Cherry Creek Basin Water Quality Authority Monitoring Report Water Year 2020

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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
Cells/ml	Cells per milliliter (phytoplankton)
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
M	Meters
mg/L	Milligrams per liter
mV	Millivolts
µg/L	Micrograms per liter
Mi	Mile
µm	Micrometers
µm/g	Micrometers per gram
μm^3/mL	Cubic Micrometers per milliliter
µS/cm	MicroSiemens per centimeter
MS4	Municipal Separate Storm Sewer System
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
#/L	Number of animals per liter (zooplankton)
ORP	Oxidation Reduction Potential
%	Percent
POR	Period of record
PRF	Pollutant Reduction Facility
PRISM	Parameter-elevation Regression on Independent Slopes Model
QA/QC	Quality Assurance/Quality Control
QAPP	Quality Assurance Project Plan
REG 31	WQCC Regulation No. 31
REG 38	WQCC 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
WWTP	Waste Water Treatment Plants

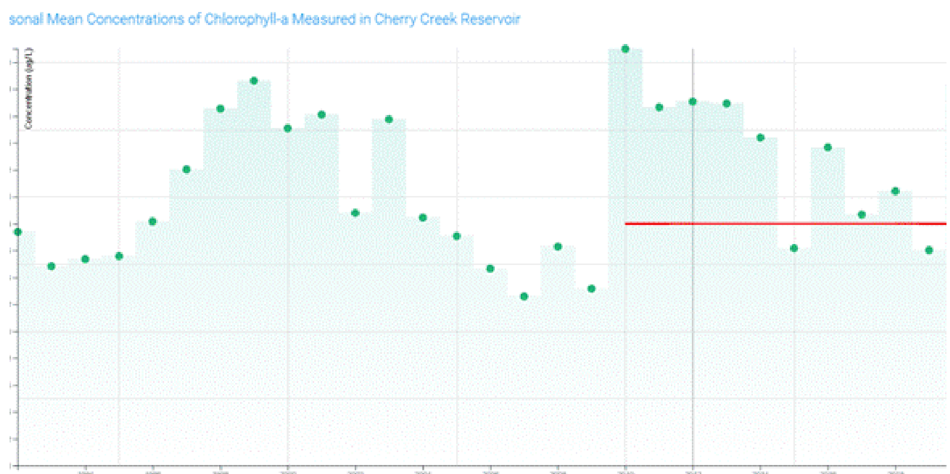
EXECUTIVE SUMMARY

The *Cherry Creek Basin Water Quality Monitoring Report – Water Year 2020* is a comprehensive description of monitoring completed for the Cherry Creek Basin Water Quality Authority (CCBWQA or Authority) of Cherry Creek Reservoir (Reservoir) and watershed for the 2020 Water Year (WY 2020) between October 1, 2019 and September 30, 2020. 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 2020 Water Year in relation to Water Quality standards, results of Authority efforts, achieving beneficial uses, and other notable details are outlined in the Executive Summary below. All CCBWQA data can be accessed at https://www.ccbwqportal.org/.

RESERVIOR HIGHLIGHTS

Chlorophyll α

During each sampling event of WY 2020, 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 7.4 µg/L and 56.0 µg/L, with a mean of 22.4 µg/L for all of WY 2020. The highest values were observed in July- September, and the lowest was observed in May.



The seasonal (July through September) chl α concentration through the WY 2020 growing season concentration was 28.44 µg/L. The WY 2020 seasonal mean was higher than the WY 2019 seasonal mean (16.03 µg/L), WY 2018 (20.2ug/L), WY 2017 (18.7µg/L) and WY 2016 (23.6 µg/L). The growing season average regulatory standard set by Regulation 38 (REG 38) is 18 µg/L which allows one exceedance frequency of once in five years. Four of the last five (4/5) and eight of the last ten (8/10) years have exceeded this value. The Reservoir last met the chl *a* standard, with a seasonal mean of 16.03 ug/L in WY 2019.

Transparency

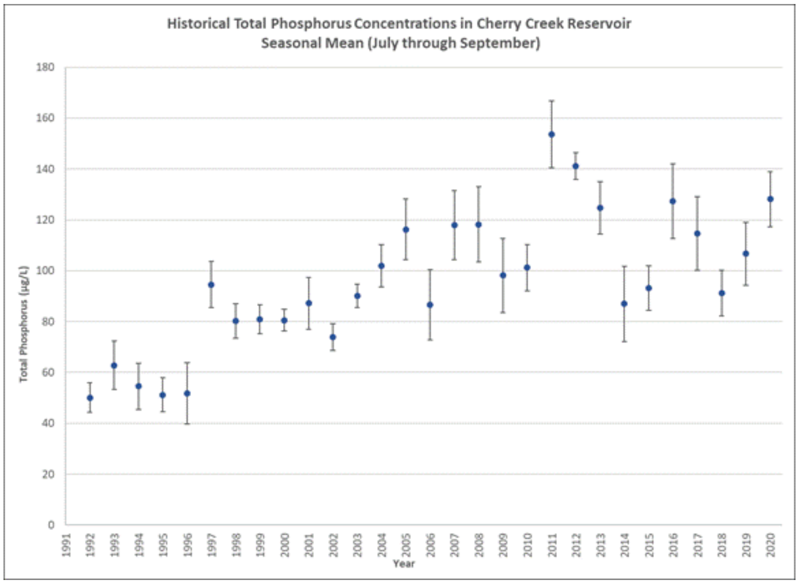
The mean Secchi depth measurements of the three reservoir monitoring sites during WY 2020 ranged between 0.52 m and 3.5 m, with an annual mean of 0.99 m for the year. The seasonal mean was 0.74 m during the months of July to September. The Secchi depth measurements were comparable for all three sites and followed similar seasonal trends when compared to previous years.

The depth of 1% light transmittance into the water column had a strong correlation to the Secchi depth and ranged between 1.2 and 6 meters. The depth of 1% light transmittance ranged between 1.6 and 3.7 times the

Secchi depth, but on average was approximately 2.9 times the Secchi depth. Transparency in Cherry Creek Reservoir is also impacted by inorganic suspended solids in the water.

Nutrients

The WY 2020 seasonal mean (July-September) Total Phosphorus (TP) of 128.2µg/L was higher than WY 2019 (107.2) µg/L, WY 2018 (91.2 µg/L), WY 2017 (114.7 µg/L) and WY 2016 (127.3 µg/L). The WY 2020 seasonal TP mean is also higher than the long-term average of 95.4 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 2020 the monthly mean TP concentrations ranged between 62 µg/L and 155 µg/L with a mean value of 97 µg/L.

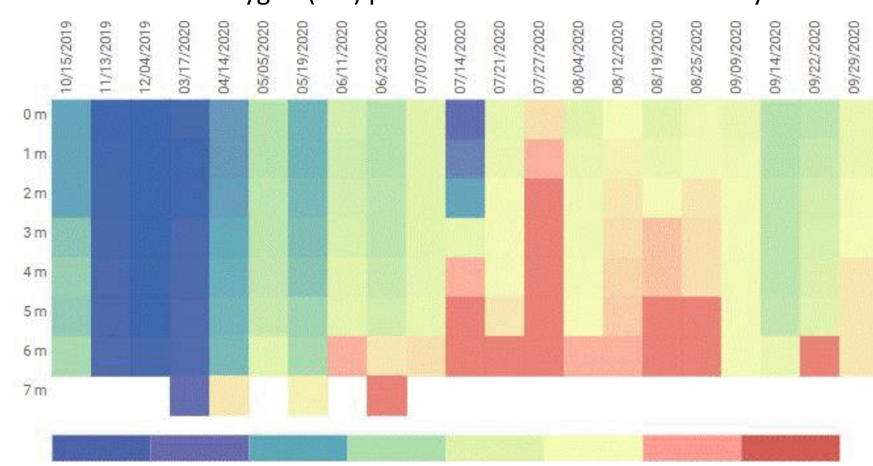
The lowest values were present in December 2019 and the highest values in July 2020. The WY 2020 data suggests that there are high levels of TP in the Reservoir throughout the year contributing to the eutrophic conditions.

The seasonal mean (July thorough Sept) of Total Nitrogen (TN) in the Reservoir in WY 2020 was 999.2 µg/L, which was higher than WY 2019 (688.8 µg/L), WY 2018 (848.1 µg/L), and WY 2017 (761.2 µg/L). The WY 2020 seasonal mean was also higher than the long-term average of 897.7 µg/L calculated from 1992-present.

During WY 2020, annual TN concentrations ranged between 610 µg/L and 1,670 µg/L with a mean value of 895 µg/L. The highest values were present in the July 2020 samples and the lowest values in December 2019.

Temperature and Dissolved Oxygen

The Class I Warm Water Aquatic Life classification established by the Water Quality Control Commission (WQCC) in REG 38 and Regulation No. 31 (REG 31) is 26.2 ˚C Maximum Weekly Average Temperature (MWAT) and 29.3 ˚C Daily Maximum (DM). Temperature and dissolved oxygen (DO) profiles were measured in Cherry Creek Reservoir during each sampling event and 15-minute temperature data was measured at CCR-2. The maximum temperature measured in the depth profiles or continuous temperature loggers was 23.8 ˚C (74.8 ^{o}F) at the surface in mid-August, which does not exceed the daily or weekly maximum. The temperature data indicated that although there was some variability from the surface to the bottom in the warmer summer months, the Reservoir did not develop consistent thermal stratification.



Dissolved Oxygen Concentrations (mg/L) in Cherry Creek Reservoir at CCR-2 in 2020.

REG 31 states that in ”the upper portion of a lake or reservoir, dissolved oxygen shall not be less than 5.0 mg/L. There needs to adequate refuge for aquatic with DO levels greater than 5.0 mg/L available at other depths or locations in the Reservoir at the same time period.”

During 2020, DO levels were below 5.0 mg/L from 5 meters to the bottom at CCR-2 in mid-July through August and at 2 m and below on July 27th. During July and August, there were events at CCR-1 where DO concentrations were below 5.0 mg/L at depth (4-5m), at 2 m and below on July 27th and at throughout the water column on August 12th. At CCR-3, the DO was at or below 5.0 mg/L at 4 m during the monitoring events in July through August and below 3 m on August 3rd.

During WY 2020, there were events when measured DO concentrations in parts of the Reservoir were below 5.0 mg/L. However, during the same time period, the DO concentrations at the other monitoring sites measured concentrations greater than 5.0 mg/L, meeting the Reg 31 standard.

pH, ORP and Conductivity

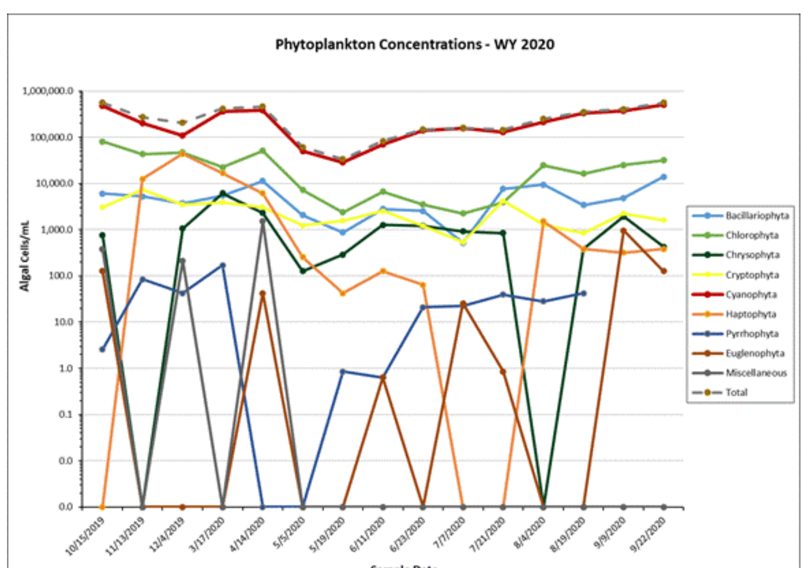
During WY 2020, the pH ranged between 7.9 and 8.8, which is similar to recent years. The higher pH values appeared to correlate with higher productivity and elevated chl α in the Reservoir. The instantaneous minimum and maximum pH standards are 6.5 and 9.0, respectively, as set by REG 38.

During WY 2020, the Oxidation Reduction Potential (ORP) in Cherry Creek Reservoir in the photic zone ranged between from 131 mV and 238.9 milliVolts (mV). The ORP in the samples near or at the bottom of the Reservoir ranged from -0.1 mV to 243.8mV. 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 which is typical and an indication of decomposition processes near and in the sediments and seasonal trends normally seen in the Reservoir.

The specific conductance (hereafter referred to as “conductivity” in this document) in Cherry Creek Reservoir ranged from 1,256.3 µS/cm to 1,460.4 µS/cm during WY 2020. There was limited variability in conductivity from top to bottom of the Reservoir and between the three monitoring sites. However, overall the conductivity in the Reservoir was higher throughout the season than seen in recent years which may be the result of the dry conditions during WY 2020, which would lead to less flushing of the reservoir.

Phytoplankton

Phytoplankton samples from Cherry Creek Reservoir were collected and analyzed to identify and quantify the populations in detail, based on cell counts (cells/ml) and biovolume (um^3/ml) (with the difference based on the relative sizes of each organism). The results from WY 2020 indicate high productivity and high species diversity, with an average of 40 phytoplankton species, and a range of 28-57 species present for the 15 sampling dates which is similar to recent years. Cell counts were dominated by the Cyanophytes (cyanobacteria or blue-green algae) which were responsible for 50% or more of the total phytoplankton cell counts on each



sampling date and averaged 85% of the total cell counts for all of WY 2020.

However, cyanobacteria only averaged 18% of the total algal biovolume. Multiple species of cyanobacteria capable of producing toxins, were observed during sampling in Cherry Creek Reservoir in WY 2020. The main culprits were *Dolicospermum circinale* and *Aphanizomenon flos-aquae*, which were responsible for the severe blooms that required closures of the Reservoir in July and early August.

Chlorophyta (green algae) and Bacillariophyta (diatoms) and made up the second and third highest algal concentration throughout most of the season at 8.6% and 2.2% of the total populations. Based on their large size, diatoms contributed 37.8% and green algae made up 22.8% of the relative biovolume for WY 2020.

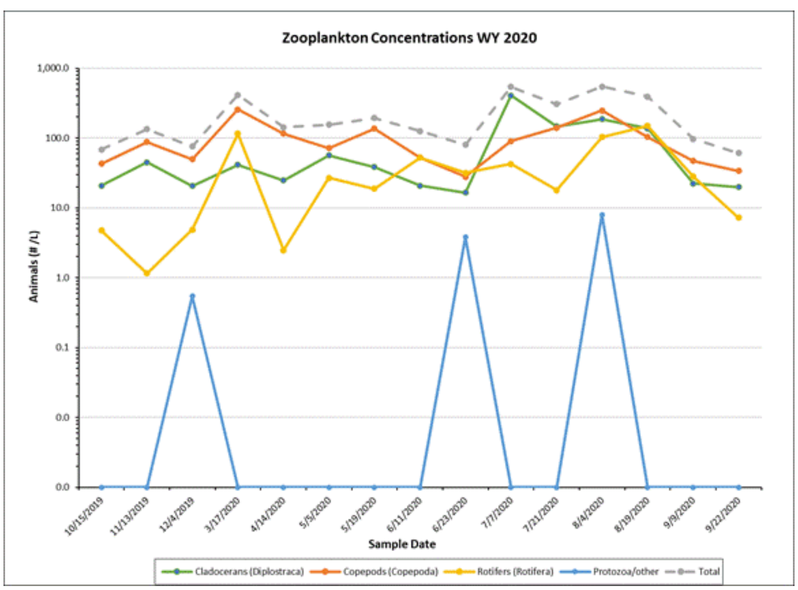
Along with the Cyanophytes, Bacillariophytes, and Chlorophytes, members of the Cryptophyte group (cryptomonads) were often present at levels of 1,000 or more cells/mL, which is a concentration associated with eutrophic conditions. The cryptomonads averaged 1.5% of the total cell count and 9.3% of the relative biovolume during WY 2020.

Haptophytes (golden algae) can be found in freshwater systems with higher salinities and are concern because they can produce toxins that are harmful to fish and other aquatic life. The Haptophyte *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 2020, with the exception of two sampling dates, and represent 2.2% of the algal population and 4.9% of the total biomass.

Zooplankton

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.

Zooplankton numbers and diversity from samples collected from Cherry Creek Reservoir during WY 2020 were both low compared to phytoplankton, which is typical in most lakes/ reservoirs.



Copepods were typically the zooplankton present in the highest numbers, averaging over 50% of the total population during WY 2020. For the year, copepods averaged 51% of the zooplankton population and 43% of the biomass.

Cladocerans frequently comprised over half of the zooplankton biomass, averaging 31% of the zooplankton population but 54% of the biomass for WY2020.

Daphnia lumholtzi, an invasive species, was first identified in Colorado in 2008 and in Cherry Creek Reservoir in 2011. *Daphnia lumholtzi* was a dominant cladoceran in Cherry Creek Reservoir on several sampling dates in WY 2018 and WY 2019, but was only observed on October 15, 2019 during WY 2020.

Trophic State Analysis

The Trophic State Index (TSI) 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 algal scums. Trophic state indices for Cherry Creek Reservoir chl α and transparency were above 50, and the TSI for total phosphorus was about 75 indicating that Cherry Creek Reservoir was eutrophic-hypereutrophic during WY 2020 (See Table 17). Although there have been some fluctuation of the historical TSI values, they remain within the eutrophic to hyper-eutrophic range.

Table A. Cherry Creek Reservoir Trophic State Characteristics

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	**0.116**	**20.7**	**1.05**	**High-Excessive**

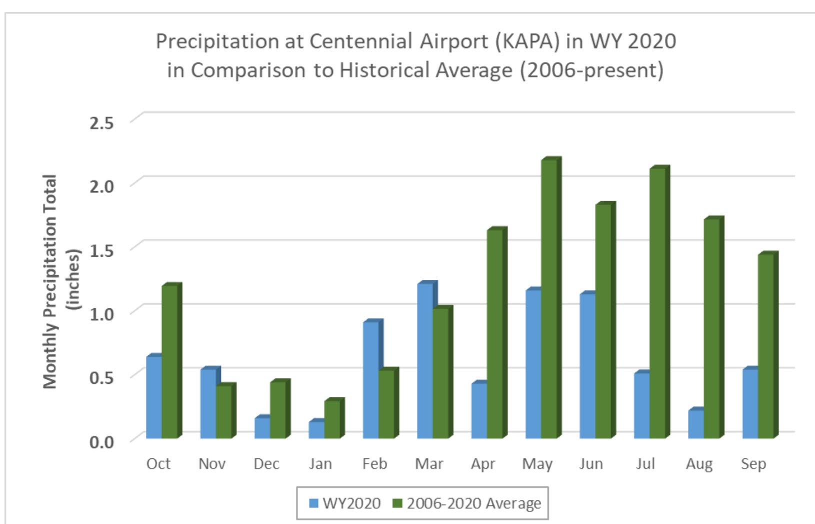
Trophic state can also be assessed by comparing monitoring data to trophic state criteria, such as those developed by the U.S. EPA (1980). A comparison of Cherry Creek Reservoir monitoring data from WY 2020 to EPA trophic state criteria (from May through September) also indicates that Cherry Creek Reservoir was eutrophic-hypereutrophic in WY 2020 (Table A). 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 National Ocean and Atmospheric Administration (NOAA) at the Centennial Airport Station (KAPA site was much lower than average during the 2020 Water Year. The historical data from the site, indicated the area received 51% of the average precipitation from 2006-2020.

The watershed as a whole appears to have received 10-32% average precipitation, based on the 30-year Parameter-elevation Regression on Independent Slopes Model (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 total annual flow of 1,736 cfs (cubic feet per second) or 3640.8 Acre Feet (AF) with an annual daily mean of 4.74 cfs (9.97 AF) for WY 2020, which is approximately 53% of the annual mean discharge calculated from WY 1940-2020.

The yearly summary for the USGS gauge, Cherry Creek Near Parker, CO, listed a provisional total annual flow of 3,678 cfs (7293.5 AF) and an annual daily mean of 10 cfs (19.83 AF), which is approximately 89% of the annual mean discharge calculated from WY 1992-2020.

It is noteworthy that the headwater flows of Cherry Creek in Castlewood Canyon were 47% lower than average, but flows were only 11% below 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.

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.

No ISCO measurements were available for Station CC-10 from April 16 to May 3, 2020, due to instrument upgrades, and for Station CT-2 from January 16 to February 10, 2020, as a result of battery failure. Daily depths for the missing dates were interpolated to estimate flows for the affected dates.

Cherry Creek

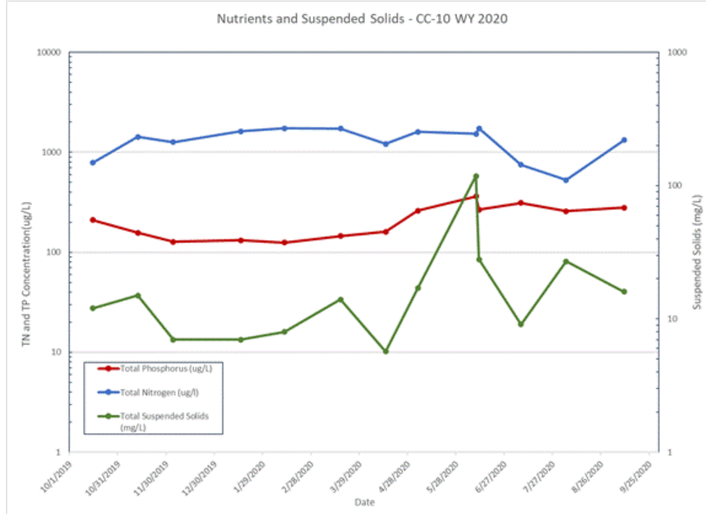
Water quality data were collected from the USGS Cherry Creek Near Franktown, CO site all the way down Cherry Creek to the Reservoir and below. Conductivity and pH were monitored as surface water moves from the upper basin downstream to the Reservoir during both monitoring events.

Both upstream to downstream monitoring events indicate limited variability of pH ranging from approximately 7.8 to 8.8 through the basin. However, the conductivity was almost 4.7 times higher downstream and appears to be increasing over time when compared to historical data.

During comprehensive upstream to downstream sampling in WY 2020, the level of TP remained relatively constant. However, total nitrogen (TN) increased from the USGS Cherry Creek Near Franktown site downstream to the USGS Cherry Creek Near Parker site, and then leveled out and decreased all the way to the Reservoir and outflow. The nutrient concentrations from the outlet were all lower than the inlet from Cherry Creek just upstream of the Reservoir.

The pH values measured at CC-10 over time appear to have slightly decreased between 2009 and 2016 but increased again over the last three years. Conductivity values measured at CC-10 indicate an increasing trend over the last 10-12 years, with most values double what they were a few years before.

The relationship between Total Phosphorus, Total Nitrogen, and Total Suspended Solids concentrations is also reflected in the difference between the concentrations in samples collected at CC-10 during storm and base flow sampling events. The TP concentrations ranged between 125 and 363 µg/L during the year. The TN concentrations ranged between 528 and 1,740 µg/L during WY 2020. The values of TSS ranged between 6 and 118 mg/L. Although only samples from one storm flow were collected in WY 2020, the mean and median concentrations of TP, TN, and TSS were all higher during the storm event than in base flow conditions.



During WY 2020, all nutrient and suspended solids mean concentrations, with the exception of NH_3-N, were significantly lower in Piney Creek (a tributary to Cherry Creek located southeast of the Reservoir) than just below the confluence with Cherry Creek during the same time period.

Cottonwood Creek

During WY 2020, the pH of water in Cottonwood Creek before it entered the Reservoir ranged from 7.7 to 8.3. The conductivity, or specific conductance, which represents dissolved solids in the water, ranged between 1,163 µS/cm and 5,719 µS/cm, with a median value of 2,301 µS/ cm at CT-2. This is higher than the median for Cherry Creek, which was 1,258 µS/cm for WY 2020.

The TP concentrations at CT-2 ranged between 33 and 183 µg/L during the year. The TN concentrations at CT-2 ranged between 784 and 3,820 µg/L during WY 2020. The TSS concentrations ranged between 4 and 11 mg/L.

POLLUTION REDUCTION FACILITIES (PRF) HIGHLIGHTS

During WY 2020, the significantly lower than average precipitation directly correlated to low flows in the streams so only one complete storm event with the level-based sampling equipment set at all sites was captured. While one data points are not enough to complete a significant analysis, calculations were included for annual reference. Table B summarizes the changes seen in the various water quality parameters upstream to downstream through each of the different PRFs.

Based upon the data collected in WY 2020, 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 10% under base flow and by 86% in the one storm flow event measured in WY 2020. Sediment concentrations, measured as TSS, were reduced by approximately 40% under base flow conditions and 97% during the one storm event.

Based on the concentrations in base and storm flow events, the Cottonwood Creek PRF ponds and treatment train as a whole reduced phosphorus and suspended sediment concentrations in downstream flows during WY 2020 but the other parameters had more variability. Cottonwood Creek between the ponds did not show any significant decreases. In WY 2020, TP, TDP, SRP, and NO_3+NO_2-N were all reduced upstream to downstream between MCM-1 and MCM-2 on McMurdo Gulch.

Table B. PRF Summary of Upstream to downstream Water Quality Change

PRF	Cottonwood Treatment Train		Peoria Pond		Perimeter Pond		Cottonwood Creek Between Ponds		McMurdo Gulch	
Upstream Site	CT-P1		CT-P1		CT-1		CT-P1		MCM-1	
Downstream site	CT-2		CT-P2		CT-2		CT-1		MCM-2	
Analyte	Increase	Decrease	Increase	Decrease	Increase	Decrease	Increase	Decrease	Increase	Decrease
TP, µg/L		X		X		X	X			X
SRP, µg/L	X			X		X	X			X
TDP, µg/L	X			X		X	X			X
TN, µg/L	X		X			X	X			X
NO2+NO3, µg/L	X		X			X	X			X
NH_3-N, µg/L	X			X	X		X			X
TSS, mg/L		X		X		X	X		X	
TVSS, mg/L		X		X		X		X	X	

GROUNDWATER HIGHLIGHTS

Data from groundwater (GW) samples collected from the three monitoring wells upstream of the Reservoir, as well as the one below, suggest that the TP concentrations remained relatively consistent during both monitoring dates in WY 2020. In contrast, TN decreased as the wells get closer to the Reservoir and were lower below the dam at the Monitoring Well (MW) Kennedy site.

The data from the comprehensive basin sampling of all Cherry Creek sites suggests slightly lower TP concentrations of surface water when compared to nearby GW monitoring wells. The mean groundwater concentration of TP was 0.32 mg/L and the mean TN concentration was 2.27mg/L during WY 2020.

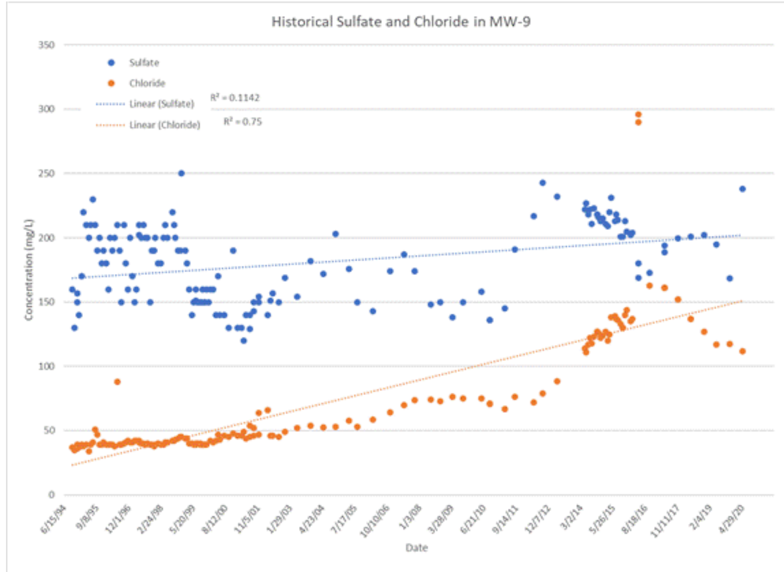
Both sampling events during WY 2020 indicated GW chloride concentrations averaged 131 mg/L and sulfate concentrations averaged 125 mg/L. The pH remained relatively constant and the conductivity seemed to follow the trend of the concentrations of chloride and sulfate.

During WY 2020, the pH values from the monitoring wells ranged between 7.0 and 7.8, with an historical mean value of near neutral at 7.4. The historical values suggest that the pH at 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 809 µS/cm between 1995 and 2005 and a mean value of 1,007 µS/cm from 2006 to 2020.

Analysis of the historical data for MW-9 from 1994-2020 appears to show that chloride and sulfate may be increasing over time, although chloride may be less variable and increasing slightly more significantly.

When looking at historical trends, the concentration of SRP in the GW upstream of the Reservoir at MW-9 also appears to be slightly increasing.



The long-term Total Organic Carbon (TOC) concentrations in the alluvial GW samples collected from MW-9 range from 2.4 mg/L to 4.3 mg/L. The TOC concentrations measured in November 2019 were 2.4 mg/L and in May 2020 were 2.72 mg/L, which are both slightly lower than the long-term average of 3.3 mg/L from 2014-2020. Historically, the dissolved fraction of the TOC in MW-9 has had a long-term average of 93% of the total.

WATER BALANCE HIGHLIGHTS

The estimated volumes of surface flow entering the Reservoir from these two surface water sources in WY 2020 are:

- Cherry Creek: 14,832 AF
- Cottonwood Creek: 3,133 AF

The estimated evaporative losses from the Reservoir were 3,605 AF during WY 2020, or approximately 40.44 inches (4.31 feet) per acre at the median surface area of 837 acres.

The USGS measured outflows for WY 2020 at Station 06713000, Cherry Creek below Cherry Creek Lake, CO, totaled 11,409 AF, which were used for nutrient balance calculations.

The Reservoir WY 2020 water balance is summarized in Table C. The net ungauged inflows(+)/outflows(-) were mathematically calculated to result in the Reservoir change in storage. This is equal the -433 AF (accounting for rounding errors) reported by the U.S. Army Corps of Engineers (USACE) for WY 2020, when including ungauged surface water inflows into the Reservoir, GW seepage from the Reservoir through the dam, and measurement uncertainties. The information used to calculate the water balance can be found in Appendix A and on the data portal. Net ungauged outflows for WY 2020 were -6,088 AF which were apportioned between the Cherry Creek and Cottonwood Creek inflows to calculate nutrient loading. Cherry Creek contributed 82.6% of the combined inflow and Cottonwood Creek contributed 17.4%, based on the 15-minute raw data from the ISCO samplers.

Table C. WY 2020 Water Balance

Water Source	Water Volume (AF)
Inflows	
Cherry Creek (CC-10)	14,832
Cottonwood Creek (CT-2)	3,133
Precipitation	504
Alluvial groundwater	2,200
Total Inflows	**20,669**
Outflows	
Evaporation	-3,605
Reservoir releases	-11,409
Total Outflows	**-15,014**
Net Ungauged Inflows/Outflows	
Calculation	-6,088
WY 2020 Change in Storage	**-433**

NUTRIENT BALANCE HIGHLIGHTS

The WY 2020 flow-weighted TP concentration of all inflows is 173 ug/L, which is lower than the WY 2019 (188µg/L), WY 2018 (206 µg/L), WY 2017 (197 µg/L), WY 2016 (213 µg/L), and the 2011-2015 median (200 µg/L). The 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 is 200 µg/L.

The WY 2020 flow weighted TN inflow concentration of 1,491 ug/L is lower than WY 2019 (1,609 µg/L) and 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 (1,344 µg/L). Flow-weighted nutrient concentrations for WY 2020 are summarized in Table D.

The Reservoir inflows (nutrient loads) considered in the WY 2020 nutrient balance are:

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

Nutrient balances for TP and TN for Cherry Creek Reservoir are calculated for WY 2020 based on the nutrient calculations for inflow and releases. The WY 2020 TP and TN mass balances are summarized in Table E. The difference between the inflow and the outflow loads indicate that a net 4,046 pounds of phosphorus and 31,044 pounds of nitrogen were retained in the Reservoir in WY 2020.

Table D. Flow-weighted Nutrient Concentrations to Cherry Creek Reservoir WY 2020.

		Source				
	Nutrient	Cherry Creek	Cottonwood Creek	Alluvial Groundwater	Precipitation	Weighted Total
Inflow Concentration (µg/L)	Total Phosphorus	127	7.4	35	3.4	173
	Total Nitrogen	1,013	345	65	67	1,491
% of Total Inflow		**67.5%**	**13.9%**	**15.1%**	**3.5%**	**100%**

The calculated total phosphorus loads were lower than any of the loadings previously reported. The total nitrogen loads were lower than the previous 3 years and the long-term historical mean from 1993-2020.

Table E. Nutrient Mass Balance for WY 2020

Water Source	Total Phosphorus (lbs)	Total Nitrogen (lbs)
Inflows		
Cherry Creek (CC-10)	5,033	40,174
Cottonwood Creek (CT-2)	294	13,693
Precipitation	136	2,668
Alluvial groundwater	1,388	2,573
Total Inflows	**6,851**	**59,108**
Outflows		
Evaporation	0	0
Reservoir releases	-2,826	-28,225
Total Outflows	**-2,826**	**-28,225**
WY 2020 Change in Storage	**4,025**	**30,883**

CONCLUSIONS AND RECOMMENDATIONS

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.

Surface water flows are the main contributor of nutrient concentrations in the inflows and nutrient loading of the reservoir. The dry year reduced overall stream flows which impacted the water quality entering the Reservoir.

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, watershed development, amount of permitted WWTP discharge outfalls, and differences in runoff from the watersheds affect the concentrations of nutrients and solids in the water, as well as PRFs and water quality controls of our partners.

The Cherry Creek watershed has seen significant increases in population and both residential and commercial construction over time. Up-basin MS4s also implement construction site programs to mitigate construction sediment runoff and post-construction permanent water quality facilities to treat urban runoff from impervious areas. These programs and facilities minimize negative water quality impacts from these changes in the watershed. In addition, many other watershed and PRF projects have been completed in order to minimize negative water quality impacts of these changes.

During the 2020 monitoring and data analysis efforts, recommendations for improvement and enhancement of the sampling program or other analysis of the Cherry Creek watershed or Reservoir were brought to light. 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.

- Adding additional monitoring of individual TDS components will help determine what is leading to the increased conductivity in Cottonwood Creek. Individual analyses for Chloride, Sulfate, Magnesium, Sodium, Potassium, Calcium, and Alkalinity have been included in the SAP for 2021.
- Increasing accuracy of level and flow gauging on Cherry Creek upstream of the Reservoir is necessary to capture information from flows during large storm events that may bypass the current gauging station. In 2021, additional work will be completed to determine when the stage discharge relationship generated from stream flow measurements will be used along with the modeled flows from the survey will be used to estimate high flows.
- Assessment of the water quality through the PRFs on Cottonwood Creek will help determine scale and frequency of maintenance of the wetland plants and sediment removal necessary to maintain storage capacity and reduce organic accumulation.
- 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.
- 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.
- 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.
- Completing sediment analyses to determine nutrient concentrations that are responsible for internal nutrient loading will provide valuable information these in-reservoir options are being considered.
- 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 such as Golden algae which can create toxins responsible for fish kills and *Daphnia lumholtzi,* known as a spiny water flea, which can outcompete other zooplankton that are a more preferred food source.

- As build-out and development continues, it may be necessary to add additional monitoring sites or equipment upstream and on tributaries to determine to changes in water quality and to measure efforts to mitigate negative effects.

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 land use changes, permitted and unpermitted point and non-point discharges, and other changes 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 mission and vision of the Cherry Creek Basin Water Quality Authority (CCBWQA) 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 also supports effective efforts by partner counties, municipalities, special districts, and landowners within the basin providing for protection of water quality; ensuring that new developments and construction activities pay their equitable share of costs for water quality preservation and facilities; and promoting 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 maximum 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 2020* describes the Authority monitoring program, data collected during the 2020 water year, and an evaluation of the results.

The WY 2020 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 CCBWQA'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, 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 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 biological productivity in the Reservoir, including chlorophyll α and plankton dynamics, and their relationship to the potential impacts to beneficial uses.
- Determine the concentrations of phosphorus and nitrogen species in the Reservoir and streams, and changes over time
- Determine annual flow-weighted nutrient concentrations entering and leaving the Reservoir.
- Evaluate the effectiveness of Pollutant Reduction Facilities.
- Provide data for CCBWQA's Internet Data Portal.

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 conducting 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. All CCBWQA data can be accessed at https://www.ccbwqportal.org/.

2.2 SAMPLING PROGRAM DESCRIPTION

The monitoring and sample collection for the 2020 Water Year (WY) was completed by SOLitude Lake Management from October 1st, 2019 to September 30, 2020. The 2020 Monitoring Program was conducted in accordance with the 2020 Cherry Creek Basin Water Quality Authority Routine SAP/QAPP[1].

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 eighteen (18) 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.

