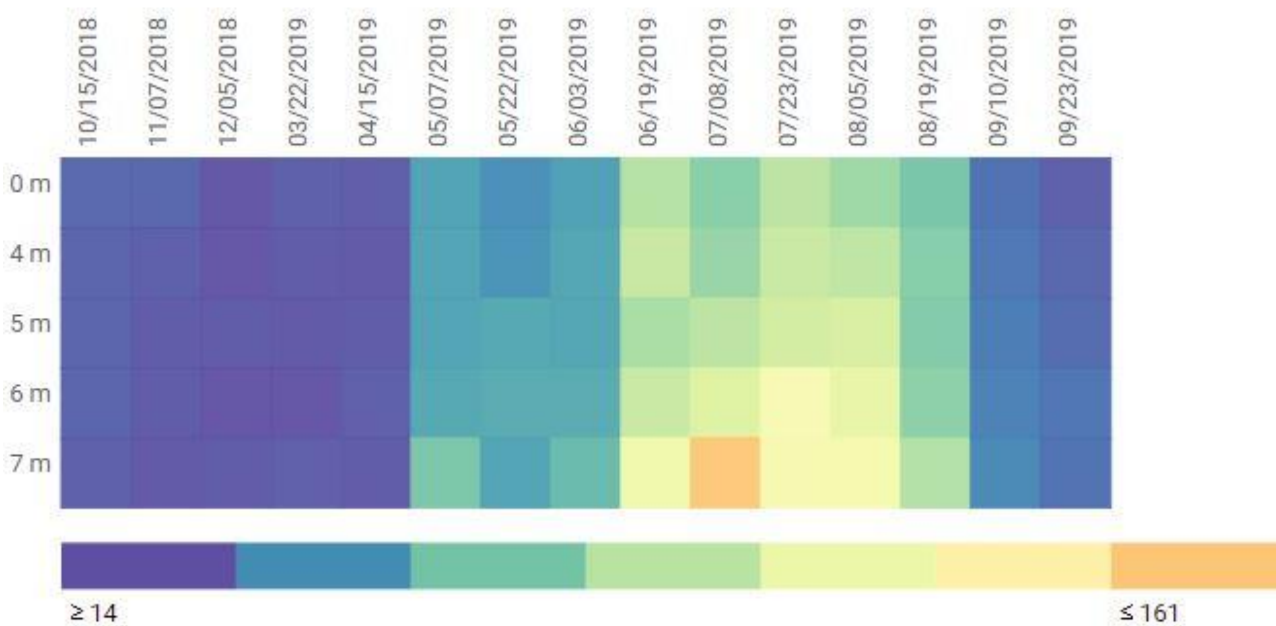


Figure 44. Total Dissolved Phosphorus (ug/L) Profile in Cherry Creek Reservoir, WY 2019. (http://ccbwqportal.org/)

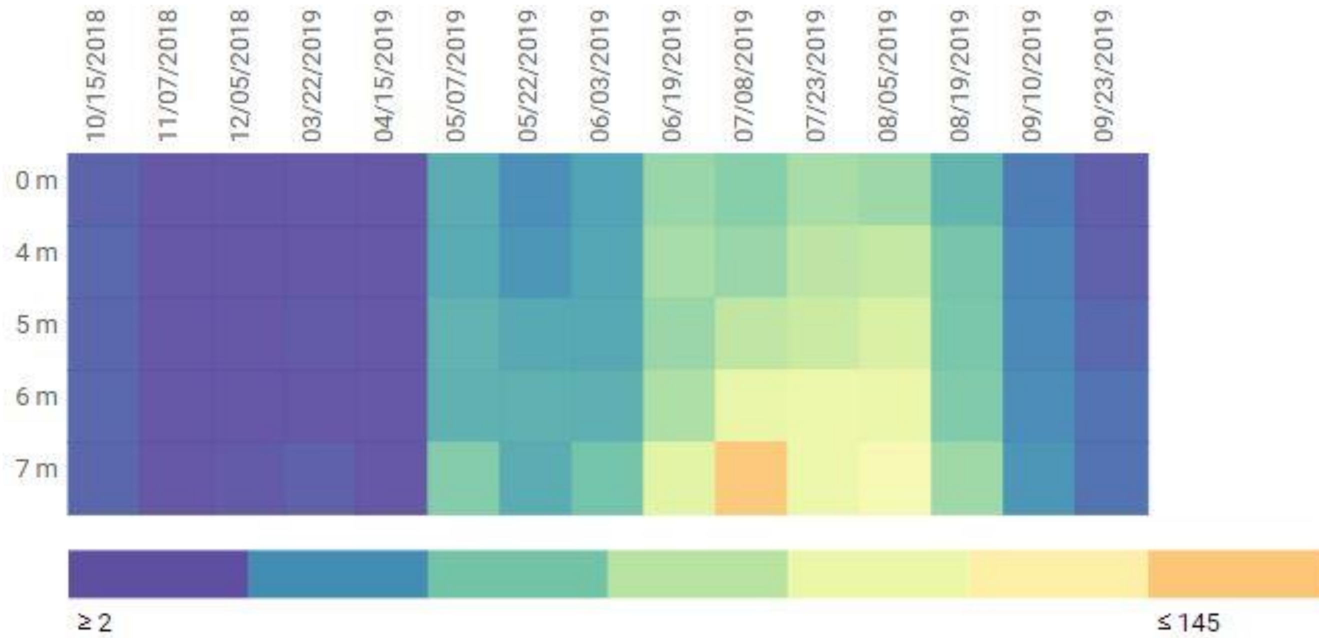


Figure 45. Soluble Reactive Phosphorus (ug/L) Profile in Cherry Creek Reservoir, WY 2019. (http://ccbwqportal.org/)

4.11 TOTAL NITROGEN

The seasonal mean (July thorough Sept) of Total Nitrogen (TN) in the Reservoir in WY 2019 was 688.8 µg/L which was lower than WY 2018 (848.1 µg/L), WY 2017 (761.2 µg/L) and WY 2016 (920.9 µg/L). The WY 2019 seasonal mean is also lower than the long-term average of 894.0 µg/L measured from 1992-present. As illustrated by Figure 46, the seasonal mean values for TN appear to be variable within the same range.

Although there is no site-specific standard for TN in Cherry Creek Reservoir, CDPHE Regulation 31 includes interim nutrient values for warm water reservoirs greater than twenty-five (>25) acres. These are criteria only, and do not become standards unless they are adopted as waterbody-specific standards during a basin-specific water quality standards rulemaking hearing. The warm water total nitrogen criterion for large reservoirs is 910 µg/L TN as a summer (July 1-September 30) average in the mixed layer (median of multiple depths), with an allowable exceedance frequency of one-in-five years. The seasonal mean for Cherry Creek in the photic zone was less than the interim values for WY 2019.

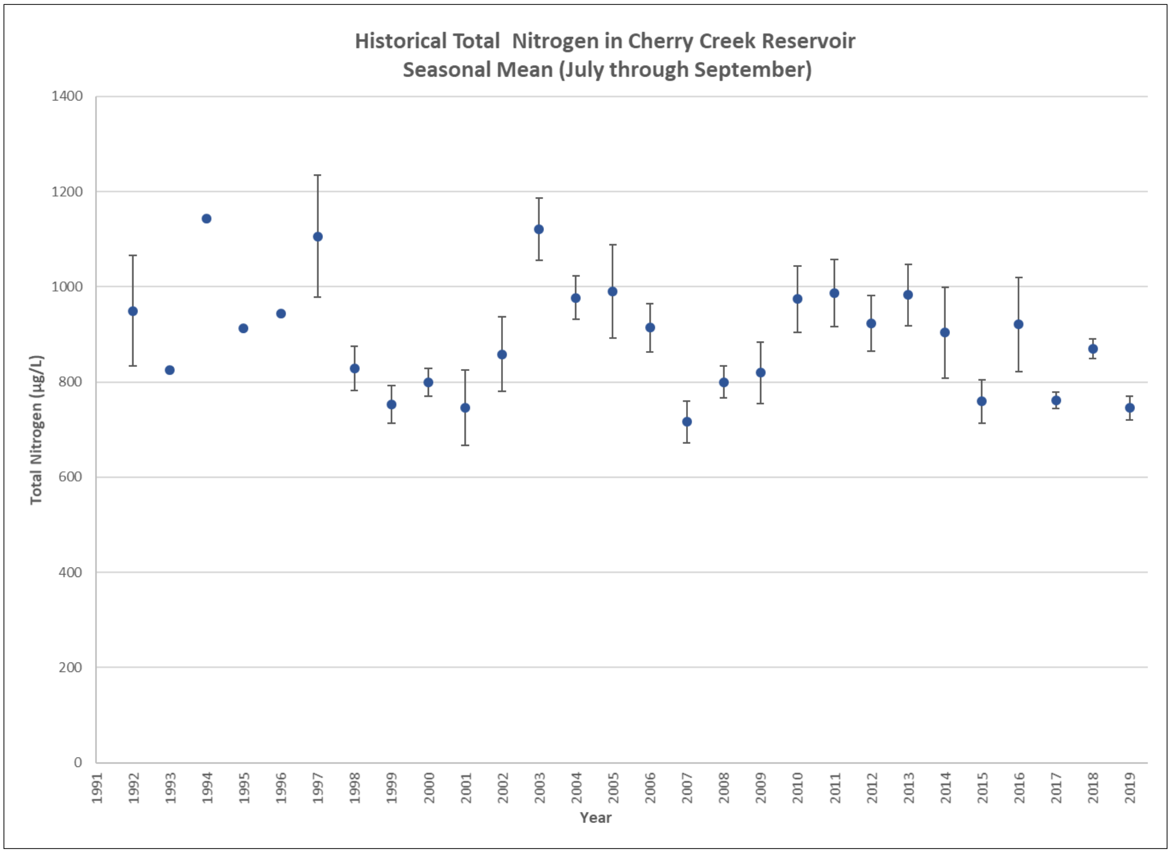


Figure 46. Historical Seasonal Mean TN Concentrations in Photic Zone of Cherry Creek Reservoir 1992-2019.

During WY 2019, annual TN concentrations ranged between 482 µg/L and 1,550 µg/L with a mean value of 778 µg/L (Figure 47). The highest values were present in the March 2019 samples and the lowest values in April and September of 2019.

During WY 2019, TN levels were higher through the water column during the May 7 and July 23 monitoring events. (Figure 48). The TN in the photic zone sample was significantly higher than the rest of the reservoir on March 22, 2019. Also, in the October and November 2018 samples the TN concentrations from the 7 m depth sample were much higher than the samples higher up in the water column.

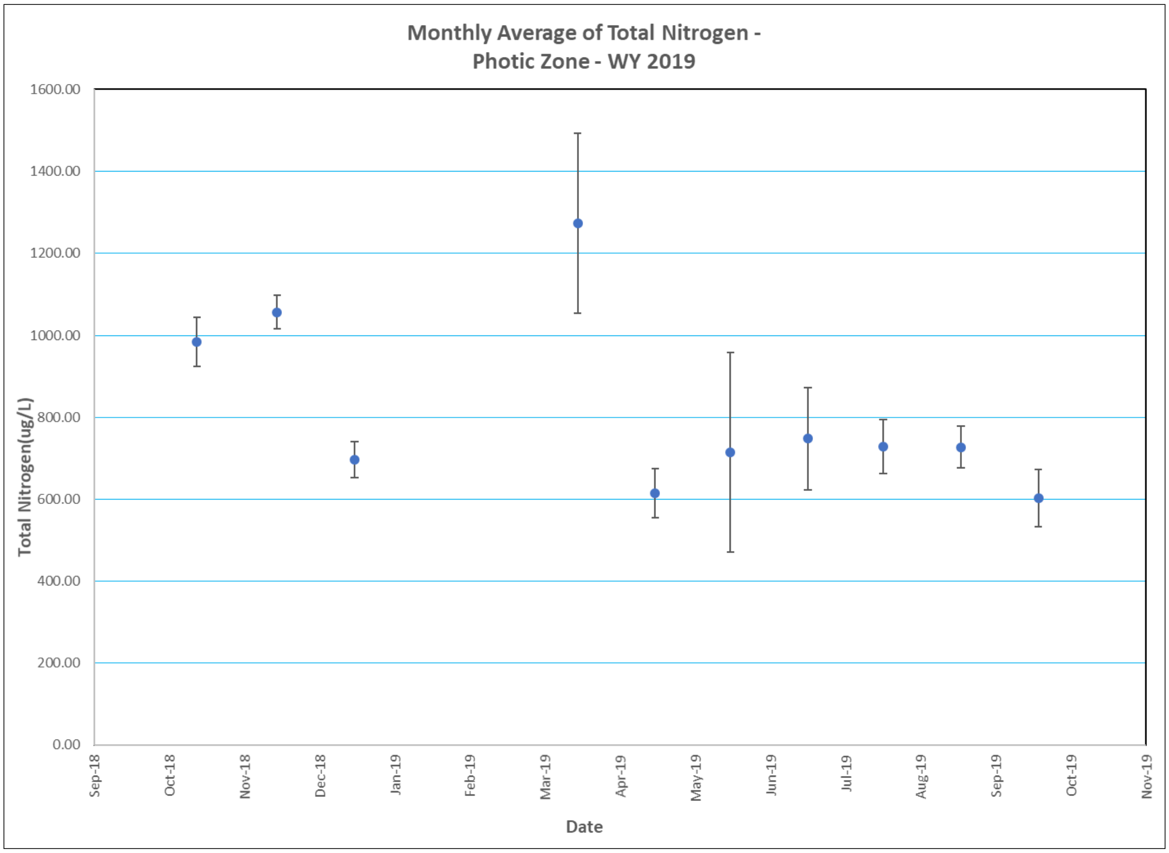


Figure 47. Monthly Average TN Concentrations in Photic Zone, Cherry Creek Reservoir, WY 2019.

