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Cherry Creek Basin Water Quality Authority Monitoring Report Water Year 2021

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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^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

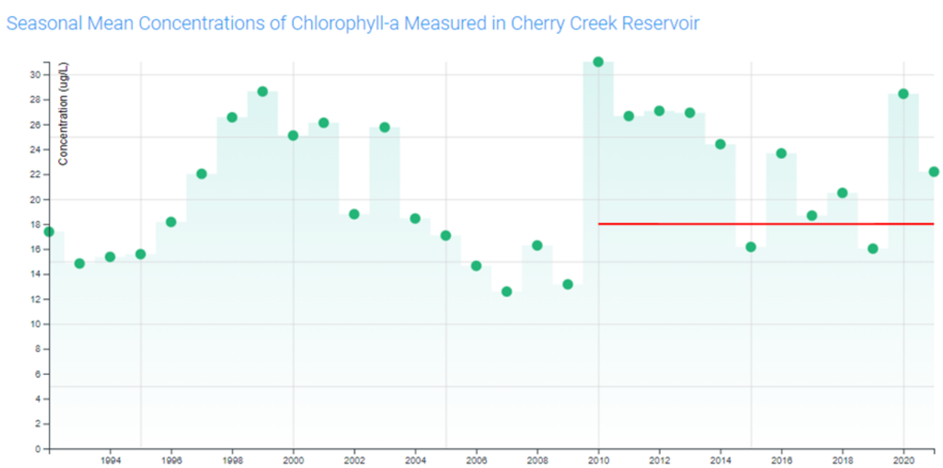
NO_3+NO_2-N	Nitrate plus Nitrite Nitrogen
#/L	Number of animals per liter (zooplankton)
ORP	Oxidation Reduction Potential
%	Percent
POR	Period of record
PRF	Pollutant Reduction Facility
PRISM	Parameter-elevation Regression on Independent Slopes Model
QA/QC	Quality Assurance/Quality Control
QAPP	Quality 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 2021* 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 2021 Water Year (WY 2021) between October 1, 2020 and September 30, 2021. 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 data were collected to evaluate how successful the requirements specified in CR72 are at achieving the chlorophyll-α (chl α) water quality standard and the water quality standards for associated parameters as outlined in Regulations 31 (REG 31) and 38 (REG 38), as directed by the CCBWQA's Statute. 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 2021 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



Seasonal Mean Chlorophyll-α concentrations (µg/L) in Cherry Creek Reservoir.

Cherry Creek Reservoir has a seasonal chl α standard of 18 µg/L as set by WQCC Regulation No. 38 (REG 38). During each sampling event of WY 2021, 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 measured chl α concentrations ranged between 4.8 µg/L and 67.8 µg/L, with a mean of 25.2 µg/L for all of WY 2021. The highest values were observed in March 2021, April 2021, and November 2020 and the lowest were observed in late May 2021 and October 2020.

The seasonal (July through September) chl α concentration through the WY 2021 growing season was 22.2 µg/L. The WY 2021 seasonal mean was lower than WY 2020 (28.4 µg/L), but higher than WY 2019 (16.0 µg/L), WY 2018 (20.2 µg/L), WY 2017 (18.7 µg/L) and similar to the WY 2016 (23.6 µg/L) seasonal means. The growing season average regulatory standard set by REG 38 allows an exceedance frequency of the standard once in five years. Four of the last five (4/5) and eight of the last ten (8/10) years have exceeded this value.