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

Figure 2. Cherry Creek Basin Monitoring Site Locations

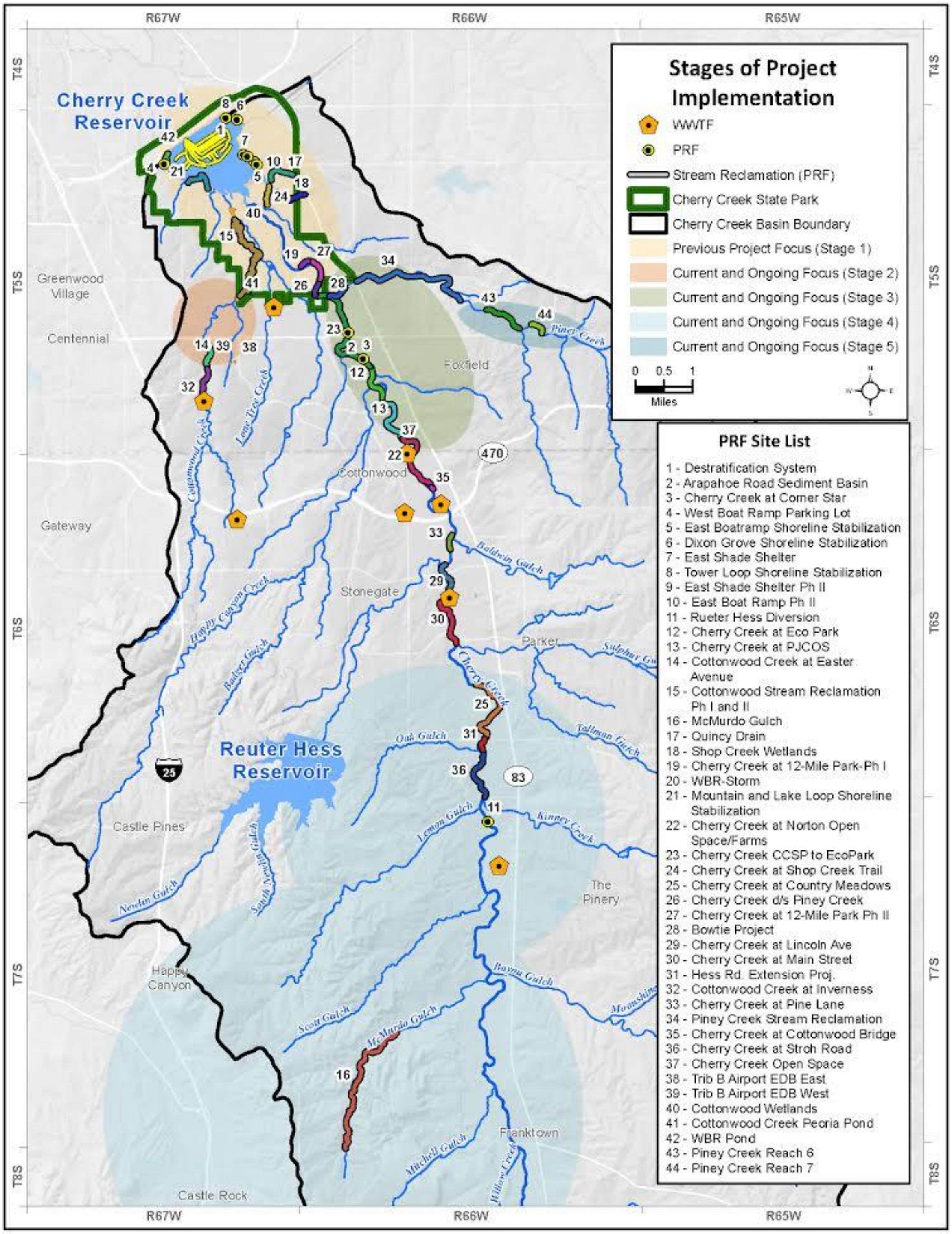


Figure 3. CCBWQA Water Quality Improvement Projects and Pollutant Reduction Facilities

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
	7 sites (CC-0, CC-10, CC-7, CT-P1, CT-P2, CT-1, CT-2, PC-1)	**2 Sites (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
Dissolved Organic Carbon	X (CC-10, CT-2				X
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. Table 4 summarizes the analytical laboratories and laboratory managers used during the monitoring program.

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. 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.

Composite phytoplankton samples were collected from the photic zone 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 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. REG 31 has a standard range for pH between 6.5 and 9.0 for aquatic life. 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 oxidizing 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 normally 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 also 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,

has the 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}, $H_2PO_4^{-}$, and H_3PO_4). 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, gaseous, 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. There are many indices that are assign numerical values to trophic state based on multiple water quality parameters

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 2020, all surface water and groundwater sites were monitored on a monthly, every other month, or bi-annual frequency. Samples are collected midstream from mid-depth and kept cool until shipped to the laboratory for chemical analysis.

Monthly Base Flow Sampling

When there is sufficient flow, one sample is collected monthly from the following sites: CT-1, CT-2, CT-P1, CT-P2, CC-10, CC-7 (EcoPark), CC-O (Outlet) and PC-1.

Every Other Month Base Flow Sampling

When there is sufficient flow, one sample is collected every other month from the following sites: MCM-1, and MCM-2.

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).

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 6 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-1, CT-2, CT-P1, CT-P2, CC-10, CC-7 EcoPark, and 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 above and below selected PRFs.

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 7.8 inches of precipitation in WY 2020, approximately 51% of the 2006-2020 average since precipitation data has been measured at this weather station
Figure 4). In WY 2020, the months of July and August were the driest by far with precipitation measuring 26% and 15% respectively based on the monthly averages of the same 12-year period.

Additionally, when looking at NOAA's annual precipitation information, the various areas of the watershed received precipitation ranged between approximately 10 and 32 percent of normal when compared to the 30-year Parameter-elevation Regression on Independent Slopes Model (PRISM) normal from 1981-2010. This data is based on observed National Weather Service (NWS) precipitation from the CONUS River Forecast Centers and is displayed as a gridded resolution of roughly 4x4 km in Figure 5. The significantly lower than average precipitation in the watershed this year contributed to the inability to capture samples to characterize the water quality from a significant number of storm flows.

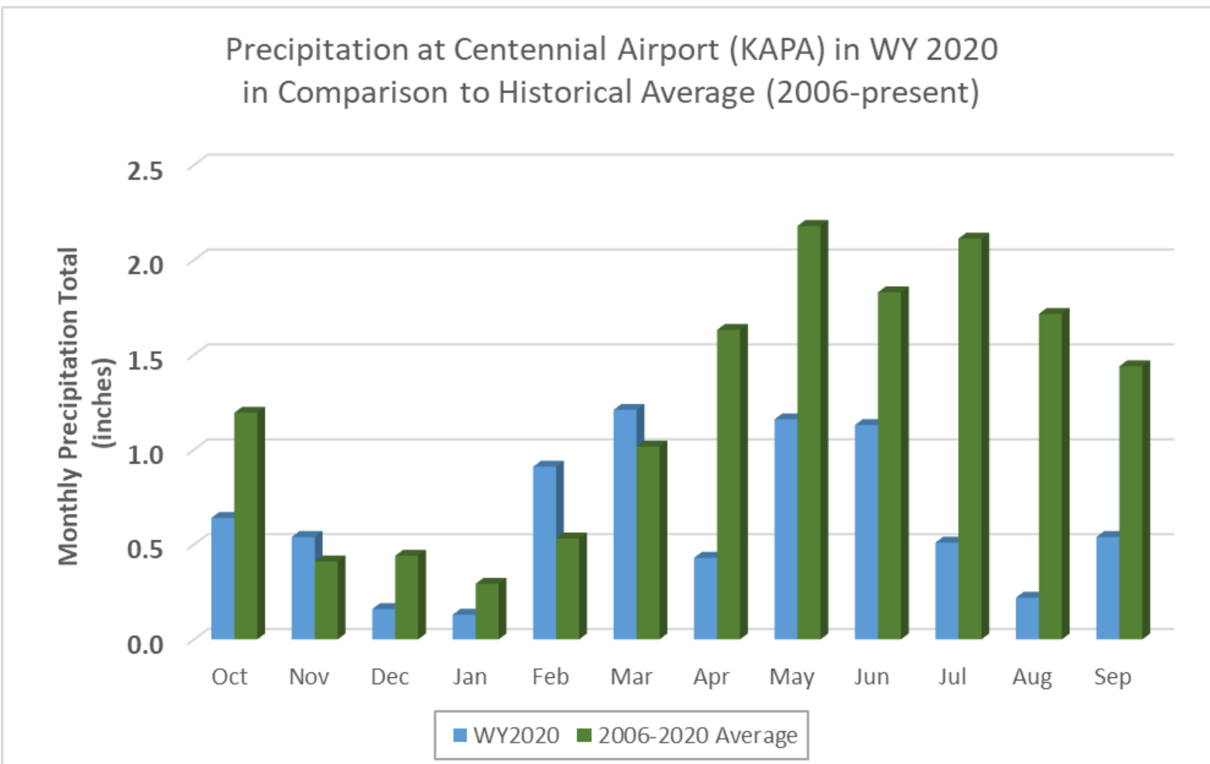


Figure 4. Monthly Precipitation in WY 2020 compared to Historical (2006-2020) average.

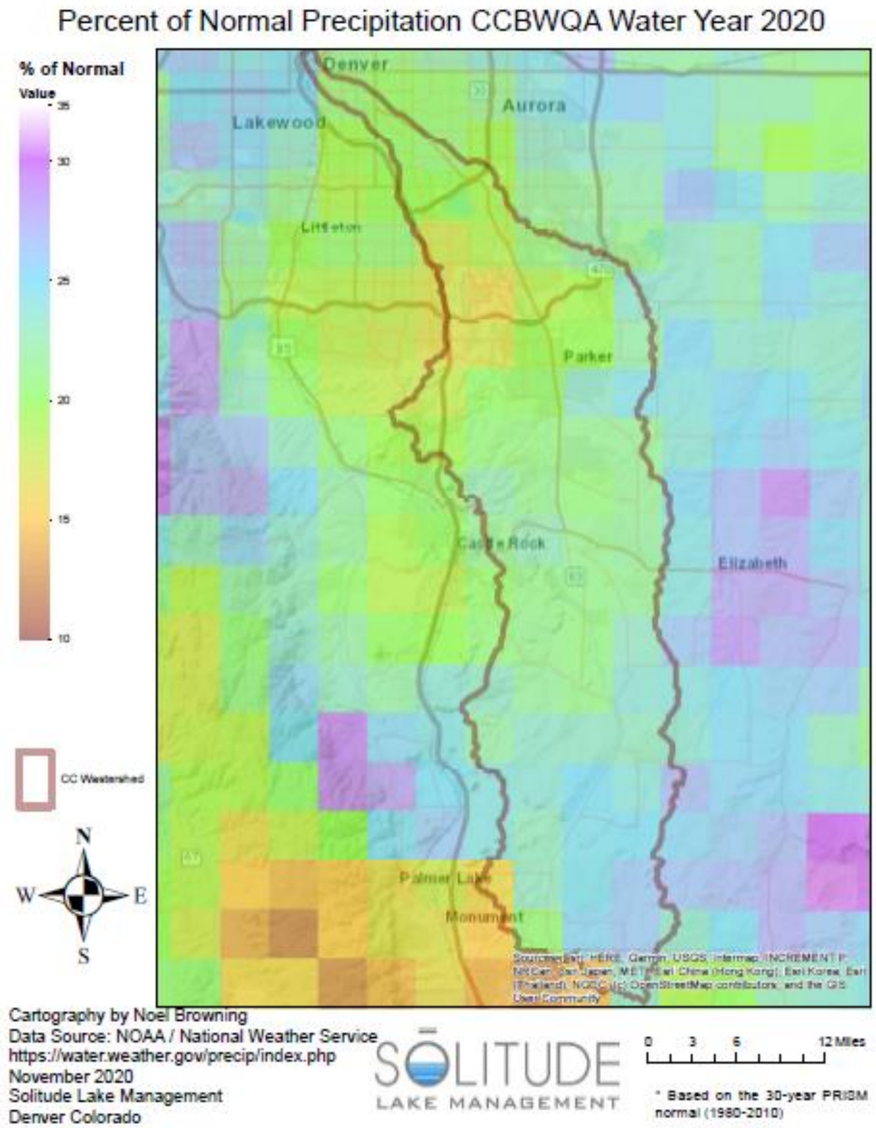


Figure 5. Percent of Normal Precipitation in the Cherry Creek Basin based on 30-year PRISM normal (1981-2010).

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 surface water monitoring locations for the SAP. The “Cherry Creek Near Franktown, CO” station (0671200) has an 80-year period of record (POR) and the “Cherry Creek near Parker, CO” station (393109104464500) has a 29-year POR.

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 2020 summary statistics list a total annual flow of 1,736 ft^3 (3,442.5 AF) with an annual daily mean flow rates of 4.74 cfs (9.43 AF/day). This rate was approximately 52.6 % of the annual mean discharge of 9.02 cfs calculated from WY1940-WY 2020. Figure 6 shows the estimated daily discharge along with the median daily statistic from the last 80 years.

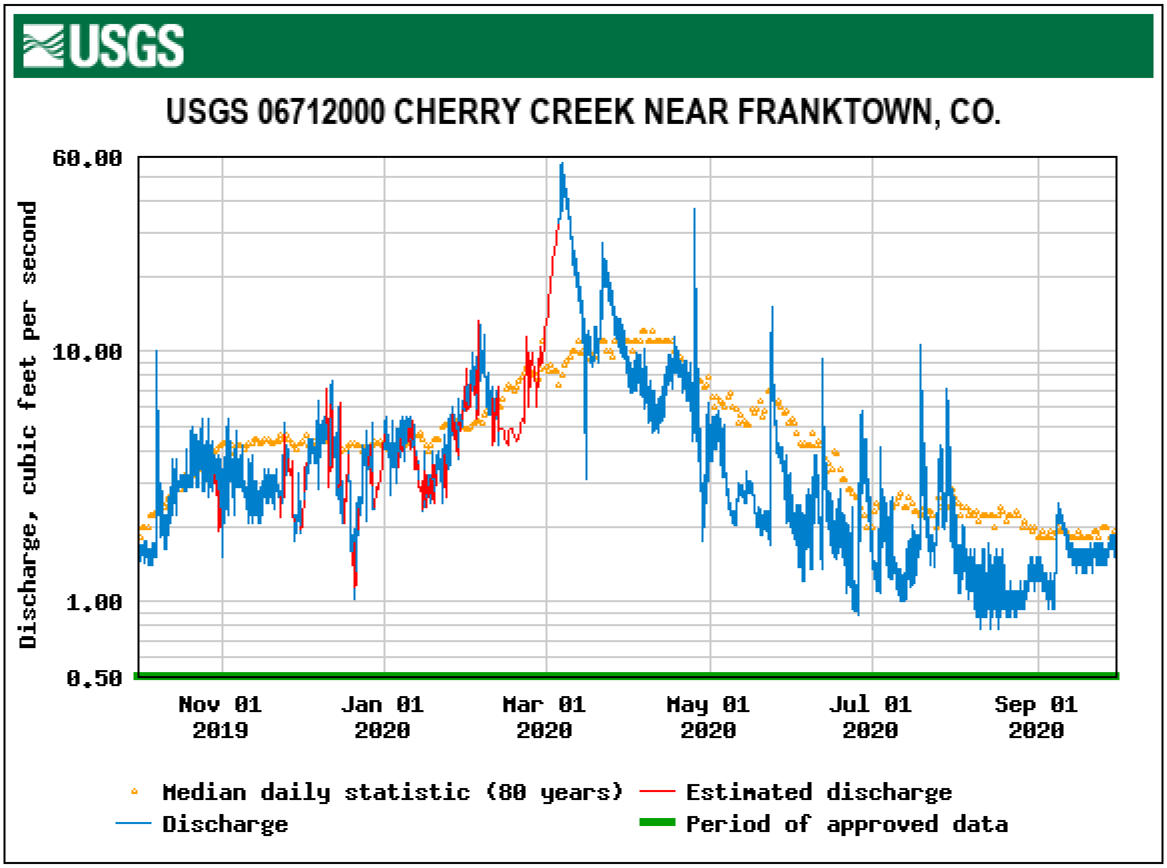


Figure 6. WY 2020 Daily Mean Discharge and Historical Median Flows for USGS Gauge near Franktown (https://nwis.waterdata.usgs.gov/)

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 Parker Rd. The station has a drainage area of 287 mi².

The USGS WY 2020 summary statistics list a total annual flow of 3,678 ft³ (7293.5 AF) with an annual daily mean flow rate of 10 cfs (19.83 AF/day). This rate was approximately 88.7% of the annual mean discharge of 11.3 AF calculated from WY 1992 -WY 2020. Figure 7 shows the estimated daily discharge along with the median daily statistic from the last 29 years.

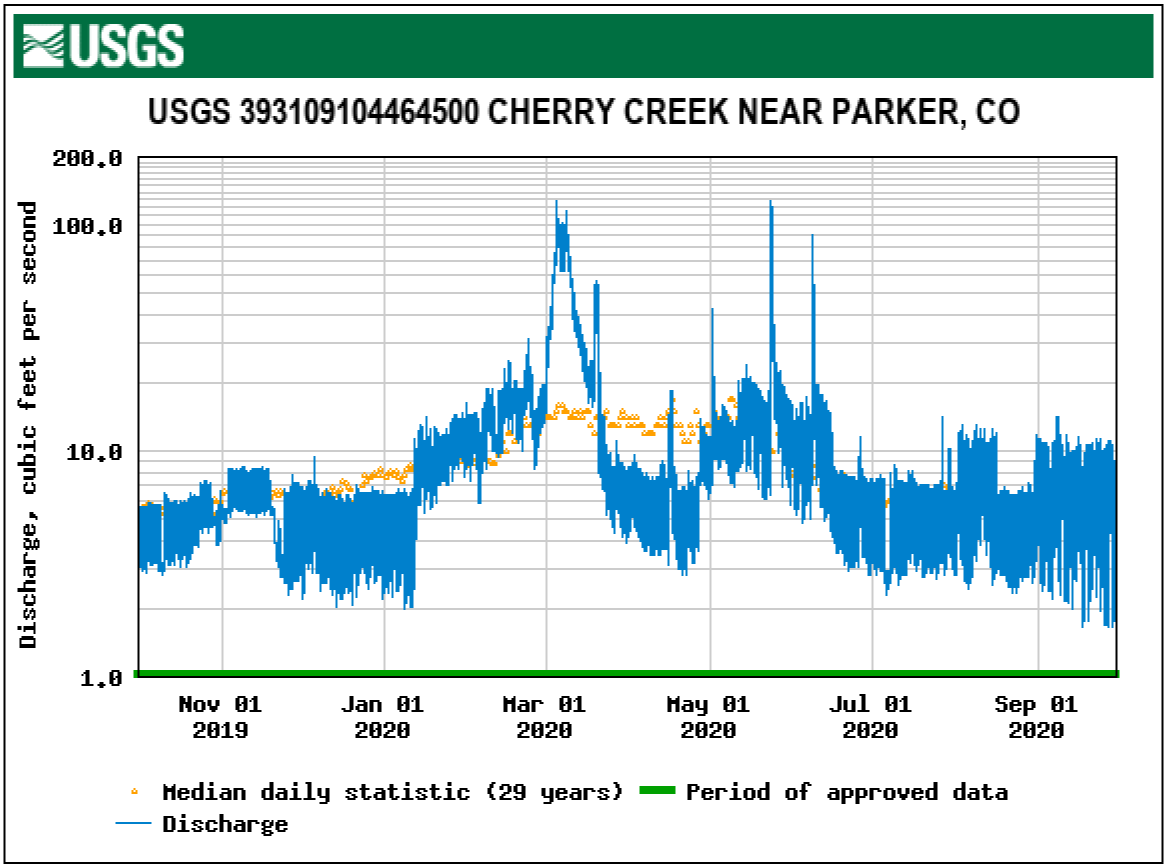


Figure 7. WY 2020 Daily Mean Discharge and Historical Median Flows for USGS Gage near Parker

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 monitoring stations on Cottonwood Creek are CT-1, CT-2, CT-P1 and CT-P2 which were added back into the SAP in 2020. 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 the CT-2 monitoring site is located at the outflow of the 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 2020 flow at the CC-10 monitoring site totals 14,832 AF with an average daily discharge of 40.6 AF. The estimated WY 2020 flow at the CT-2 monitoring site total 3,133 AF with an average daily discharge of 8.6 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 2020 daily inflow estimates are included in Appendix A.

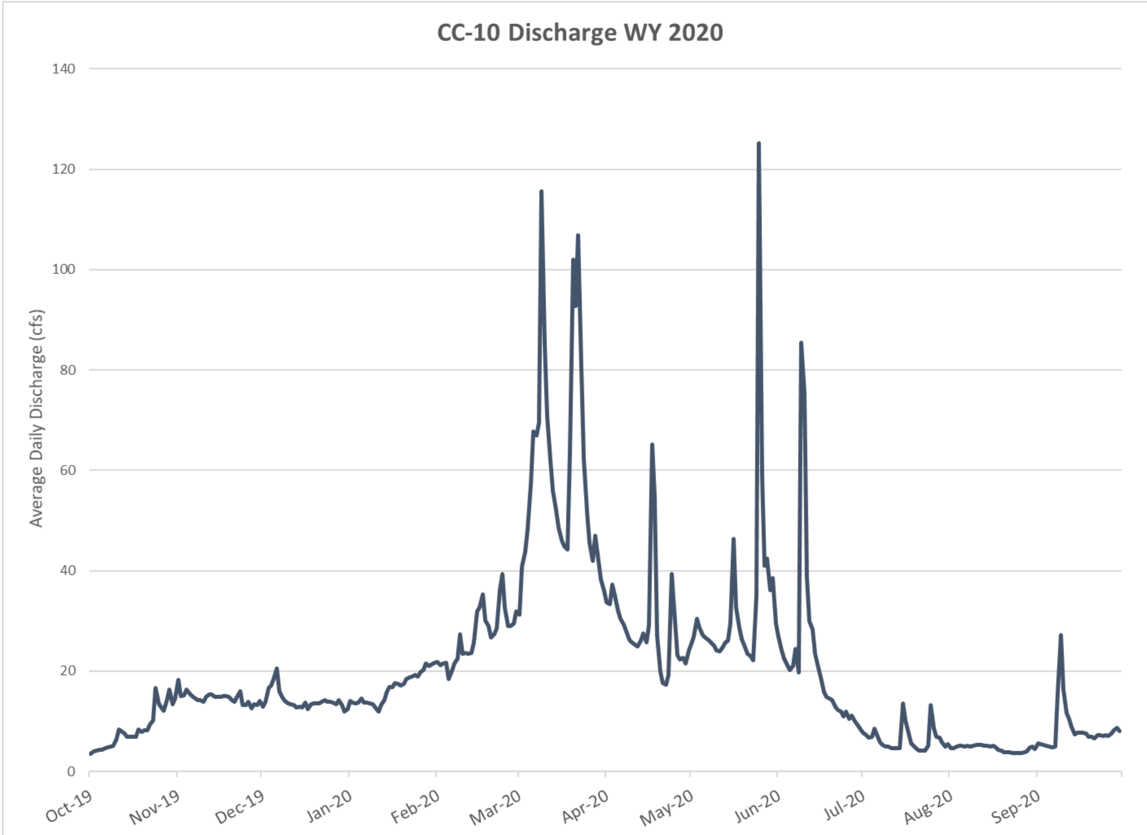


Figure 8. Daily Discharge Rates at CC-10 during WY 2020.

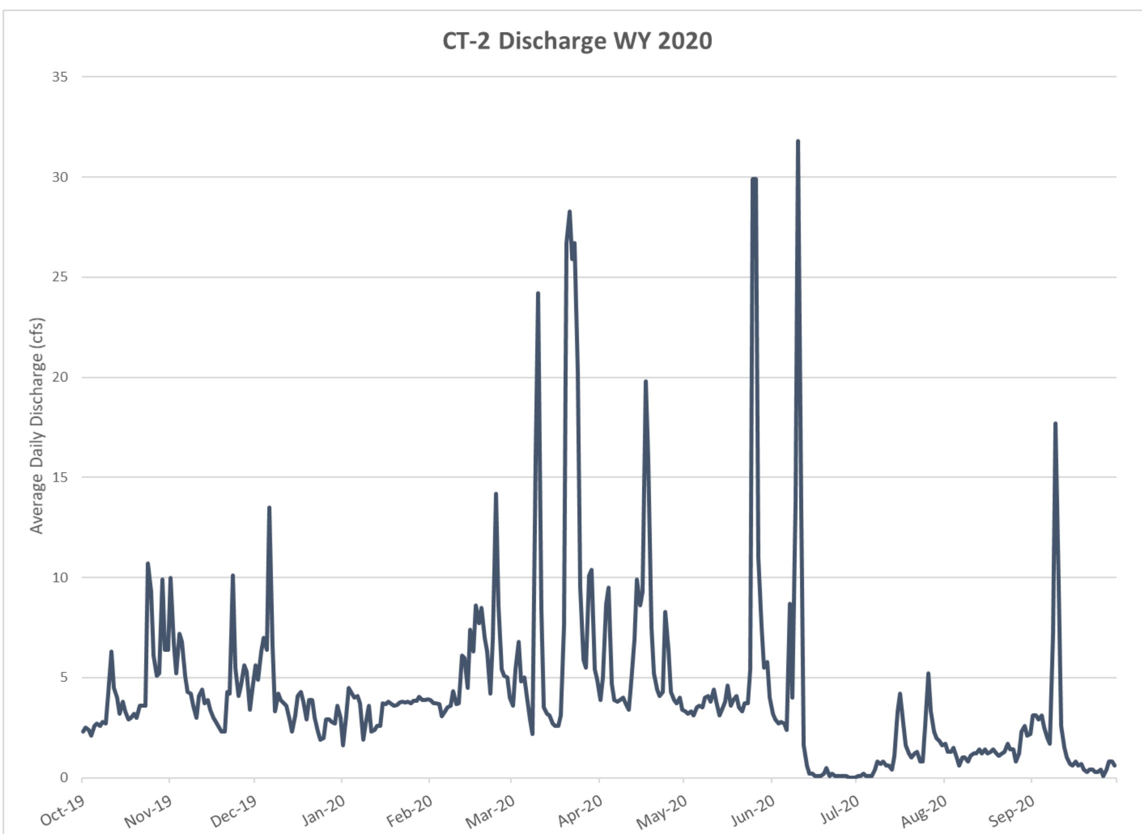


Figure 9. Average Daily Discharge at CT-2 during WY 2020.

3.3 CHERRY CREEK SURFACE 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 Franktown) site and moving downstream towards the Reservoir.

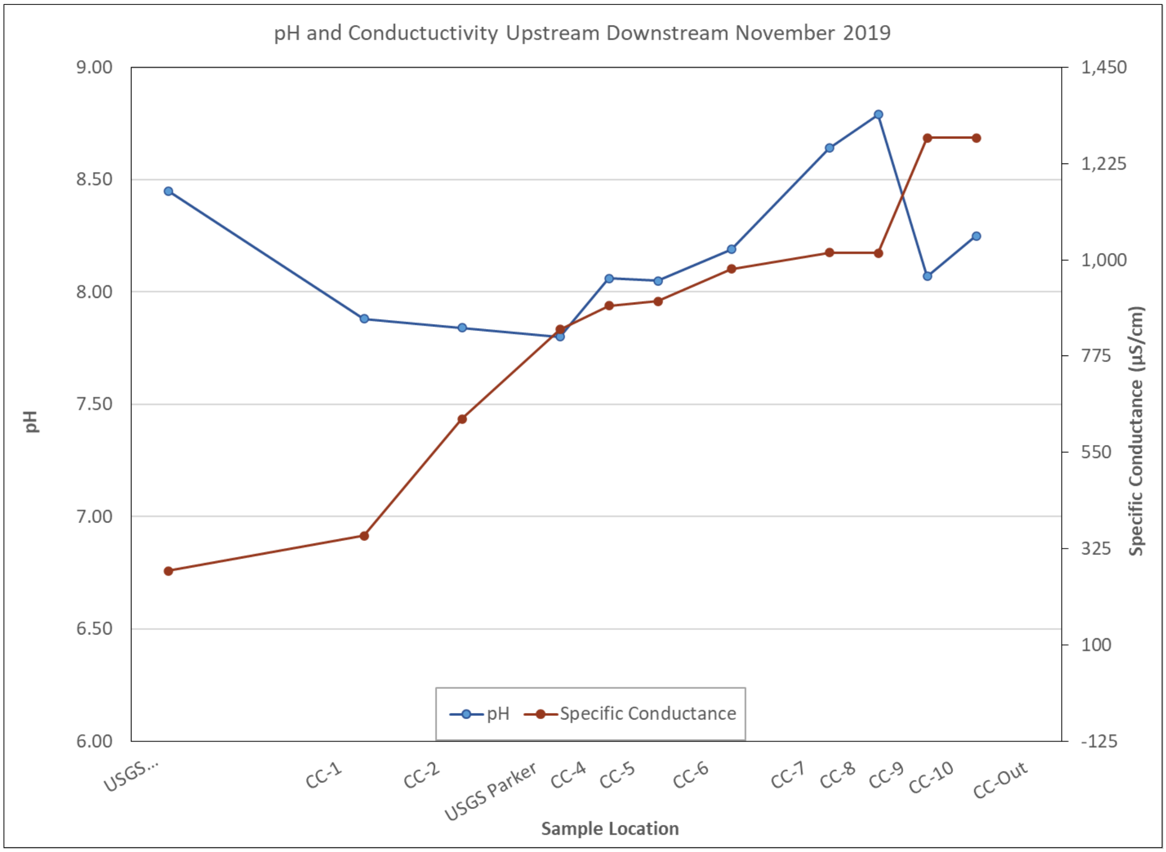


Figure 10. pH and Conductivity Upstream to Downstream on Cherry Creek, November 2019.

The specific conductance (conductivity) and pH were monitored from the surface water sites from the upper basin downstream to the Reservoir in November 2019 and May 2020 (Figure 11 and Figure 11. pH and Conductivity Upstream to Downstream on Cherry Creek, May 2020.). In November 2019, due to construction activities, no water was being released from the outlet of the Reservoir, so data was not collected at that time. The conductivity was almost 4.7 times higher from the furthest upstream site (USGS Franktown) to just above the Reservoir at CC-10 in Nov 2019. Conductivity values were almost 5 times higher from the furthest upstream (USGS Franktown) to lowest downstream site (CC-O below the Reservoir) in May 2020. 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 7.8 to 8.8 throughout the basin.

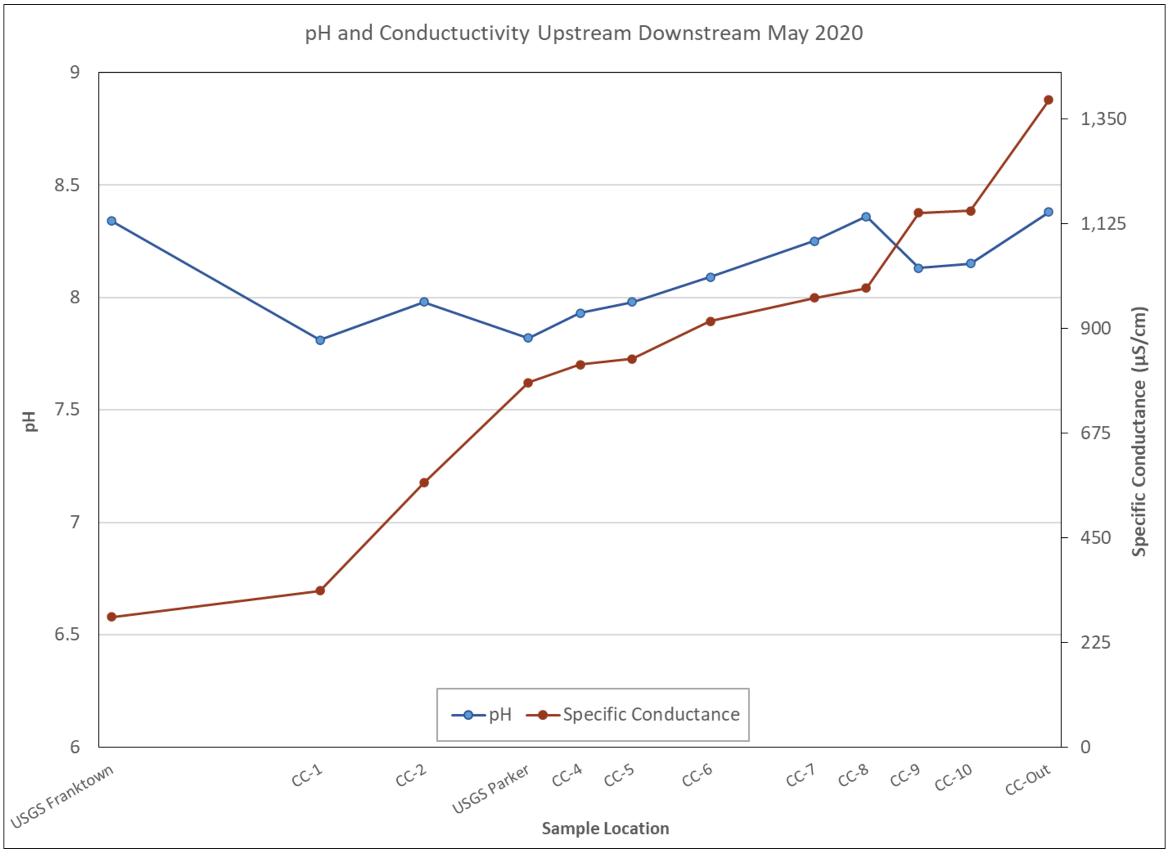


Figure 11. pH and Conductivity Upstream to Downstream on Cherry Creek, May 2020.

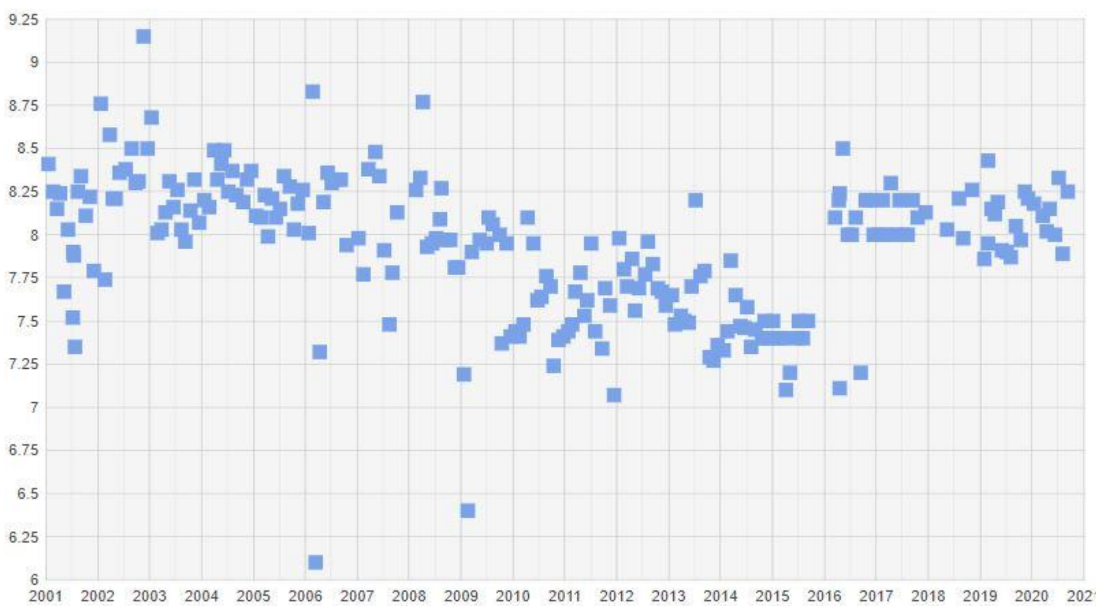


Figure 12. Historical pH Values at CC-10 through WY2020 (X-axis) and pH (Y-axis)

The historical pH values measured at CC-10 appear to have slightly decreased between 2009 and 2016 but have shown higher values more recently (Figure 12). In WY 2020, the pH values sampled at CC-10 ranged from 7.9 to 8.3, which was similar to the last three years.

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 2020, the specific conductance values sampled at CC-10 ranged from 1,000 to 1,608 µS/cm. The mean specific conductance in Cherry Creek of 1,258 µS/cm was significantly lower than the mean in Cottonwood Creek, which was 2,301 µS/cm during WY 2020, and also had more seasonal variability than Cherry Creek. Figure 18 in Section 3.4 displays the historical trends in conductivity at both sites.

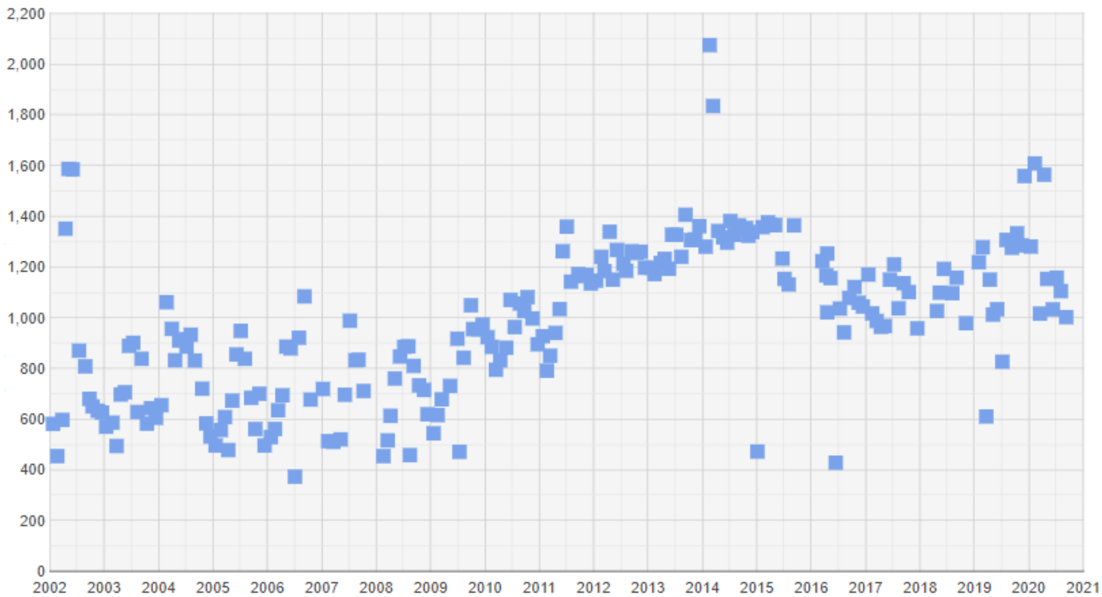


Figure 13. Historic Conductivity at CC-10 through WY 2020. Specific Conductance µS/cm (Y-axis)

During both comprehensive upstream to downstream sampling events, the level of TP had limited variability. In both November 2019 and May 2020, the TN increased from the USGS Franktown site downstream to the USGS Near Parker site then leveled out and decreased all the way to the Reservoir and outflow (Figure 14 and Figure 15.