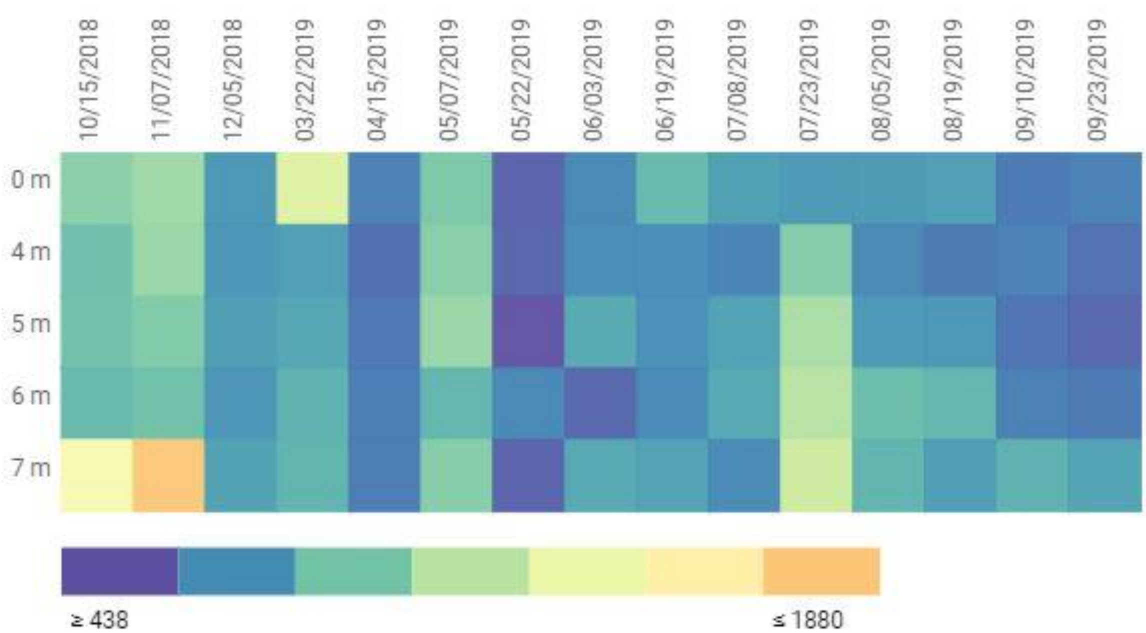


Figure 48. Total Nitrogen (ug/L) Profile in Cherry Creek Reservoir, WY 2019. (http://ccbwqportal.org/)

4.12 TOTAL INORGANIC NITROGEN (TIN)

Total Inorganic Nitrogen (TIN) is calculated as the sum of nitrate-nitrite-N (NO_3+NO_2-N) and ammonia-N (NH_3-N) concentrations and represents the forms of nitrogen that are immediately available for algal growth. Figures 49 and 50 illustrate NO_3+NO_2-N and NH_3-N concentrations separately. TIN concentrations were elevated in June and July at the deeper sampling sites. Possible reasons for the high TIN concentrations in the hypolimnion are decomposition processes and internal nitrogen loading.

In general, nitrate concentrations are favored when DO is present and nitrates are converted to ammonia in the absence of oxygen. Nitrates were generally absent from the photic zone of Cherry Creek Reservoir throughout WY 2019, which may be an indication that algal growth in the Reservoir is limited by nitrogen concentrations.

Ammonia concentrations (shown as NH_3-N in Figure 50) were elevated at depth throughout most of the year and were also often present in surface waters. This is an indication of a highly productive reservoir. The increases in ammonia concentrations in the deeper layers (5, 6, and 7 m) were most pronounced in June and July, which correlated to the periods of lower oxygen at the bottom of the Reservoir.

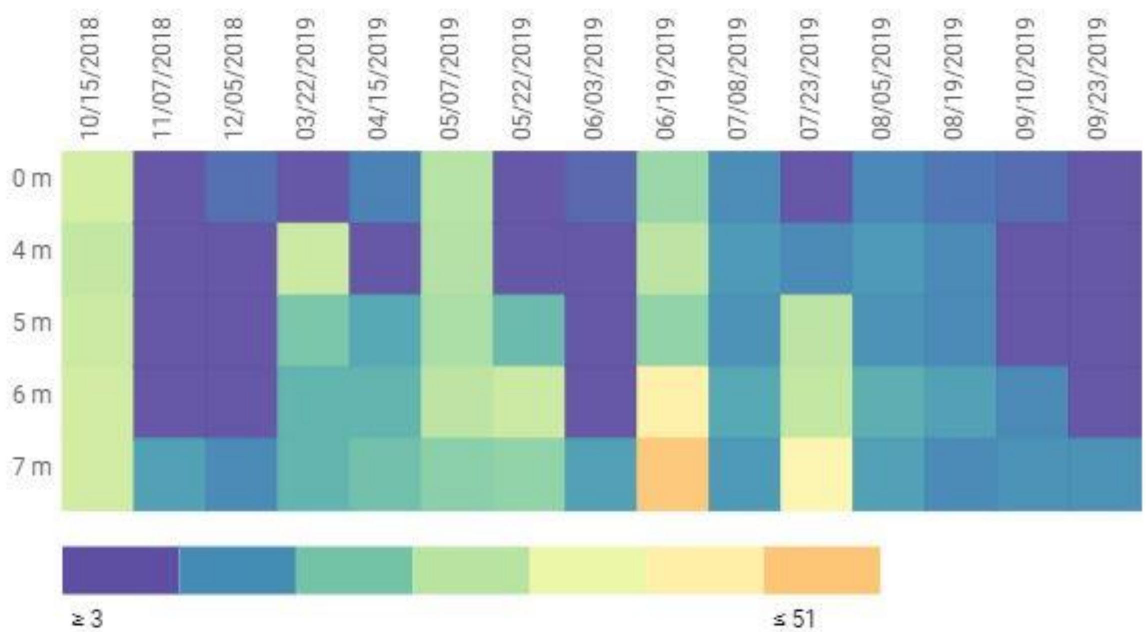


Figure 49. Nitrate and Nitrite Profile(ug/L) at CCR-2 in Cherry Creek Reservoir, WY 2019.
(http://ccbwqportal.org/)

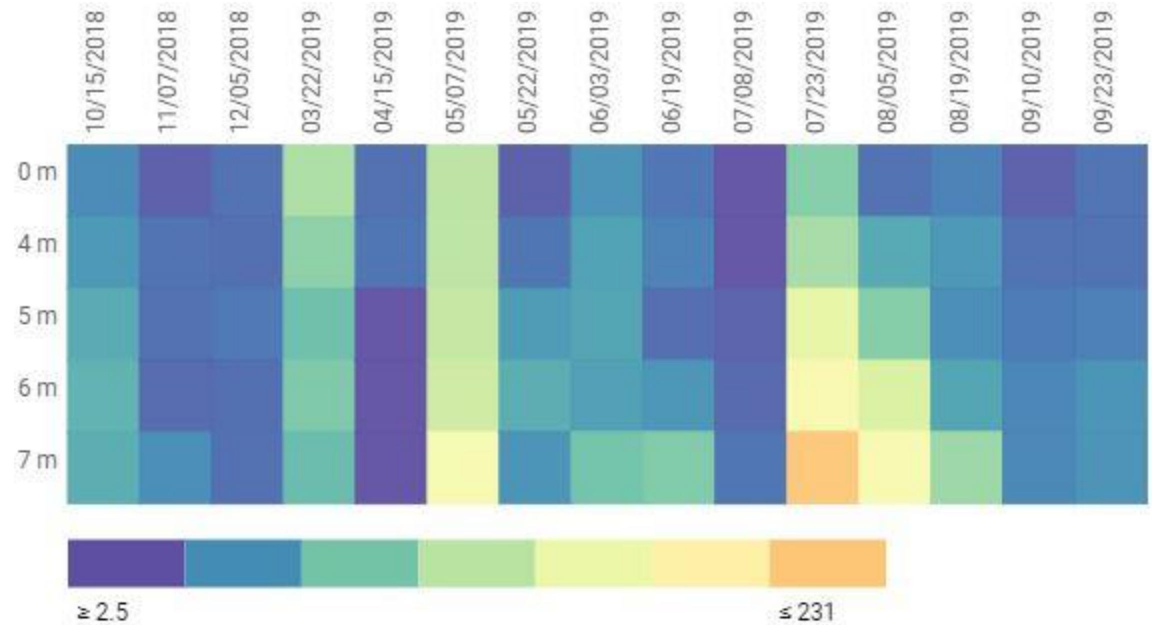


Figure 50. Ammonia (ug/L) Profile at CCR-2 in Cherry Creek Reservoir, WY 2019. (http://ccbwqportal.org/)

4.13 LIMITING NUTRIENT

Nitrogen and phosphorus are the nutrients that usually limit algal growth in natural waters. Both the relative concentrations of nitrogen and phosphorus and the absolute concentrations of these nutrients play important roles in structuring phytoplankton communities (Schindler, 1977; Reynolds, 1986). The average Nitrogen to Phosphorus (N:P) ratio of healthy, growing algal cells is about 7 to 1 by weight (or between 15 and 16 to 1 by molar ratio). This value, known as the Redfield ratio, is generally assumed to be the ratio in which these nutrients are ultimately required by algal cells (Reynolds, 1986). Generally, large N:P ratios (>7) indicate that the growth of the phytoplankton community will be limited by the concentration of phosphorus present, while small N:P ratios (<7) indicate that growth will be limited by nitrogen concentrations (Schindler, 1977). The ratios of total inorganic nitrogen (TIN = nitrate+nitrite-N + ammonia-N) to soluble reactive phosphate (SRP) may be more meaningful than the ratio of total nitrogen to total phosphorus because the inorganic nutrient forms are more directly available to support the growth of aquatic organisms. Figure 50 plots the nutrient ratios of TN:TP, TIN:SRP and TDN:TDP. The line indicates the mass ratio of nitrogen to phosphorus indicating whether nitrogen or phosphorus is limiting. Chl α is plotted on the secondary axis. The TN:TP ratios indicate that TN was limiting in late May, and during the July to August monitoring events. The TDN:TDP ratio indicates a similar trend during July and early August.

Based on the data here and the correlation to the concentrations of chl α at site CCR-2 during WY 2019, it appears that the biologically available forms of nitrogen may limit algal growth during at least part of the growing season in Cherry Creek Reservoir (Figure 51). The potential for cyanobacteria to fix atmospheric nitrogen, may be one of the main factors leading to a phytoplankton community dominated by cyanobacteria (see Section 5.1). During March 2019, the TIN:SRP ratio was very high, which correlated to a very high chl α concentration. As seen in the phytoplankton analysis, when the Reservoir experienced nitrogen limitation, increased cyanobacteria cell counts were also observed.

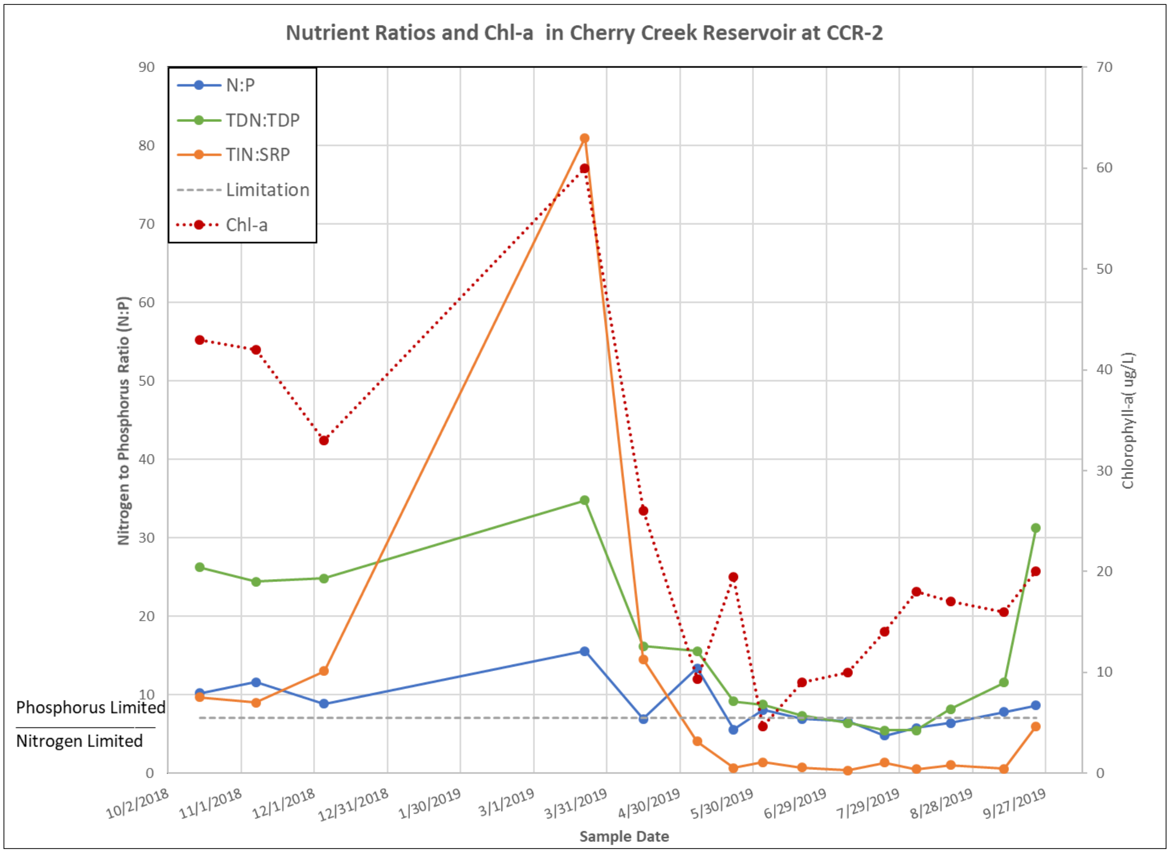


Figure 51. Nutrient Ratios for and Chlorophyll *a* in Cherry Creek Reservoir in WY 2019.