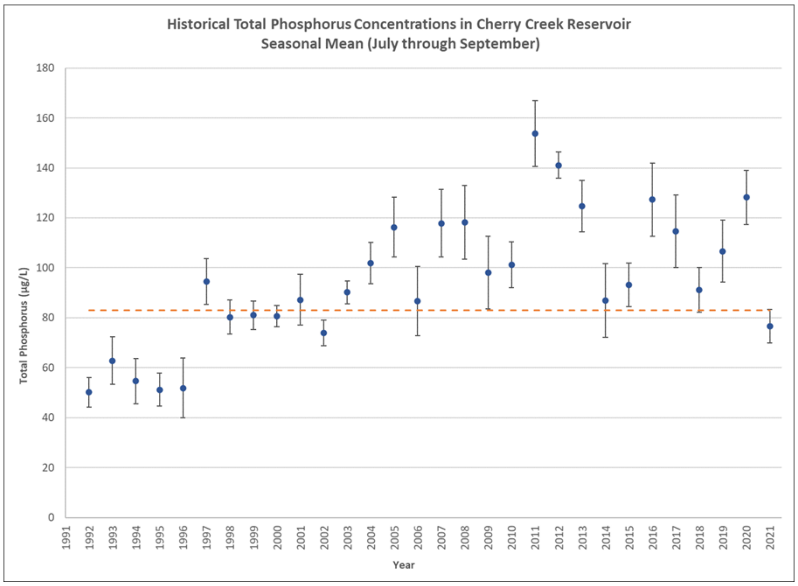
Transparency

Transparency of the Reservoir is measured using a Secchi disk which measures water clarity impacts from productivity (alage growth) and suspended solids in the water. The mean Secchi depth measurements of the three reservoir monitoring sites during WY 2021 ranged between 0.52 m and 3.5 m, with an annual mean of 0.99 m for the year. The seasonal mean (July –September) was 0.74 m. 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 suspended particles including sediment and other inorganic and organic solids.

Nutrients

Nutrients in the Reservoir are monitored since they directly impact algal growth and chl α concentrations. The WY 2021 seasonal mean (July-September) Total Phosphorus (TP) was 76.7 µg/L, which was lower than the long-term seasonal average of 94.47 µg/L measured from 1992- present. The seasonal mean values for TP have significant annual variability on a long-term scale. However, 4 of the last 5 years have been below the interim standard goal of 83µg/L.



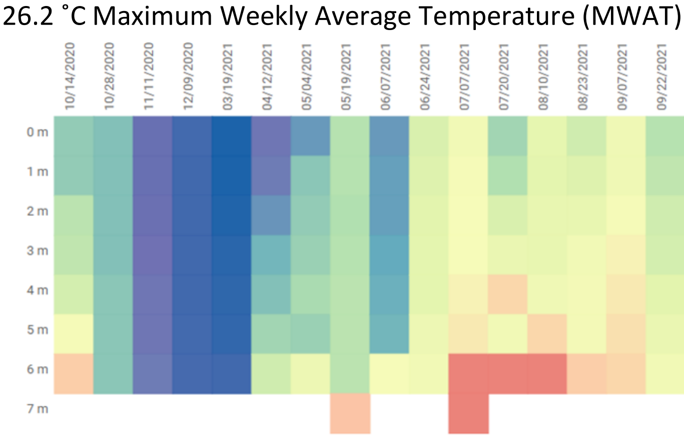
Historical Seasonal TP (µg/L) in CCR. (Interim standard (83ug/l---)

During WY 2021, the monthly mean TP concentrations ranged between 69 µg/L and 115 µg/L with a mean value of 87 µg/L. The lowest values were present in September 2021 and the highest values in April 2021. The WY 2021 data suggests that although the TP concentrations in the Reservoir were lower than some recent years, the high levels throughout the year contribute to the eutrophic and productive conditions in the Reservoir.

The WY 2021 seasonal mean (July thorough Sept) for Total Nitrogen (TN) in the Reservoir was 861 µg/L, which was slightly lower than the long-term average of 896 µg/L calculated from 1992-present. During WY 2021, annual TN concentrations ranged between 605 µg/L and 1,240 µg/L with a mean value of 942 µg/L. The highest TN values were present in November 2020, April 2021 and the lowest were seen in June.

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 was 26.3 ˚C (79.3 ºF) at the surface on July 30, 2021 from the thermistors for a period of 15 minutes or less, which does not exceed the daily or weekly maximum. The temperature data indicated the maximum temperature change from top to bottom was 6.1˚ C in mid-June.



Dissolved Oxygen Concentrations (mg/L) in CCR at CCR-2 in 2021.

However, the mean difference was only 1.75˚ C indicating that for the most part the Reservoir did not develop consistent significant thermal stratification.