In May 2020 concentrations of all nutrients were lower below the lake at CC-0 than the sites on Cherry Creek just above the Reservoir. The concentrations from the bi-annual sampling in WY 2020, along with previous upstream to downstream sampling events, indicate nutrient retention or utilization within the Reservoir before release from the outlet.

Summary statistics for TP, TN, and TSS concentrations at CC-10 during base and storm flows during WY 2020 are provided in Table 5. Due to the low flows, water quality samples from only one storm event were collected in WY 2020. The TP concentrations ranged between 125 and 363 µg/L during the water year. The TN concentrations ranged between 528 and 1,740 µg/L during WY 2020. The values of TSS ranged between 6 and 118 mg/L. Although only samples from one storm flow were collected in WY 2020, the mean and median concentrations of TP, TN, and TSS were all higher during the storm event.

The relationship between nutrients and TSS concentrations is also reflected in the water quality of samples collected at CC-10 during storm and base flow sampling events. Figure 16 illustrates TP, TN, and TSS at each monitoring event during WY 2020. Typically storm flows increase the suspended sediments in the water, represented by higher values of TSS. During WY 2020, the storm event captured on June 9th, 2020 indicated a correlation of higher nutrient concentrations with higher TSS levels. These data, along with historical trends, suggest that storm events may contribute a large percentage of the total nutrient and sediment loading to the Reservoir.

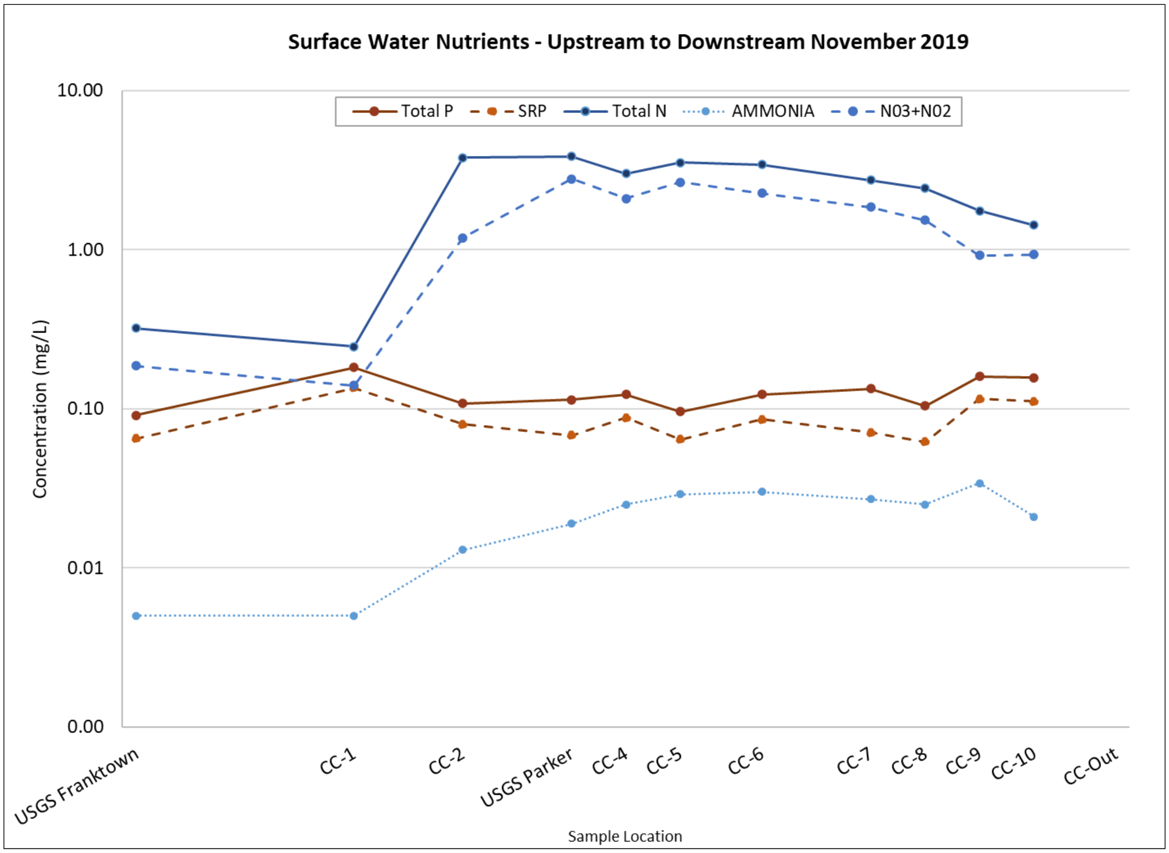


Figure 14. Surface Water Nutrient Sampling of Cherry Creek, November 2019 .

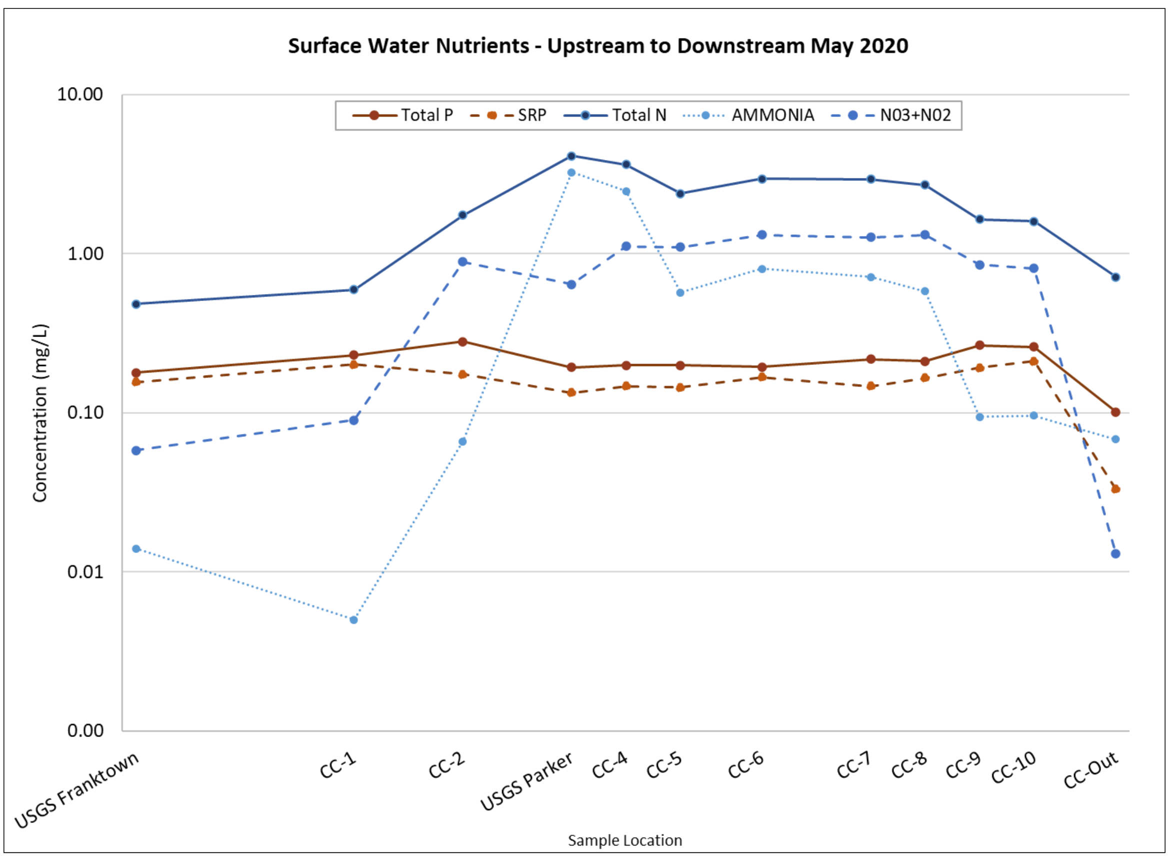


Figure 15. Surface Water Nutrient Sampling of Cherry Creek, May 2020.

Table 5. WY 2020 Total Phosphorus, Nitrogen, and Suspended Solids at CC-10, Base and Storm Flow Conditions.

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	1	-	12	1	-	12	1	-
Minimum	125	363	66%	528	1,530	65%	6	118	95%
Maximum	311	363	14%	1740	1,530	-14%	28	118	76%
Mean	202.8	363	44%	1,309.5	1,530	14%	14	118	88%
Median	185.5	363	49%	1375	1,530	10%	13	118	89%

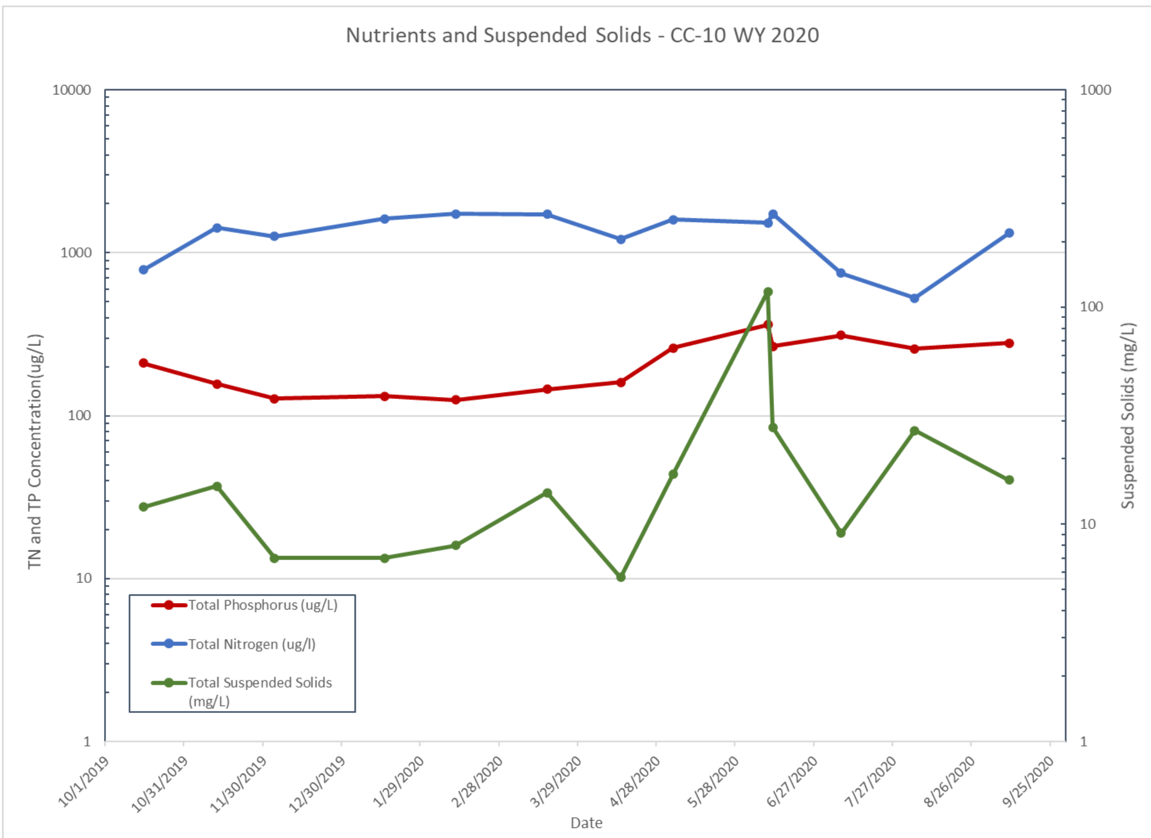


Figure 16. Total Phosphorus, Total Nitrogen and Total Suspended Solids at CC-10, WY 2020.

3.3.1 PINEY CREEK

Piney Creek is one of the primary tributaries which feeds Cherry Creek and is monitored to determine water quality from this sub-basin and potential influence on the water quality in Cherry Creek. Summary statistics for total phosphorus, total nitrogen, and TSS concentrations at PC-1 during base and storm flows during WY 2020 are provided in Table 6. Due to the low flows in 2020, only one storm sample was collected from this site.

The TP concentrations ranged from 36 and 390 µg/L during the year. The TN concentrations ranged from 310 and 1,860 µg/L. The values of TSS ranged from 0.9 to 140 mg/L. Although only samples from one storm flow were collected in WY 2020, the mean and median concentrations of TP, TN and TSS were all higher during the storm event.

Table 6. WY 2020 Total Phosphorus, Nitrogen and Suspended Solids at PC-1, Base and Storm Flow Conditions.

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	1	-	12	1	-	12	1	-
Minimum	36	390	91%	301	1860	84%	0.9	140	99%
Maximum	187	390	52%	1690	1860	9%	43	140	69%
Mean	91	390	77%	937	1860	50%	10	140	93%
Median	73	390	81%	868.5	1860	53%	6	140	96%

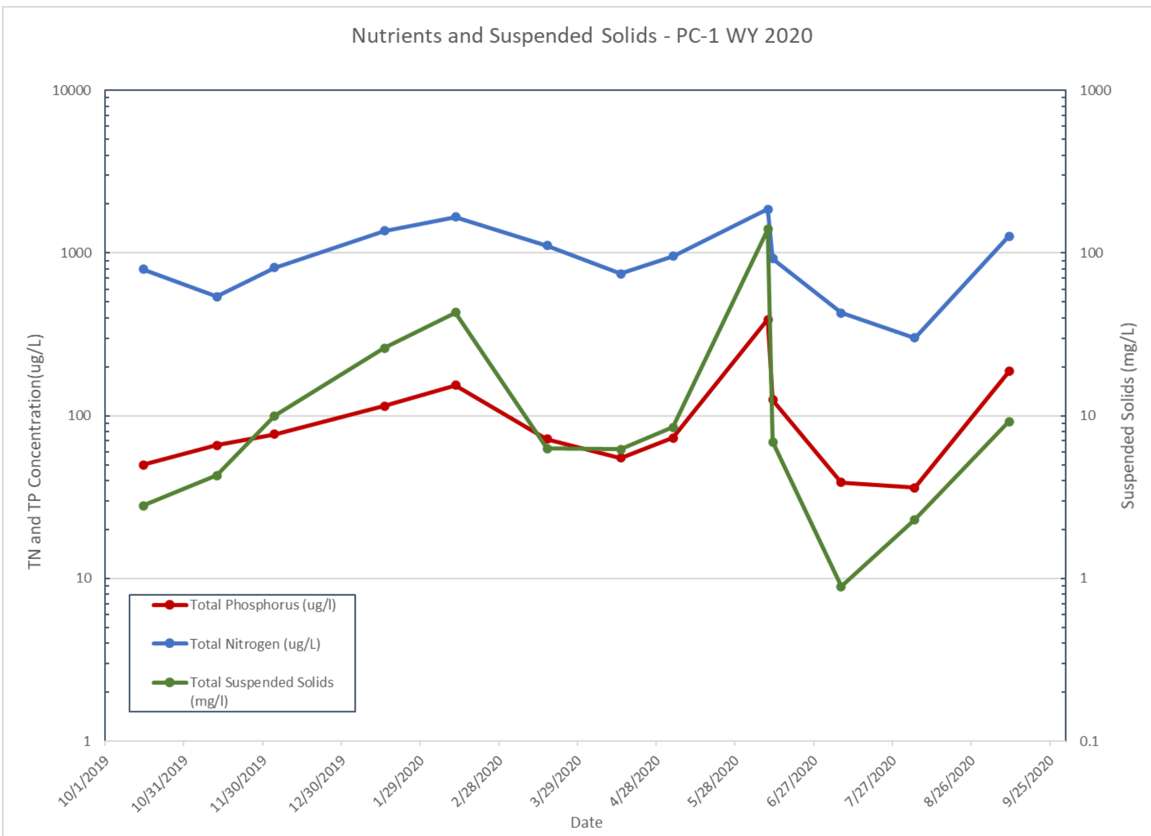


Figure 17. Total Phosphorus, Total Nitrogen and Total Suspended Solids at PC-1, WY 2020.

During WY 2020 the pH values in Piney Creek ranged between 8.1 and 8.6, and the specific conductance values ranged from 911 to 2,527 µS/cm. The mean specific conductance on Piney Creek was 1,652 µS/cm, which was slightly higher than the specific conductance of 1,258 µS/cm in Cherry Creek, but still significantly lower than the mean of 2,301 µS/cm on Cottonwood Creek during WY 2020.

As a comparison of Piney Creek to Cherry Creek, the mean values for all nutrients and suspended solids from PC-1 and upstream (CC-7) and downstream (CC-10) of the confluence with Cherry Creek included in Table 7. During WY 2020 all nutrient and suspended solids mean concentrations with the exception of NH_3-N were significantly lower in Piney Creek than either the upstream (CC-7) or downstream (CC-10) sites in Cherry Creek, indicating that the Piney Creek inflow had little impact on overall water quality in Cherry Creek.

Table 7. Water Quality in Piney Creek and Upstream and Downstream of Confluence with Cherry Creek, WY 2020.

Base Flow	Mean Concentration		
N=	12	12	12
	Site		
Analyte	**CC-7**	**PC-1**	**CC-10**
TP, µg/L	158	87	203
SRP, µg/L	89	50	160
TDP, µg/L	105	57	168
TN, µg/L	2403	910	1310
NO_3+NO_2-N, µg/L	1637	379	736
NH_3-N, µg/L	77	76	32
TSS, mg/L	12	10.5	13.8
VSS, mg/L	3	2.4	3.1

3.4 COTTONWOOD CREEK SURFACE 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 one permitted wastewater discharge as compared to multiple permitted wastewater discharges to 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-1, CT-2, CT-P1, and CT-P2 have 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 regarding the evaluation of the effects of the PRFs in Section 3.5 below.

During WY 2020, the pH of water in Cottonwood Creek before it entered the Reservoir ranged from 7.7 to 8.3, but it has remained relatively consistent over time.

Conductivity, or specific conductance, at CT-2 ranged between 1,163 µS/cm and 5,719 µS/cm with a mean value of 2,301µS/cm. This is higher than the mean for Cherry Creek, which was 1,258 µS/cm for WY 2020. Historical conductivity is plotted in Figure 18 and shows an increasing trend with greater variability over time.

Summary statistics for total phosphorus, total nitrogen, and TSS concentrations at CT-2 during base and storm flows during WY 2020 are provided in

Table 8. The TP concentrations ranged between 33 and 183 µg/L during the year. The TN concentrations ranged between 784 and 3,820 µg/L during WY 2020. The TSS concentrations ranged between 4 and 11 mg/L. Only one storm event was collected in WY 2020 so comparisons between base and storm flow conditions were not

meaningful. Although only one sample from a storm flow was collected in WY 2020, the mean and median concentrations of TP and TSS were both higher during the storm event than in the base flow samples, but the TN concentration was actually lower than the maximum concentration during base flow conditions.

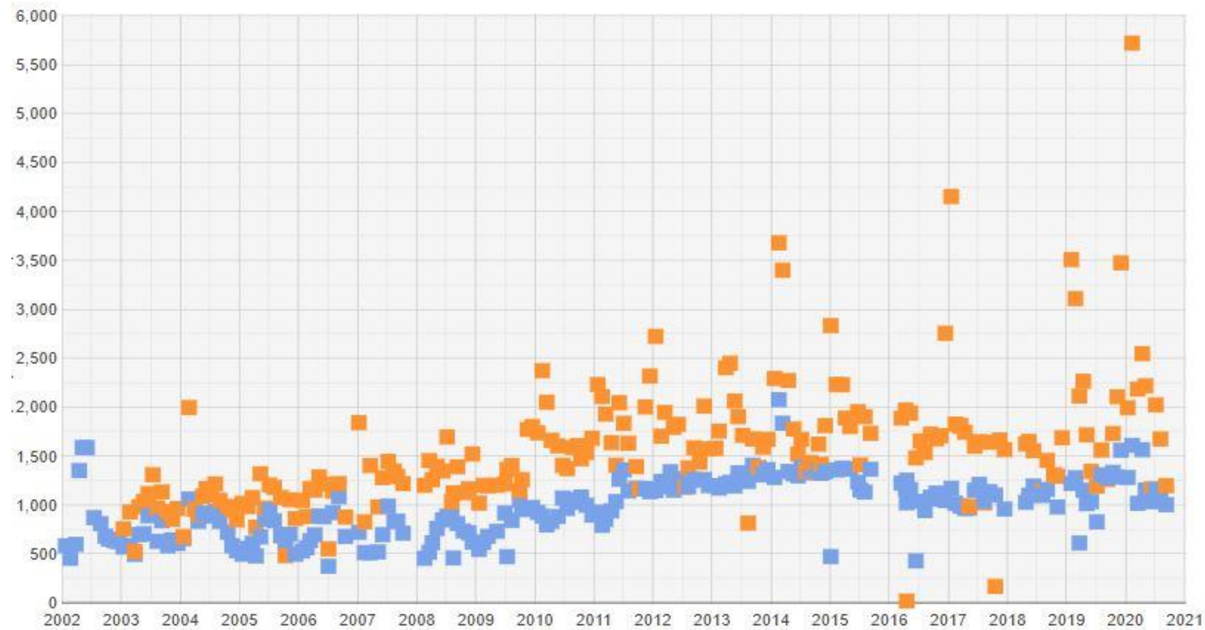


Figure 18. Historic Conductivity at CC-10 and CT-2 through WY 2020. Specific Conductance µS/cm (Y-axis)

CC-10 CT-2

Table 8. Total Phosphorus, Nitrogen and Suspended Solids at CT-1 during Base and Storm Flows, WY 2020.

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	1	-	12	1	-	12	1	-
Minimum	33	118	72%	784	1830	57%	4	11	64%
Maximum	183	118	-55%	3820	1830	-109%	15	11	-36%
Mean	58	118	51%	2154	1830	-18%	8.0	11	28%
Median	43	118	64%	2180	1830	-19%	7.8	11	29%

The concentrations of TP and TN measured at CT-2 in WY 2020 are shown in Figure 19 with the TSS values on the second axis as a comparison. As displayed in the graph, a similar relationship between nutrients and TSS is present on Cottonwood Creek at CT-2, although it is much less significant than seen in Cherry Creek. In addition, the TP concentrations are much higher entering the Reservoir at the monitoring site CC-10 on Cherry Creek than on Cottonwood Creek at CT-2 during WY 2020.

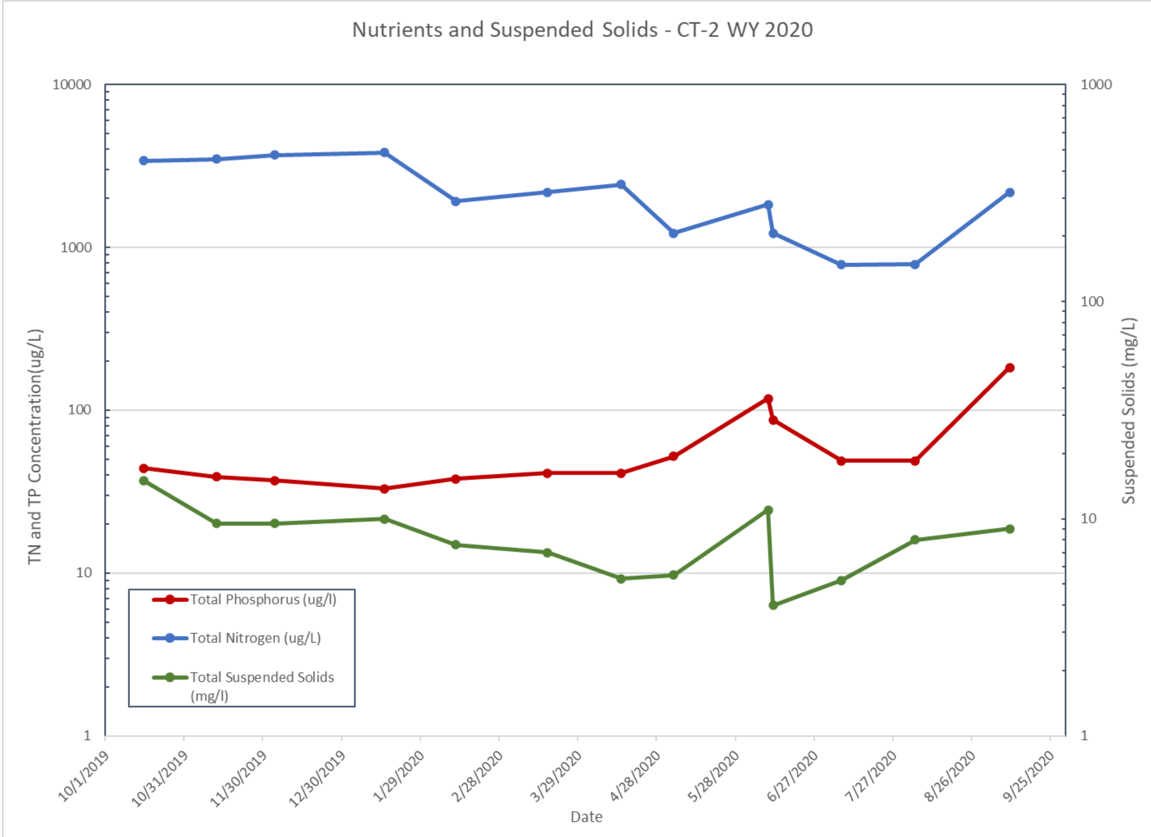


Figure 19. Total Phosphorus, Total Nitrogen and Total Suspended Solids CT-2, WY 2020.

A summary of the mean water quality concentrations at CT-2 during base flow conditions for WY 2020 is provided in Table 9.

Table 9. Water Quality Summary for CT-2 Base flow conditions WY 2020.

Base Flow	CT-2
Analyte	Mean Concentration
TP, µg/L	58
SRP, µg/L	15
TDP, µg/L	29
TN, µg/L	2,259
NO3+NO2-N, µg/L	1,263
NH3-N, µg/L	67
TSS, mg/L	8.0
VSS, mg/L	2.6

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 base flow sampling, as well as storm conditions above and below these sites.

Samples are collected during base flow and 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). In addition, changes in water quality on Cottonwood Creek between the two ponds is evaluated by looking at the changes in water quality between CT-P2 and CT-1.

During WY 2020, the significantly lower than average precipitation directly correlated to low flows in the streams so only one complete storm event with the level-based sampling equipment set at all sites was captured. While one data points are not enough to complete a significant analysis, calculations were included for annual reference.

Table 10 summarizes the upstream to downstream changes seen in the various water quality parameters in base flow conditions in each of the different PRFs. Table 11, Table 12, Table 13, and Table 14 provide the mean upstream to downstream concentrations, net difference, and percent change in both base and storm flows for WY 2020.

Table 10. Summary of Base Flow Water Quality in Cottonwood PRFs, WY 2020.

PRF	**Cottonwood Treatment Train**		**Peoria Pond**		**Perimeter Pond**		**Cottonwood Creek Between Ponds**		**McMurdo Gulch**	
Upstream Site Downstream site	**CT-P1 CT-2**		**CT-P1 CT-P2**		**CT-1 CT-2**		**CT-P1 CT-1**		**MCM-1 MCM-2**	
Analyte	**Increase**	**Decrease**	**Increase**	**Decrease**	**Increase**	**Decrease**	**Increase**	**Decrease**	**Increase**	**Decrease**
TP, µg/L		X		X		X	X			X
SRP, µg/L	X			X		X	X			X
TDP, µg/L	X			X		X	X			X
TN, µg/L	X		X			X	X			X
NO2+NO3, µg/L	X		X			X	X			X
NH_3-N, µg/L	X			X	X		X			X
TSS, mg/L		X		X		X	X		X	
TVSS, mg/L		X		X		X		X	X	

Based upon the data collected in WY 2020, the Cottonwood Treatment Train as a whole (between Peoria Pond and Perimeter Pond), reduced TP concentrations by approximately 10% under base flow conditions and 86% during the one storm event (Table 11). Suspended sediment concentrations, measured as TSS, were reduced by approximately 40% under base flow conditions and 97% during the storm flow measured. The other nutrients showed higher concentrations in downstream, in base and storm flow conditions and TN concentrations were actually almost twice as high downstream in base flow conditions. Based on the concentrations in base and storm flow events, the PRFs reduced phosphorus and suspended sediment concentrations in downstream flows during WY 2020 but the other parameters displayed more variability.

Table 11. Pollutant Reduction Analysis of the Cottonwood Creek Treatment Train PRF, WY 2020.

	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	1	1	Difference	Difference
Analyte								
TP, µg/L	64.4	57.8	-6.7	-10.3	846.0	118.0	-728.0	-86.1
SRP, µg/L	14.3	14.9	0.6	4.1	28.0	36.0	8.0	28.6
TDP, µg/L	23.5	26.3	2.8	11.7	36.0	57.0	21.0	58.3
TN, µg/L	1,126	2,259	1,132.6	101	2,670	1,830	-840.0	-31.5
NO2+NO3,µg/L	415.9	1,234.1	818.2	197	368.0	624.0	256.0	69.6
NH_3-N, µg/L	62.4	66.8	4.4	7.0	15.0	20.0	5.0	33.3
TSS, mg/L	13.2	8.0	-5.2	-40	368.0	11.0	-357.0	-97
TVSS, mg/L	4.3	2.6	-1.6	-38	50.0	4.0	-46.0	-92

When evaluating the two sections individually (Peoria Pond and Perimeter Pond Wetland System), (Table 12 and Table 13) it appears that there were similar reductions on TP in both pond PRFs during WY 2020. During WY 2020, the TP concentrations of the Peoria Pond PRF demonstrated a similar trend as the entire treatment train with approximately 11% reduction in TP upstream to downstream in base flow and approximately 75% reduction in the mean storm flow. SRP, TDP and NH_3-N were lower downstream, but TN and NO2+NO3 concentrations were higher at downstream sites under base flow conditions. It is important to note that during the summer of 2020 a sediment removal project was completed within the Peoria Pond and flows through the pond were intermittently impacted by those operations.

Concentrations of nutrients and suspended solids, with the exception of NH_3-N, were lower in the downstream samples than the upstream samples in the Perimeter Pond in WY 2020 under both base and storm flows (Table 13).

Concentrations of nutrients and suspended solids were higher in the downstream samples (CT-1) than the upstream samples (CT-P2) of Cottonwood Creek between the ponds in base flows conditions WY 2020 (Table 14).

Table 12. Pollutant Reduction Analysis of the Peoria Pond PRF, WY 2020.

Peoria Pond	Base Flow				Storm Flow			
	Mean Concentration		Upstream to Downstream		Mean Concentration		Upstream to Downstream	
Site	CT-P1	CT-P2	Net Difference	Percent Difference	CT-P1	CT-P2	Net Difference	Percent Difference
Events	12	11			1	2		
Analyte								
TP, µg/L	64.4	57.5	-6.9	-10.7	846.0	215.0	-631.0	-74.6
SRP, µg/L	14.3	7.4	-7.0	-48.6	28.0	84.0	56.0	200.0
TDP, µg/L	23.5	15.3	-8.2	-35.0	36.0	102.5	66.5	184.7
TN, µg/L	1,126	1,371	245.0	21.8	2,670	1,800	-870.0	-32.6
NO2+NO3, µg/L	415.9	551.1	135.2	32.5	368.0	519.5	151.5	41.2
NH_3-N, µg/L	62.4	38.3	-24.1	-38.6	15.0	158.0	143.0	953.3
TSS, mg/L	13.2	13.0	-0.2	-1.4	368.0	20.0	-348.0	-94.6
TVSS, mg/L	4.3	4.4	0.1	3.5	50.0	6.2	-43.8	-87.7

Table 13. Pollutant Reduction Analysis of the Perimeter Pond PRF, WY 2020.

Perimeter Pond	Base Flow				Storm Flow			
	Mean Concentration		Upstream to Downstream		Mean Concentration		Upstream to Downstream	
Site	CT-1	CT-2	Net Difference	Percent Difference	CT-1	CT-2	Net Difference	Percent Difference
Events	12	11			1	2		
Analyte								
TP, µg/L	64.6	57.8	-6.9	-10.7	168.0	118.0	-50.0	-29.8
SRP, µg/L	15.1	14.9	-0.2	-1.2	53.0	36.0	-17.0	-32.1
TDP, µg/L	24.9	26.3	1.3	5.4	69.0	57.0	-12.0	-17.4
TN, µg/L	2404.5	2258.6	-146.0	-6.1	1,830	1,830	0.0	0.0
NO2+NO3, µg/L	1402.3	1234.1	-168.2	-12.0	644.0	624.0	-20.0	-3.1
NH_3-N, µg/L	44.9	66.8	21.9	48.8	94.0	20.0	-74.0	-78.7
TSS, mg/L	15.0	8.0	-7.0	-46.8	42.0	11.0	-31.0	-73.8
TVSS, mg/L	3.8	2.6	-1.1	-30.0	6.7	4.0	-2.7	-40.3

Table 14. Pollutant Reduction Analysis of the Treatment Train between the PRF ponds, WY 2020

Cottonwood Creek Between PRF Ponds	Base Flow				Storm Flow			
	Mean Concentration		Upstream to Downstream		Mean Concentration		Upstream to Downstream	
Site	CT-P2	CT-1	Net Difference	Percent Difference	CT-P2	CT-1	Net Difference	Percent Difference
Events	12	11			1	2		
Analyte								
TP, µg/L	57.5	64.6	7.1	12.3	215.0	168.0	-47.0	-21.9
SRP, µg/L	7.4	15.1	7.7	104.9	84.0	53.0	-31.0	-36.9
TDP, µg/L	15.3	24.9	9.6	63.1	102.5	69.0	-33.5	-32.7
TN, µg/L	1,370.9	2,404.5	1,033.6	75.4	1,800.0	1,830.0	30.0	1.7
NO2+NO3, µg/L	551.1	1402.3	851.2	154.5	519.5	644.0	124.5	24.0
NH_3-N, µg/L	38.3	44.9	6.5	17.1	158.0	94.0	-64.0	-40.5
TSS, mg/L	13.0	15.0	2.0	15.2	20.0	42.0	22.0	110.0
TVSS, mg/L	4.4	3.8	-0.6	-14.5	6.2	6.7	0.5	8.9

One of the upper tributaries of Cherry Creek is McMurdo Gulch, which had a reclamation project completed early in the areas' urbanization to install 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 15. Pollutant Reduction Analysis of the McMurdo Gulch in WY 2020.

Mean Concentration			Upstream to Downstream	
Flow	Base			
Site	MCM-1	MCM-2	Mean Difference	Percent Change
Events	6	6		
Analyte				
TP, µg/L	392.0	277.5	-114.5	-29.2%
SRP, µg/L	318.5	246.8	-71.7	-22.5%
TDP, µg/L	267.1	245.2	-21.9	-8.2%
TN, µg/L	774.5	531.8	-242.7	-31.3%
NO2+NO3, µg/L	287.8	111.4	-176.4	-61.3%
NH_3-N, µg/L	18.4	31.8	13.4	72.9%
TSS, mg/L	3.1	17.8	14.8	484.1%
VSS, mg/L	1.3	2.5	1.1	84.9%

In WY 2020, TP, TDP, SRP, and NO_3+NO_2-N were all reduced upstream to downstream of the McMurdo stream reclamation project (Table 15). During the sampling period, measured values of both TSS and VSS were higher downstream of the PRF. Although the percent increases of TSS and VSS were high, 484% and 85% respectively, there was one sampling event in June that was responsible for the above average values. When that event is removed from the analysis the upstream to downstream percent reductions in TSS and VSS were 21% and 41% respectively. There was an in-stream reclamation project that was completed at and below MCM-1 between June and November 2020 which may have affected the McMurdo Gulch results. When the results from that time period are excluded, reductions in all parameters were seen upstream to downstream during the other four sapling events in WY 2020.

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 downstream of the Reservoir (MW- Kennedy) (Figure 2).

3.6.1 LEVEL AND TEMPERATURE

The groundwater level in MW-9 has been equipped with a continuous water level and temperature monitoring device since 2016. This equipment records pressure transducer levels and temperature every 15 minutes. The daily mean water level and temperature values measured in MW-9 can be found in Figure 20.