4.14 TROPHIC STATE ANALYSIS

The trophic state of a lake is a relative expression of the biological productivity of a lake. The Trophic State Index (TSI) developed by Carlson (1977) is among the most commonly used indicators of lake trophic state. This index is usually expressed as three separate indices based on observations of total phosphorus concentrations, chl α concentrations, and Secchi depths from a variety of lakes. Total phosphorus was chosen for the index because phosphorus is often the nutrient limiting algal growth in lakes. Chl α is a plant pigment present in all algae and is used to provide an indication of the algal biomass in a lake. Secchi depth is a common measure of the transparency of lake water. Transparency is often limited by algal growth in productive lakes.

Mean values of TP, chl α, and Secchi depth for an individual lake are logarithmically converted to a scale of relative trophic state ranging from 1 to 100. Elevated values for the Trophic State Index are indicative of higher productivity. A TSI of less than 35 indicates oligotrophic conditions, a TSI between 35 and 50 indicates mesotrophic conditions, and a TSI greater than 50 indicates eutrophic conditions. Hypereutrophic, or excessively productive lakes, have TSI values greater than 70. Higher numbers are associated with increased probabilities of encountering nuisance conditions, such as excessive macrophyte growth and algal scums.

Trophic state indices for Cherry Creek Reservoir are presented in Table 13. These values were calculated using the average of the photic zone (0-3 m) composite samples collected at Stations CCR-1, CCR-2, and CCR-3 during the months of May through September because Carlson (1977) suggested that summer average values may produce the most meaningful results. Calculated trophic state indices were 71 for TP, 57 for chl α, and 57 for Secchi depth. These values indicate that Cherry Creek Reservoir is hypereutrophic in relation to TP and eutrophic in regard to chl- *a* and Secchi depths.

Table 13. Trophic State Indices for Cherry Creek Reservoir WY 2019.

Station	Trophic State Index (TSI)		
	Total P	Secchi Depth	Chlorophyll *a*
CCR-2	71	57	57

Trophic state can also be assessed by comparing monitoring data to trophic state criteria, such as those developed by the U.S. EPA (1980). Table 14 presents a comparison of Cherry Creek Reservoir monitoring data from WY 2019 to EPA trophic state criteria. Values for the various parameters were the same averages used to calculate the trophic state indices.

Table 14. Comparison of Cherry Creek Reservoir Monitoring Data to Trophic State Criteria WY 2019.

Trophic State	Characteristic			
	Total P (mg/L)	Chlorophyll *a* (µg/L)	Secchi Depth (m)	Relative Productivity
Oligotrophic	< 0.005	< 2.0	> 8	Low
Mesotrophic	0.005 -0.030	2.0 - 6.0	4 – 8	Moderate
Eutrophic	***0.030 - 0.100***	***6.0 - 40.0***	2 – 4	***High***
Hypereutrophic	> 0.100	> 40.0	***< 2***	Excessive
Cherry Creek Reservoir	**0.100**	**14.5**	**1.24**	**High**

The trophic state criteria in Table 14, like calculated trophic state indices, are based on somewhat arbitrary concentrations that are typically found when the average lake user perceives that water quality problems exist. Comparisons of monitoring data to trophic state criteria indicate that conditions in Cherry Creek Reservoir are in the eutrophic range with respect to both total phosphorus and chl α concentrations.

Secchi depth is in the hypereutrophic range according to the EPA criteria. However, sometimes this can be misleading since conventional trophic state criteria assume that Secchi depth is related primarily to algal turbidity. Inorganic turbidity can be more important factor in determining water clarity for many reservoirs, and Secchi depth does not always provide a good indication of trophic state for reservoirs since these measurements cannot distinguish between algal productivity and inorganic suspended sediment.

4.12 PLANKTON SAMPLES

Analyses of phytoplankton and zooplankton samples were used to assess biological conditions in Cherry Creek Reservoir during WY 2019. Both numbers of individuals (cells/mL for phytoplankton and animals/L for zooplankton) and biovolume (µm^3/mL for phytoplankton) or biomass (µg/L for zooplankton) were reported.

4.12.1 PHYTOPLANKTON

Phytoplankton are photosynthetic organisms that are the primary producers in aquatic systems. They form the base of aquatic food chains and are grazed upon by zooplankton and herbivorous fish. A healthy lake should support a diverse assemblage of phytoplankton, in which many algal groups are represented.

In many environmental instances, algal numbers (cells/mL) and algal biovolume (µm^3/mL) closely correlate with one another, but that is not always the case. It is possible, and a common occurrence, for a phytoplankton community to have a large number of very small-sized algal cells, particularly in systems, such as Cherry Creek Reservoir, that have high numbers of cyanobacteria (Cyanophyta, commonly referred to as blue-green algae). At other times, the phytoplankton community can be dominated by a few algal species that are very large in size.

Phytoplankton samples were collected at site CCR-2 from the photic zone (0-3 m composite sample) and analyzed to identify and quantify the populations present on each sampling date. The results from WY 2019 indicate high productivity with diverse populations.

Phytoplankton populations in Cherry Creek Reservoir were very diverse, with an average of 41 species present on each sampling date. The minimum number of species present was 28 on May 22, 2019, and the maximum number was 60 on September 12, 2019.

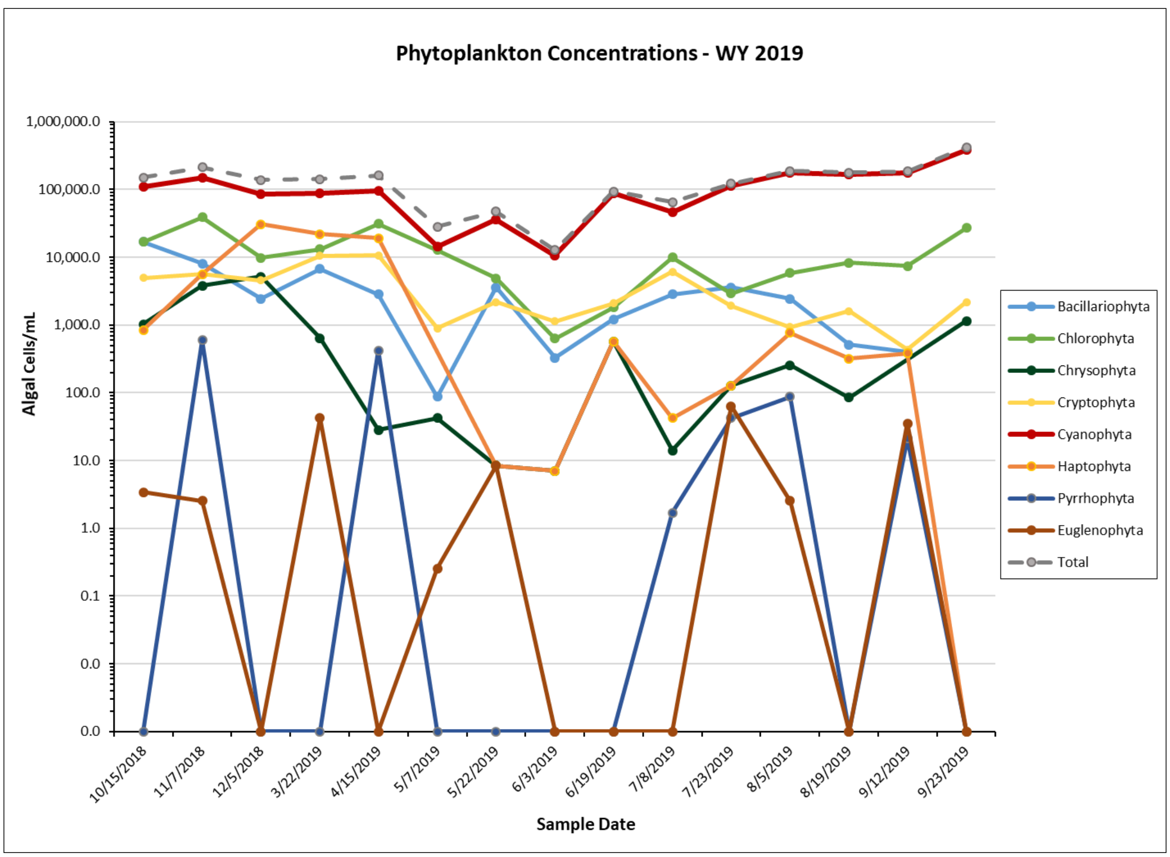


Figure 52. Phytoplankton Concentrations in Cherry Creek Reservoir, WY 2019.

Chlorophyta (green algae) provided the highest number of species, with a range of 12 to 31 and an average of 20 species present on each sampling date. Bacillariophyta (diatoms) and Cyanophytes (blue-green algae) also had high diversities, with averages 6 and 8 species, respectively, on each date. Cryptophytes (cryptomonds) were the only other group of algae that were present on each sampling date, with an average of 3 species per sampling event. All other groups were absent on at least one or more dates.

Cell counts were dominated by the Cyanophytes, which were present in higher numbers than any of the other groups on each sampling date (Figure 52), with concentrations averaging 116,620 cells/mL and ranging from 10,631 cells/mL on June 3, 2019 to 389,672 cells/mL on September 23, 2019. The cyanophytes were responsible for 50% or more of the total phytoplankton population throughout the year and averaged 78% of the total counts (Figure 53). Total algal cell counts peaked at 419,978 cells/mL on September 23, 2019, with just two species of cyanophytes, *Aphanocapsa delicastissima* (158,819 cells/mL) and *Chroococcaceae* spp. (126,290 cells/mL), comprising 68% of the total.

Chroococcaceae spp. and *Synechococcus* sp. 1, both relatively small (<1 µm) species, were the most common cyanobacteria, with both species present on all sampling dates. *Chroococcaceae* spp. concentrations peaked at over 100,000 cells/mL on August 5 and September 23, 2019 and concentrations were always greater than 7600 cells/mL.

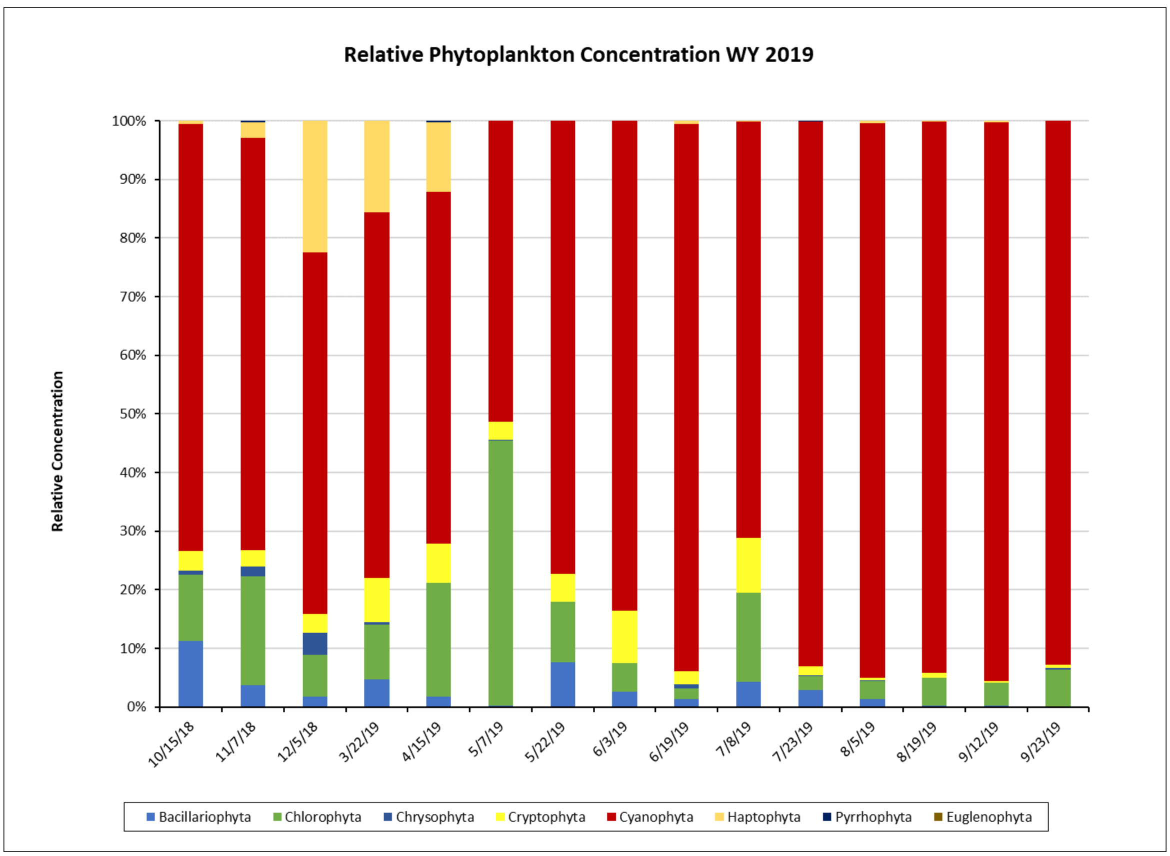


Figure 53. Relative Phytoplankton Concentration, WY 2019.

In contrast to WY 2018, when the cyanobacteria as a whole usually made up less than 10% of the total algal biovolume, in WY 2019 cyanobacteria constituted over 50% of the total biovolume on five dates (Figures 53 and 54). And on four dates, a single species made up over 70% of the total biovolume. *Dolichospermum circinale* contributed 1.06 x 10^8 µm^3/mL of the total 1.18 x 10^8 µm^3/mL (89.8%) on July 23rd, *Dolichospermum* sp. contributed 3.24 x 10^7 µm^3/mL of the total 3.54 x 10^7 µm^3/mL (91.5%) on June 3rd, *Aphanothece nidularis* contributed 2.70 x 10^7 µm³/mL of the total 3.78 x 10^7 µm³/mL (71.4%) on June 19th, and *Aphasocapsa delicatissima* contributed 1.59 x 10^7 µm³/mL of the total 2.17 x 10^7 µm³/mL (73.3%) on September 23, 2019.

On Tuesday July 23rd a notable cyanobacteria bloom was noted in the Reservoir by CPW staff which was also identified as *Dolichospermum*. While the areas with accumulated scums tested negative following an Algal Toxin Strip Test, levels of microcystin (1.52 ug/L) were found when a sample was sent to the lab for detailed analysis (M. May, personal communication July 23 and 24, 2019). After two days the bloom appeared to dissipate and did not require any additional testing.

Cyanophytes are probably responsible for the majority of algal blooms that occur in freshwater ecosystems. They have the ability to use atmospheric nitrogen as a nutrient source and regulate their position within the water column by altering their buoyancy with the use of gas vacuoles. These characteristics give cyanobacteria a competitive advantage over other groups of phytoplankton. Nuisance blooms of cyanobacteria usually occur in neutral to alkaline waters that are still, relatively warm, and have low N:P ratios, which are all characteristics of Cherry Creek Reservoir. Some species of cyanobacteria are capable of producing toxins, but those species were not commonly observed during sampling in Cherry Creek Reservoir in WY 2019.

Chlorophytes were present in high numbers throughout the year and were usually second only to the cyanophytes in total cell concentrations, averaging 10.9% of the total cell counts (Figure 53). *Chlamydomonas* sp., was the only species of green algae present on all sampling dates, but it was never present in very high numbers or high biovolume. *Dimorphococcus lunatus* was the green alga present at the highest concentrations, with cell counts of 7,654 cells/mL on April 15 and 7,335 on November 7, 2018. In each case, this represented less than 0.1% of the total cell counts for the date.

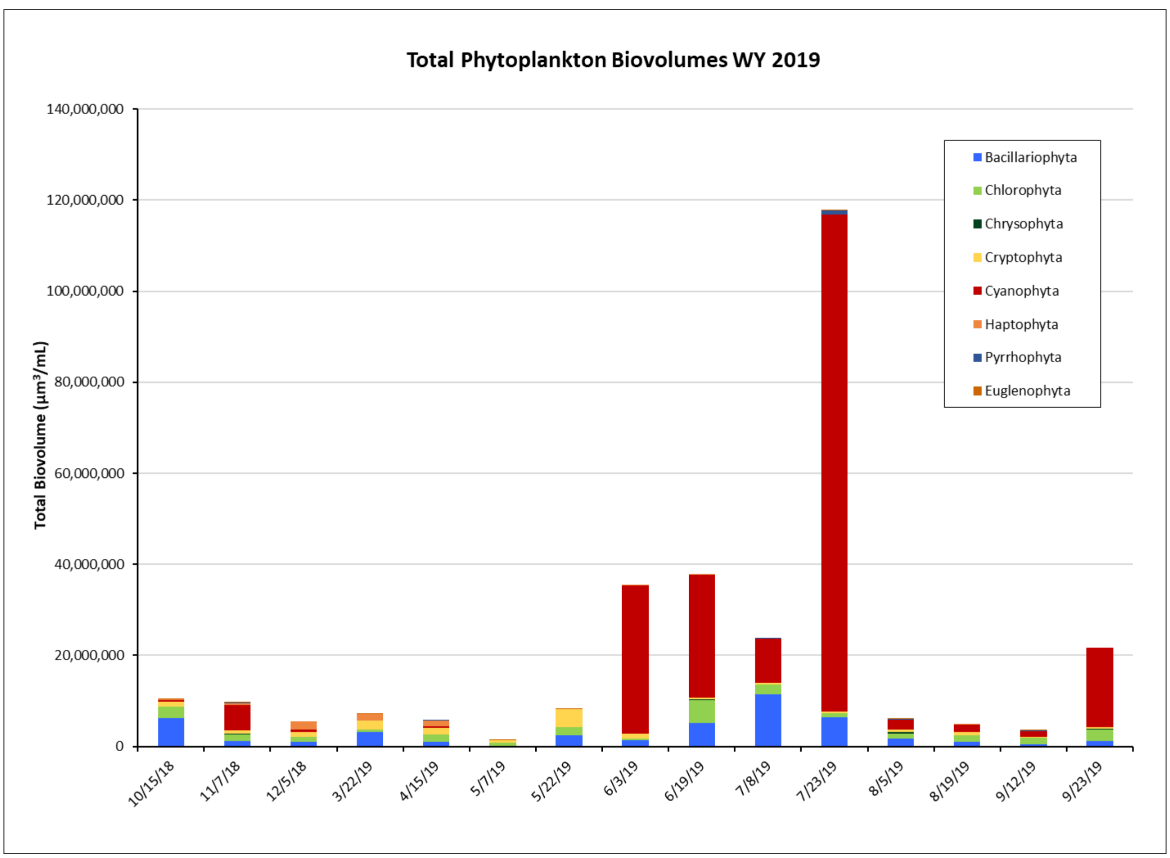


Figure 54. Phytoplankton Biovolumes in Cherry Creek Reservoir in WY 2019.

The green algae also typically made up a large portion of total algal biovolume, averaging 19.8% of the total (Figures 54 and 55). *Oocystis lacustris* was the species with the highest biovolume at 3.23 x 10^6 μm^3/mL (8.6% of the total) on June 19. *Oocystis parva* had the highest relative biovolume, contributing 3.65 x 10^5 μm^3/mL (25.6% of the total) on May 7th.

Nuisance blooms of Bacillariophyta (diatoms) are not as common as nuisance cyanobacteria blooms; however, when they do occur, it tends to be most common during the late spring or early summer months when water temperatures are still relatively low. Diatom cell counts in Cherry Creek Reservoir in Water Year 2019 peaked at 16,902 cells/mL on October 15, 2018. *Cyclotella atomus* was the most abundant diatom on that date, with a concentration of 3,915 cells/mL (Figure 52). Cell counts averaged 2.9% of the relative phytoplankton cell counts during WY 2019. *Fragillaria filiformis* was the diatom with the highest concentration (5,102 cells/mL) during WY 2019, but that represented only 2.6% of the total algal cell count on that date.

Because of their relatively large size, diatoms contributed 21.6% of the relative algal biovolume in WY 2019 (Figure 54), with a maximum of 59.8% on October 15, 2018. *Fragillaria crotensis* was the diatom present with the highest biovolume (2.99 x 10^6 μm^3/mL, but only 2.5% of the on the total biomass, on July 23, 2019) and *Stephanodiscus alpinus* was the diatom with the highest relative biomass (2.53 x 10^6 μm^3/mL, 24.3% of the total biomass on October 15, 2019).

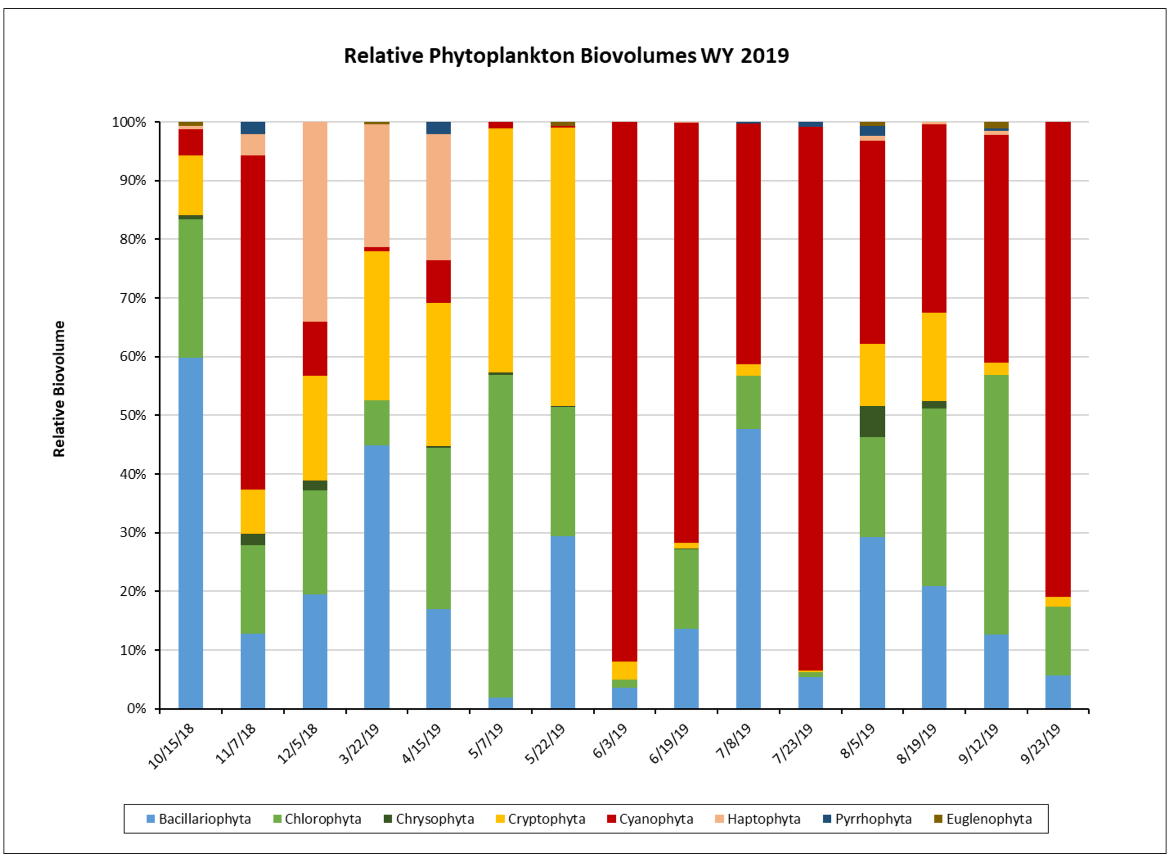


Figure 55. Relative Phytoplankton Biovolumes in Cherry Creek Reservoir in WY 2019.

Along with the Cyanophytes, Bacillariophytes, and Chlorophytes, members of the Cryptophtye group (cryptomonads) were often present at the level of 1,000 or more cells/mL associated with eutrophic conditions on all but three sampling dates (Figure 51). Only seven species of cryptomonads were identified in Cherry Creek Reservoir during Water Year 2019, but two of those species, *Rhodomonas minuta nannoplnctica* and

Cryptomonass erosa, were present on each sampling date. *Rhodomonas minuta nannoplnctica* was usually the cyptomonad present in the highest numbers, peaking at 9,625 cells/mL on April 15, 2019, when it comprised 9.8% of the total cell count. For all of WY 2019, the cryptomonads contributed 3.7% of the total cell counts.

The crytomonads are typically relatively large algae and often made up a significant portion of the relative phytoplankton biovolume, averaging 14 % of the relative algal biovolume for the year (Figures 53 and 54). The large species, *Cryptomonass erosa*, was usually the cryptomonad species with the highest biovolume on most sampling dates. The biovolume for this species peaked at 1.93 x 10^6 μm^3/mL on May 22, 2019, when it comprised 23.4% of the total algal biovolume.

Phyrrophyta (dinoflagellate) concentrations peaked in November 2018, and in April, and from June through August 2019, but were never present at more than 1,000 cells/mL (Figure 51). The maximum dinoflagellate count was only 595 cells/mL on November 7, 2018. Peridinium sp. and *Peridinium inconspicuum* each had a cell count of 255 cells/mL on that date, representing 82% of the dinoflagellates present on that date, but only 0.2% of the total algal cell count. Dinoflagellates of the genera *Peridinium* and *Ceratium* are known to be responsible for taste and odor problems in freshwater ecosystems when present in high concentrations. In addition to *Peridinium*, *Ceratium hirundinella* was present in Cherry Creek Reservoir only on July 8, 2019, and *Ceratium brachyceros* was present only on August 5, 2019, but both were present only at very low (<3 cells/mL) concentrations.

The frequency of dinoflagellate blooms appears to be highly correlated to levels of organic pollution. Dinoflagellates are comparatively large algae, but dinoflagellate biovolumes never accounted for more than 2.1% (April 15, 2019) of the total algal biovolume in Cherry Creek Reservoir during Water Year 2019 due to their low populations (Figures 55 and 56). The maximum biovolume for a dinoflagellate was 4.68 x 10^6 μm^3/mL for *Peradinium umbonatum* on July 23, 2019, but this was less than 0.4% of the total algal biovolume on that date.

Other groups present at various times during the year included the Chrysophtes (yellow-brown algae), Euglenophytes, and Haptophytes (golden algae). All of these groups include some large species, but only the golden algae made a noticeable contribution to either algal cell counts or biovolumes in Cherry Creek Reservoir during WY 2019 (Figures 51 and 53).

Golden algae are widely distributed in brackish and marine waters and can also occur in freshwater systems, particularly those with higher salinities. They are of potential concern because they can produce toxins that are harmful to fish and other aquatic life. The conditions required for toxin production are not well understood, but high N:P ratios may be involved. The Haptophyte, *Prymnesium parvum,* well-known to be responsible for fish kills, was present in March and April 2019. This was the first time this organism was detected in Cherry Creek Reservoir. During WY 2019, *Prymnesium parvum* was present at 957 cells/ml on March 22 and 106 cells/ml on April 15, 2019, both less than 0.007% of the total population and less than 0.021% of the total biovolume. *Chrysochromulina parva*, a lesser known golden alga, but also a known toxin producer, was first noted in Cherry Creek Reservoir in March 2016 and has been present in most samples since that date. During Water Year 2019, *Chrysochromulina parva* was present on all sampling dates except May 7 and September 12, 2019. Although concentrations of *Chrysochromulina parva* were highest during the cooler months (Figures 54 and 55), and peaked on December 5, 2018, when this species was present at 30,912 cells/mL (22% of the total algal population) and 9.34 x 10^6 μm^3/mL (34% of the total algal biovolume).

4.12.2 ZOOPLANKTON

Zooplankton are microscopic animals that consume algae and bacteria in the water column. Some types of zooplankton feed on algae, others on other zooplankters, and some take in both plant and animal particles. Larger zooplankton can exert a significant grazing pressure on algal cells; however, they are also subject to predation as they are a food source for larger crustaceans, aquatic insects and fish. Zooplankton populations in lakes vary with temperature, food supply, and other environmental factors, with reported populations ranging from a few to several hundred individuals per liter (Hutchinson, 1967). Very little detailed information is available on zooplankton dynamics and populations in reservoirs, although turbidity, increased flow and other factors probably reduce their numbers to below those observed in natural lakes (Marzolf, 1990).