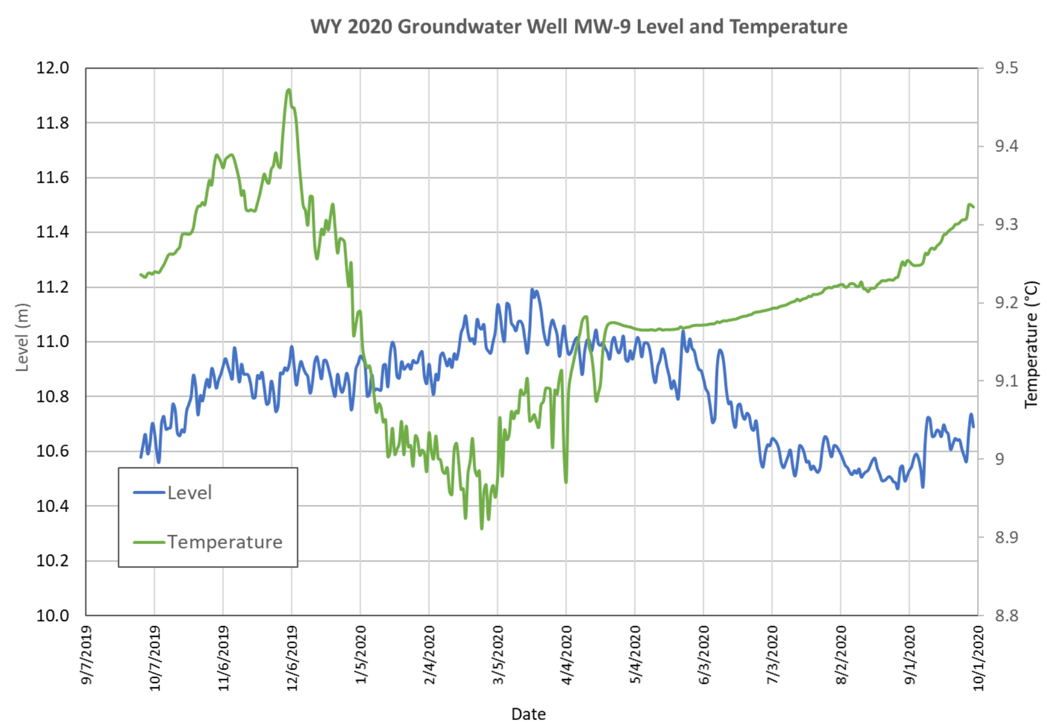


Figure 20. Daily Mean Level and Temperature in Groundwater Well MW-9.

The groundwater level and temperature groundwater in MW-9 displayed some seasonal fluctuation. The temperature ranged from 8.9 to 9.5˚C with highest temperatures observed in early November, decreasing through late February. Temperatures increased again through the summer months. The water levels in MW-9 increased to the highest level of 11.19 m in late March then showed a decreasing trend to the lowest level observed of 10.46 m in late August. The trend of water depth was similar to 2019 with the highest water levels recorded in late March, although the average water depth was 0.2 m less in 2020 than 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. MW-1 is the groundwater site furthest upstream in the watershed that is currently being monitored.

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 site has been sampled since 1994 and is located in Cherry Creek State downstream of the State Park's Perimeter Road 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 mean concentration of TP from the GW sites during the two monitoring events was 0.32 mg/L, with concentrations averaging 0.34 mg/L in November 2019 and 0.30 mg/L in May 2020. The TP concentrations ranged between 0.2 mg/L and 0.57 mg/L in November 2019, and between 0.25 mg/L and 0.40 ug/L in May 2020. In November 2019, the TP concentrations were lowest at MW-1, highest at MW-5, then decreased at MW-9 and were even lower below the Reservoir at MW-Kennedy. In May, the TP concentrations were relatively consistent between MW-1, MW-5, and MW-9, but were actually slightly higher at MW-Kennedy below the Reservoir.

The mean concentration of TN from the GW sites during the two monitoring events was 2.27 mg/L, with concentrations averaging 2.38 mg/L in November 2019 and 2.16 mg/L in May 2020. The TN concentrations ranged between 0.45 mg/L and 6.6 mg/L in November 2019, and between 0.53 mg/L and 4.2 ug/L in May 2020. In both November 2019 and May 2020, the TN concentrations were highest at MW-1 and lowest below the Reservoir at MW-Kennedy.

During both monitoring events, concentrations of NO_3+NO_2-N, followed a similar decreasing trend as TN downstream with the exception of significantly lower concentrations at MW-Kennedy. The maximum concentration of 4.6 mg/L was observed in November 2019 from MW-1 and the lowest concentration of 0.01 mg/L was observed at MW-Kennedy on the same date. The state drinking water standard for nitrate is 10 mg/L (5 CCR 1002-41.8).

In both November 2019 and May 2020, the TP concentrations furthest upstream were similar between the surface water site (CC-1) and the nearest groundwater site (MW-1). In November 2019, the TP concentrations in the nearby surface water sites were actually lower than the GW sites at MW-5 and MW-9, but in May 2020 the SW and GW concentrations were similar with the exception of lower concentrations at CC-O than the nearby MW-Kennedy site. Due to construction, no sample was able to be collected at the outlet in November 2019 so SW and GW concentrations cannot be compared on that date.

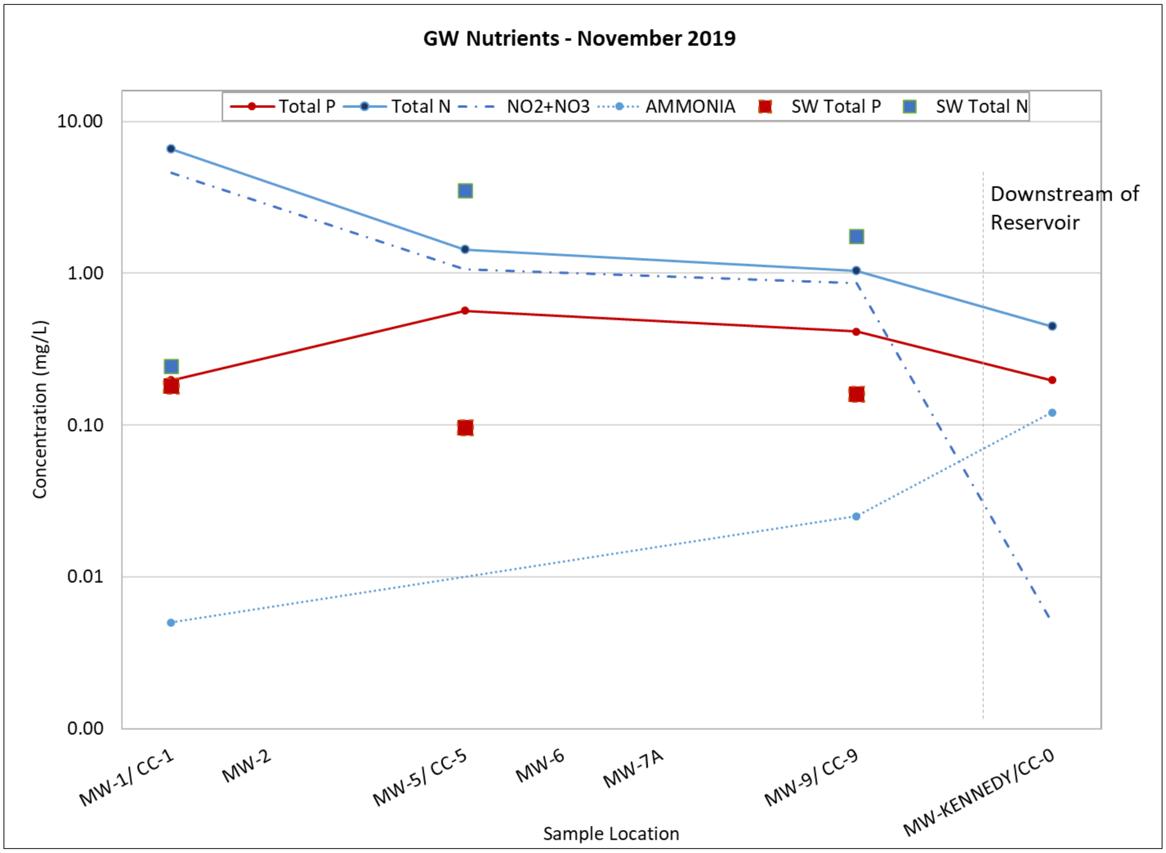


Figure 21. Groundwater Nutrients in Monitoring Well Samples in November 2019.

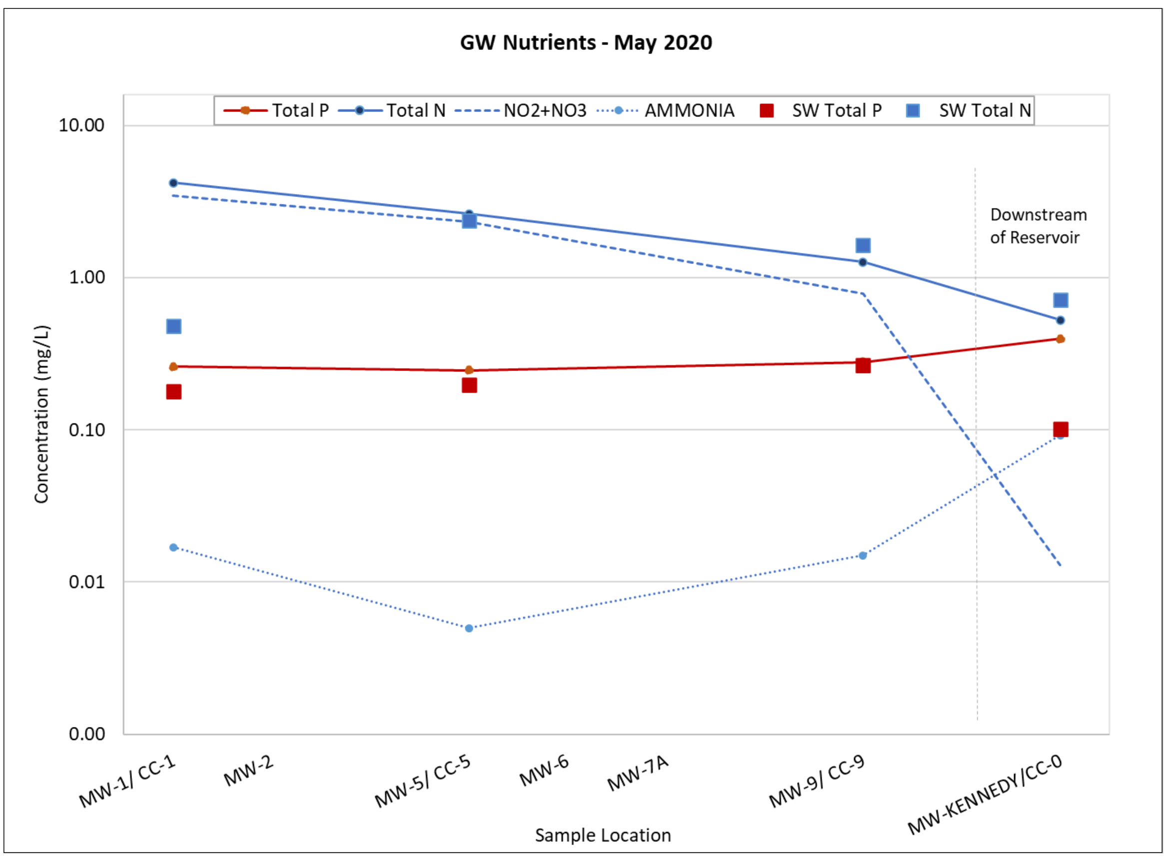


Figure 22. Groundwater Nutrients in Monitoring Well Samples in May 2020.

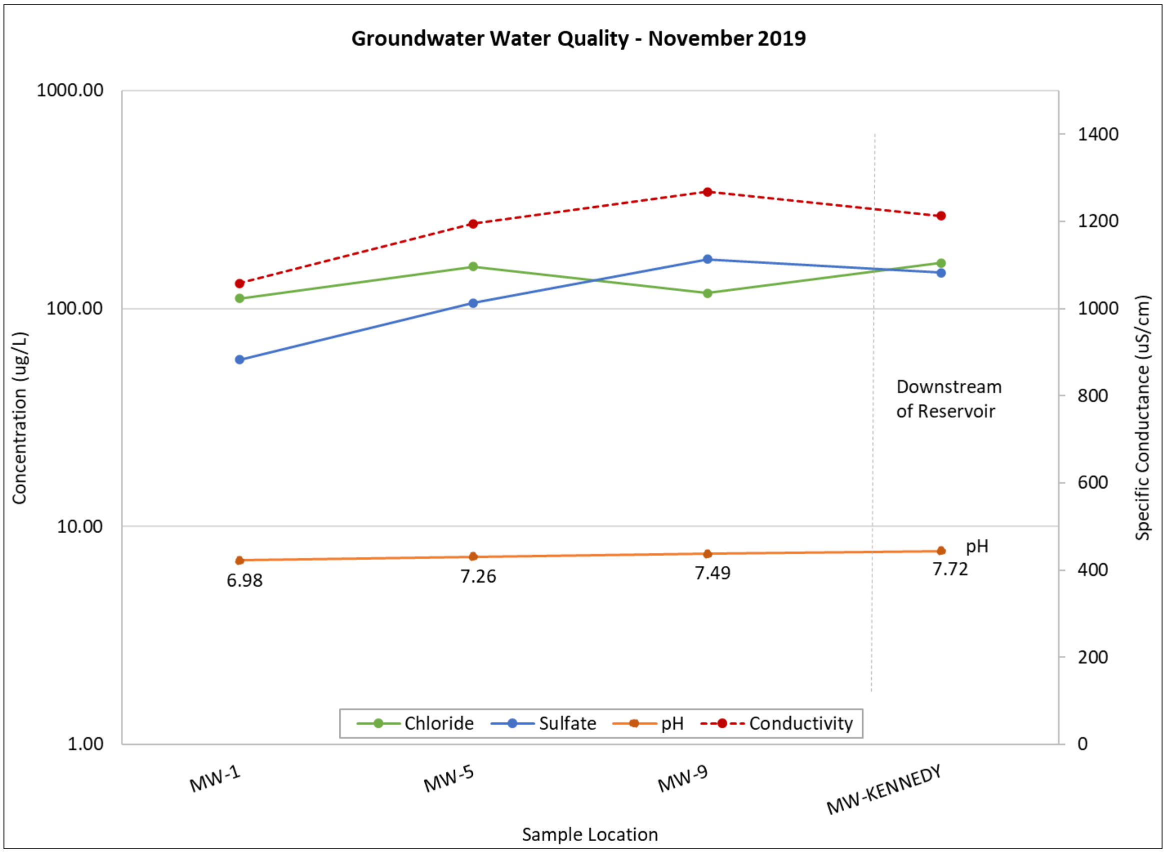


Figure 23. Groundwater Levels of Sulfate, Chloride, Specific Conductance, and pH, November 2019.

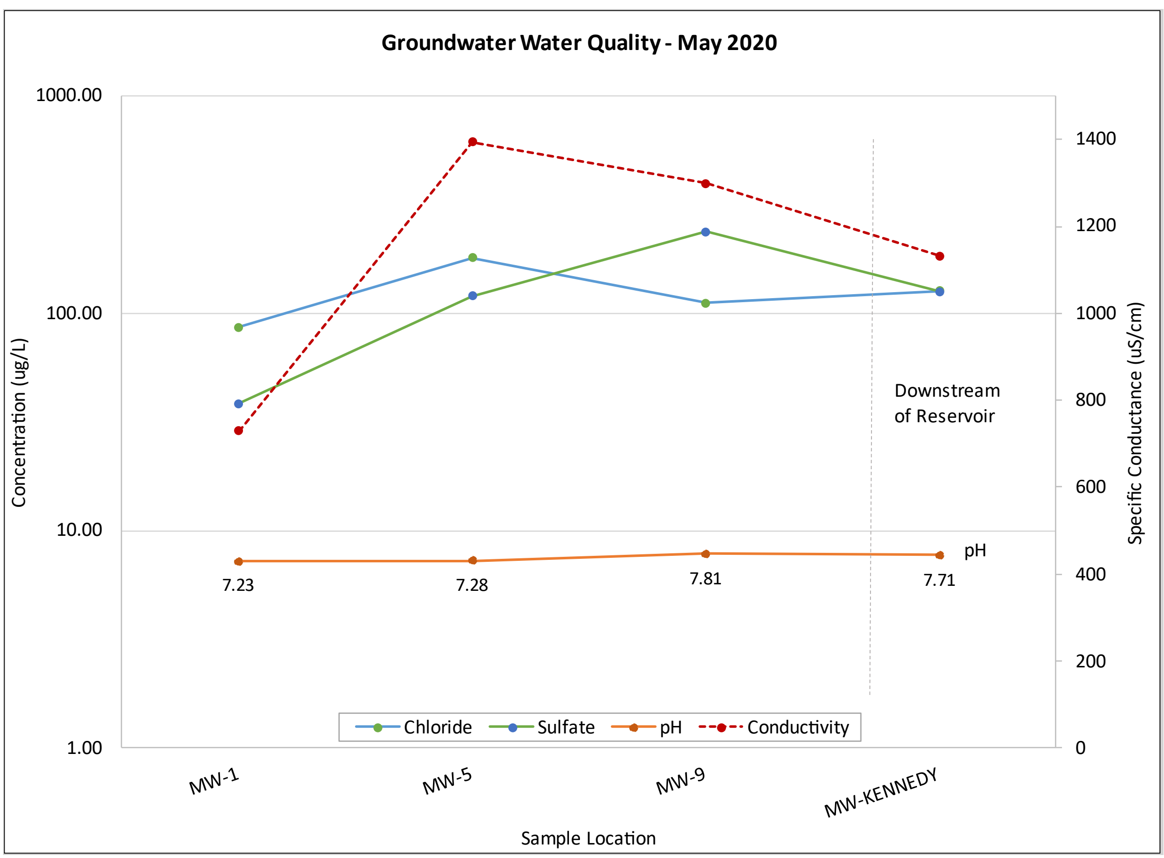


Figure 24. Groundwater Levels of Sulfate, Chloride, Specific Conductance, and pH, May 2020.

In both November 2019 and May 2020, the TN concentrations furthest upstream were lower at the nearest surface water site (CC-1) than at the nearest groundwater site (MW-1). Below MW-1, TN concentrations were similar or slightly higher in the SW than in the GW in November 2019, and similar results were similar in May 2020.

As shown in Figure 23 and Figure 24, data from both sampling events during WY 2020 indicated groundwater concentrations of chloride averaged 131 mg/L and sulfate averaged 125 mg/L. Concentrations during both events varied slightly, but both sulfate and chloride were higher overall at the wells just upstream (MW-9) and downstream of the Reservoir (MW-Kennedy) than the furthest upstream (MW-1). Although these are not drinking water wells, the state water supply standard for both chloride and sulfate is 250 mg/L (5 CCR 1002-41.8). The pH values were relatively constant, ranging from 7.0 to 7.8 and a mean of 7.4, but increased slightly in the wells closer to the Reservoir. The conductivity was highest at the MW-5 site in November 2019 and at MW-9 in May 2020.

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 7.49 in November 2019 and 7.81 in May 2020. The historical pH values from MW-9 from 1994-2020 are plotted in Figure 25. The data suggest that the pH at site MW-9 is somewhat variable, but for the most part pH values have range between 6.5 and 8.2.

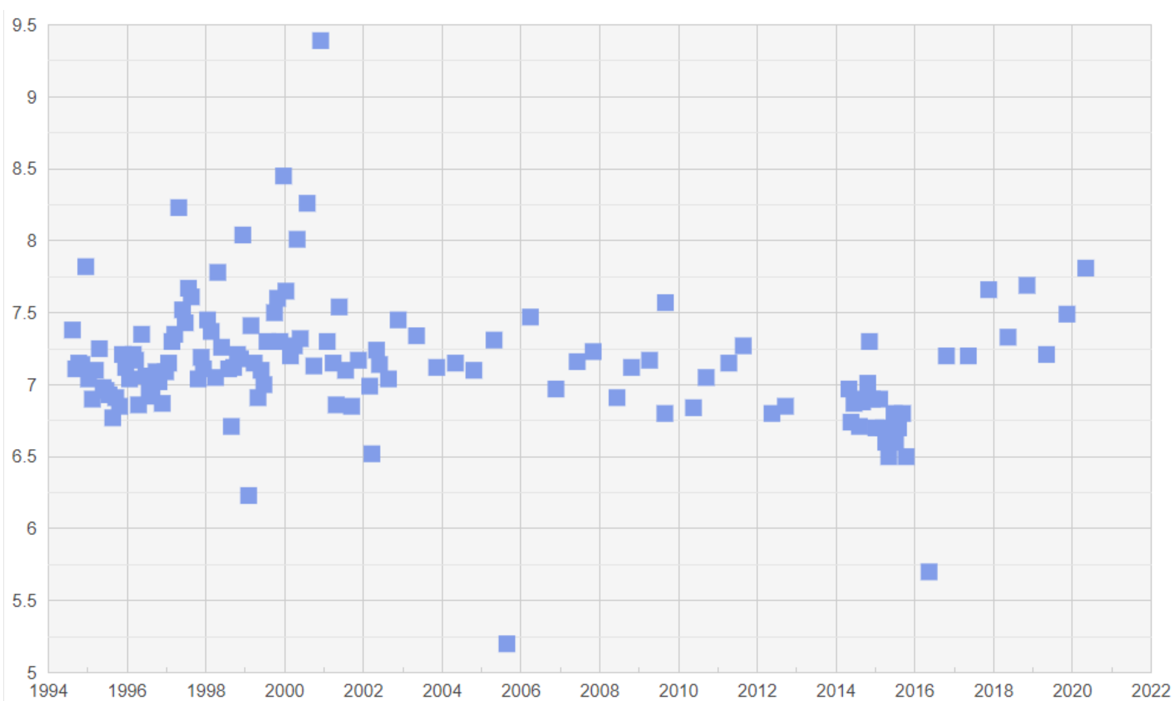


Figure 25. Historic pH Values in Well MW-9, 1994-2020. (http://ccbwqportal.org/)

The conductivity at MW-9 was 1,267 µS/cm in November 2019 and 1,290 µS/cm in May 2020. The historical conductivity values at MW-9 suggest a slightly increasing trend over time with a mean value of 809 µS/cm between 1995 and 2005 and a mean value of 1,007 µS/cm from 2006 to 2020. (Figure 26.)

Figure 27 illustrates the historical chloride and sulfate concentrations from 1994-2020. It appears that both may be increasing over time, although chloride may be less variable and increasing slightly more significantly. However, there may be a slight decreasing trend in the chloride concentrations in recent history, from 2017 to present.

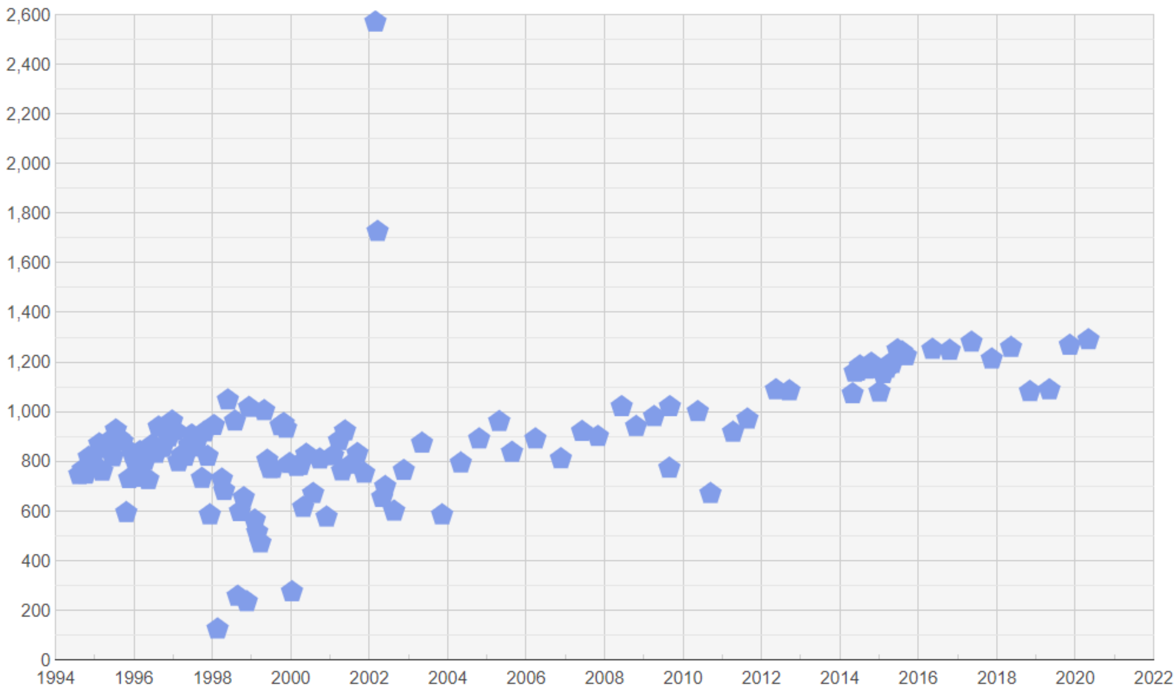


Figure 26. Historic Specific Conductance (µS/cm) Concentration at MW-9, 1994-2020. (http://ccbwqportal.org/)

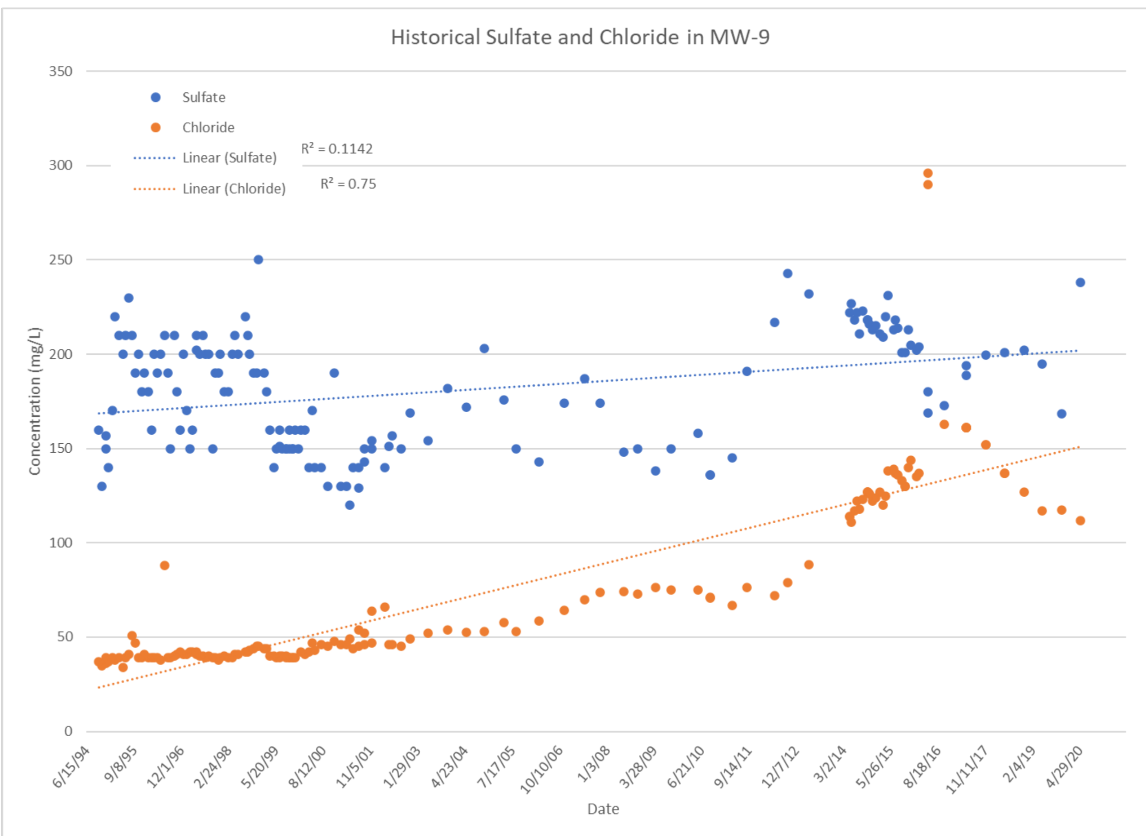


Figure 27. Historical Sulfate and Chloride (mg/L) at MW-9, 1994-2020.

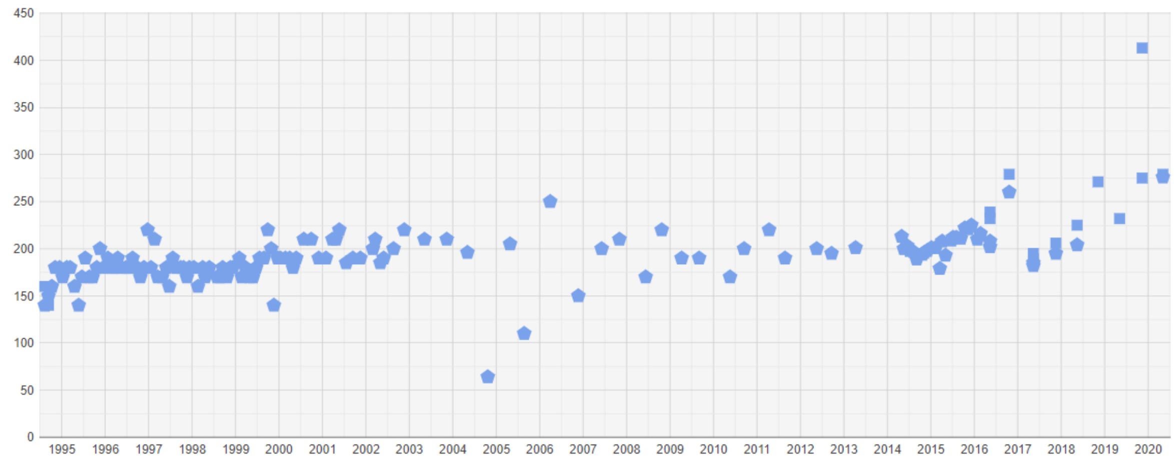


Figure 28. Historic SRP (µg/L) Concentrations at Groundwater MW-9 (1994–2020). (http://ccbwqportal.org/)

Historically, the concentration of SRP in the groundwater upstream of the Reservoir at MW-9 also appears to be slightly increasing (Figure 28).

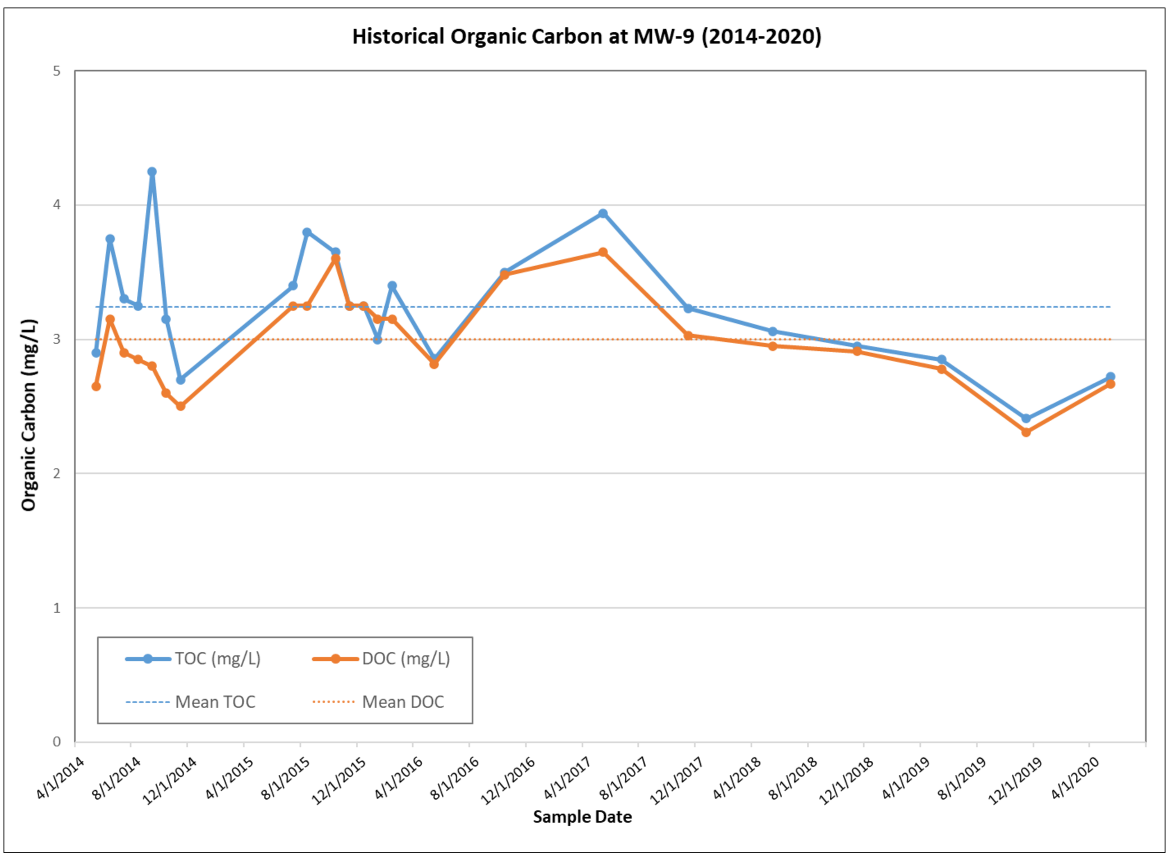


Figure 29. Total and Dissolved Organic Carbon Data from MW-9, 2014-2020.

The long-term TOC concentrations in the alluvial groundwater samples collected from well MW-9 range from 2.4 µg/L to 4.3 µg/L (Figure 29). The TOC concentrations measured in November 2019 were 2.4 mg/L and in May 2020 were 2.72 mg/L, which are both slightly lower than the long-term average of 3.3 mg/L from 2014-2020. Historically, the dissolved fraction of the TOC in well MW-9 has and 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, is 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 where the streams enter the Reservoir.

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. In WY 2020, the sampling program was amended to include extra monitoring events weekly July through September to provide additional data during the extended operation of the Reservoir's destratification system. During the added visits, water quality profile measurements were collected at CCR-1 and CCR-2 and samples were sent to the lab for nutrient analysis at CCR-2 from the photic zone (0-3m composite) and at the bottom (7m).

In addition to the physical and chemical water quality monitoring, the analysis of reservoir plankton concentrations also helps determine the overall health of Cherry Creek Reservoir and the 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

On May 27, 2020, beginning at 9:00 am and continuing through 1:10 pm, 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 150 cfs to 1300 cfs for durations of 10-40 minutes each. During this event, approximately 36,130,909 gallons of water (110 AF) were released from the Reservoir.

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, respectively, 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 it is 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-hypereutrophic conditions through most of the year, with the exception of one date in mid-May. The Secchi depths were very similar between CCR-1, 2, and 3, with the highest variance of 36% but an average of approximately 12% variance between the sites. The measured Secchi depth ranged between 0.52 and 3.35 m, with an annual mean of 0.99 m. Figure 30 depicts the Secchi depth measurements from the three sites during each sampling event in WY 2020.

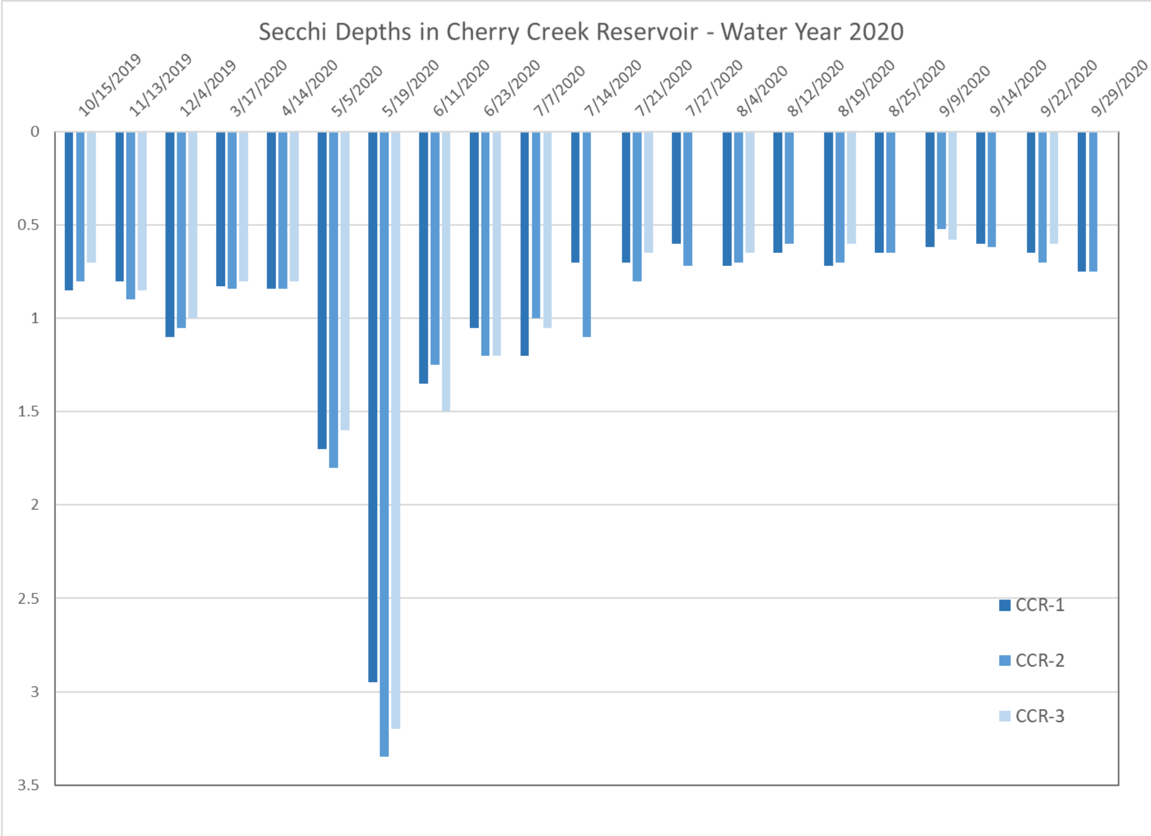


Figure 30. Secchi Depths in Cherry Creek Reservoir, Stations CCR-1, CCR-2 and CCR-3 during WY 2020.