Most freshwater zooplankton are part of only three phyla: *Arthropoda*, which include both cladocerans and copepods; *Rotifera*; and *Protozoa*. Cladocerans and copepods are microscopic crustaceans that feed primarily on phytoplankton. These organisms can be an important food source for fish and can also exert grazing pressure on phytoplankton populations when present in high enough numbers. Rotifers are microscopic animals that feed on detritus and smaller organisms, such as bacteria. They can also serve as a food source for larger zooplankton. Protozoans are single-celled organisms that feed on other microorganisms, organic matter, and debris.

Zooplankton samples were collected as vertical tows from a depth of 6 m to the surface at Station CCR-2 on each sampling date. Zooplankton numbers and diversity were both low compared to average phytoplankton populations in freshwater lakes.

The zooplankton population in Cherry Creek Reservoir was much less diverse than the phytoplankton population, but this is typical of Colorado lakes. A classic study by Pennak (1957) found there were rarely more than 1-3 copepods, 2-4 cladocerans, and 3-7 rotifers present in any given lake. The numbers for Cherry Creek Reservoir were slightly higher than that in WY 2019, with 1-5 cladocerans, 2-6 copepods, and 2-8 rotifers present on each date, plus 0-2 protozoa. The average was only 11.6 species, including immature forms, and never more than 16 species present on any sampling date.

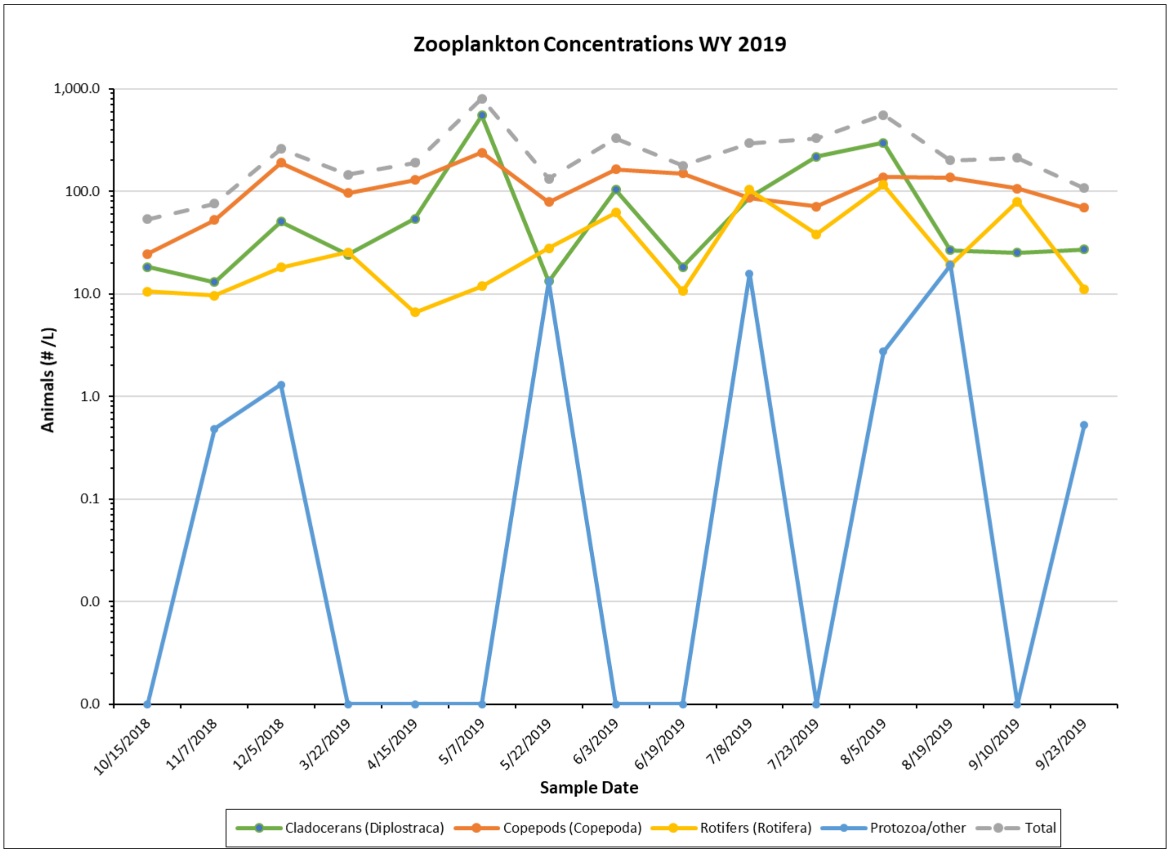


Figure 56. Total Zooplankton Concentrations – WY 2019.

Copepods were typically the zooplankton present in the highest numbers in Cherry Creek Reservoir during WY 2019, accounting for over 50% of the total population on most sampling dates (Figures 56 and 57). Copepods averaged 54% of the zooplankton population, ranging from 22% on July 23, 2019, to 84% on June 19, 2019. Immature forms of calanoid and cyclopoid copepods accounted for the majority of the organisms present. Only seven adult species of copepods were present, *Diachyclops thomasi* and *Leptodiaptomus ashlandi* were each present on at least 10 sampling dates and were often the only adult copepods present. *Leptodiaptomus ashlandi* was the adult form reaching the highest concentration during the year, with 17.6/L on July 8, 2019; however, that represented only 6% of the zooplankton population on that date.

Copepod biomass made up a smaller fraction of the zooplankton population than copepod concentrations because they are not as large as the cladocerans. Copepod biomass averaged 34% of zooplankton biomass in WY 2019, ranging from less than 6% on July 23, 2019, to over 80% on December 5, 2018 (Figures 58 and 59). *Acanthocyclops vernalis*, a relatively large, carnivorous species, only appeared in June. It had a high biomass on both June sampling dates, and its biomass of 148 µg/L on June 19th was the highest for any copepod during the year.

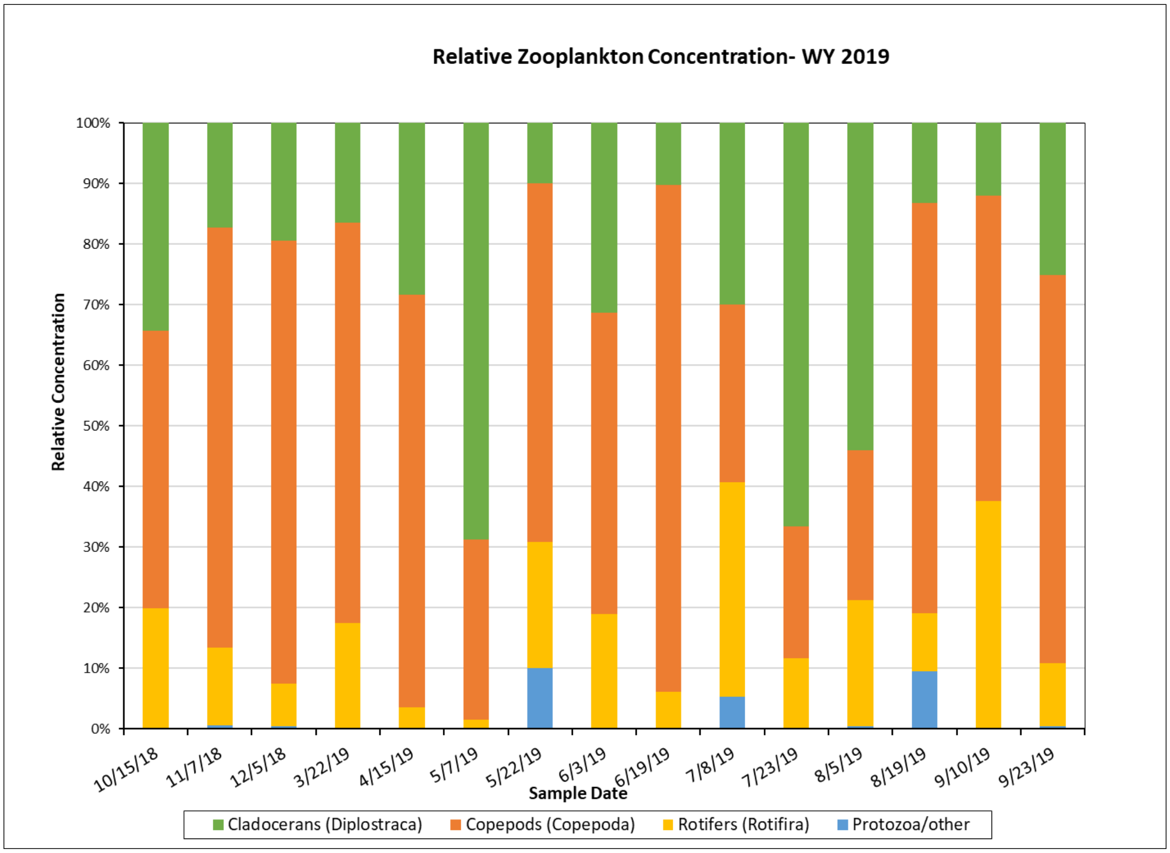


Figure 57. Relative Zooplankton Concentrations in WY 2019, Percent of Total.

Unlike WY 2018, cladocerans were present on all sampling dates in WY 2019. Cladoceran populations averaged 29% of the total zooplankton population during the year, with the highest (69%) and lowest (10%) relative populations occurring on May 7th and May 22nd, respectively (Figures 55 and 56). The most common cladocerans in Cherry Creek Reservoir were *Bosmina longirostris*, present on all sampling dates, and *Daphnia ambigua*, present on 9 dates. Both organisms were present at high concentrations on May 7th, with the *Daphnia ambigua* population of 298 organisms/L on that date was the highest cladoceran population in WY 2019. The *Bosmina longirostris* population of 254 organisms/L on May 7th was the third highest cladoceran population for the year.

The large change in cladoceran populations between the two May sampling dates may be related to the presence of high populations of gizzard shad (*Dorosoma cepedianum*) in the reservoir. Gizzard shad are an important part of the food base for the Cherry Creek Reservoir walleye (*Sander vitreus*) fishery, but they are also effective filter feeders on zooplankton especially at the larval stage (Johnson, 2014).

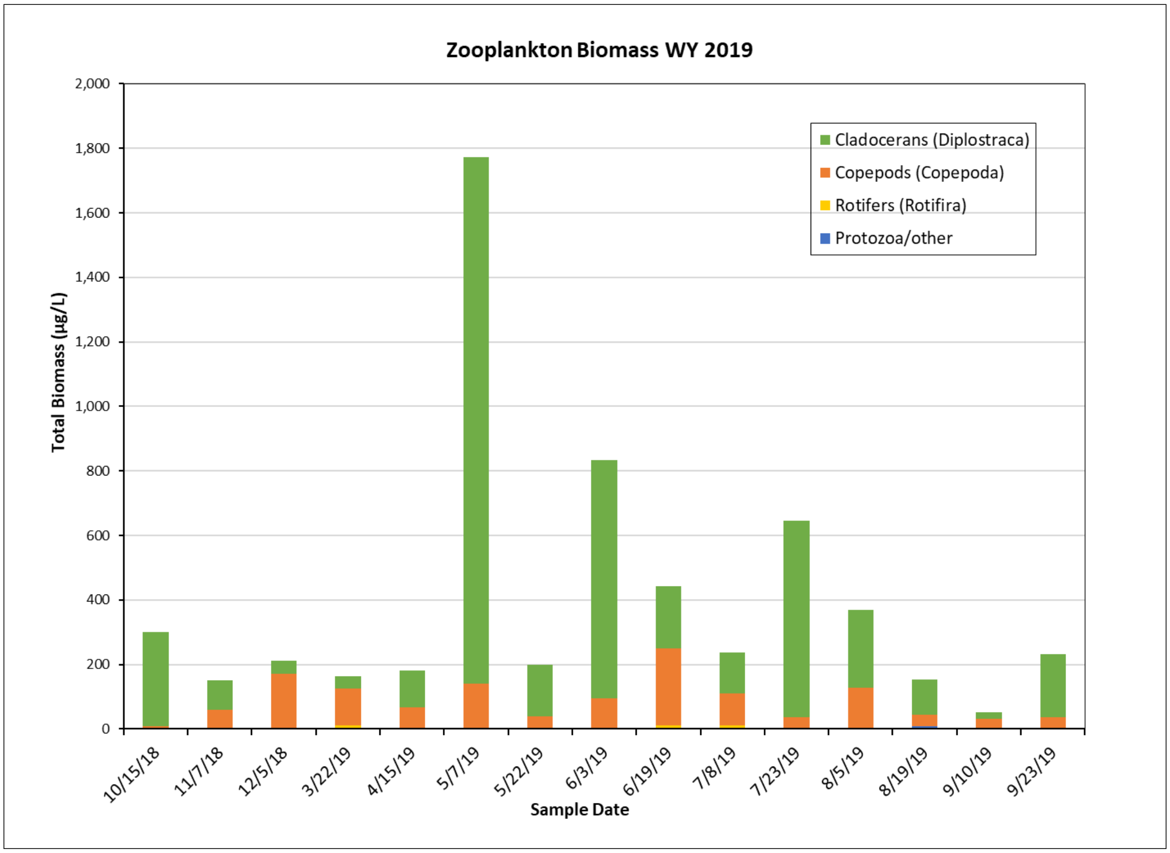


Figure 58. Total Zooplankton Biomass (ug/L) in WY 2019.

Cladocerans frequently comprised over half of the zooplankton biomass on all except four sampling dates in WY 2019 (Figure 58 and 59), with an average of 65% and a range of 20% (December 5, 2018) to 96% (October 15, 2018). The cladoceran species present in Cherry Creek Reservoir typically did not include large-bodied *Daphnia* that are an important source of fish food in many lakes. *Daphnia ambigua* is one of the smaller *Daphnia* and the bosminads, in general, are small cladocerans. The highest biomass of any cladoceran during the year was *Daphnia ambigua*, which was present at 1,315 µg/L on May 7, 2019. That concentration was over 2.5 times as high as the cladoceran with the second highest biomass. That was *Daphnia rosea*, with a biomass of 500 µg/L on May 7, 2019.

Daphnia lumholtzi, an invasive species, is a larger daphnia that is characterized by long spines that help it avoid predation. This species was first identified in Colorado in 2008 (USGS, Non-Indigenous Aquatic Species fact sheet, https://nas.er.usgs.gov/queries/FactSheet.aspx?speciesID=164) and in Cherry Creek Reservoir in 2011 (Johnson, 2014). *Daphnia lumholtzi* was present in October and November 2018, and once each month from July through September 2019. *Daphnia lumholtzi* concentrations peaked during WY 2019 at a concentration of 7.7 organisms/L and a biomass of 79 µg/L on October 15, 2019. Those numbers represented 14% of the total zooplankton population and 42% of the cladoceran population, and 92% of the total zooplankton biomass and 96% of the cladoceran biomass on that date *Daphnia lumholtzi* comprised over half of the total zooplankton biomass on 4 of the 5 dates on which it was present.

Rotifers had a diverse population in Cherry Creek Reservoir during WY 2019, with 14 different species present. Rotifers averaged 15.5% of the total zooplankton population during the year, with a maximum of 37.6% of the total on September 10, 2019, and a minimum of 1.5% on May 7, 2019, which was the date with the highest zooplankton population during the year of 802 organisms/L. Rotifer populations reached a maximum of 115 organisms/L on August 5, 2019, which was 21% of the total zooplankton population on that date (Figures 55 and 56). The rotifer species with the highest concentration was *Keratella cochlearis*, with a population of 100 organisms/L on July 8, 2019 which represented 96% of the rotifer population and 34% of the total zooplankton population on that date. *Keratella cochlearis* was present on 13 of the 15 sampling dates and was the most common rotifer in WY 2019.

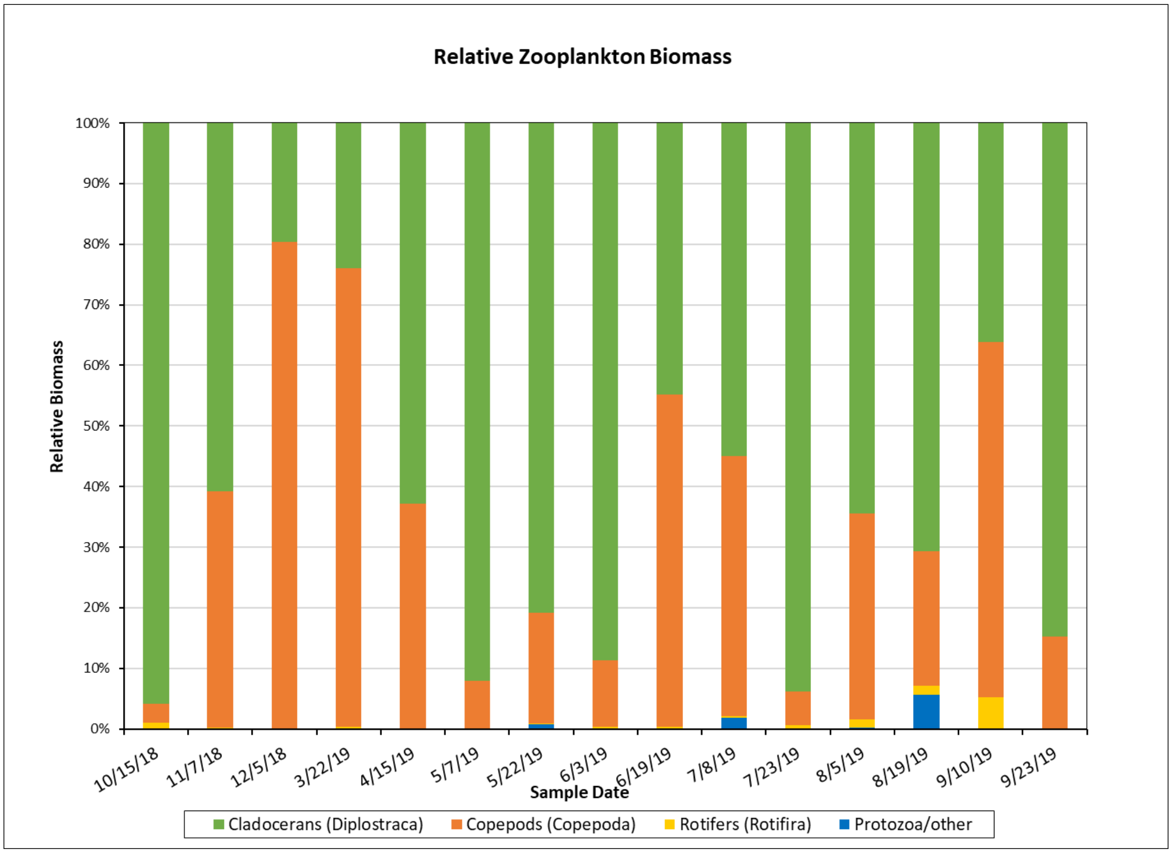


Figure 59. Relative Zooplankton Biomass in Cherry Creek Reservoir in WY 2019.

Due to their small size, rotifer concentrations averaged only 1.6 µg/L, which was only 0.8% of the total zooplankton biomass for the year. The maximum relative biomass for the rotifers was only 5.3% of the total on September 10, 2019 (Figures 57 and 58). The rotifer with the highest biomass was *Asplancha girodi*, one of the larger rotifer species, which was present at 3.8 µg/L on August 5, 2019. That represented 76% of the rotifer biomass and 5% of the total zooplankton biomass on that date.

The protozoa made only minor contributions to the zooplankton community in Cherry Creek Reservoir. Only two protozoan pecies, *Centropyxis* sp. and *Difflugia* sp. were present during WY 2019. Protozoa were present on only 8 of the 15 sampling dates, with only one of the two species appearing on each date. The protozoa averaged only 1.8% of the total zooplankton population and 0.6% of the zooplankton biomass for the year (Figures 57 and 59).

5.0 WATER BALANCE

The calculated WY 2019 water balance for Cherry Creek Reservoir was calculated from the following equation:

Ending $Storage_{9/30/2019}$ + ∑Reservoir Inflows – ∑Reservoir Outflows - Starting $Storage_{10/1/2018}$ = Δ Storage

Storage was based on daily surface elevations and area-capacity tables for Cherry Creek Reservoir provided by the USACE (Appendix C). The lake surface elevation and volume were 5548.56 ft and 11,380 AF on October 1, 2018, and 5549.09 ft and 11,810 AF on September 30, 2019. This results in a gain in storage of 430 AF (Δ Storage) during WY 2019.

The reservoir inflows (gains) considered in the water balance include:

1. Direct precipitation on the Reservoir surface.
2. Alluvial groundwater.
3. Cherry Creek surface water.
4. Cottonwood Creek surface water.
5. Ungauged inflows.

The reservoir outflows (losses) considered in the water balance include:

1. Evaporation.
2. Alluvial groundwater.
3. Reservoir releases.

Precipitation (Inflow 1) was calculated by multiplying the daily precipitation amounts reported for at the nearby Centennial Airport (KAPA) precipitation gauge (Section 3.1) by the corresponding lake surface areas, as provided by the USACE, on the dates with measurable precipitation. A total of 12.09 inches (1.01 feet) of precipitation was recorded at the KAPA weather station during WY 2019. This marked the fourth consecutive year (based on the 12-year average from this site) that annual precipitation was below the annual average (currently 15.61 inches) for this weather station (Figure 4). Based on these calculations, precipitation contributed an estimated 838 AF of water to the Reservoir during WY 2019.

The surface area of Cherry Creek Reservoir during WY 2019 varied between 787 acres from November 10-12, 2018, and 866 acres on from June 24-26, 2019, with a median value of 819 acres. The median surface area was based on elevations and area-capacity tables for Cherry Creek Reservoir provided by the USACE.

Alluvial groundwater inflow (Inflow 2) is estimated at a constant 2,200 AF/year. This number is based on evaluations conducted by Lewis, et al. (2005) and used by Hydros (2015) in the reservoir model.

The Authority has automated ISCO samplers at Stations CC-10 on Cherry Creek and CT-2 on Cottonwood Creek to measure water levels at 15-minute intervals and to collect storm samples. A rating curve was developed for Station CC-10 to convert elevation measurements from the ISCO sampler to flows (Inflow 3). While the rating curve is valid for the gage height versus measured flows, changes in the channel since the sampler was installed resulted in an over-estimation of stream flow for the heights measured by the ISCO sampler. Measurements made on 10 December 2019 confirmed that 0.56 ft of sediment had been deposited over the bottom of the staff gage. To compensate, the depth of the deposited sediment was subtracted from the average of 1.612 ft for all ISCO measurements at Station CC-10 for WY 2018 and WY 2019. The flow of 5.011 cfs calculated from the resulting corrected ISCO height of 1.052 ft was subtracted from all calculated ISCO flows. A similar error was probably present for the WY 2018 measurements and would help explain the large negative value of -4,358 AF reported last year (SLM, 2019).

Weir calculations provided by Bill Ruzzo (2014. unpublished, included in Appendix D of GEI, 2016) were used to calculate flows from the recorded elevations at Station CT-2 (Inflow 4). The average of the calculated 15-minute flows for each date were averaged to produce daily flows that could be used to provide a daily time step for Cherry Creek modeling efforts.

Due to instrument failure, water levels were not recorded at Station CT-2 from December 5, 2018, through January 31, 2019. Flows for the missing dates were estimated by calculating flows at CT-2 as a percentage of flows at CC-10 for the dates when flows were measured at both stations. Although there was considerable variability, flows at CT-2 averaged 25.0% of the flow at CC-10 in WY 2019. This is similar to the percentages of 19.7% reported for WY 2017 (TetraTech, 2018) and 19.8% for WY 2018 (SLM, 2019), indicating this estimation should provide reasonable values for the missing flow data.

The estimated volumes of surface flow entering the Reservoir from surface water sources in WY 2019 are:

- Cherry Creek: 14,477 AF
- Cottonwood Creek: 3,754 AF

Flow data from the Authority's gaging stations are provided on the Authorities data portal.

The net influence of ungauged surface water inflows and groundwater losses through seepage (inflow item 5 *less* outflow item 2) is calculated based on the difference between the measured and estimated inflows and outflows, and the net inflow calculated from changes in lake volume based on data provided by the USACE.

Evaporation estimates (Outflow 1) are typically provided by the USACE on a daily basis, although issues with the USACE methods in WY 2019 led to reporting on a monthly basis for most of WY 2019. The estimated evaporative losses from the reservoir were 2,757 AF during WY 2019, or approximately 3.37 feet (40.4 inches) per acre at the median surface area of 819 acres.

Water is released from the Reservoir through the dam's outlet works. The USGS measures outflow (Outflow 3) at Station 06713000, Cherry Creek below Cherry Creek Lake, CO (Figure 59). The gauge is located approximately 2,300 ft downstream of the Reservoir. Other than releases from the Reservoir, there are no major surface water contributions to flow measured at this gauge. Preliminary WY 2019 flows at the USGS gauge below the Reservoir averaged a daily flow of 24.5 AF, and an annual total of 17,799 AF. The 2019 annual mean flow is 245% of the long-term average from 1951-2019, but 85.9% of the average of the last 5 years (2015-2019).

The Reservoir WY 2019 water balance is summarized in Table 15. Following methods developed by TetraTech (2018), the net ungauged inflow(+)/outflow(-) was mathematically calculated to result in the Reservoir change in storage to equal the 430 ac-ft reported by the USACE for WY 2019 (Appendix A). Components included in this calculated term are ungauged surface water inflows into the reservoir, groundwater seepage from the reservoir through the dam, and measurement uncertainties. Net ungauged inflows for WY 2019 were -294 AF. Based on previous practice, this change was apportioned between the Cherry Creek and Cottonwood Creek inflows to calculate nutrient loading (Section 6). For WY 2019, Cherry Creek contributed 75.8% of the combined inflow and Cottonwood Creek contributed 24.2%, based on the 15-minute raw data from the ISCO samplers. The ungauged inflows were calculated and allocated based on the daily values for all inflows and outflows used in the allocation equations, resulting in decreases in surface inflows of 129 AF for Cherry Creek and 165 AF for Cottonwood Creek. The adjusted inflows are included in Table 15.

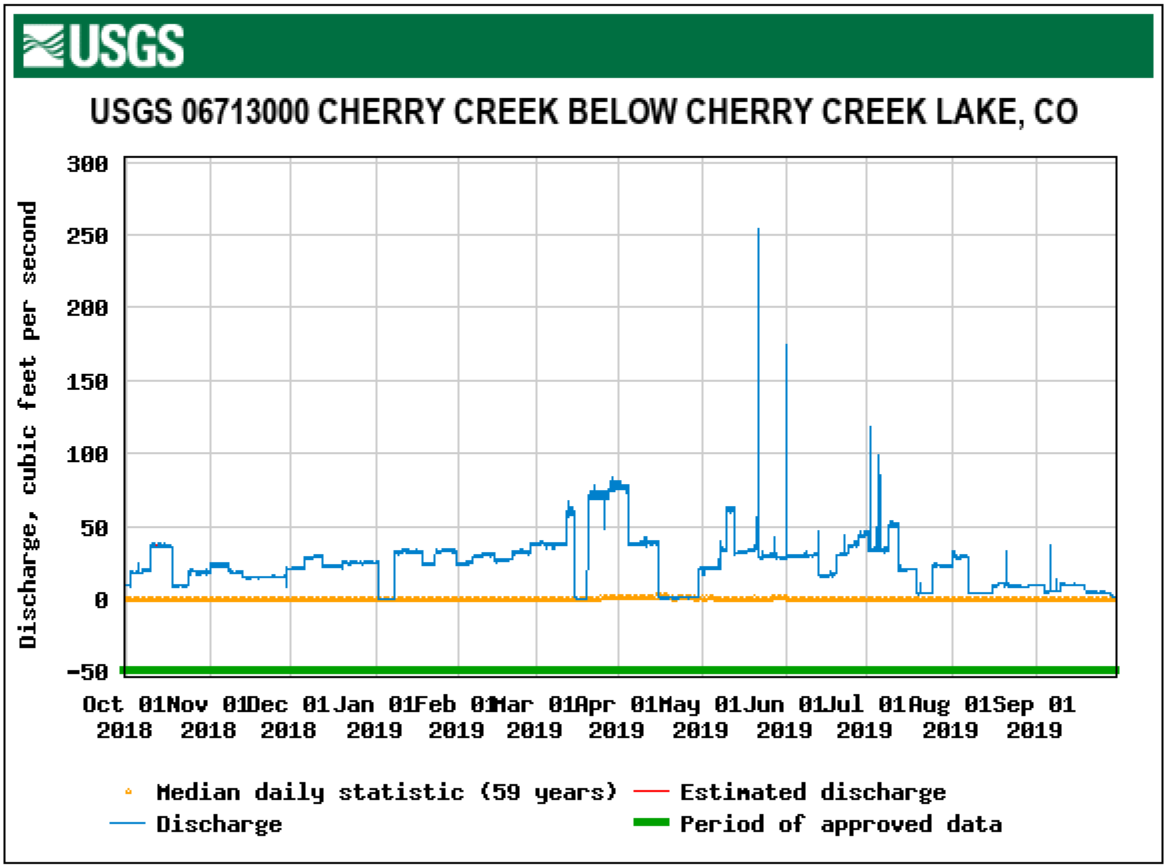


Figure 60. WY 2019 Hydrograph and Historical Median Flows for USGS Gauge Cherry Creek below Cherry Creek Lake.