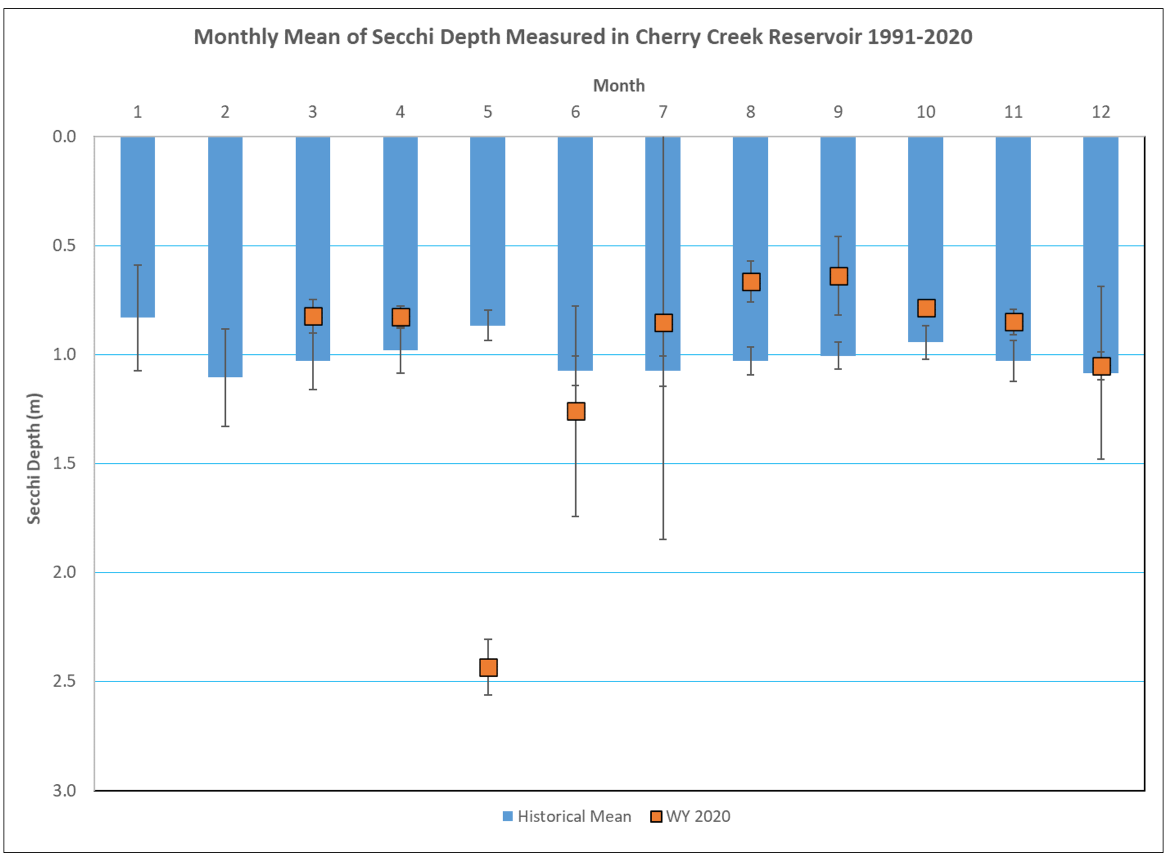


Figure 31. Historical and Monthly Mean Secchi Depth in Cherry Creek Reservoir from 1992- 2020.

Figure 31 shows the historical monthly mean Secchi depth as well as the mean monthly values from WY 2020 and the error bars represent the standard deviation. The seasonal mean was 0.72 m during the months of July to September. The Secchi depth followed similar seasonal trends in WY 2020 when compared to the values collected during the same months in previous years. The long-term monthly means seem to show less of a seasonal trend but increased variability during the colder months of January-March and December. In WY 2020, the values in May and June were higher than the historical average.

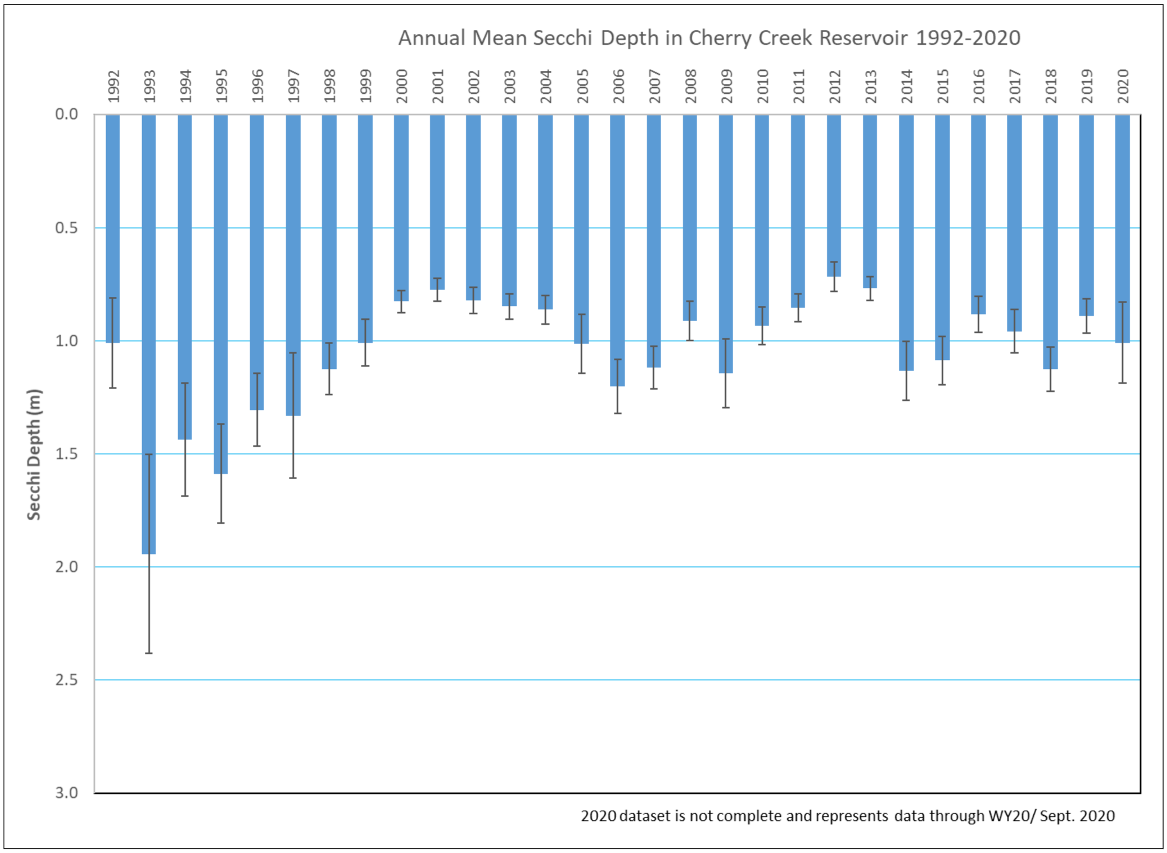


Figure 32. Annual Mean of Secchi Depth in Cherry Creek Reservoir from 1992- 2020.

The historical annual mean Secchi depth values for Cherry Creek Reservoir are pictured in Figure 32. From approximately 1998 to present, the annual mean Secchi depth has been in the eutrophic range, varying between approximately 0.72 m to 1.94 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 1.2 m to 6 m during WY 2020. The lowest values were observed in the late summer and the maximum depth was observed in mid-May. There is a clear relationship between Secchi depth and depth of 99% light attenuation (Figure 32).

In WY 2020, the depth of 1% light transmittance ranged between 1.6 and 3.7 times the Secchi depth, but on average was approximately 2.9 times the Secchi depth.

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 33 illustrates the relationship calculated on the data portal. The trendline equation is Y = 1.74x +2.5 with a Pearson correlation coefficient of 0.86.

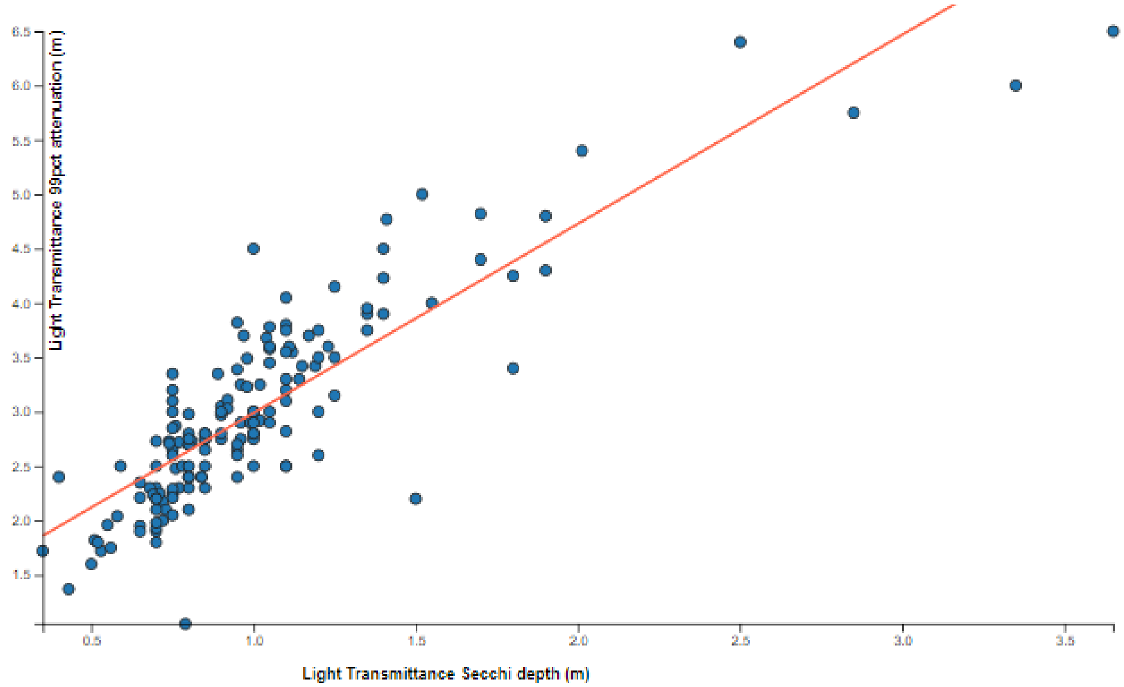


Figure 33. Relationship between Secchi Depth and Depth of 1% Light Transmittance at CCR-2. (http://ccbwqportal.org/)

4.3 CHLOROPHYLL A

During each sampling event of WY 2020 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 7.4 µg/L and 56.0 µg/L, with an average annual value of 22.4 µg/L in WY 2020 (Figure 34). The highest values were observed in July, August, and September, and the lowest in May.

The seasonal chl α concentration for WY 2020 through the growing season (July through September) concentration was 28.44 µg/L, which is significantly higher than the previous 5 years (Figure 35). None of the mean values during the six sampling events during the season (July 1-September 30), were at or below the standard of 18 µg/L.

The seasonal mean for WY 2020 did not meet the growing season average regulatory standard set by Regulation 38 (REG 38) of 18 µg/L. The standard only allows an exceedance frequency of once in five years, but four of the last five (4/5) and eight of the last ten (8/10) years have exceeded this value. The Reservoir is not meeting the chl α water quality standard.

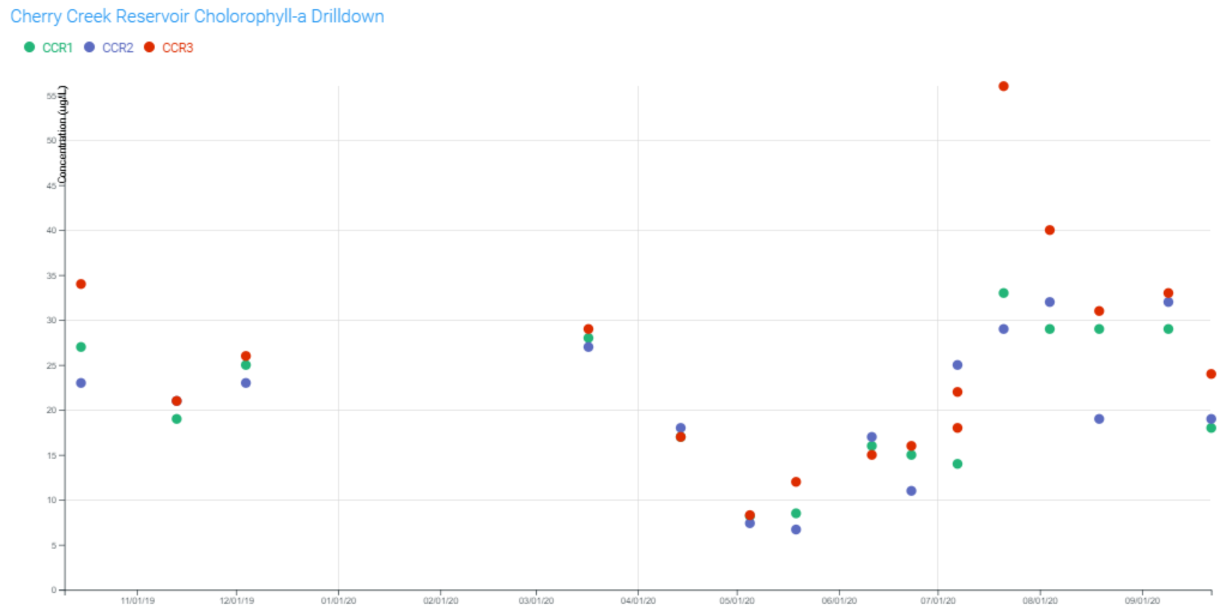


Figure 34. Monthly Chlorophyll *a* (µg/L) Concentrations in Cherry Creek Reservoir During WY 2020. (http://ccbwqportal.org/)

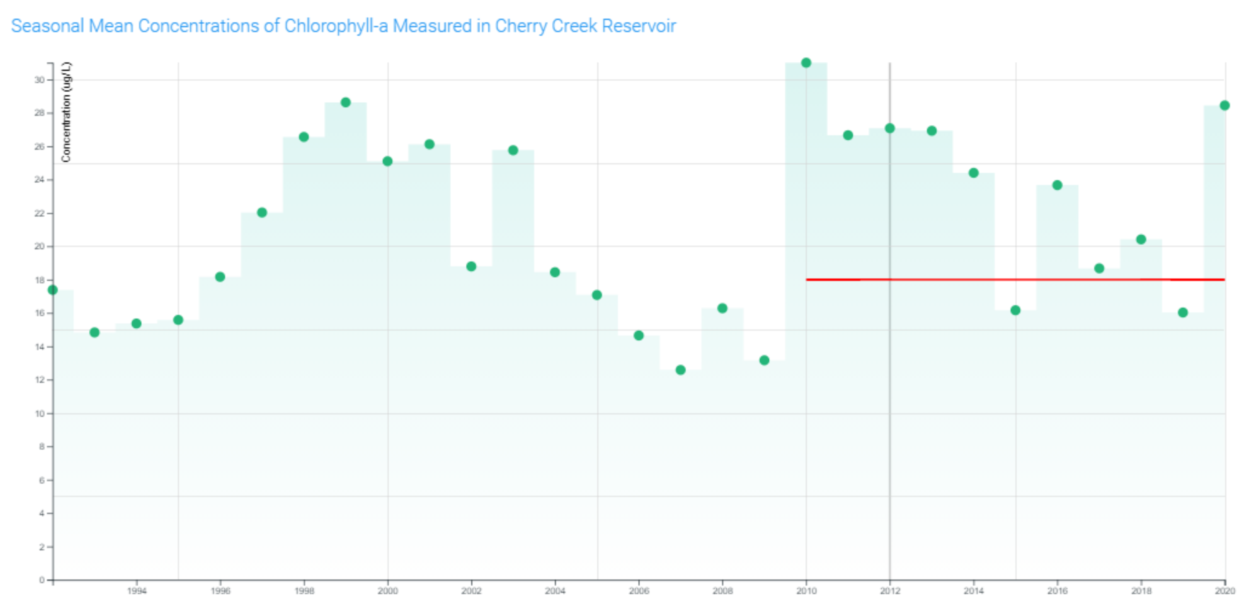


Figure 35. Historical Seasonal Mean of Chlorophyll *a* in Cherry Creek Reservoir 1991-2020.

(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 16) to describe perceptions of water quality by typical lake users.

Table 16. 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

The minimum monthly mean chl-α concentration in Cherry Creek Reservoir in WY 2020 was 8.52 µg/L in May. The maximum monthly average was 30 µg/L in August. The highest mean concentrations for the 3 sites were 39.3 µg/L during the end of July and 33.7 µg/L in the beginning of August. This would indicate that severe nuisance conditions, and algal scums were present that could affect lake use. On Wednesday July 8^{th,} the first significant bloom of the season was noted at the marina which required warning signs to be posted and the Reservoir to be closed to swimming for a period of weeks. The blooms tested by Colorado Parks and Wildlife were identified as *Dolichospermum* and *Aphanizomenon* and water samples found the presence of a cyanobacteria toxin, microcystin at concentrations ≥10 µg/L, which required closures of the Reservoir intermittently in July through early August.

4.4 TEMPERATURE

The Class I Warm Water Aquatic Life classification (WQCC Regulation No. 31) has a standard of 26.2˚C (79.2^{o}F) Maximum Weekly Average Temperature (MWAT) and 29.3˚C (84.6 ^{o}F) Daily Maximum (DM).

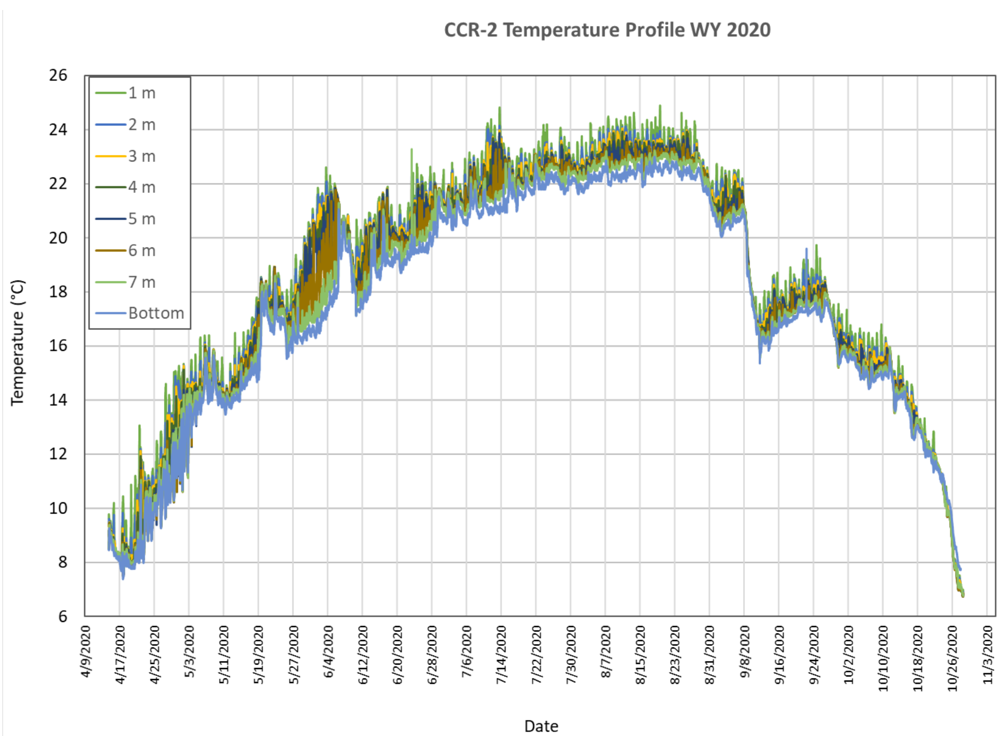


Figure 36. 2020 Temperature Profile of CCR-2 in Cherry Creek Reservoir.

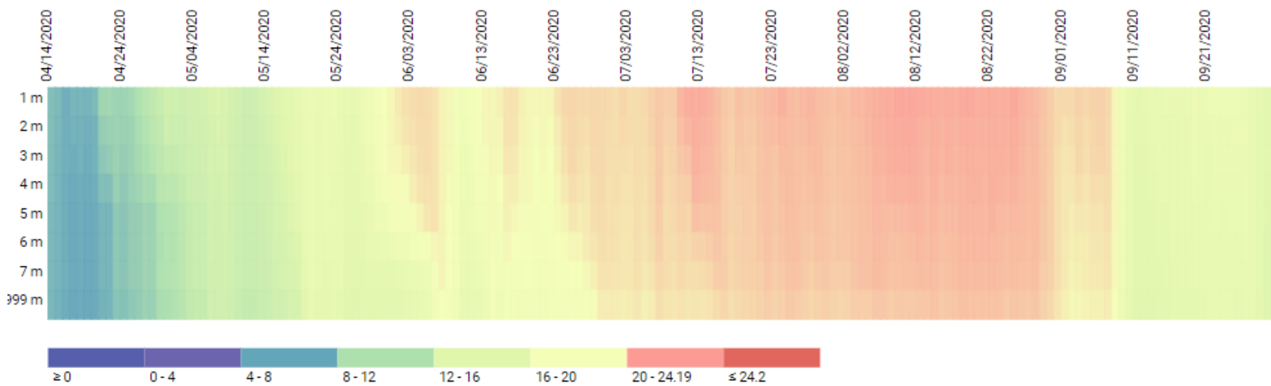


Figure 37. 15-min Temperature Profile at CCR-2, WY 2020.

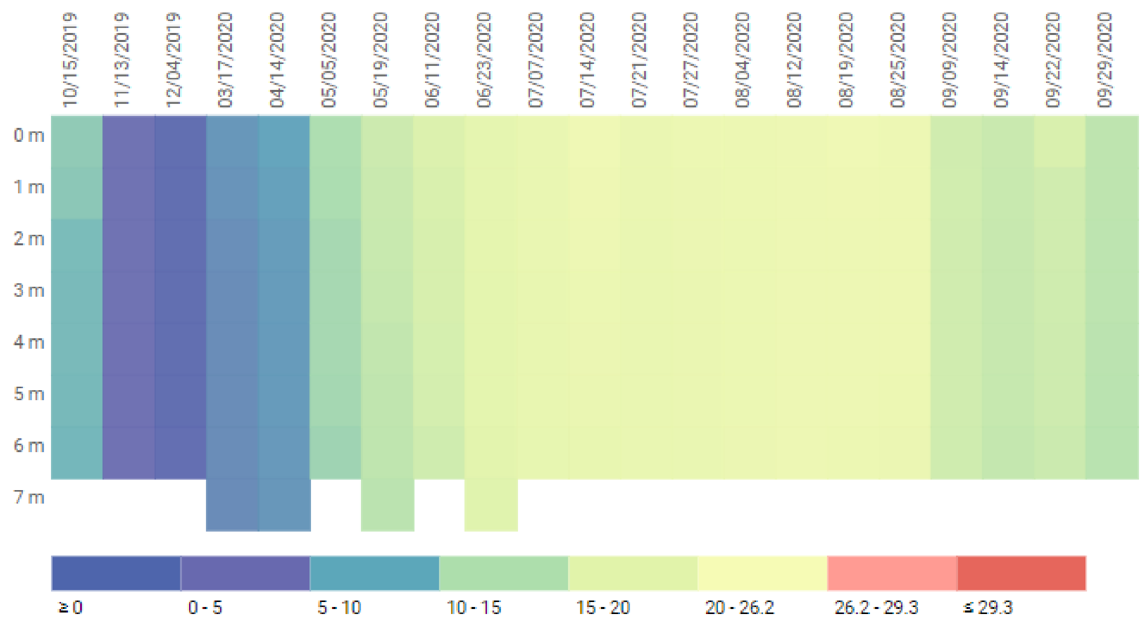


Figure 38. WY 2020 Temperature (˚C) Profile in Cherry Creek Reservoir at CCR-2. (http://ccbwqportal.org/)

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 Park buoy. The continuous temperature data from 2020 is plotted in

Figure 36. 2020 Temperature Profile of CCR-2 in Cherry Creek Reservoir.

and Figure 37, which illustrates the thermal stratification throughout the period of time the thermistors are installed.

In addition to the continuous temperature loggers installed at CCR-2, temperature profiles were also collected during each monitoring event. Figure 38 illustrates the temperature profiles collected at Reservoir station CCR-2 during the routine monitoring events in WY 2020.

The maximum temperature measured in the surface during the reservoir monitoring events and the continuous monitoring thermistors was 23.8˚C (74.8 ^{o}F) on August 19, 2020.

The biggest temperature range measured in the vertical profiles during the monitoring events was 1.83˚C on June 11, 2020 from 19.3˚C (66.7^{o}F) to 17.5˚C (63.5^{o}F). The largest temperature range logged by the thermistors was approximately 5˚C on June 3, 2020 from top to bottom. However, as the season progressed and water levels dropped, the thermistors at the bottom of the Reservoir had lowered into the sediment and some temperatures seen at and near the bottom were affected and were even slightly higher than the surface water temperatures late in the season.

Although there was some variability from the surface to the bottom in the warmer summer months, overall thermal stratification was limited in the Reservoir.

4.5 DISSOLVED OXYGEN

REG 31 states that in "the upper portion of a lake or reservoir, dissolved oxygen shall not be less than 5.0 mg/L. There needs to adequate refuge for aquatic with DO levels greater than 5.0 mg/L available at other depths or locations in the Reservoir at the same time period."

Dissolved oxygen concentrations are measured through the water column during each monitoring event. Figure 39 illustrates the DO levels in the Reservoir at Station CCR-2 over time from the surface (0 m) to the bottom (depth varies). During 2020, DO levels were below 5.0 mg/L from 5 meters to the bottom at CCR-2 in mid-July through August and at 2 m and below on July 27th.

During July and August, there were events at CCR-1 where DO concentrations were below 5.0 mg/L at depth (4-5m), at 2 m and below on July 27th and at throughout the water column on August 12th.

At CCR-3, the DO was at or below 5.0 mg/L at 4 m during the monitoring events in July through August and below 3 m on August 3rd.

During WY 2020, there were events when measured DO concentrations in parts of the Reservoir were below 5.0 mg/L. However, during the same time period, the DO concentrations at the other monitoring sites measured concentrations greater than 5.0 mg/L, meeting the Reg 31 standard. Periods of low dissolved oxygen indicate high microbial activity or decomposition in the hypolimnion and sediments which reduces DO concentrations.

The DO concentrations from CCR-2 are displayed in Figure 40 and the profiles from the other two sites are available on the data portal.

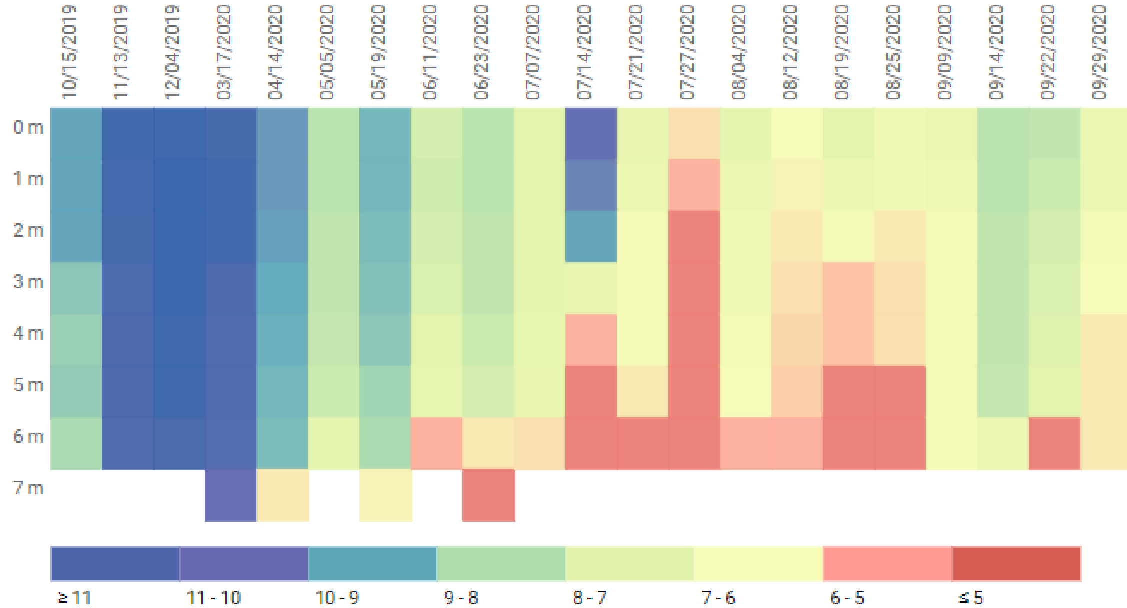


Figure 39. WY 2020 Dissolved Oxygen (mg/L) Profile in Cherry Creek Reservoir at CCR-2. (http://ccbwqportal.org/)

4.6 PH

REG 31 has a standard range for pH that must remain between 6.5 and 9.0 for aquatic life. The pH in Cherry Creek Reservoir during WY 2020 ranged from 7.9 to 8.8. The lowest value was recorded at the bottom of the Reservoir on July 14, 2020 and the highest values of 8.8 at the Reservoir surface on November 13, 2020. Similar high pH values of 8.7 were observed on December 4, 2019 and July 14, 2020. The pH values from CCR-2 are displayed in Figure 40 and the profiles from the other two sites are available on the data portal. Although chl α concentrations were not measured on July 14, the highest seasonal concentrations of WY 2020 were measured on July 21, 2020. Higher pH values usually correlated with higher productivity and elevated chl α concentrations in the Reservoir.

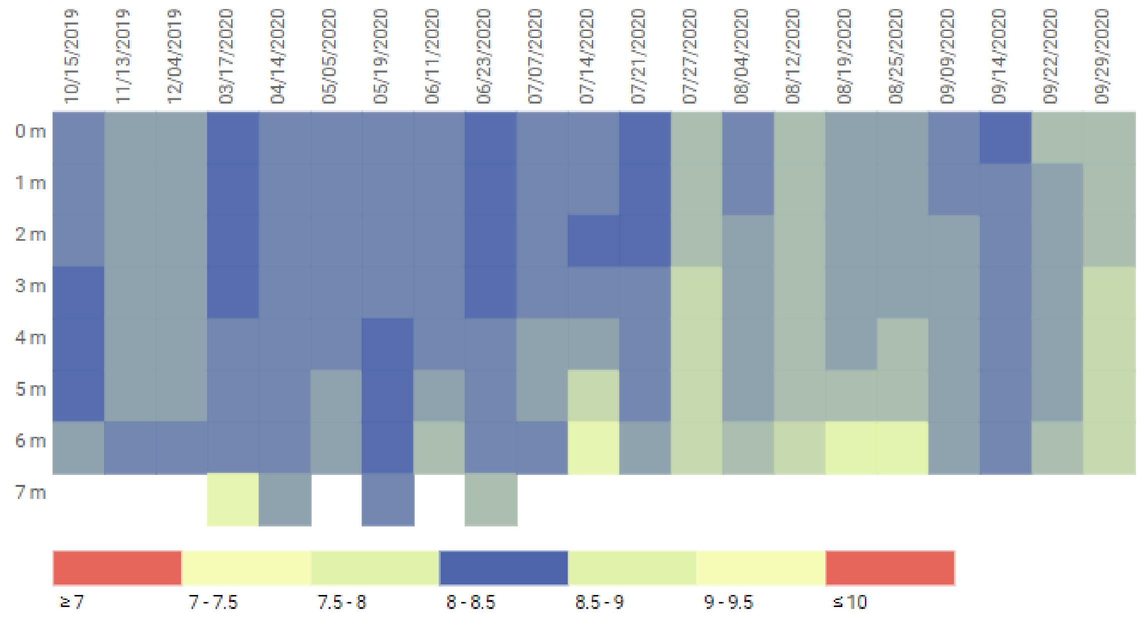


Figure 40. WY 2020 pH Profile from CCR-2 in Cherry Creek Reservoir. (http://ccbwqportal.org/)

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 41). The ORP in the photic zone ranged from 131 mV in October 2019 to 238 mV in late September 2020. The ORP in the samples near or at the bottom of the Reservoir ranged from -0.1 mV on November 13, 2019 to 243.8 mV on September 29, 2020. 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 which is an indication of decomposition processes near and in the sediments.

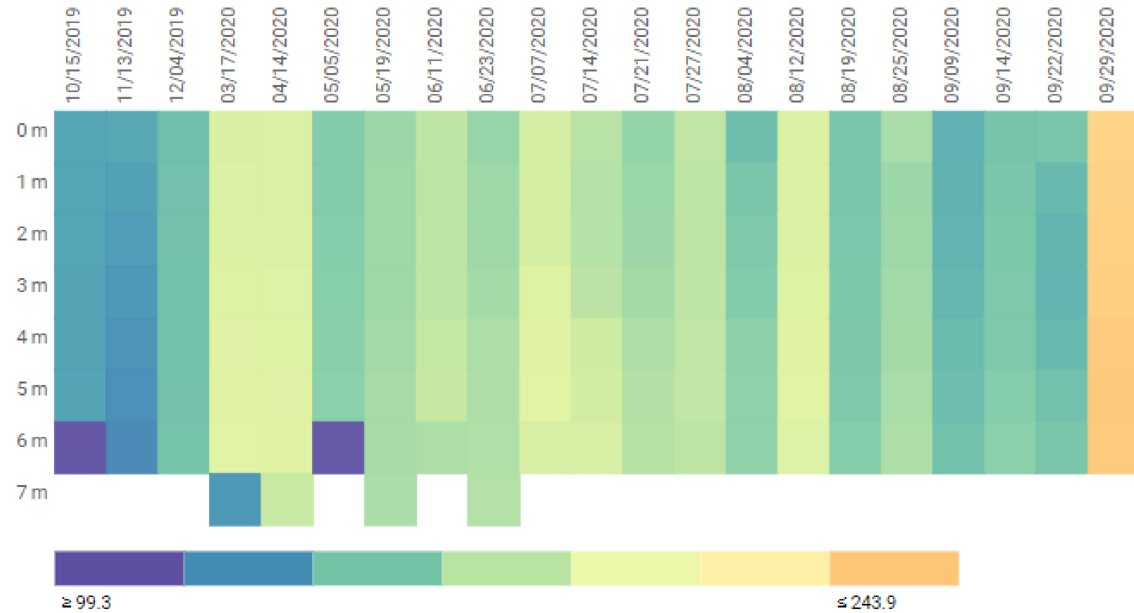


Figure 41. WY 2020 Oxidation Reduction Potential (mV) Profile in Cherry Creek Reservoir at CCR-2. (http://ccbwqportal.org/)

4.8 CONDUCTIVITY

The specific conductance, or conductivity, in Cherry Creek Reservoir ranged from a minimum of 1,256.3 µS/cm from October 2019 to 1,460.4 µS/cm during September WY 2020 (Figure 42). 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 occurring in September 2020.

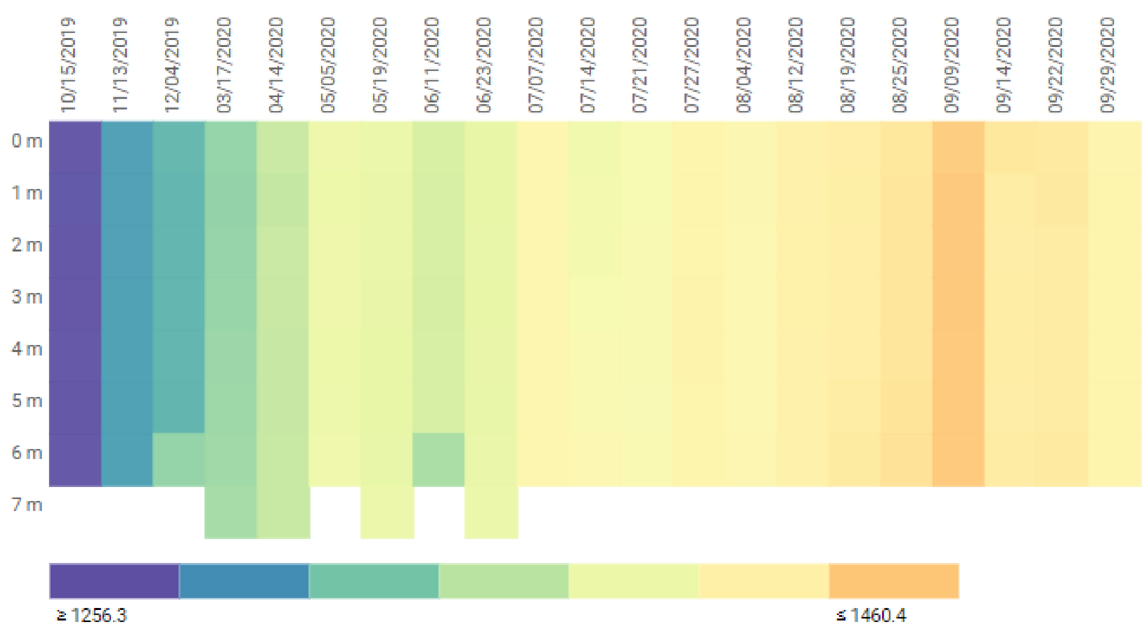


Figure 42. Conductivity (Specific Conductance µS/cm) Profile in Cherry Creek Reservoir at CCR-2, WY 2020. (http://ccbwqportal.org/)

4.9 TOTAL PHOSPHORUS

The SAP includes TP sampling at all three sites in the Reservoir. Figure 43 shows the historical seasonal mean (July to September) TP concentration from the three sites in the photic zone. The WY 2020 seasonal mean of 128.2 µg/L was higher than WY 2019 (107.2 µg/L), WY 2018 (91.2 µg/L), WY 2017 (114.7 µg/L), and WY 2016 (127.3 µg/L). The WY 2020 seasonal TP mean is also higher than the long-term average of 95.4 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 43 indicates that TP levels in Cherry Creek Reservoir have exceeded 83 µg/L every year since 2003.