Table 15. Cherry Creek Reservoir WY 2019 Water Balance

Water Source	Water Volume (AF)
Inflows	
Cherry Creek (CC-10)	14,349
Cottonwood Creek (CT-2)	3,588
Precipitation	838
Alluvial groundwater	2,200
Total Inflows	**20,095**
Outflows	
Evaporation	-2,757
Reservoir releases	-17,799
Total Outflows	**-20,556**
Net Ungauged Inflows/Outflows	
Calculation (Total- USACE inflows)	**-294**
WY 2019 Change in Storage	**430**

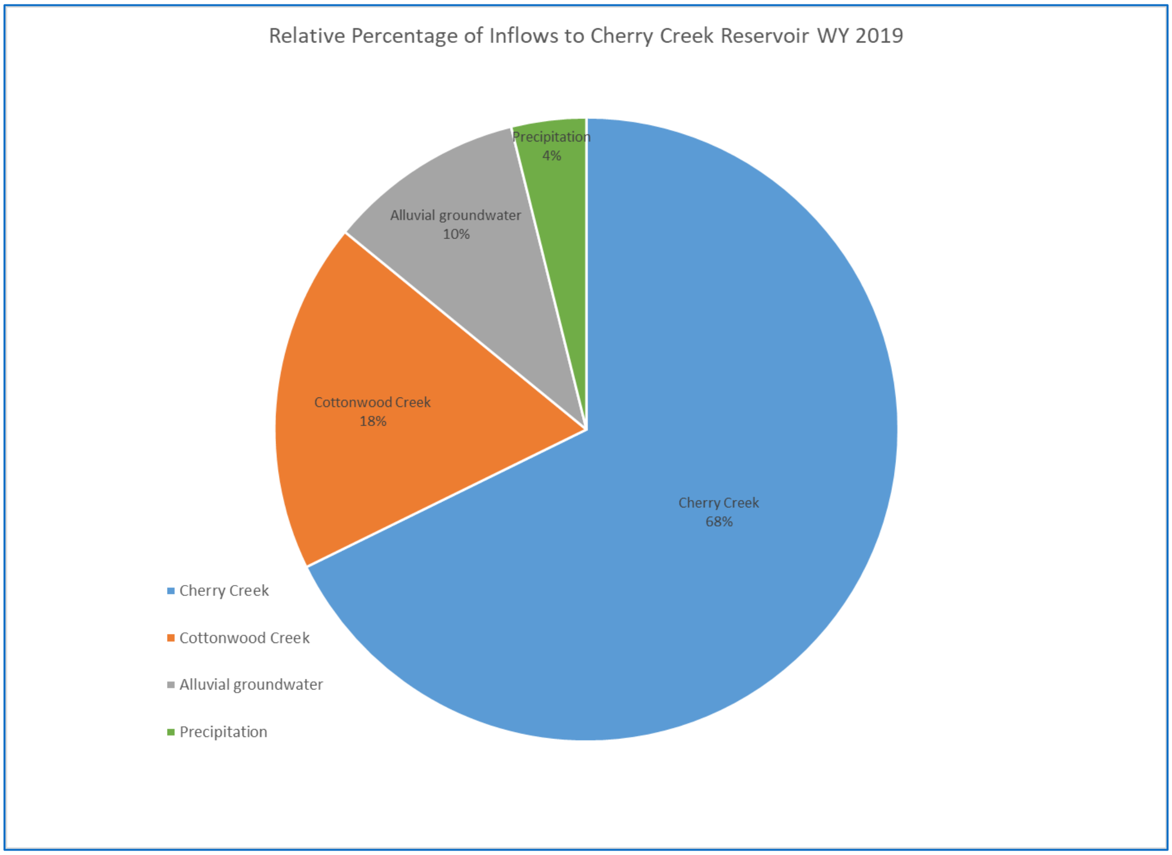


Figure 61. Relative Inflows to Reservoir Water Balance in WY 2019.

The relative inflows to the Reservoir from Cherry Creek, Cottonwood Creek, groundwater, and precipitation are pictured in Figure 60.

6.0 FLOW WEIGHTED NUTRIENT CONCENTRATIONS

Nutrient concentrations for Cherry Creek and Cottonwood Creek were calculated by interpolating concentrations between all sampling dates and multiplied by the daily inflows and outflows at Stations CC-10 and CT-2 to provide nutrient loading on a daily time step. The sum of the daily nutrient loads was divided by the annual inflows to calculate the annual flow-weighted inflow concentration. The flow weighted nutrient concentrations for WY 2019 as well as the concentrations from previous years are outlined in Table 16.

The WY 2019 flow-weighted total phosphorus concentration for Cherry Creek Station CC-10 was 222 µg/L, which was lower than the recent (2011 – 2018) flow-weighted total phosphorus concentration of 254 µg/L. The WY 2019 flow-weighted total nitrogen concentration of 1,565 µg/L for Station CC-10 was higher than the recent (2011 – 2018) flow-weighted total nitrogen concentration of 1,308 µg/L.

The WY 2019 flow-weighted total phosphorus concentration for Cottonwood Creek Station CT-2 was 49.1 µg/L, which was much lower than the 2011 – 2018 flow-weighted total phosphorus concentration of 75.5 µg/L. In contrast, the WY 2019 flow-weighted total nitrogen concentration for Station CT-2 was 2,427 µg/L was higher than the 2011 – 2018 flow weighted total nitrogen concentration of 1,722 µg/L.

Similar to the 2011 – 2018 averages, the flow-weighted total phosphorus concentrations for WY 2019 were much higher for Station CC-10 than for Station CT-2. In contrast, both the WY 2019 and 2011 – 2018 average flow-weighted total nitrogen concentrations were higher for Station CT-2 than for Station CC-10.

Table 16. Flow-Weighted Nutrient Concentrations for Surface Water Inflows to Cherry Creek.

Location	Cherry Creek		Cottonwood Creek	
Nutrient	Total Phosphorus	Total Nitrogen	Total Phosphorus	Total Nitrogen
Water Year	Concentration (µg/L)			
WY 2019	222	1,565	49	2,427
WY 2011-2018	254	1,308	75	1,722

- The median groundwater concentrations of 228 µg/L of total phosphorus and 373 µg/L of total nitrogen for the period 2015-2019 were used in the calculation of flow-weighted nutrient concentrations for WY 2019. The median nutrient concentrations in precipitation samples for the period of 2001-2019 of 101 µg/L of total phosphorus and 2,009 µg/L of total nitrogen were also used in that calculation.

Flow-weighted nutrient concentrations for all inflows and the flow-weighted total concentration based on the relative inflow contributions to Cherry Creek for WY 2019 are summarized in Table 17.

Table 17. Flow-Weighted Inflow Concentrations of TN and TP, WY 2019

		Source				
	Nutrient	**Cherry Creek**	**Cottonwood Creek**	**Alluvial Groundwater**	**Precipitation**	**Weighted Total**
Inflow Concentration (µg/L)	Total Phosphorus	222	49	228	101	**188**
	Total Nitrogen	1,565	2,427	410	2,009	**1,609**
% of Total Inflow		68.4%	17.1%	10.5%	4.0%	**100%**

The WY 2019 flow-weighted TP concentration of all inflows of 188 ug/L is lower than WY 2018 (206 µg/L), WY 2017 (197 µg/L), WY 2016 (213 µg/L), and the 2011-2015 median of 200 µg/L. The flow weighted TP concentration is just below than the 200 ug/l set by the Cherry Creek Reservoir Control Regulation 72 (REG72).

In contrast, the WY 2019 flow-weighted TN inflow concentration of 1,609 µg/L is lower than WY 2018 (1,691 µg/L), but higher than WY 2017 (1,284 µg/L), WY 2016 (1,175 µg/L), and the 2011-2015 median of 1,344 µg/L.

In addition to the above sources, both phosphorus and nitrogen can be added to Cherry Creek Reservoir through internal nutrient loading. No current estimates of internal nutrient loading are available, but Nurnberg and LaZerte (2008) provided estimates for the 1992-2006 period of 1,895 lbs/yr (average) and 1,383 lbs/yr (median) for internal phosphorus loading. More detail is provided in Section 8.0 below. In addition, nitrogen can be added to the reservoir through the process of nitrogen fixation. Cyanobacteria can use atmospheric nitrogen as a nutrient source and incorporate it into algal cells. This process is not easy to measure and no estimates for nitrogen fixation in Cherry Creek Reservoir are available. This source is probably small relative to the other sources listed.

The flow-weighted nutrient concentrations for the outflows (losses) during WY 2019 are shown in Table 18. Water leaves the reservoir through the outlet at the Cherry Creek Reservoir dam and surface evaporation.

Table 18. Flow-Weighted TP and TN Concentrations at CC-0 and Evaporation, WY 2019

Nutrient	Concentration (µg/L)	
	Cherry Creek Outflow	Evaporation
Total Phosphorus	109	0
Total Nitrogen	854	0

While nitrogen losses through evaporation are assumed to be zero, nitrogen can be lost from the system through the process of denitrification, which converts nitrate-N to nitrogen gas. Since nitrate concentrations in Cherry Creek Reservoir are very low, these losses are considered negligible.

7.0 NUTRIENT BALANCE

The calculated WY 2019 phosphorus and nitrogen balances in the Cherry Creek Reservoir were calculated using a mass-balance approach:

$\sum \text{Reservoir Inflows}_{\text{Nutrient}} - \sum \text{Reservoir Releases}_{\text{Nutrients}} = \Delta\ \text{Storage}_{\text{Nutrients}}$

A positive change in storage ($+\Delta\ \text{Storage}_{\text{Nutrients}}$) indicates that inflows exceed releases and that nutrients are being retained (stored) within the Reservoir. A negative change in storage ($-\Delta\ \text{Storage}_{\text{Nutrients}}$) would suggest that previously stored nutrients are being exported from the Reservoir.

The reservoir inflows (nutrient loads) considered in the WY 2019 nutrient balance are:

- Precipitation (incident to the reservoir's surface).
- Alluvial groundwater.
- Cherry Creek and Cottonwood Creek surface water.
- Internal loading

The only physical release mechanism considered from the Reservoir in the WY 2019 nutrient mass balance is surface water released through the dam's outlet works. Nutrient loss through evaporation is considered zero as the evaporating water is assumed to not contain any nutrients. The net ungauged outflows were accounted for in Table 15 and in the nutrient loading concentrations calculated in Table 17 based on the flow adjustments described in Section 6.0.

7.1 SURFACE WATER LOADS

The Authority collects water quality samples on a monthly basis at surface water monitoring stations CC-10, CT-2, and CC-Out (Table 3). The Authority also periodically collects storm event samples at CC-10 and CT-2 (Table

3). These samples were analyzed for the parameters indicated in (Table 3), which include total phosphorus and total nitrogen.

The nutrient concentrations in samples collected at CC-10, CT-2 and CC-Out in WY 2019 are summarized in Tables 17 and 18. Nutrient concentrations in were combined with the WY 2019 daily flows to calculate annual total phosphorus and total nitrogen loads for the surface water inflows and outflows (releases) to/from the reservoir (Table 19). The Cherry Creek and Cottonwood Creek loads presented in Table 19 were adjusted to apportion the ungauged inflows as discussed in Section 5.0.

Table 19. Surface Water Nutrient Loads to Cherry Creek Reservoir, WY 2019.

	WY 2019 Nutrient Loading	
Site	**Total Phosphorus (Pounds)**	**Total Nitrogen (Pounds)**
Inflows		
Cherry Creek @ CC-10	8,662	61,065
Cottonwood Creek @ CT-2	479	23,682
Releases		
USGS Gage & CC-Out	-5,287	-41,319

7.2 PRECIPITATION LOADS

In WY 2019, total phosphorus and total nitrogen were measured at the PRECIP site located in Cherry Creek State Park during storm sampling events. Seven precipitation samples were collected after storm events during WY 2019 which were analyzed for total phosphorus and total nitrogen concentrations. These values represent atmospheric loading and dry deposition. Table 20 lists the statistics of the concentration, maximum, minimum and mean value and the addition to the historical mean values which were used to calculate the total loading from precipitation during WY 2019.

Table 20. Cherry Creek Reservoir WY 2019 Precipitation Nutrient Loads

	WY 2019 Nutrient Loading	
PRECIP	**Total Phosphorus**	**Total Nitrogen**
Maximum (µg/L)	101	2,370
Minimum (µg/L)	26	1,370
Median (µg/L)	41	2,005
Updated Historical Median(µg/l)	*101*	*2,009*
Inflow WY 2019 (AF)	*838*	*838*
Total (lbs)	**230**	**4,579**

- Total phosphorus concentrations ranged from 26 µg/L to 101 µg/L, with a median value of 41 µg/L which was lower than WY 2018 (116 µg/L). The WY 2019 mean value is also lower than the historical median of 101ug/L (1991-2019).