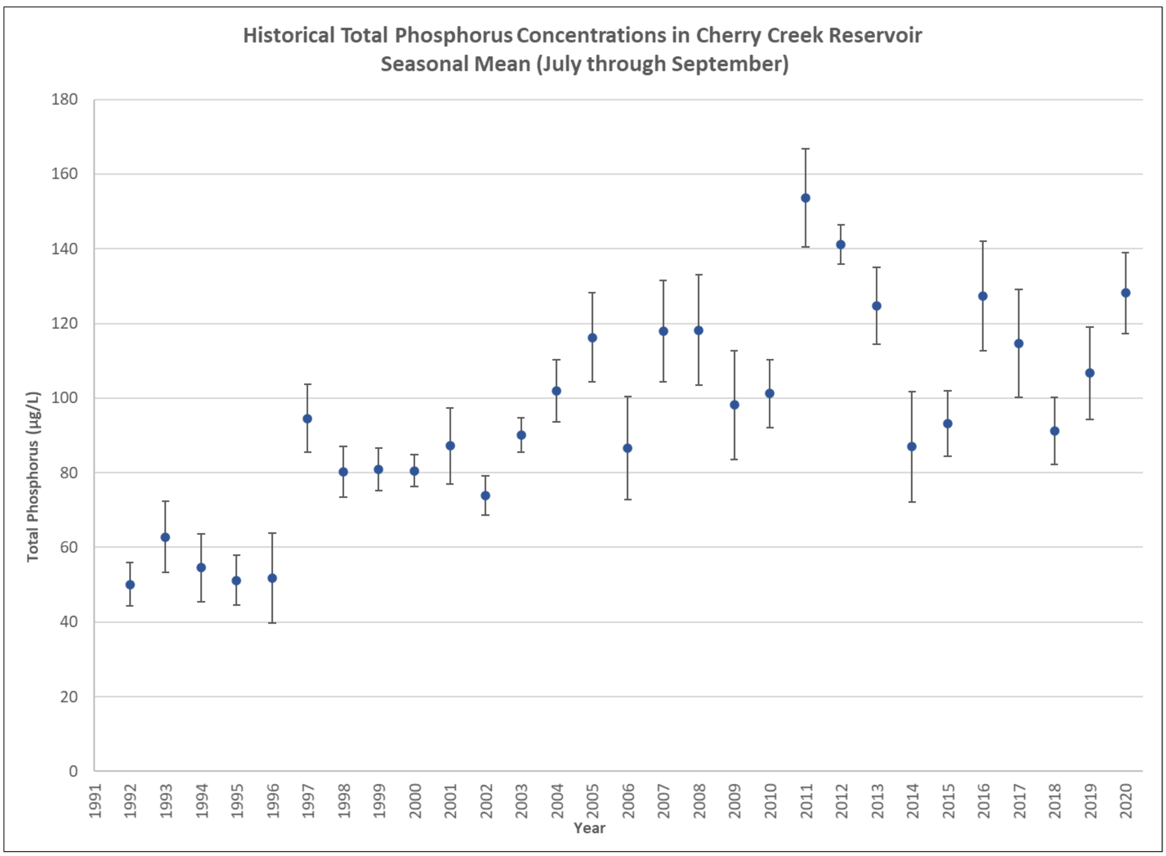


Figure 43. Historical Seasonal Mean TP Concentrations in Photic Zone of Cherry Creek Reservoir 1992-2020.

During WY 2020, the monthly mean TP concentrations ranged between 62 µg/L and 155 µg/L, with a mean value of 97 µg/L (Figure 44). The lowest values were present in December 2019 and the highest values in July 2020. Most TP levels were above 75 µg/L, but only June, July, and August had mean TP levels above 100 µg/L. The WY 2020 data suggests that there are high levels of TP in the Reservoir throughout the year contributing to eutrophic conditions.

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 4-7 m at CCR-2. These samples usually had TP concentrations that generally increased with depth. TP concentrations at station CCR-2 ranged from 51 µg/L to 330 µg/L in samples collected in the water column at 4 m, 5 m, 6 m, and 7 m. Figure 45 illustrates the TP profiles with depth at Reservoir monitoring station CCR-2, and the composite Photic zone samples from the other 2 sites are available on the data portal but show similar trends.

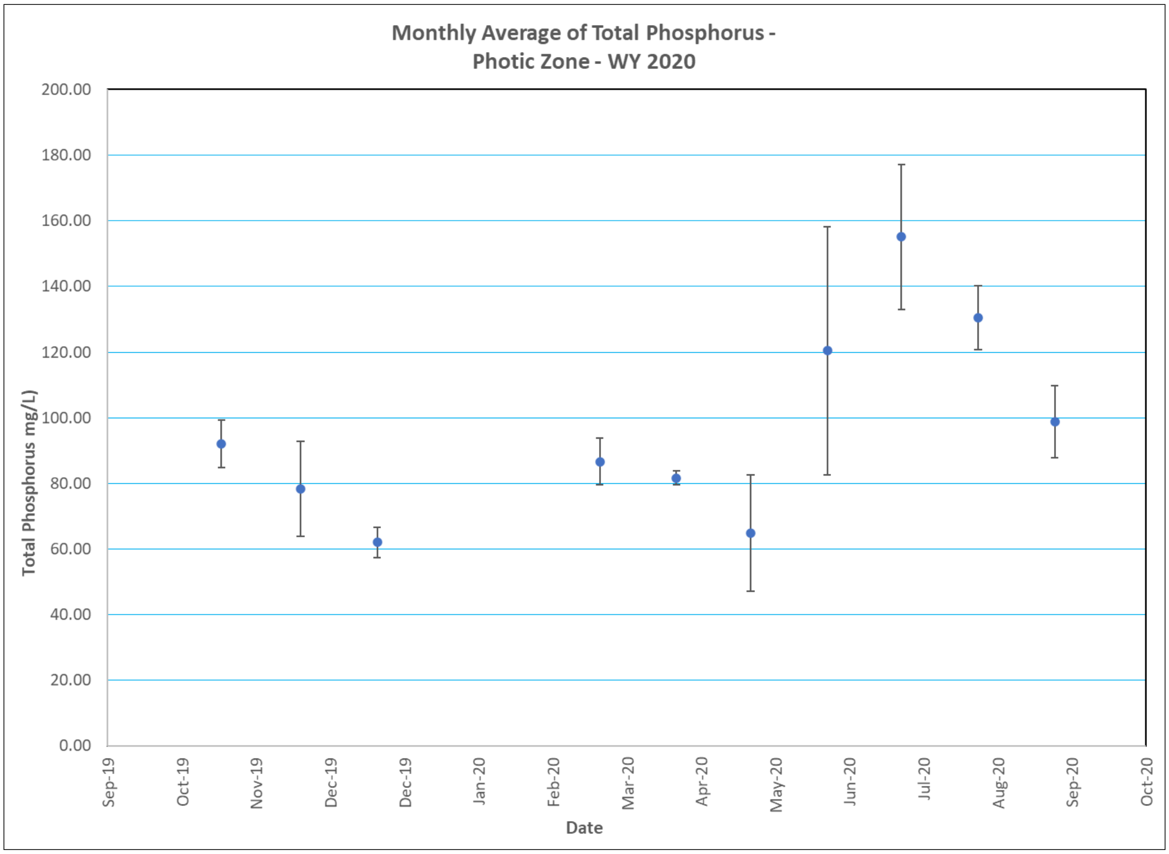


Figure 44. Monthly Average of Total Phosphorus in the Photic Zone, Cherry Creek Reservoir, WY 2020.

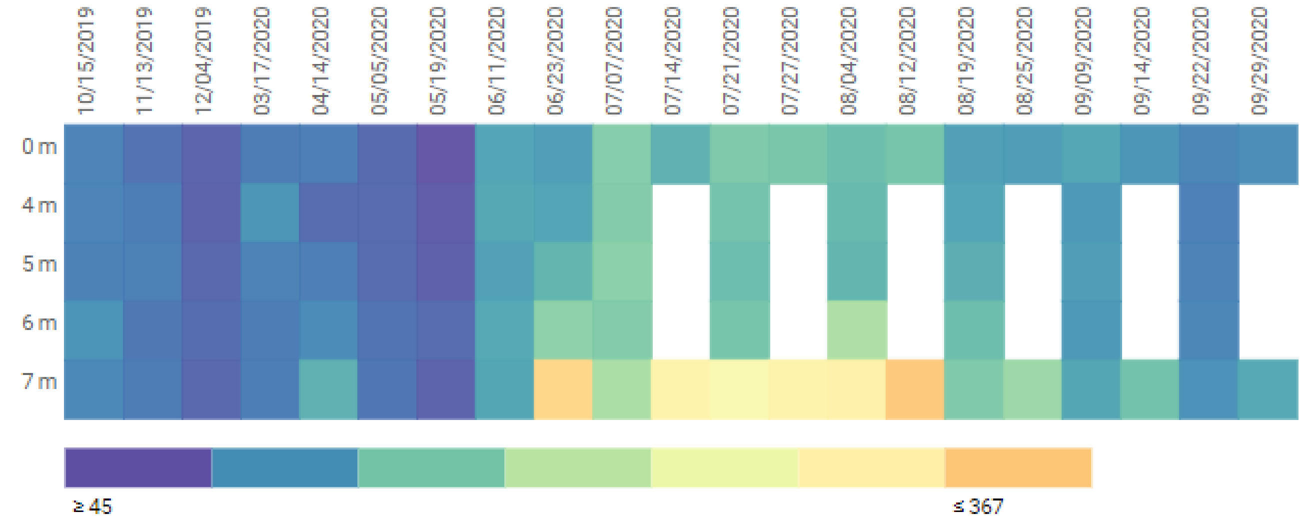


Figure 45. Total Phosphorus (ug/L) Profile at CCR-2 in Cherry Creek Reservoir, WY 2020. (http://ccbwqportal.org/)

Figure 45 displays how TP concentrations increased at the season progressed from early spring through summer, seeming to peak and then decrease again after August. The highest concentration in the photic zone was 161 µg/L on July 7, 2020. However, the highest concentrations overall were 367 µg/L on August 12, and 351 µg/L on June 23, both at a depth of 7 m at the bottom of the Reservoir. Phosphorus increases in the hypolimnion can be caused by internal legacy sediment 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. In years with limited storm flows, the higher nutrient concentrations at depth are more likely due to organic deposition or internal loading.

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. Figure 46 and Figure 47 depict the profiles of TDP and SRP from site CCR-2 during WY 2020.

During WY 2020, it appeared that both TDP and SRP remained relatively constant through late fall and winter 2019-20, but levels in the photic zone began to increase in early May (Figure 46 and Figure 47). 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. TDP and SRP levels at the bottom (7 m) increased from May through mid-July when they started to show a decreasing trend again. On July 14th, concentrations of TDP and SRP from the samples collected at 7 m were 217 µg/L and 189 µg/L respectively, the highest concentrations seen all year. But the TDP and SRP concentrations in the photic zone were lower than samples collected at the bottom for the majority of the season with the exception of one date. On August 12th, the sample from CCR-2 at 7 m was the highest seen all year for TP (367ug/L), but TDP and SRP concentrations at 7 m were lower than the surface samples on those dates. With the exception of this date, the 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.

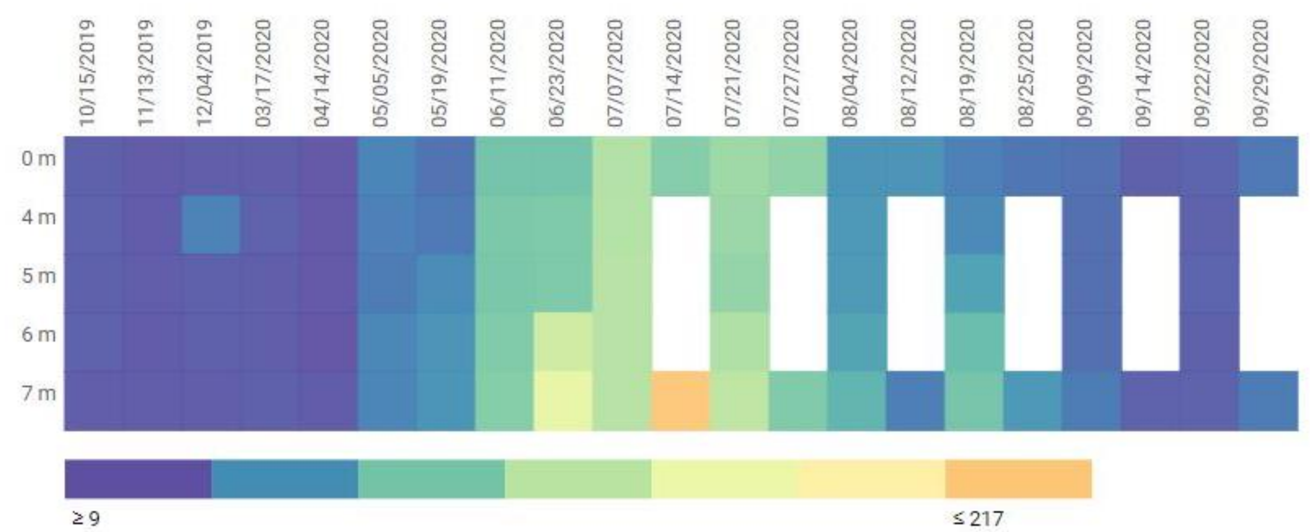


Figure 46. Total Dissolved Phosphorus (ug/L) Profile at CCR-2 in Cherry Creek Reservoir, WY 2020. (http://ccbwqportal.org/)

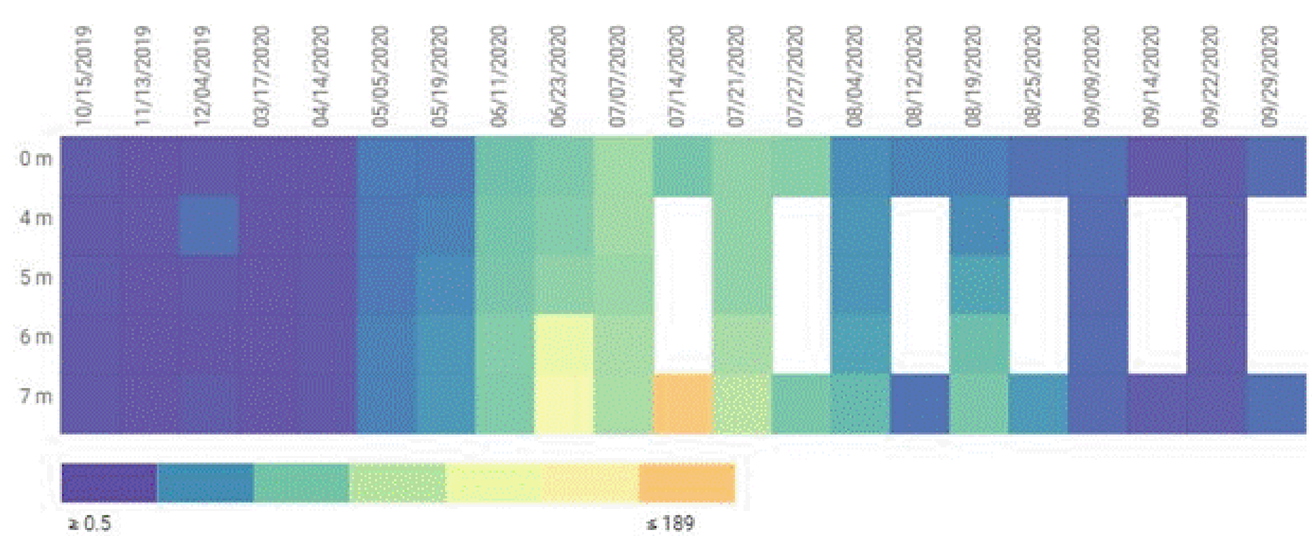


Figure 47. Soluble Reactive Phosphorus (ug/L) Profile at CCR-2 in Cherry Creek Reservoir, WY 2020. (http://ccbwqportal.org/)

4.11 TOTAL NITROGEN

The seasonal mean (July thorough Sept) of Total Nitrogen (TN) in the Reservoir in WY 2020 was 999.2 µg/L, which was higher than WY 2019 (688.8 µg/L), WY 2018 (848.1 µg/L), and WY 2017 (761.2 µg/L). The WY 2020 seasonal mean was also higher than the long-term average of 897.7 µg/L calculated from 1992-present. As illustrated by Figure 48, 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. Figure 48 indicates that TN concentrations in Cherry Creek Reservoir have exceeded this level a high percentage of the time dating back to 1994.

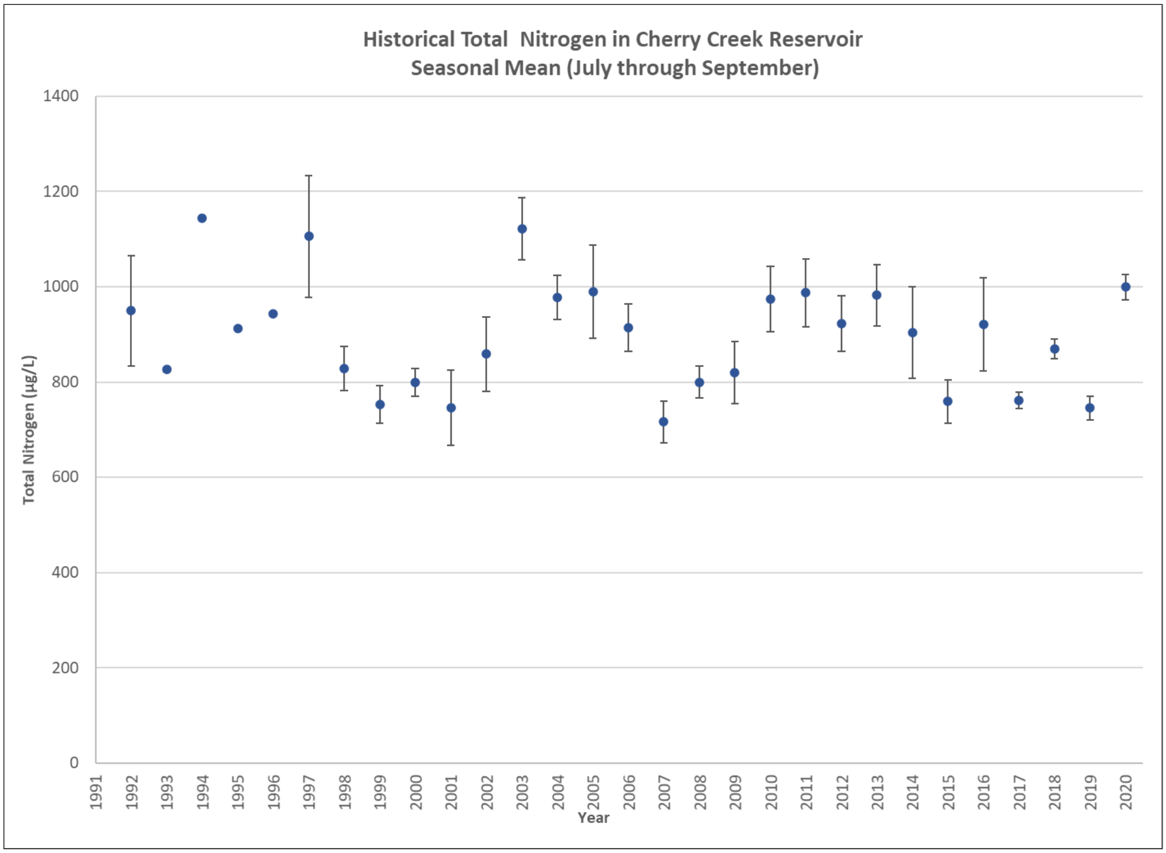


Figure 48. Historical Seasonal Mean TN Concentrations in Photic Zone of Cherry Creek Reservoir 1992-2020.

During WY 2020, annual TN concentrations ranged between 610 µg/L and 1,670 µg/L with a mean value of 895 µg/L (Figure 48) The highest values were present in the July 2020 samples and the lowest values in December 2019.

During WY 2020, TN levels were highest in the photic zone during the July 21st, August 12th, and September 29th monitoring events (Figure 50). Also, in the August 12th samples, the TN concentrations from the 7 m depth sample were much higher than other sampling dates at that depth throughout the year.

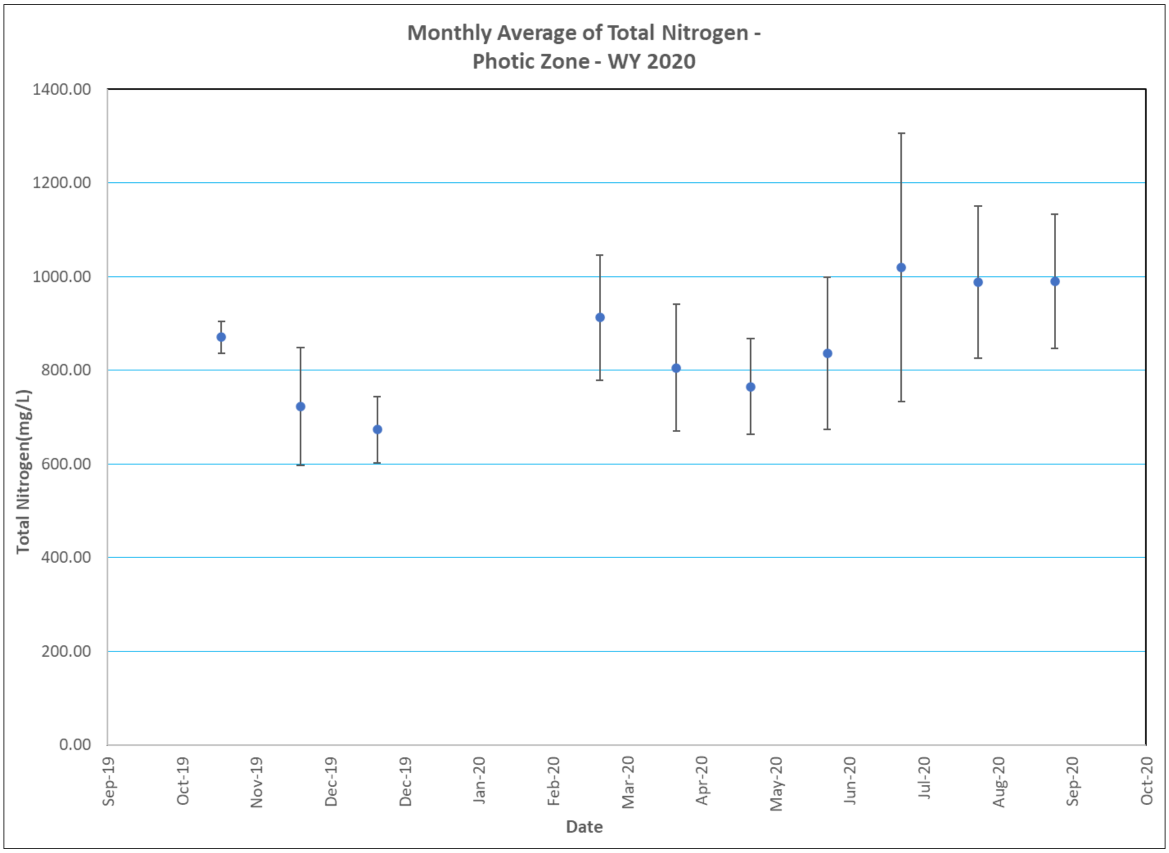


Figure 49. Monthly Average TN Concentrations in Photic Zone, Cherry Creek Reservoir, WY 2020.

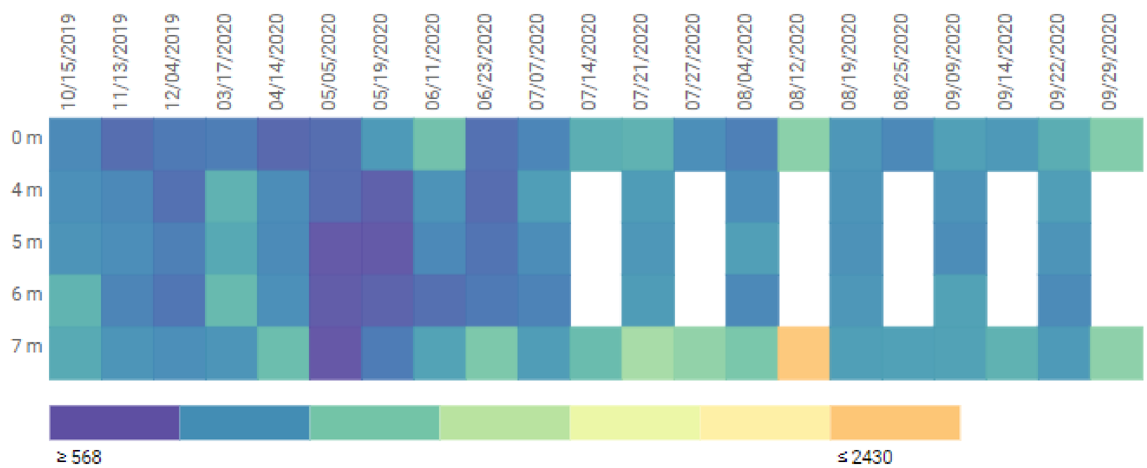


Figure 50. Total Nitrogen (ug/L) Profile at CCR-2 in Cherry Creek Reservoir, WY 2020. (http://ccbwqportal.org/)

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. Figure 51 and Figure 52 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.

Nitrate is the predominant form of inorganic nitrogen when oxygen is present, and ammonia is the predominant form in the absence of oxygen. Phytoplankton can incorporate ammonia directly into cellular material but readily convert nitrate to ammonia when nitrate predominates.

Nitrates were generally absent from the photic zone of Cherry Creek Reservoir throughout WY 2020, with the exception of December 2019, March 17, June 11, July 21, July 27, and August 25, 2020. When NO_3+NO_2-N concentrations are low, it may be an indication that algal growth in the Reservoir is limited by nitrogen concentrations.

Ammonia concentrations (shown as NH_3-N in Figure 52) were elevated at depth from May through early September but present in surface waters less often. 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 July and August, which also correlated to the periods of lower oxygen at the bottom of the Reservoir. NH_3-N was highest in the photic zone on July 21 and July 27, 2020 at 97 ug/L and 153 ug/L respectively.

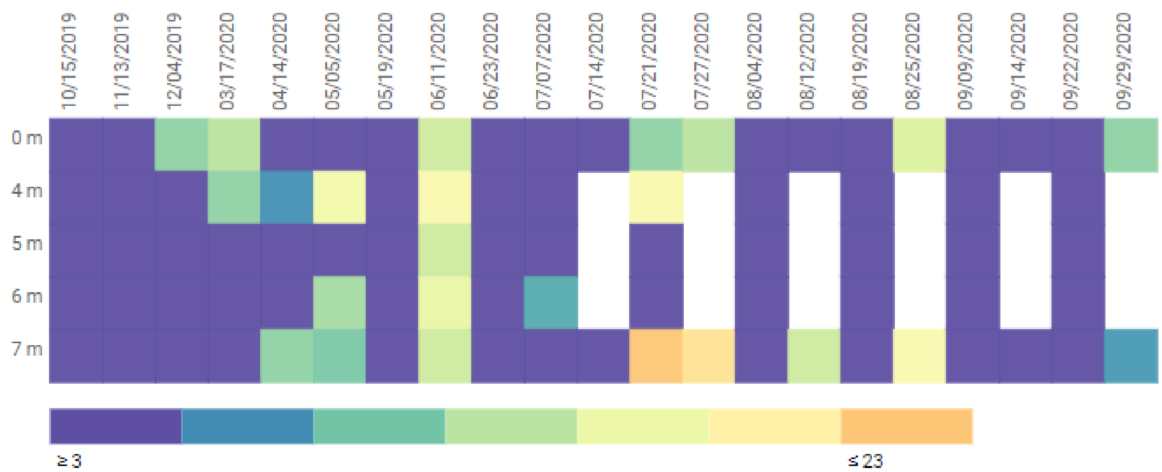


Figure 51. Nitrate and Nitrite Profile(ug/L) at CCR-2 in Cherry Creek Reservoir, WY 2020. (http://ccbwqportal.org/)

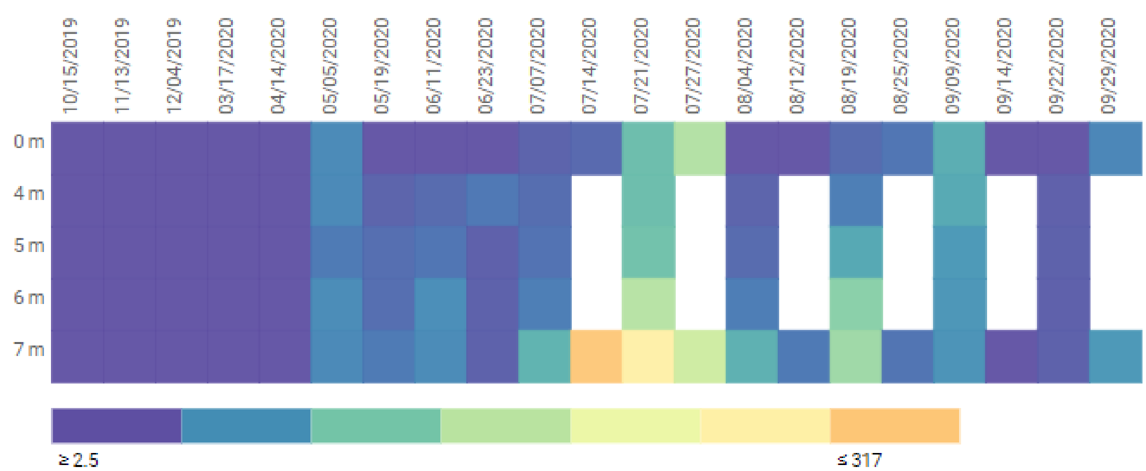


Figure 52. Ammonia (ug/L) Profile at CCR-2 in Cherry Creek Reservoir, WY 2020. (http://ccbwqportal.org/)

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 about 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. 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). In lakes and reservoirs with nitrogen limitation, cyanobacteria populations have an advantage over other types of algae and can easily dominate populations and limit diversity.

Figure 53 plots the nutrient ratios of TN:TP, TIN: SRP, and TDN:TDP. The lines indicate 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 June through early August, with the exception of one date in July. The TDN:TDP ratio indicates a similar trend during the entire month of July. However, the TIN:SRP ratio indicated that the more biologically available forms of nitrogen were limiting all year, with the exception of March 2020.

Based on the nutrient ratios and the concentrations of chl α at site CCR-2 during WY 2020, it appears that the biologically available forms of TP and TDP may have limited algal growth during May, but the nitrogen limitation may have controlled chl-a concentrations later in the summer. As seen in the phytoplankton analysis, increased cyanobacteria cell counts were observed when the Reservoir experienced nitrogen limitation.

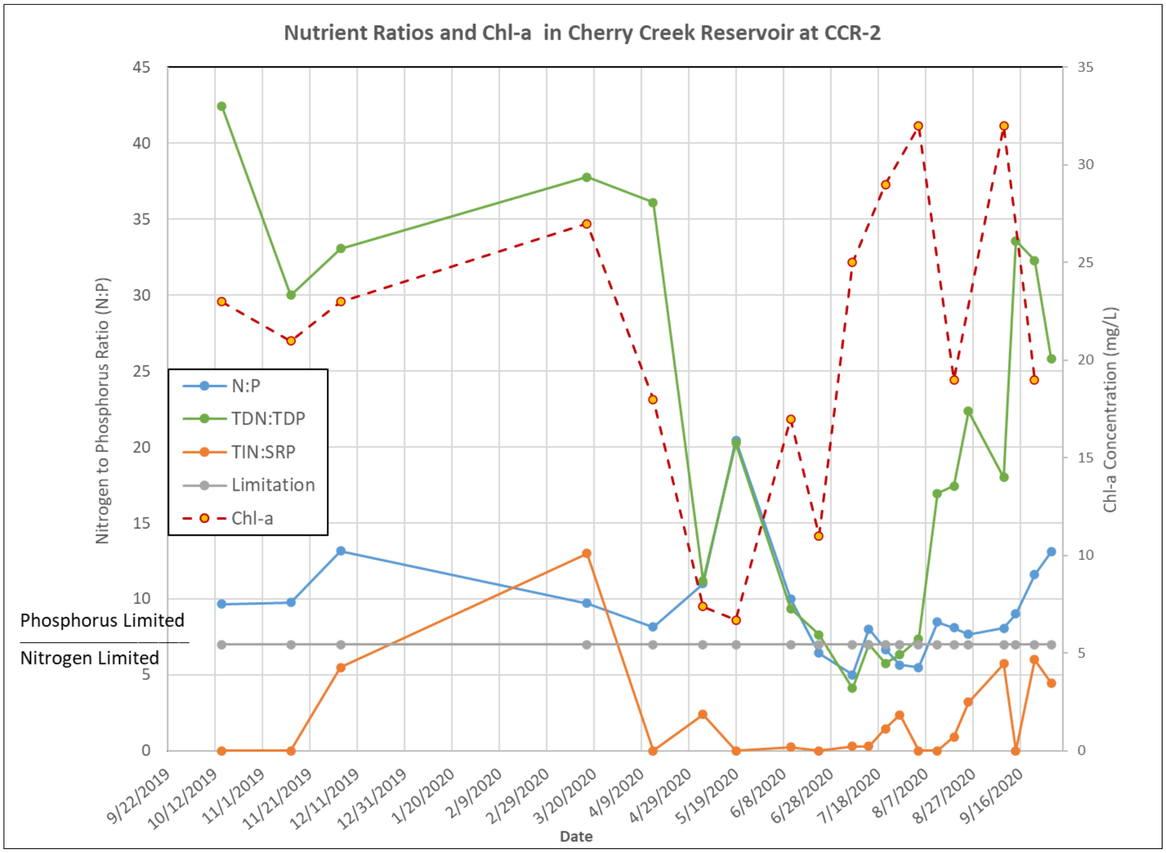


Figure 53. Nutrient Ratios for and Chlorophyll *a* in Cherry Creek Reservoir in WY 2020.

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 algal scums.

Trophic state indices for Cherry Creek Reservoir are presented in Table 17. 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. During this time period in 2020, concentrations in Cherry Creek Reservoir averaged 116 µg/L for TP, 20.7 µg/L for chl α and 1.05 m for the Secchi depth. Based on these values, calculated trophic state indices were 75 for TP, 60 for chl α, and 60 for Secchi depth. These values indicate that Cherry Creek Reservoir is hypereutrophic in relation to TP and eutrophic in regard to chl α and Secchi depth.

Table 17. Trophic State Indices for Cherry Creek Reservoir WY 2018-2020.

Year	Trophic State Index (TSI)		
	Total P	Secchi Depth	Chlorophyll *a*
2018	69	58	59
2019	71	57	57
2020	73	60	60
Trophic State	**Hypereutrophic**	**Eutrophic**	**Eutrophic**

Figure 54 displays the historical TSI for Cherry Creek Reservoir for each of the parameters for the May- Sept average for Total Phosphorus, Secchi Depth, and chl α from 2002 to 2020. Based on this index, Cherry Creek Reservoir is considered Eutrophic for Secchi depth and chl α, and ranges between Eutrophic and Hyper Eutrophic based on Total Phosphorus concentrations. Although the TSI has shown variability in regards to TP, the index in relation to this parameter has increased over the last 3 years (2018-2020.) The TSI based on the other parameters have also shown year to year variability but always remained in the Eutrophic range.

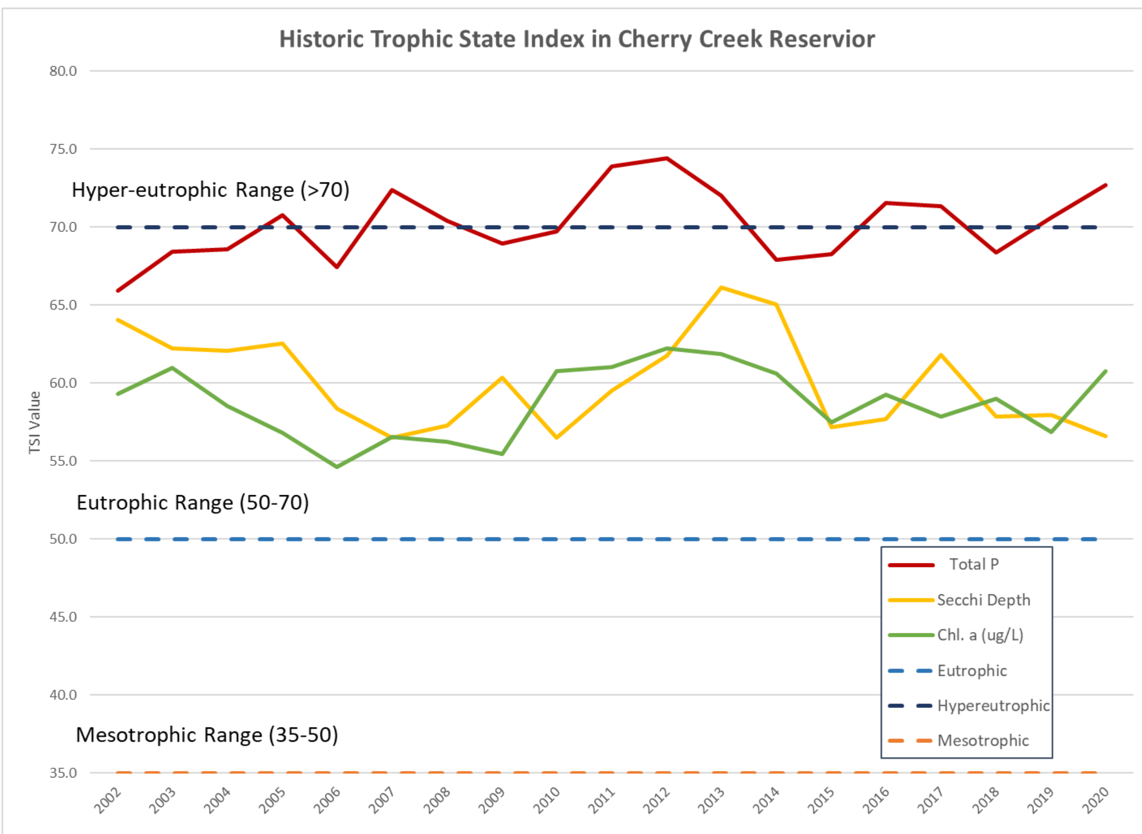


Figure 54. Historical Trophic State Index for Cherry Creek Reservoir (2002-2020).

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 17 presents a comparison of Cherry Creek Reservoir monitoring data from WY 2020 to EPA trophic state criteria. Values for the various parameters were the same averages used to calculate the trophic state indices.

Table 18. Comparison of Cherry Creek Reservoir Monitoring Data to EPA Trophic State Criteria WY 2020.

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	**0.116**	**20.7**	**1.05**	**High-Excessive**

The trophic state criteria in Table 18, 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 chl α concentrations. The trophic state criteria for TP with respect to both total phosphorus and Secchi depth were in the hypereutrophic range according to the EPA criteria during WY 2020. It is important to consider that sometimes the trophic state related to Secchi depth alone 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 2020. 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 2020 indicate high productivity with diverse populations.

Phytoplankton populations in Cherry Creek Reservoir had an average of 40 species present on each sampling date. The minimum number of species present was 28 on May 19, 2020, and the maximum number was 57 on October 15, 2019. These results were very similar to WY 2019, when the average number of species present was 41, the minimum number of species present was 28 on May 22, 2019, and the maximum number of species present was 60 on September 14, 2019. September also had high species diversity in WY 2020, with more than 50 species present on each of the September 2020 sampling dates.

Chlorophyta (green algae) provided the highest number of species, with a range of 8 species in July 2020 to 30 species in October 2019, and an average of 17 species present on each sampling date. Bacillariophyta (diatoms) and Cyanophytes (blue-green algae) also had high diversities, each with an average of 8 species per sampling date. As in WY 2019, Cryptophytes (cryptomonds) were the only other group of algae that were present on each sampling date, with an average of 2.5 species per sampling event. All other groups were absent on at one or more dates and averaged less than 2 species per sampling event.

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, such as *Dolichospermum* and *Aphanizomenon*, are capable of producing toxins. These two species contributed to the severe blooms found at Cherry Creek Reservoir during July 2020. Algal toxins were identified during blooms from mid-July through early August and led to beach closures at Cherry Creek State Park.

As in WY 2019, cell counts were dominated by the Cyanophytes, which were present in higher numbers than any of the other groups on each sampling date (Figure 55). In general, algal cell counts were higher in WY 2020 than in WY 2019 (Figure 55) and the relative concentration of cyanophytes was also higher (Figure 56).

Cyanophyte concentrations averaged 235,478 cells/mL during WY 2020, over twice as high as the WY 2019 average of 116,620 cells/mL. The minimum observed cyanophyte cell count was 28,235 cells/mL on May 19, 2020, and total counts peaked at 510,191 cells/mL on September 22, 2020, which comprised over 91% of the total algal cell count on that date. The cyanophytes were responsible for 50% or more of the total phytoplankton population on each sampling date and averaged 85% of the total algal cell counts for all of WY 2020 (Figure 56). For comparison, cyanophytes averaged 74% of the total algal cell counts for all of WY 2019.

Chroococcaceae spp. and *Synechococcus* sp. 1, both small (<1 µm) species, were the most common cyanobacteria, with both species present on all sampling dates. *Chroococcaceae* spp. concentrations peaked at over 306,158 cells/mL on March 17, 2020 and concentrations averaged 88,870 cells/mL for all of WY 2020. *Synechococcus* sp. 1 averaged 21,839 cells/mL for all of WY 2020. Together, these two species comprised 47% of all cyanobacteria counts and over 40% of the total algal cell count for WY 2020.

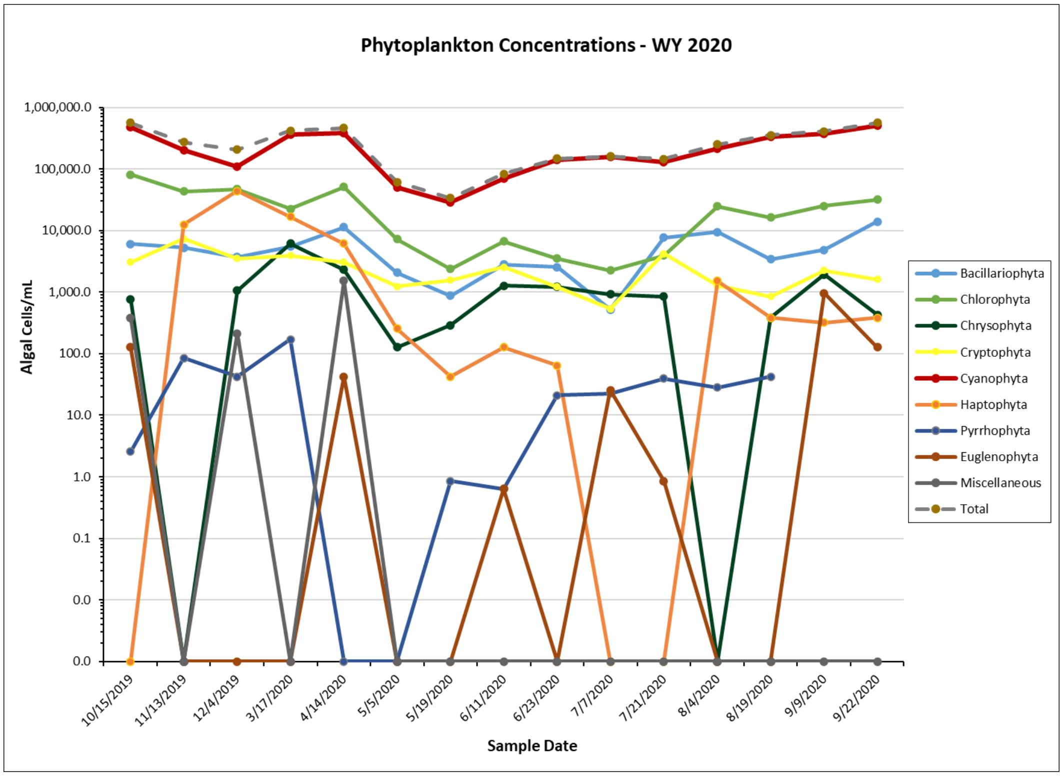


Figure 55. Phytoplankton Concentrations in Cherry Creek Reservoir, WY 2020.

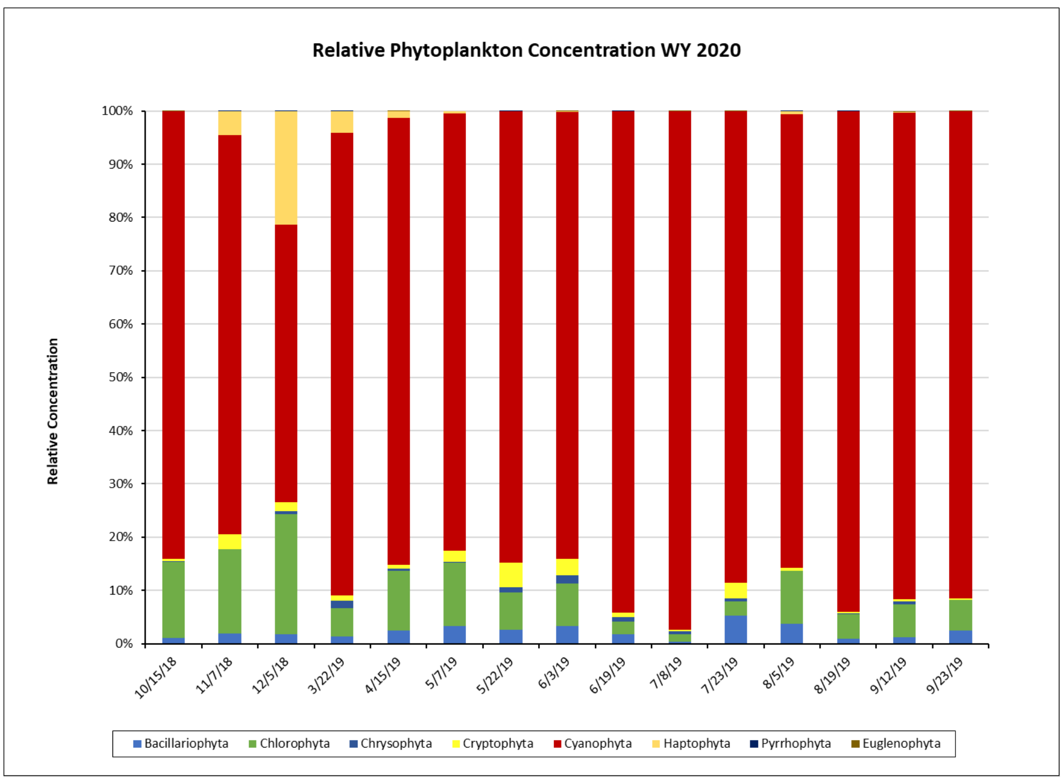
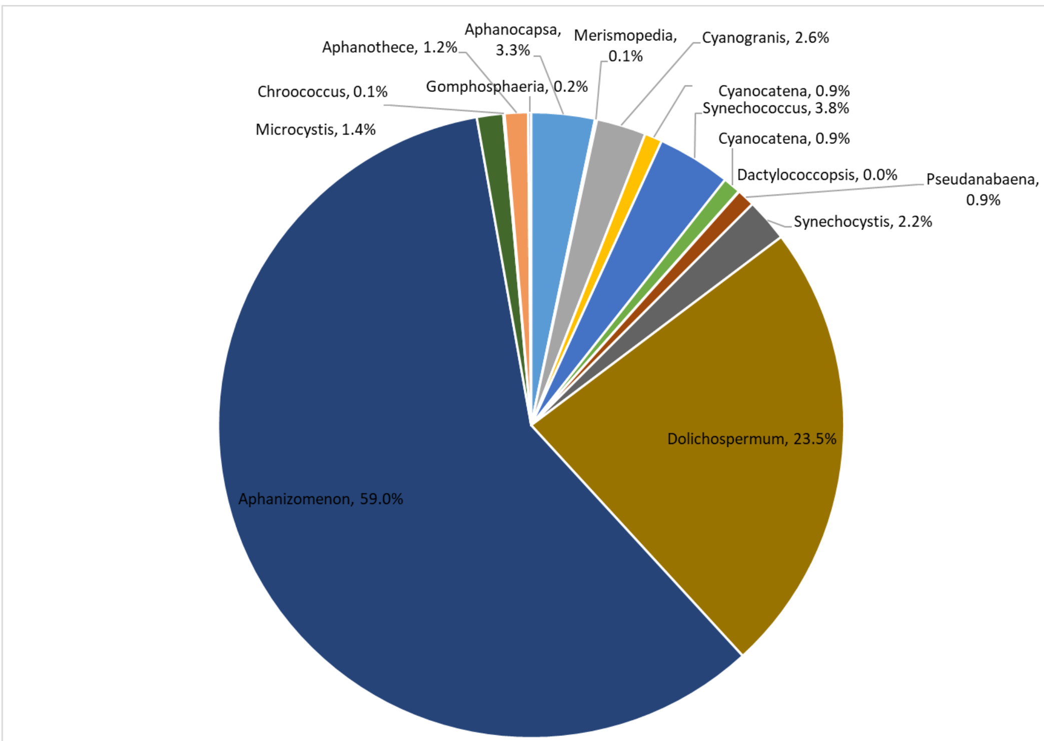


Figure 56. Relative Phytoplankton Concentration, WY 2020.

Cyanobacteria range from very small unicellular picoplankton (≤1 µm) to larger macroscopic filaments or multicellular colonies that are several millimeters in size. Many cyanophytes are smaller than other algal species, which is evidenced by the higher contribution of other algal groups to the total biovolume on most sampling dates (Figure 58). In contrast to their significant contributions to total cell counts, cyanophytes comprised only 18% of the total algal biovolume in WY 2020. The impact of *Chroococcaceae* spp. and *Synechococcus* sp. 1 was even less significant than other cyanophytes due to their small size. These two species were responsible for only 3.9% of the cyanophyte biovolume and 0.91% of the total algal biovolume for WY 2020.

Cyanophytes averaged 18.1% of the total algal biovolume in WY 2020, which was slightly lower than the 21.6% average in WY 2019. Although peak cyanophyte biovolumes in WY 2020 were high, they were generally an order of magnitude lower than peak biovolumes in WY 2019 and none matched the 1.06 x 10^8 μm^3/mL for *Dolicospermum circinale* last summer on July 23, 2019. The high cyanophyte biovolumes in WY 2020 were heavily influenced by significant blooms of the large cyanophytes *Dolicospermum circinale* on May 19, 2020 (390,315 μm^3/mL, 27.9% of total algal biovolume) and July 7, 2020 (376,425 μm^3/mL, 5.4% of the total), *Dolicospermum crassum* on June 11, 2020 (685,277 μm^3/mL, 7.3% of the total), and *Aphanizomenon flos-aquae* on July 7, 2020 (5,475,571 μm^3/mL, 79.0% of the total) and July 21, 2020 (3,567,319 μm^3/mL, 70.8% of the total). *Aphanizomenon flos-aquae* cell are so large that they are easily seen with the naked eye.



Relative Biovolumes of Cyanobateria in Cherry Creek Reservoir WY2020

Figure 57. Annual Relative Biovolumes of Cyanobacteria Populations in WY2020

When looking at the total cyanobacteria populations in more detail a few key factors are apparent. Although the *Chrooococcaceae* accounted for a large percentage of the total algal and cyanobacteria population cell counts, due to their small size, they did not contribute a large percentage of the overall biovolume at any sampling event during the year. In contrast, the *Dolichospermum* and *Aphanizomenon* blooms seen in June through August which only contributed 1.1% and 4.9% of the total cyanobacteria populations for the year accounted for 23.5% and 59% of the total cyanobacteria biovolume percentages for WY 2020 (Figure 57). This demonstrates how cyanobacteria with large cell size can easily be responsible for visible nuisance blooms.

Chlorophytes were present in high numbers throughout the year and were usually second only to the cyanophytes in total cell concentrations, averaging 8.6% of the total cell counts in WY 2020, slightly lower than the 10.1% in WY 2019 (Figure 56). *Oocystic parva* was the only species of green algae present on all sampling dates, but it was never present in very high numbers or high biovolume. *Chlamydomonas* sp., *Monoraphidium capricornutum*, and green algae of the family Chlorococcaceae were each present on all except one sampling date. *Tetrastrum staurogeniaeforme* was the green alga present at the highest concentrations, with cell counts of 12,757 cells/mL on November 13, 2019, which was 4.7% of the total cell count on that date.

Some chlorophyte species are fairly large, and most are larger than the cyanophytes. Green algae made up 22.8% of the total algal biovolume in WY 2020, higher than the 19.8% of total algal biovolume in WY 2019 (Figures 56 and 57). *Pyramichlamys dissecta*, a very large species, had the highest biovolume of any chlorophyte, peaking at 801,519 μm^3/mL on September 9, 2020, which was 23.4% of the total biovolume on that date. *Pyramichlamys dissecta* reached biovolumes of greater than 100,000 μm^3/mL on 6 of the 9 dates when it was present. *Chlamydomonas* sp., another large chlorophyte, reached a maximum of 729,382 μm^3/mL on November 13, 2019, which was 12.4% of the algal biovolume on that date. *Chlamydomonas* sp. was present with biovolumes of over 100,000 μm^3/mL on 7 of the 13 dates when it was present.

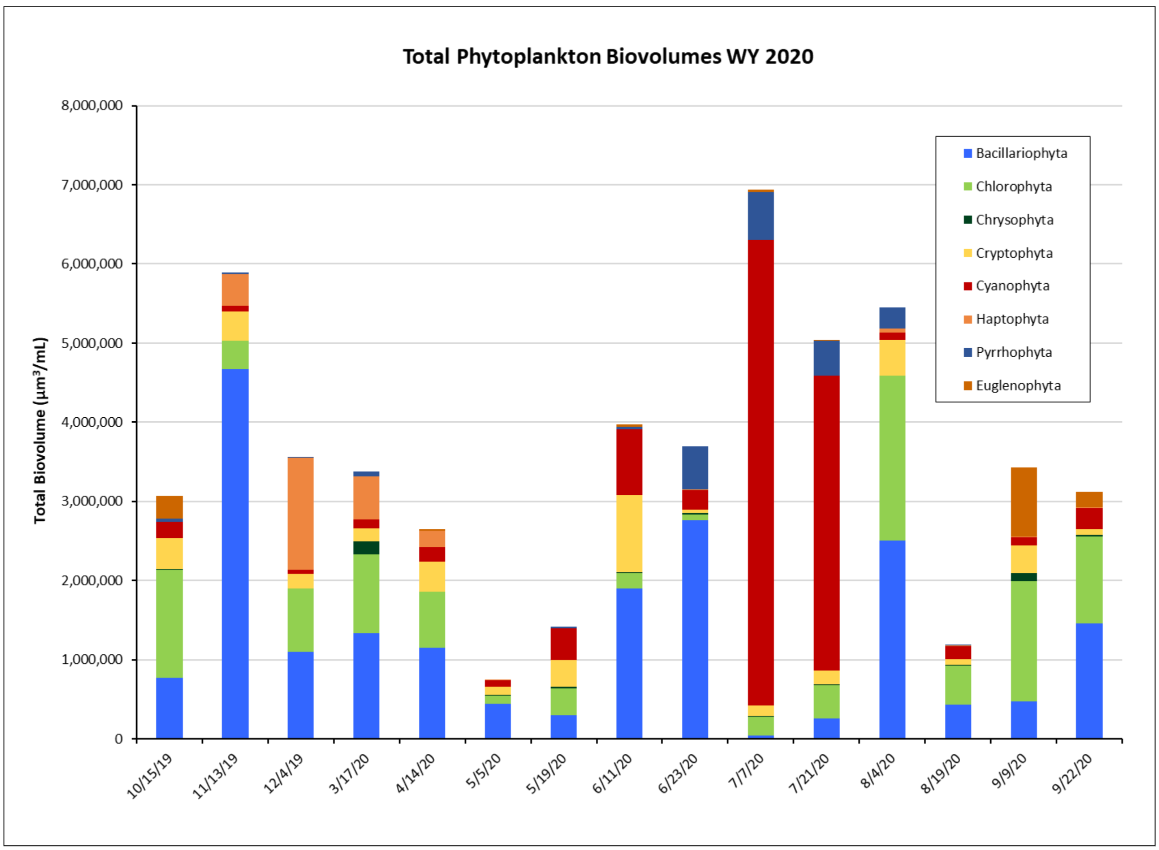


Figure 58. Phytoplankton Biovolumes in Cherry Creek Reservoir in WY 2020. *

(*Cherry Creek Reservoir Swim beach closed due to blooms July 9th-24th and July 31st - Aug 3rd.)

Nuisance blooms of Bacillariophyta (diatoms) are not as common as nuisance cyanobacteria blooms; however, when they do occur, they tend to be most common during the spring or fall months when water temperatures are relatively low. Diatom cell counts in Cherry Creek Reservoir peaked at 11,329 cells/mL on April 14, 2020, and 13,928 cells/mL on September 22, 2020, which was 2.5% of the total cell count on each of those dates. *Cyclotella* sp. 1 reached a concentration of 9,950 cells/mL on September 22, 2020, which was the highest concentration for any diatom species in WY 2020. The highest percentage of diatoms, 5.2%, occurred on July 21, 2020, at a concentration 7,656 cells/mL. *Cyclotella* sp. 1 was the most abundant diatom on that date, with a concentration of 6,293 cells/mL, which was 4.3% of the total cell count. Diatom cell counts averaged 2.2% of the relative phytoplankton cell counts during WY 2020, lower than the 2.9% in WY 2019. *Fragillaria filiformis* was the diatom with the highest concentration (5,102 cells/mL) during WY 2020, but that represented only 2.6% of the total algal cell count on that date.

Because of their relatively large size, diatoms contributed 37.8% of the relative algal biovolume in WY 2020, much higher than the 21.6% of the relative algal biovolume in WY 2019 (Figure 58). The maximum of relative diatom biovolume of 79.3% occurred on November 13, 2019. *Stephanodiscus alpinus* was the diatom with the highest biovolume on that date (1.73 x 10^6 µm^3/mL, which was 29.4% of the total algal biovolume on that date). *Stephanodiscus hantzschii* also had a high biovolume on November 13, 2019 (832,504 µm^3/mL), which added 12.4% to the total algal biovolume.

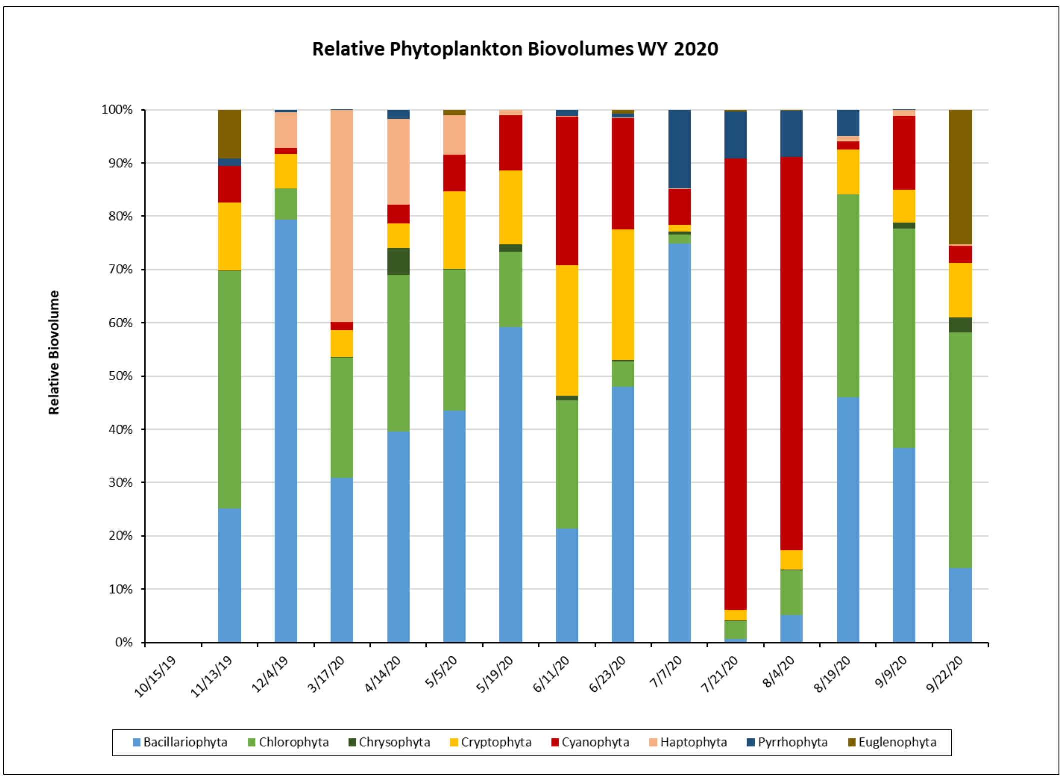


Figure 59. Relative Phytoplankton Biovolumes in Cherry Creek Reservoir in WY 2020.

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, being present at that level on all but four sampling dates in WY 2020 (

Figure 55). Only five species of cryptomonads were identified in Cherry Creek Reservoir during WY 2020, but two of those species, *Rhodomonas minuta nannoplnctica* and *Cryptomonas erosa*, were present on each sampling date. *Rhodomonas minuta nannoplnctica* was usually the cyptomonad present in the highest numbers, peaking at 4,784 cells/mL on November 13, 2019, which was only 1.8% of the total cell count on that date. The cryptomonads contributed 1.5% to the total cell count in WY 2020 compared to 3.5% in WY 2019.

The crytomonads are typically relatively large algae and often made up a significant portion of the relative phytoplankton biovolume, averaging 9.3% of the relative algal biovolume for WY 2020 (Figure 59). 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 514,122 μm^3/mL on June 11, 2020, when it comprised 12.9% of the total algal biovolume. June 11, 2020 was also the date when the cryptomonads reached their highest relative biovolume at 24.5%. For WY 2020, the cryptomonads contributed 9.3% of the total algal biovolume compared to 14.0% in WY 2019.

Chrysophyte (yellow-brown algae) concentrations were generally low during WY 2020, comprising only 0.52% of the total, nearly the same as the 0.51% of the total for WY 2019. Chrysophytes did reach bloom conditions of more than 1,000 cells/mL on six sampling dates during WY 2020 (

Figure 55). Chrysophyte concentrations peaked at only 6,123 cells/mL (1.5% of the total cell count) on March 17, 2020. *Ochromonas* sp. had a concentration of 3,062 cells/mL on that date, the highest concentration of any chrysophyte during WY 2020.

Chrysophytes are not particularly large algae and made up only 0.88% of the total algal biovolume in WY 2020, slightly higher than the 0.78% for WY 2019. The maximum chrysophyte biovolume of 170,496 μm^3/mL (5.1% of the total algal biovolume) occurred on March 17, 2020. *Ochromonas* sp. was also the chrysophyte with the highest biovolume with 151,020 μm^3/mL (4.5% of the total algal biovolume) on that date.

Haptophytes (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, *Chrysochromulina parva*, a lesser known golden alga, but a known toxin producer that can be responsible for fish kills, was first noted in Cherry Creek Reservoir in March 2016 and has been present in most samples since that date. During WY 2020, *Chrysochromulina parva* was the only haptophyte present and it occurred on 12 of the 15 sampling dates.

Haptophytes made up 2.2% of the alga cell counts and 4.9% of the total algal biovolume in Cherry Creek Reservoir in WY 2020 (Figure 56 and Figure 59). These numbers are both slightly lower than the 3.4% of cell counts and 5.5% of algal biovolumes observed in WY 2019. Concentrations of *Chrysochromulina parva* were highest during the cooler months (

Figure 55), and peaked on March 17, 2020 when this species was present at 16,829 cells/mL (4.0% of the total algal population) and 541,924 μm^3/mL (16.1% of the total algal biovolume).

Other groups present at various times during the year included the Phyrrophytes (dinoflagellates), Euglenophytes, and miscellaneous microflagellates. The phyrrophytes and euglenophytes include some large species, but concentrations never reached bloom conditions in WY 2020 and these two groups contributed less than 0.02% and 0.03%, respectively, of the total cell counts (Figure 56). Because of their relatively large size, the phyrrophytes and euglenophytes each contributed 2.9% to the total algal biovolume for WY 2020 (Figure 59). The miscellaneous microflagellates did reach a bloom concentration of 1,531 cells/mL on April 14, 2020 (0.3% of the total) with a biovolume of 225,738 μm^3/mL (7.8% of the total). The miscellaneous microflagellates were only present on three sampling dates and contributed 0.03% of the total cell counts and 0.5% of the total algal biovolume for WY 2020.

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 zooplankton, 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 includes 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.

While the zooplankton population in Cherry Creek Reservoir was less diverse than the phytoplankton population, 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 in WY 2020 were 1-4 cladocerans, 3-6 copepods, 1-7 rotifers, and either 0 or 1 protozoa present on each date. The average was only 10.8 zooplankton species per sampling date, including immature forms, with a range of 8-15 species per date. This was slightly lower than the 11.6 species per date observed in WY 2019.

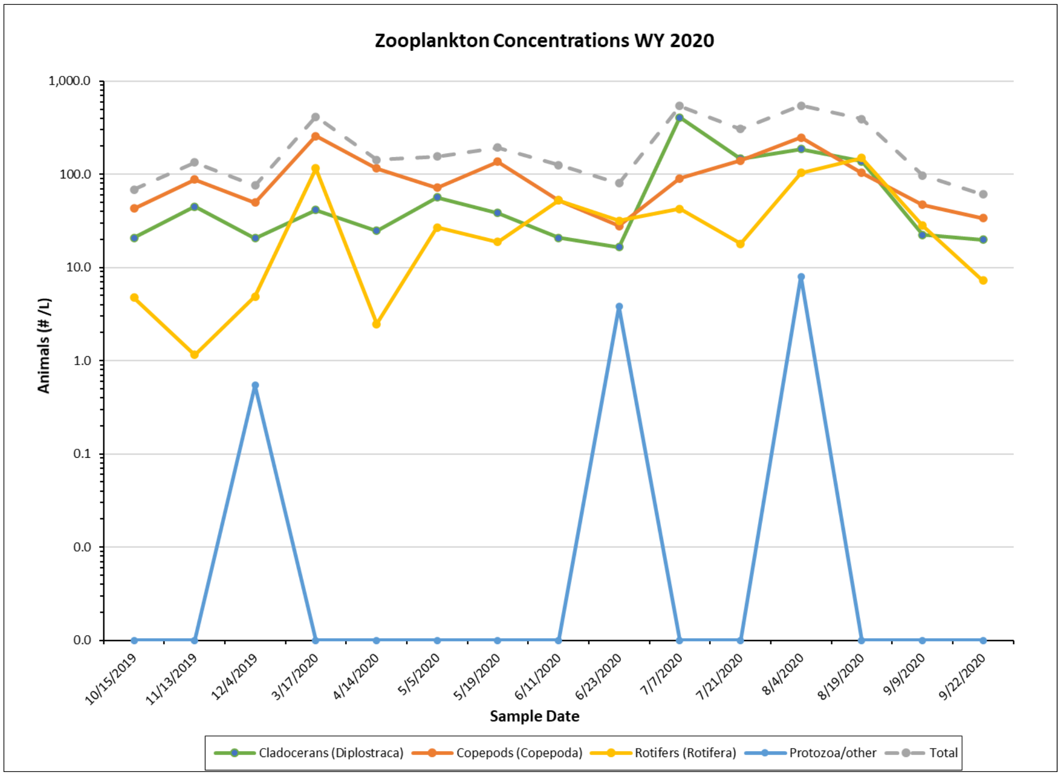


Figure 60. Total Zooplankton Concentrations – WY 2020.

Copepods were typically the zooplankton present in the highest numbers in Cherry Creek Reservoir during WY 20, accounting for over 50% of the total zooplankton population from October 2019 through May 2020 (except for May 5, 2020) and again on September 22, 2020 (Figure 60 and Figure 61). Copepods averaged 51% of the total zooplankton population in WY 2020, ranging from 17% on July 7 to 81% on April 14, 2020, which is similar to the 54% average for WY 2019. Immature forms of cyclopoid copepods and other unidentified, immature copepods were the only zooplankton present on each sampling date, with immature calanoid copepods present on 9 dates. These immature copepods accounted for 39% of the total zooplankton present. Immature cyclopoid copepods reached the highest number of any copepod with 195 organisms/L on March 17, 2020, which was 47% of the total zooplankton population on that date.

Only six adult species of copepods were present in Cherry Creek Reservoir during WY 2020. *Diachyclops thomasi* was present on all sampling dates except July 7, 2020, and *Leptodiaptomus ashlandi* was present on 9 of the 15 sampling dates. These were often the only adult copepods present. *Diachyclops thomasi* was the adult form reaching the highest concentration during the year, with 23.4 organisms/L on August 19, 2020; however, that represented only 6% of the total 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 84 µg/L in WY 2020, which was 43% of the total zooplankton biomass. Relative copepod biomass ranged from less than 9.2% of the total on July 7, 2020, to over 76.3% on November 13, 2019 (Figure 62 and Figure 63). Relative copepod biomass in WY 2020 was higher than the 34% observed in WY 2019. Immature cyclopoid copepods had the highest biomass of any copepod, with a concentration of 202 µg/L (50.4% of total zooplankton biomass) on March 17, 2020.

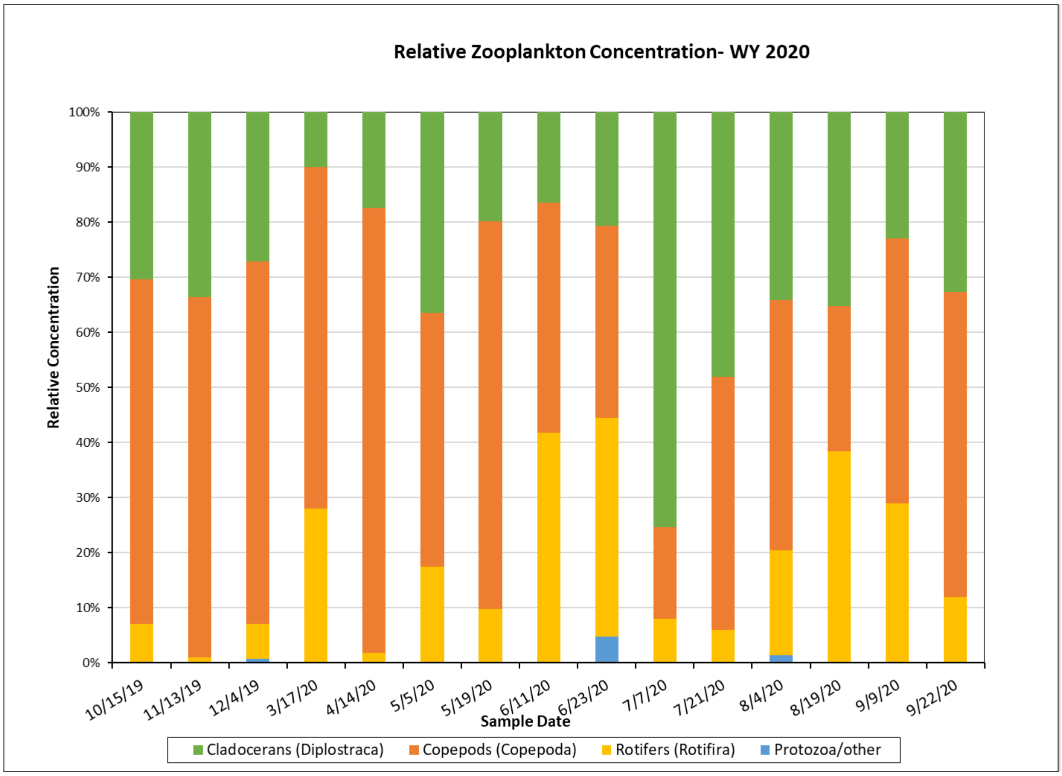


Figure 61. Relative Zooplankton Concentrations in WY 2020, Percent of Total.

Cladocerans were present on all sampling dates in WY 2020, with an average concentration of 80.5 organisms/L. Cladoceran populations averaged 31% of the total zooplankton population during the year, which was similar to the 29% observed in WY 2019. The highest (75%) and lowest (10%) relative populations occurred on July 7 and March 17, 2020, respectively (Figure 60 and Figure 61). Only nine species of cladocerans were present in Cherry Creek Reservoir during WY 2020, with *Bosmina longirostris* being the only species present on all sampling dates. *Daphnia ambigua* was also common and was present on 8 dates. The *Bosmina longirostris* population of 264 organisms/L on July 7, 2020, was the highest individual cladoceran population for the year and comprised 49% of the total zooplankton population on that date.

Cladocerans comprised over half of the total zooplankton biomass on 8 of the 15 sampling dates in WY 2020 (Figure 62 and Figure 63), with an average of 54% and a range of 20% (March 17, 2020) to 88% (July 7, 2020). The average relative zooplankton biomass in WY 2020 was lower than the 65% observed in WY 2019. The cladoceran species present in Cherry Creek Reservoir typically did not include the 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 individual zooplankton biomass of any cladoceran during the year was 526 µg/L (58% of the total) for *Daphnia ambigua* on July 7, 2020. That concentration was over twice as high as the cladoceran with the second highest biomass, which was *Bosmina longirostris* with a biomass of 233 µg/L, also on July 7, 2020. The two combined for 83% of the relative zooplankton biomass on that date.

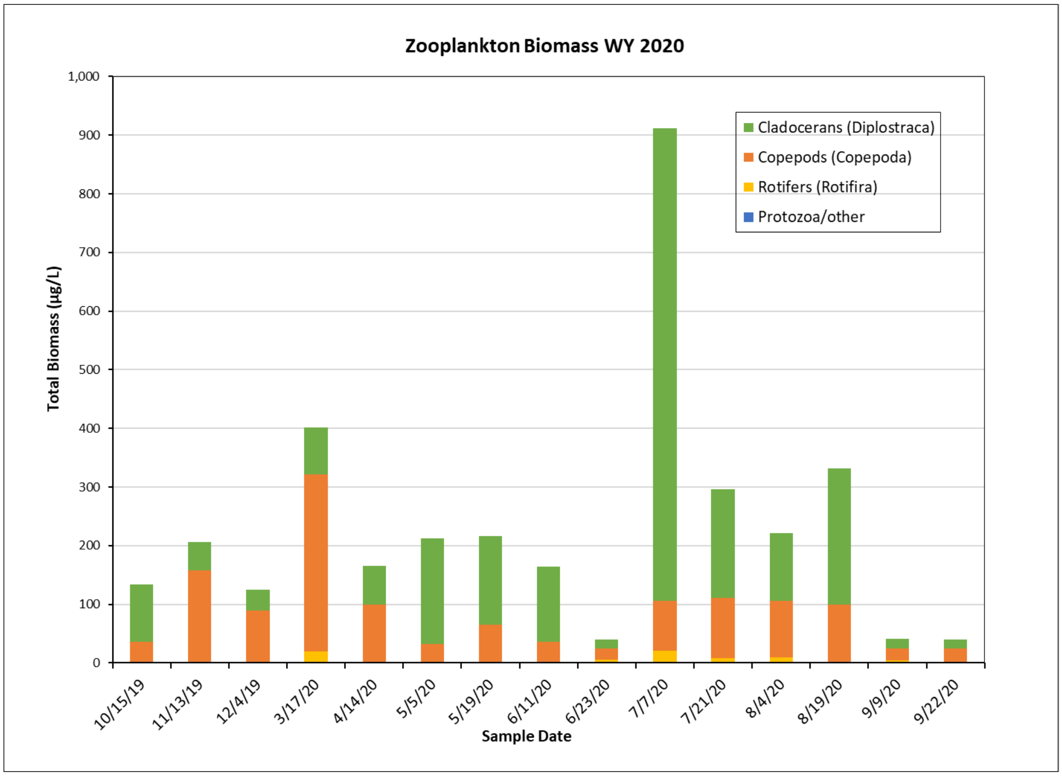


Figure 62. Total Zooplankton Biomass (ug/L) in WY 2020.