- Total nitrogen concentrations ranged from 1,370 µg/L to 2,370 µg/L, with a median value of 2,005 µg/L. which was lower than WY 2018 (2,580 µg/L). The WY 2019 value is slightly lower than the historical median of 2,009ug/L (1991-2019).

Nutrient loads from precipitation were calculated by multiplying the observed WY 2019 precipitation of 838 AF/yr by the 2001-2019 median nutrient concentrations of 101 µg/L of total phosphorus and 2,009 µg/L of total nitrogen. The calculated precipitation loads for WY 2019 were:

- Total Phosphorus: 230 pounds
- Total Nitrogen: 4,579 pounds

7.3 ALLUVIAL GROUNDWATER LOADS

During WY 2019 (November 2018 and May 2019) water samples from monitoring well MW-9 were collected and analyzed for total phosphorus and total nitrogen. The results are summarized in Table 21.

Table 21. Cherry Creek Reservoir WY 2019 Groundwater Loading

	WY 2019 Nutrient Load	
MW-9	**Total Phosphorus**	**Total Nitrogen**
Maximum (µg/L)	271	909
Minimum (µg/L)	232	573
Median (µg/L)	252	741
Updated Historical Median (µg/L)	*228*	*410*
Inflow WY19 (AF)	2,200	2,200
Total (lbs)	**1,364**	**2,453**

- The median TP concentration in MW-9 for WY 2019 was 252 µg/L which is higher than WY 2018 (228 µg/L). Using the WY 2019 median, the medians from WY 2018 (228 µg/L), WY 2017 (237 µg/L), WY 2016 (206 µg/L) and the long-term median of 190 µg/L (GEI, 2016), the historical median TP concentration was updated to 228 µg/L.
- The median TN for WY 2019 was 741ug µg/L which is much higher than the median TN of WY 2018 (315 ug/ L). Using the WY 2019 median, the medians from WY 2018 (315 ug/L), WY 20171 (241 µg/L) and the long-term median of 430 µg/L (GEI, 2016) an updated historical median concentration of 410 µg/L TN was calculated.

The updated long-term median total phosphorus and total nitrogen concentrations were combined with the estimated 2,200 AF of inflow to calculate the nutrient loads from the alluvial groundwater inflow to the Reservoir for WY 2019.

- Total Phosphorus: 1,137 pounds
- Total Nitrogen: 2,453 pounds

8.0 NUTRIENT MASS BALANCES

As summarized in Table 15 the phosphorus and nitrogen loading to the Reservoir is derived from three external sources: surface water from Cherry and Cottonwood Creeks, precipitation, and alluvial groundwater. The total nutrient balances are calculated from the inflows and releases as outlined in Table 18.

Nutrient balances for total phosphorous and total nitrogen for Cherry Creek Reservoir are calculated for WY 2019 based off the nutrient calculations for inflow and releases. Internal nutrient loading is not included in the mass balances since data to evaluate values was not collected. Previous studies (Nurnberg and LaZerte, 2008; AMEC et al. 2005) provided estimates of internal phosphorus loading ranging from 810 to 2,000 lbs of phosphorus/year, or 7.56-18.6% of the phosphorus loading from external sources listed in Table 22. Internal phosphorus loading in WY 2019 would have been expected to be towards the low end of this range because the water column was well-mixed for most of the year and because there were relatively low concentrations of phosphorus in the hypolimnion of Cherry Creek Reservoir during summer 2019. Based on the data presented in Section 7.1 through 7.3, the WY 2019 total phosphorus and nitrogen mass balances are summarized in Table 22. The difference between the inflow and the outflow loads (Δ $\text{Storage}_{\text{Nutrients}}$) indicate that a net 5,449 pounds of phosphorus and 50,461 pounds of nitrogen were retained in the reservoir in WY 2019.

Table 22. Total Phosphorus and Nitrogen Mass Balance in Cherry Creek Reservoir WY 2019

Source	Total Phosphorus Mass (pounds)	Total Nitrogen Mass (pounds)
Surface Water		
Cherry Creek (CC-10)	8,662	61,066
Cottonwood Creek (CT-2)	479	23,682
Reservoir Release (CC-Out)	-5,287	-41,319
Alluvial Groundwater		
Inflow	1,364	2,232
Atmospheric		
Precipitation	230	4,579
Evaporation	0	0
WY 2019 Change in Storage	**5,449**	**50,461**

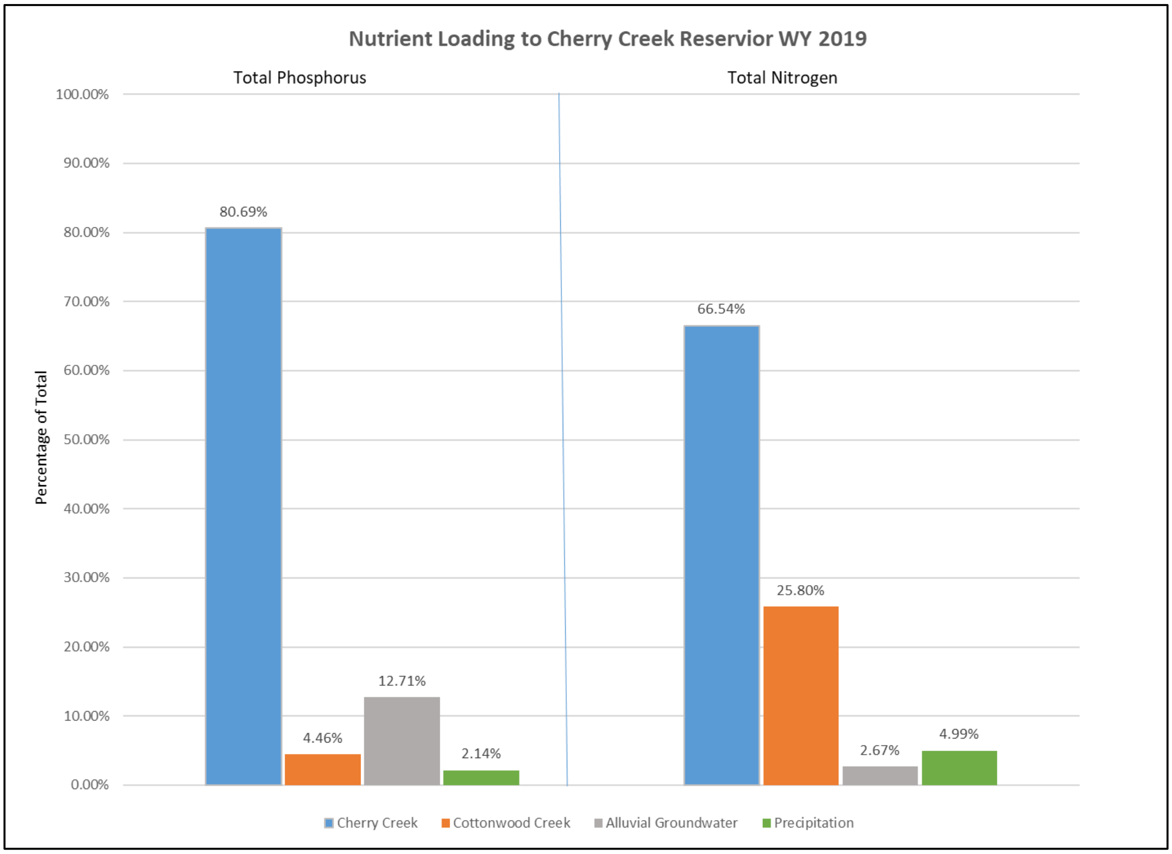


Figure 62. Nutrient Loading Percentages by Source to Cherry Creek Reservoir, WY 2019.

The relative contributions of the inflow sources of phosphorus and nitrogen loading to the Reservoir in WY 2019 are represented in Figure 62.

Table 23 presents the historical total nutrient mass loads, outflows and resulting storage in Cherry Creek reservoir in comparison to previous years. The total phosphorus inflow loads calculations for WY 2019 were lower than WY 2018, WY 2017, and WY 2016, but were higher than the historical means from 2011-2015 and 1995-2015. The total nitrogen loads from WY 2019 are higher than values any other previous years.

Table 23. Historical Comparison of Total Phosphorus and Nitrogen Loading to Cherry Creek Reservoir.

Analyte	Period Median	Inflows (pounds) Surface Water	Alluvial Groundwater	Precipitation	Total	Outflow (pounds)	Δ Storage (pounds)
Phosphorus	1993 – 2015*	7,868	1,033	379	**9,301**	*-4,113*	**5,599**
Nitrogen		59,573	2,337	6,578	**68,592**	*-35,727*	**32,865**
Phosphorus	2011 – 2015*	7,164	1,033	323	**8,588**	*-4,114*	**5,187**
Nitrogen		54,126	2,337	5,720	**62,234**	*-32,120*	**21,434**
Phosphorus	WY 2015	15,141	1,033	526	**16,701**	*-8,222*	**8,479**
Nitrogen		68,630	2,339	8,546	**79,515**	*-58,186*	**21,329**
Phosphorus	WY 2016	13,212	1,136	435	**14,783**	*-9,156*	**5,627**
Nitrogen		73,148	2,573	5,898	**81,619**	*-60,627*	**20,992**
Phosphorus	WY 2017	11,379	1,136	280	**12,795**	*-6,093*	**6,702**
Nitrogen		76,365	2,573	4,650	**83,588**	*-42,900*	**40,688**
Phosphorus	WY 2018	8,724	1,137	280	**10,143**	*-4,622*	**5,519**
Nitrogen		77,173	2,572	3,637	**82,695**	*-35,373*	**48,010**
Phosphorus	**WY 2019**	9,141	1,364	230	**10,736**	*-5,287*	**5,449**
Nitrogen		84,748	2,453	4,579	**91,779**	*-41,319*	**50,461**

*Note: Historic data modified from GEI (2016) Table 4-6.

9.0 2019 RECOMMENDATIONS AND CONCLUSIONS

RECOMMENDATIONS AND CONCLUSIONS

During the 2019 monitoring and data analysis efforts, recommendations for improvement and enhancement of the sampling program and analysis were developed. The following recommendations could help facilitate more detailed examination of long-term water quality trends and additional factors impacting water quality within the watershed and sub-basins of Cherry Creek.

- Increasing accuracy of level and flow gaging on Cherry Creek upstream of the Reservoir is recommended. Installing a stable cross section at this site may help with variability of changes in the stream channel and sedimentation. Additional flow monitoring upstream of the perimeter road to capture information from flows during large storm events that may bypass the current gauging station will be implemented to help quantify these ungauged flows.

- Collecting additional data to analyze the individual Cottonwood PRF ponds using a mass balance approach similar to the Reservoir will provide more information on long term trends and relationships with pond maintenance activities. In 2020, the monitoring sites and frequency will support this effort.
- Comparing data from USACE Tri-Lakes Monitoring Program could be valuable in evaluating trends in Cherry Creek Reservoir based on additional monitoring dates and sites.
- Continuing to analyze nitrogen and phosphorus ratios, limiting nutrient trends, and relationships between chl α and phytoplankton populations will help evaluate the potential for cyanobacteria blooms in Cherry Creek Reservoir throughout the season.
- As development continues, it may be necessary to add additional monitoring sites or equipment to determine potential impacts to changes in water quality.
- The evaluation of additional in-reservoir options to improve water quality will be helpful to determine if increasing oxygen, reducing phosphorus, shifting nutrient ratios, etc. will help reduce chlorophyll α to meet the standard and help maintain the beneficial uses of the Reservoir.
- It is important to continue to monitor the potential negative impacts to beneficial uses that may occur due to the presence of aquatic nuisance organisms (ANS) present in Cherry Creek Reservoir. Golden algae, *Prymnesium parvum* along with the lesser known *Chrysochromulina parva*, present direct risks to the fishery due to their ability to create toxins responsible for fish kills. In addition, the presence of, *Daphnia lumholtzi,* known as a spiny water flea, poses indirect threats of an imbalance in high quality forage available to support the fishery.

Continued management of the watershed is vital to maintaining the water quality in Cherry Creek Reservoir in order to preserve the beneficial uses. External loading from the watershed, as well as internal loading from the Reservoir sediments, are contributing to the high nutrient concentrations in the water which drive phytoplankton productivity and higher chl α concentrations.

Precipitation and storm events appear to play a large role in nutrient concentrations in the inflows and nutrient loading of the reservoir. Assessment of the water quality through the PRFs on Cottonwood Creek will help determine scale and frequency of maintenance of the wetlands plants and sediment removal necessary to maintain storage capacity and reduce organic accumulation.

There continues to be a significant difference in water quality between Cherry Creek and Cottonwood Creek. Differences in the stream channel morphology, flow patterns, wetlands, vegetation growth patterns, large variability from storm events, and differences in the runoff from the watershed affect the concentrations of nutrients and solids in the water, as well as PRFs and water quality controls of our partners.

As development continues, it may be necessary to add additional monitoring sites or equipment to determine potential impacts to changes in water quality.

The additional evaluation of options for alternative destratification/oxygen injection systems will help determine if higher levels of mixing or increased oxygen concentrations in the Reservoir will improve water quality. Looking at in-reservoir options for nutrient control may also prove to be an effective option at reducing phosphorus, shifting nutrient ratios, and limiting algae and cyanobacteria growth.

Cherry Creek Reservoir and its tributaries are important assets to all users. Recreational boaters, fishermen, hikers, bikers, wildlife enthusiasts, and others value the many aspects of the watershed that these resources provide. The Cherry Creek Basin Water Quality Authority is very proactive in monitoring effects of development land use, discharges, and other aspects that may impact the water quality within the watershed. The current partnerships with local, state, and federal entities support the Authority's efforts to monitor and maintain watershed improvements to protect all beneficial uses.

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APPENDICES

APPENDIX A – USACE DATA - WY 2019