Daphnia lumholtzi, an invasive species, is a larger daphnid 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) and in Cherry Creek Reservoir in 2011 (Johnson, 2014). *Daphnia lumholtzi* was a dominant cladoceran in Cherry Creek Reservoir on several sampling dates in WY 2018 and WY 2019, but was only observed on October 15. 2019 during WY 2020. This species was present at a concentration of 3.5 organisms/L and a biomass of 76.9 µg/L on October 15. Those concentrations represented 5.1% of the total zooplankton concentration and 57.4% of the total zooplankton biomass on that date.

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 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).

Rotifers had a diverse population in Cherry Creek Reservoir during WY 2020, with 17 different species present. Rotifers averaged 17.6% of the total zooplankton population during the year, which was slightly higher than the 15.5% average for WY 2019. The maximum relative rotifer population was 41.8% of the total on June 11, 2020, and the minimum was 0.9% on November 13, 2019. Rotifer populations reached a maximum of 150 organisms/L on August 19, 2020. The rotifer species with the highest concentration was *Conochiloides dossuarius*, with a population of 115 organisms/L, also on August 19, 2020. That represented 77% of the rotifer population but only 38% of the total zooplankton population on that date (Figure 60 and Figure 61). *Keratella cochlearis*, present on 10 dates, and *Brachionus angularis angularis*, present on 8 dates, were the only rotifers present on at least half of the sampling dates during WY 2020.

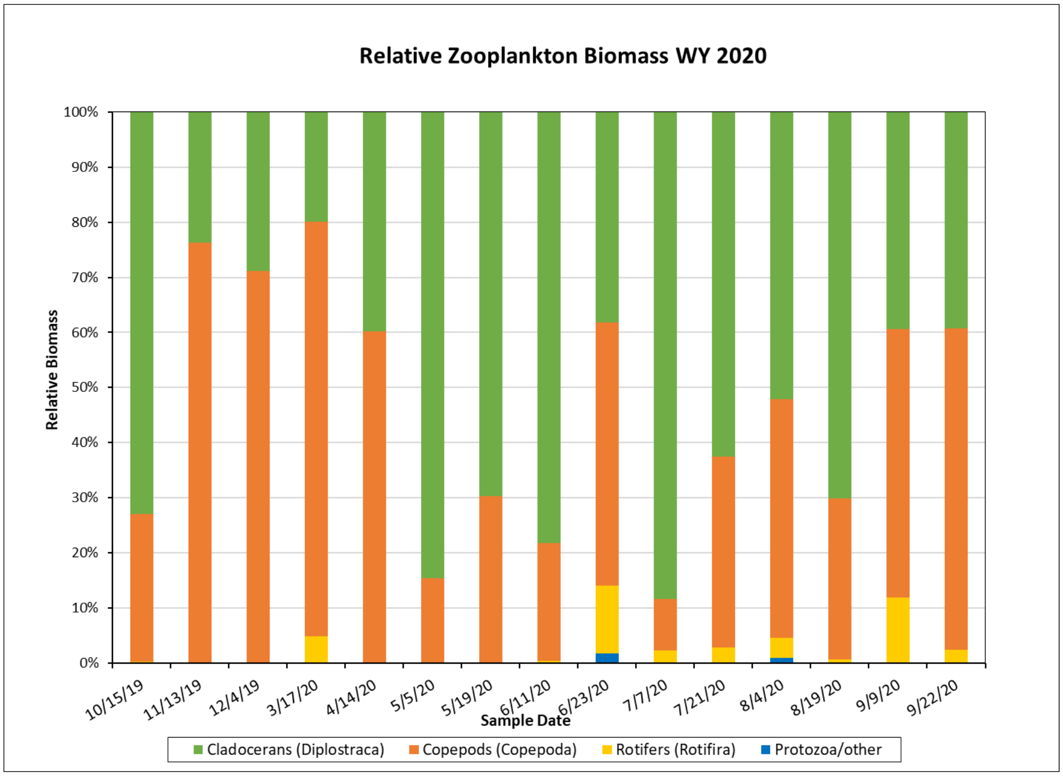


Figure 63. Relative Zooplankton Biomass in Cherry Creek Reservoir in WY 2020.

Due to their small size, rotifer concentrations averaged only 4.7 µg/L, which was only 2.8% of the total zooplankton biomass for the year. This was still higher than the 1.6 µg/L observed during WY 2019. The maximum biomass for the rotifers was 20.6 µg/L on July 7, 2020, but that was only 2.3% of the total relative zooplankton biomass on that date. The maximum relative rotifer biomass was 12.2% of the total on June 23, 2020, when the rotifer biomass was 4.8 µg/L and the total zooplankton biomass was only 39.6 µg/L. The rotifer with the highest biomass was *Asplancha girodi*, one of the larger rotifer species, which had a biomass of 19.0 µg/L on July 7, 2020. That comprised 92% of the rotifer biomass but only 2.1% of the total zooplankton biomass on that date.

The protozoa made only minor contributions to the zooplankton community in Cherry Creek Reservoir. The protozoa averaged only 0.82% of the total zooplankton population and 0.17% of the total zooplankton biomass for the year (Figures 60-63). Only two protozoan species, *Centropyxis* sp. and *Difflugia* sp., were present during WY 2020. Protozoa were present on only 3 of the 15 sampling dates, with only one of the two species appearing on each date. *Difflugia* sp.was present on December 4, 2020, and *Centropyxis* sp. was present on June 23 and August 4, 2020. *Centropyxis* sp. has both the highest protozoan concentration, 8.0 organisms/L, and the highest biomass, 1.88 µg/L, on August 4, 2020. Those numbers represented only 0.13% of the total zooplankton concentration and 0.31% of the total zooplankton biomass for that date.

5.0 WATER BALANCE

The WY 2020 water balance for Cherry Creek Reservoir was calculated from the following equation:

$$\text{Ending Storage}_{9/30/2020} + \sum\text{Reservoir Inflows} - \sum\text{Reservoir Outflows} - \text{Starting Storage}_{10/1/2019} = \Delta\ \text{Storage}$$

Storage was based on daily surface elevations and area-capacity tables for Cherry Creek Reservoir provided by the USACE (Appendix A). The lake surface elevation and volume were 5549.10 ft and 11,840 AF on October 1, 2019, and 5548.55 ft and 11,377 AF on September 30, 2020. This results in a loss in storage of 433 AF (Δ Storage) during WY 2020.

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 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 7.58 inches (0.631 feet) of precipitation was recorded at the KAPA weather station during WY 2020. This marked the fifth consecutive year that annual precipitation was below the long-term average of 14.97 inches from 2006-2020 (Figure 5). Based on these calculations, precipitation contributed an estimated 504 AF of water to the Reservoir during WY 2020.

The surface area of Cherry Creek Reservoir during WY 2020 varied between 766 acres on September 30, 2020, and 856 acres on March 25, 2020, with a median value of 837 acres. Surface areas were 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). 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 calculated 15-minute flows for both CC-10 and CT-2 used to produce daily flows that could be used to provide a daily time step for Cherry Creek modeling efforts.

No ISCO measurements were available for Station CC-10 from April 16 to May 3, 2020, due to instrument upgrades and for Station CT-2 from January 16 to February 10, 2020, as a result of battery failure. Daily depths for the missing dates were interpolated to estimate flows for the affected dates.

The estimated volumes of surface flow entering the Reservoir from surface water sources in WY 2020 are:

- Cherry Creek: 14,832 AF
- Cottonwood Creek: 3,133 AF

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

Evaporation estimates (Outflow 1) are typically provided by the USACE on a daily basis. The estimated evaporative losses from the Reservoir were 3,605 AF during WY 2020, or approximately 4.31 feet (51.7 inches) per acre at the median surface area of 837 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 64). 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. WY 2020 flows at the USGS gauge below the Reservoir averaged 31.2 AF/day for an annual total of 11,409 AF. The 2020 outflow is 156% of the long-term average from 1950-2020, but only 55% of the average for the previous 5 years (2015-2019).

The Reservoir WY 2020 water balance is summarized in Table 19. Following methods developed by TetraTech (2018), the net ungauged inflow(+)/outflow(-) was mathematically calculated to result in the Reservoir loss in storage of 433 ac-ft reported by the USACE for WY 2020 (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. The unadjusted inflows are shown in Table 19 to show ungauged inflows/outflows.

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. The calculated net ungauged inflows for WY 2020 were -6,088 AF. It is likely that groundwater inflows to the Reservoir were lower than average and groundwater losses were higher than average in WY 2020 due to the extremely dry conditions. It is also possible that the stage-discharge relationship for CC-10 is overestimating inflows at that site. That relationship is continuously being updated and evaluated.

Based on previous practice, the ungauged inflows (outflows in WY2020) were apportioned between the Cherry Creek and Cottonwood Creek inflows to calculate nutrient loading (Section 6). For WY 2020, Cherry Creek contributed 82.6% of the combined inflow and Cottonwood Creek contributed 17.4%, based on the daily 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 4,986 AF for Cherry Creek and 1,102 AF for Cottonwood Creek. The adjusted inflows were 9,846 AF for Cherry Creek and 2,031 AF for Cottonwood Creek.

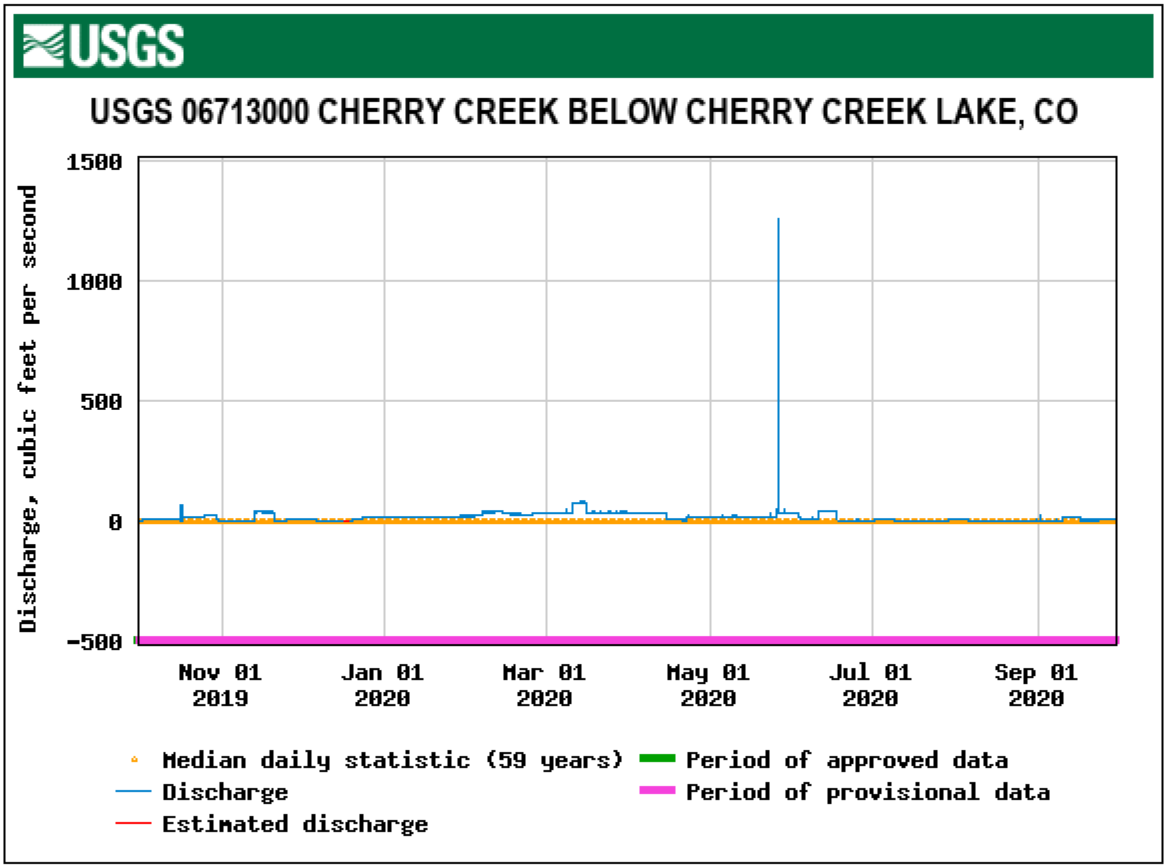


Figure 64. WY 2020 Hydrograph and Historical Median Flows for USGS Site Cherry Creek below Cherry Creek Lake.

Table 19. Cherry Creek Reservoir WY 2020 Water Balance

Water Source	Water Volume (AF)
Inflows	
Cherry Creek (CC-10)	14,832
Cottonwood Creek (CT-2)	3,133
Precipitation	504
Alluvial groundwater	2,200
Total Inflows	**20,669**
Outflows	
Evaporation	-3,605
Reservoir releases	-11,409
Total Outflows	**-15,014**
Net Ungauged Inflows/Outflows	
Calculation	**-6,088**
WY 2020 Change in Storage	**-433**

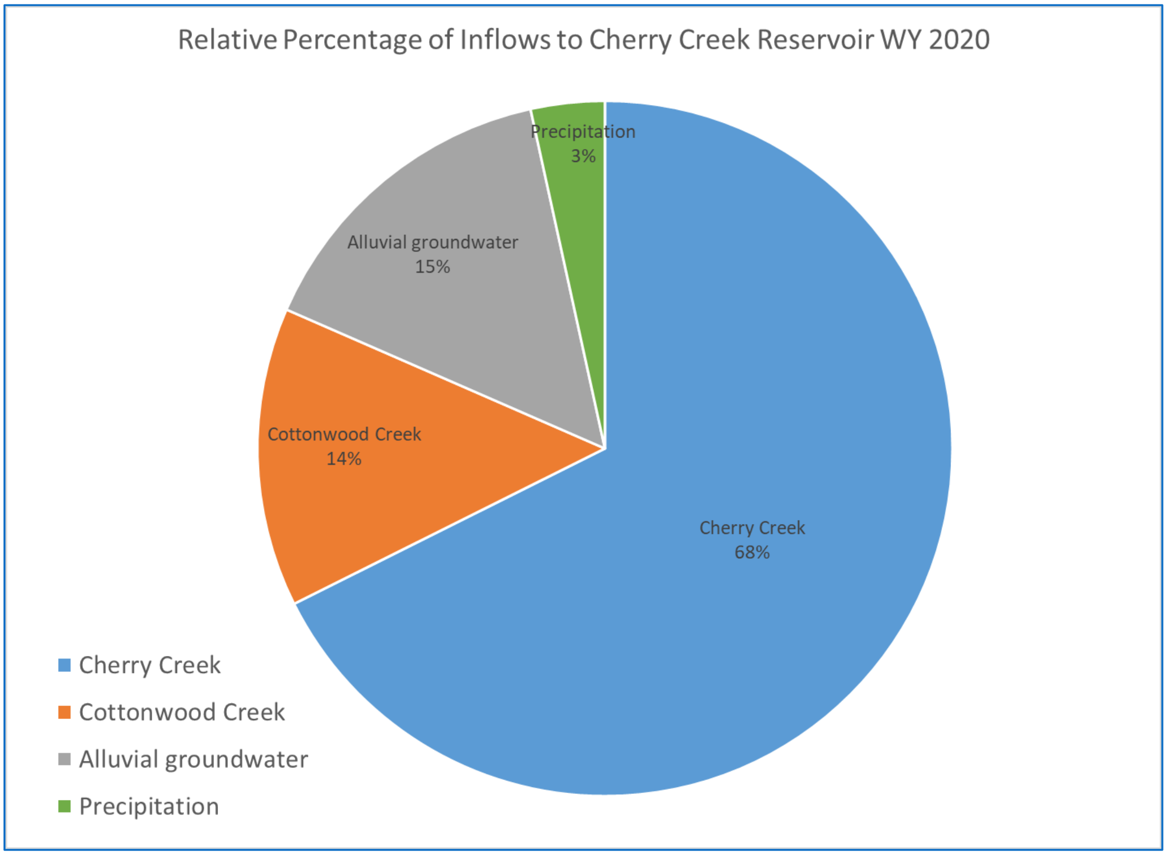


Figure 65. Relative Inflows to Reservoir Water Balance in WY 2020.

The relative inflows to the Reservoir from Cherry Creek, Cottonwood Creek, groundwater, and precipitation are pictured in Figure 65.

6.0 FLOW WEIGHTED NUTRIENT CONCENTRATIONS

Nutrient concentrations for Cherry Creek and Cottonwood Creek were calculated by interpolating concentrations between all sampling dates and multiplying by the daily inflows, adjusted for ungauged inflows, 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 2020 as well as the concentrations from previous years are outlined in Table 20.

The WY 2020 flow-weighted TP concentration for Cherry Creek Station CC-10 was 188 µg/L, which was lower than WY 2019 concentration of 222 µg/L and the average 2011 – 2019 flow-weighted total phosphorus concentration of 250 µg/L (Table 20). The WY 2020 flow-weighted TN concentration of 1,500 µg/L for station CC-10 was slightly lower than the WY 2019 concentration of 1,565 µg/L, but higher than the 2011 – 2019 average flow-weighted total nitrogen concentration of 1,336 µg/L.

The WY 2020 flow-weighted TP concentration for Cottonwood Creek Station CT-2 was 53 µg/L, which was slightly lower than the WY 2019 concentration of 49 µg/L, but much lower than the average 2011 – 2019 total phosphorus concentration of 72 µg/L. The WY 2020 flow-weighted TN concentration for Station CT-2 of 2,479 µg/L was slightly higher than the WY 2019 concentration of 2,427 µg/L and much higher than the 2011 – 2019 average total nitrogen concentration of 1,800 µg/L.

Similar to the 2011 – 2019 averages, the flow-weighted total phosphorus concentrations for WY 2020 were much higher for Station CC-10 than for Station CT-2 (Table 20). In contrast, both the WY 2020 and 2011 – 2019 average flow-weighted total nitrogen concentrations were higher for Station CT-2 than for Station CC-10, and the differences appear to be increasing.

Table 20. 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 2011-2019	250	1,336	72	1,800
WY 2018	212	1,646	78	1,984
WY 2019	222	1,565	49	2,427
WY 2020	**188**	**1,500**	**53**	**2,479**

The median groundwater concentrations of 232 µg/L of total phosphorus and 430 µg/L of total nitrogen for the period 2015-2020 were used in the calculation of flow-weighted nutrient concentrations in groundwater for WY 2020. The median nutrient concentrations in precipitation samples for the period of 2001-2020 of 99 µg/L of total phosphorus and 1,947 µg/L of total nitrogen were used to calculate flow-weighted concentrations in precipitation.

Flow-weighted nutrient concentrations for all inflows and the flow-weighted total concentration based on the relative inflow contributions to Cherry Creek for WY 2020 are summarized in Table 21.

Table 21. Flow-Weighted Inflow Concentrations of TN and TP, WY 2020

		Source				
	Nutrient	**Cherry Creek**	**Cottonwood Creek**	**Alluvial Groundwater**	**Precipitation**	**Weighted Total**
Inflow Concentration (µg/L)	Total Phosphorus	127	7.4	35	3.4	173
	Total Nitrogen	1,013	345	65	67	1,491
% of Total Inflow		**67.5%**	**13.9%**	**15.1%**	**3.5%**	**100%**

The WY 2020 flow-weighted TP concentration of all inflows of 173 µg/L is lower than previous water years (Table 22) which could be attributed to the lack of precipitation leading to a decrease in the number of storm flow events that historically exhibit high TP concentrations. The flow weighted TP concentration limit set by the Cherry Creek Reservoir Control Regulation 72 (REG72) is 200 µg/L. In contrast, the WY 2020 flow-weighted TN inflow concentration of 1,491 µg/L is lower than the WY 2019 and WY 2018 concentrations, but higher than WY 2017, WY 2016, and the 2011-2015 median.

Table 22. Flow-Weighted Nutrient Concentrations for Surface Water Inflows to Cherry Creek.

Water Year	Total Flow-Weighted Nutrient Concentrations (ug/L)	
	Total Phosphorus	Total Nitrogen
WY 2011-2015 Median	200	1,344
WY 2016	213	1,175
WY 2017	197	1,284
WY 2018	206	1,691
WY 2019	188	1,609
WY 2020	**173**	**1,491**

In addition to the above inflow 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 of nitrogen is probably relatively small because of the magnitude of the other sources listed.

The flow-weighted nutrient concentrations for the outflows (losses) during WY 2020 are shown in Table 23. Water leaves the Reservoir through the outlet at the Cherry Creek Reservoir dam and surface evaporation.

Table 23. Flow-Weighted TP and TN Concentrations at CC-0 and Evaporation, WY 2020

Nutrient	Concentration (µg/L)	
	Cherry Creek Outflow	**Evaporation**
Total Phosphorus	91	0
Total Nitrogen	911	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 2020 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 (+Δ $\text{Storage}_{\text{Nutrients}}$) indicates that inflows exceed releases and that nutrients are being retained (stored) within the Reservoir. A negative change in storage (-Δ $\text{Storage}_{\text{Nutrients}}$) would suggest that previously stored nutrients are being exported from the Reservoir.

The Reservoir's inflows (nutrient loads) considered in the WY 2020 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 2020 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 nutrient loading concentrations calculated in Table 19 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. The Authority also periodically collects storm event samples at CC-10 and CT-2 which are analyzed for the parameters indicated in Table 3, which include TP and TN.

The nutrient concentrations in samples collected at CC-10, CT-2 and CC-Out in WY 2020 are summarized in Table 20 and Table 21. Nutrient concentrations in were combined with the WY 2020 daily flows to calculate annual total phosphorus and total nitrogen loads for the surface water inflows and outflows (releases) to/from the reservoir (Table 24). The Cherry Creek and Cottonwood Creek loads presented in Table 25 were adjusted to apportion the ungauged inflows as discussed in Section 5.0.

Table 24. Surface Water Nutrient Loads to Cherry Creek Reservoir, WY 2020.

	WY 2020 Nutrient Loading	
Site	**Total Phosphorus (Pounds)**	**Total Nitrogen (Pounds)**
Inflows		
Cherry Creek @ CC-10	5,033	40,173
Cottonwood Creek @ CT-2	294	13,693
Releases		
USGS Gage & CC-Out	-2,826	-28,255

7.2 PRECIPITATION LOADS

In WY 2020, TP and TN were measured at the PRECIP site located in Cherry Creek State Park during storm sampling events. Because of the lack of precipitation in WY 2020, only one sample was collected after a storm event during WY 2020 and it was analyzed for total phosphorus and total nitrogen concentrations. These values represent atmospheric loading and dry deposition. Table 25 lists nutrient concentrations in the precipitation sample collected in WY 2020 and the updated historical mean values which were used to calculate the total loading from precipitation during WY 2020.

Table 25. Cherry Creek Reservoir WY 2020 Precipitation Nutrient Loads

	WY 2020 Nutrient Loading	
PRECIP	**Total Phosphorus**	**Total Nitrogen**
Maximum (µg/L)	101	2,370
Minimum (µg/L)	26	1,370
Concentration (µg/L)	50	1,031
Updated Historical Median(µg/l)	99	1,947
Inflow WY 2020 (AF)	504	504
Total (lbs)	**136**	**2,668**

- The total phosphorus concentration in the WY 2020 sample of 50 µg/L was higher than the median value for WY 2019 (41 µg/L), but lower than median values for WY 2018 (116 µg/L) and the historical median of 99 µg/L (1991-2020).
- The total nitrogen concentration in the WY 2020 sample was 1,031 µg/L was much lower than the median value for WY 2019 (2,005 µg/L) and the historical median value of 1,947 µg/L (1991-2020).

Nutrient loads from precipitation were calculated by multiplying the 1991 - 2020 median nutrient concentrations by the total precipitation volume of 504 AF falling on the reservoir surface during WY 2020. The calculated precipitation loads for WY 2020 were:

- Total Phosphorus: 136 pounds
- Total Nitrogen: 2,668 pounds

These loadings were much lower than in previous years because rainfall was only 51% of the historical (2006-2020) average in WY 2020.

7.3 ALLUVIAL GROUNDWATER LOADS

Water samples from monitoring well MW-9 were collected in November 2019 and May 2020 during WY 2020 and analyzed for total phosphorus and total nitrogen. The results are summarized in Table 26.

- The median TP concentration from MW-9 for WY 2020 was 312 µg/L, which is higher than WY 2019 (252 µg/L), WY 2018 (228 µg/L), WY 2017 (237 µg/L) and WY 2016 (206 µg/L). The WY 2020 median, the medians for water years 2016 – 2019, and the long-term median from 1994 – 2015 (190ug/L, GEI, 2016) were used to update the historical median TP concentration to 232 µg/L.

- The median TN from MW-9 for WY 2020 was 1,155 µg/L was much higher than the median for WY 2019 (741 µg/L), which in turn was much higher than median TN values for WY 2018 (315 µg/L), WY 2017 (241 µg/L), WY 2016 (217 µg/L), and the long-term median from 1994-2015 (430 µg/L, GEI, 2016). These values were combined to calculate an updated historical median concentration for TN of 430 µg/L.

Table 26. Cherry Creek Reservoir WY 2020 Groundwater Loading

	WY 2020 Nutrient Load	
MW-9	**Total Phosphorus**	**Total Nitrogen**
Maximum (µg/L)	344	1,270
Minimum (µg/L)	279	1,040
Median (µg/L)	312	1,155
Updated Historical Median (µg/L)	232	430
Inflow WY20 (AF)	2,200	2,200
Total (lbs)	**1,388**	**2,573**

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 2020.

- Total Phosphorus: 1,388 pounds
- Total Nitrogen: 2,573 pounds

8.0 NUTRIENT MASS BALANCES

As summarized in Table 21 the phosphorus and nitrogen loading to the Reservoir is derived from four 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 24 through Table 26.

Mass balances for total phosphorous and total nitrogen for Cherry Creek Reservoir were calculated from the data presented in Sections 7.1 through 7.3 and are summarized in Table 27. The difference between the inflow and the outflow loads (Δ Storage$_{Nutrients}$) indicate that a net 4,025 pounds of phosphorus and 30,883 pounds of nitrogen were retained in the reservoir in WY 2020.

As noted previously, inputs from Internal nutrient loading and nitrogen fixation and losses from denitrification are not included in the mass balances since collecting the data required to evaluate these factors were beyond the scope of this program. 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 11.8 – 29.0% of the phosphorus loading from external sources listed in Table 27. Internal phosphorus loading in WY 2020 may been towards the upper end of this range because there were low dissolved oxygen levels in the hypolimnion during the summer months that were accompanied by high phosphorus levels in the lower part of the water column.

Table 27. Total Phosphorus and Nitrogen Mass Balance in Cherry Creek Reservoir WY 2020

Water Source	Total Phosphorus Mass (pounds)	Total Nitrogen Mass (pounds)
Inflows		
Cherry Creek (CC-10)	5,033	40,174
Cottonwood Creek (CT-2)	294	13,693
Precipitation	136	2,668
Alluvial groundwater	1,388	2,573
Total Inflows	**6,851**	**59,108**
Outflows		
Evaporation	0	0
Reservoir releases	-2,826	-28,225
Total Outflows	**-2,826**	**-28,225**
WY 2020 Change in Storage	**4,025**	**30,883**

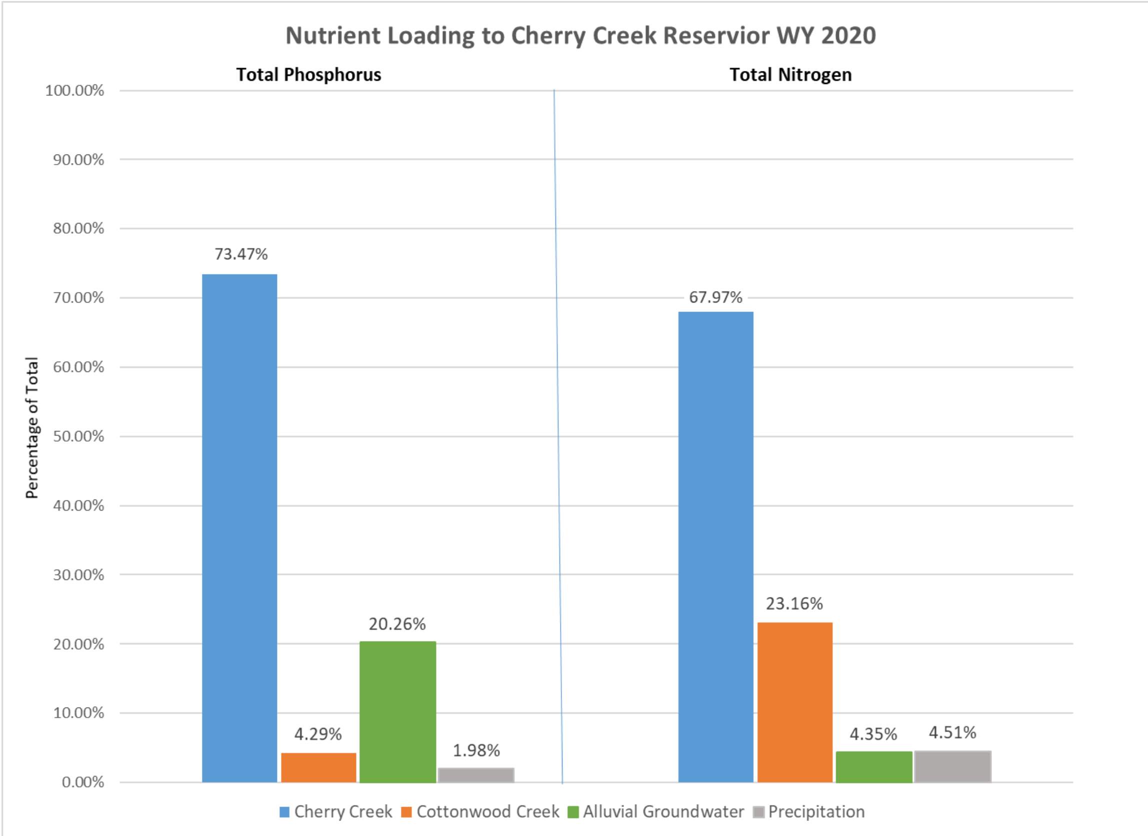


Figure 66. Nutrient Loading Percentages by Source to Cherry Creek Reservoir, WY 2020.

The relative contributions of the inflow sources of phosphorus and nitrogen loading to the Reservoir in WY 2020 are represented in Figure 66.

Table 28 and Figure 67 present the historical total nutrient mass loads, outflows and resulting storage in Cherry Creek Reservoir in comparison to previous years. The calculated total phosphorus loads were lower than any of the loadings previously reported. The total nitrogen loads were lower than the previous 3 years and the long-term historical mean from 1993-2020. These values can be attributed primarily to the very low amount of rainfall in WY 2020, which was the lowest for the period of record at the KAPA station, where precipitation measurements have been collected since WY 2006.

Table 28. Historical Comparison of Total Phosphorus and Nitrogen Loading to Cherry Creek Reservoir.

		Inflows (pounds)					
Analyte	Period Mean	Surface Water	Alluvial Groundwater	Precipitation	Total	Outflow (pounds)	Δ Storage (pounds)
Phosphorus	1993 – 2020	8,429	1,069	365	9,880	-4,525	5,678
Nitrogen		62,305	2,375	6,239	70,976	-37,594	33,407

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
Phosphorus	**WY 2020**	**5,327**	**1,388**	**136**	**6,851**	**-2,826**	**4,025**
Nitrogen		**53,867**	**2,573**	**2,668**	**59,108**	**-28,225**	**30,883**

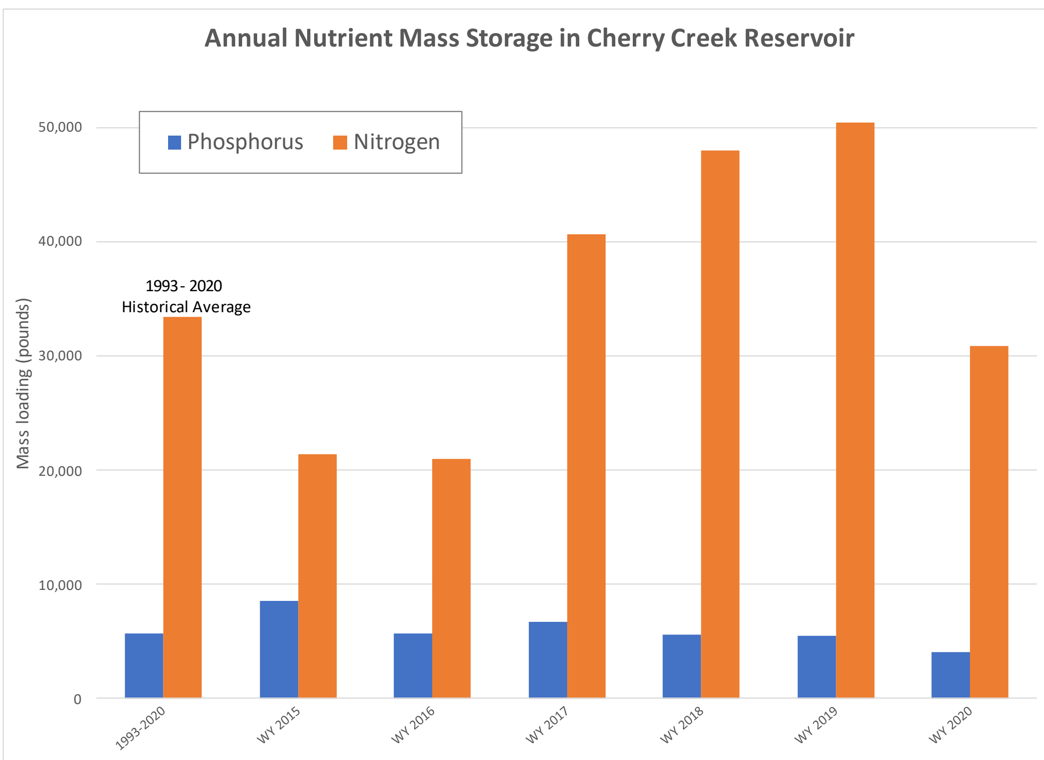


Figure 67. Historical Comparison of Total Phosphorus and Nitrogen Loading to Cherry Creek Reservoir.

(Historical averages – 2020)

9.0 2020 CONCLUSIONS

CONCLUSIONS AND RECOMMENDATIONS

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.

Surface water flows are the main contributor of nutrient concentrations in the inflows and nutrient loading of the reservoir.

The Cherry Creek watershed has seen significant increases in population and both residential and commercial construction over time. Up-basin MS4s also implement construction site programs to mitigate construction sediment runoff and post-construction permanent water quality facilities to treat urban runoff from impervious areas. These programs and facilities minimize negative water quality impacts from these changes in the watershed. In addition, many other watershed and PRF projects have been completed in order to minimize negative water quality impacts of these changes.

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

During the 2020 monitoring and data analysis efforts, recommendations for improvement and enhancement of the sampling program or other analysis of the Cherry Creek watershed or Reservoir were brought to light. 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.

- Adding additional monitoring of individual TDS components will help determine what is leading to the increased conductivity in Cottonwood Creek. Individual analyses for Chloride, Sulfate, Magnesium, Sodium, Potassium, Calcium, and Alkalinity have been included in the SAP for 2021. These analyses will be completed at the furthest upstream and downstream sites on Cottonwood Creek (CT-P1 and CT-2), along with Cherry Creek just upstream of the Reservoir (CC-10) and within the Reservoir at CCR-2 from the photic zone and bottom samples. These analyses will be completed in March and September.
- Increasing accuracy of level and flow gauging on Cherry Creek upstream of the Reservoir is necessary to capture information from flows during large storm events that may bypass the current gauging station. In 2020, a detailed survey was completed on Cherry Creek where it goes under East Lakeview Dr. in addition to the CC-10 monitoring site. In 2021, additional work will be completed to determine when the stage discharge relationship generated from stream flow measurements will be used along with the modeled flows from the survey will be used to estimate flows. Eventually installing a stable cross section at this site may help with variability of changes in the stream channel and sedimentation.
- Assessment of the water quality through the PRFs on Cottonwood Creek will help determine scale and frequency of maintenance of the wetland plants and sediment removal necessary to maintain storage capacity and reduce organic accumulation.

- 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.
- 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.
- 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.
- Completing sediment analyses to determine nutrient concentrations that are responsible for internal nutrient loading will provide valuable information these in-reservoir options are being considered.
- 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. Although present in previous years, the samples from WY 2020 did not reflect the presence of *Prymnesium parvum* and *Daphnia lumholtzi* was only observed on the October 2019 sampling date.
- As build-out and development continues, it may be necessary to add additional monitoring sites or equipment upstream and on tributaries to determine to changes in water quality and to measure efforts to mitigate negative effects.

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 land use changes, permitted and unpermitted point and non-point discharges, and other changes 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 2020