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

During 2021, DO levels were below 5.0 mg/L at 6 m meters or below at CCR-2 in early-July through early August. During May through Sept, there were events at CCR-1 where DO concentrations were below 5.0 mg/L at variable depths from 5 m and the bottom at CCR-1 and at CCR-3, the DO was at or below 5.0 mg/L at depths between 4-5 m to the bottom from late June through August. However, during the same time periods in which DO concentrations were below 5.0mg/L at depth, the DO concentrations near the surface measured concentrations greater than 5.0 mg/L, meeting the REG 31 standard.

pH, ORP and Conductivity

The instantaneous minimum and maximum pH standards are 6.5 and 9.0, respectively, as set by REG 38. During WY 2021, the pH ranged between 7.9 and 8.8, which is similar to recent years, meeting the standard. The higher pH values appeared to correlate with higher productivity and elevated chl α in the Reservoir

During WY 2021, the Oxidation Reduction Potential (ORP) in Cherry Creek Reservoir in the photic zone ranged between from 141 and 264 milliVolts (mV). The ORP in the samples near or at the bottom of the Reservoir ranged from 141 mV in early July to 274 mV in March. The lower ORP values, indicating a reducing environment, at the bottom of the Reservoir coincided with the lower DO measurements and higher ORP values, indicating an oxidative environment, were present during higher DO levels and colder water temperatures. These trends are typical and an indication of decomposition processes in the sediments and sediment-water interface and seasonal trends normally seen in the Reservoir.

The specific conductance (hereafter referred to as "conductivity" in this document) indicating dissolved solids (ie salts minerals, etc.) in Cherry Creek Reservoir ranged from 1,198 µS/cm to 1,437 µS/cm during WY 2021. There was limited variability in conductivity from top to bottom of the Reservoir and between the three monitoring sites. Overall, the conductivity in the Reservoir was lower than WY 2020 but has demonstrated an increasing trend since monitoring of this parameter started in 1999.

Trophic State Analysis

Trophic State	Characteristic			
	Total P	Chlorophyll *a*	Secchi	Relative
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	**0.087**	**19.8**	**1.02**	**High**

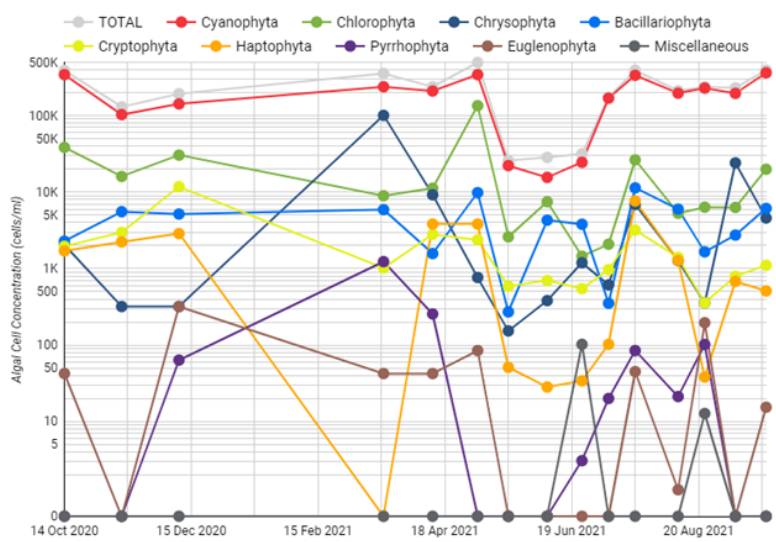
Table A. Cherry Creek Reservoir Trophic State Characteristics

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 levels of algal growth. 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 67, indicating that Cherry Creek Reservoir was eutrophic during WY 2021 (See Section 4.14). Although there has been some fluctuation of the historical TSI values, they remain within the eutrophic to hypereutrophic range.

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 2021 to EPA trophic state criteria (from May through September) also indicates that Cherry Creek Reservoir was eutrophic-hypereutrophic in WY 2021 (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.

Phytoplankton

Phytoplankton, the organisms responsible for chl α production in Cherry Creek Reservoir are 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 2021 indicate high productivity and high species diversity, with an average of 40 phytoplankton species, and a range of 27-66 species present for the 15 sampling dates, which is similar to recent years. Cell counts were dominated by the Cyanophytes (cyanobacteria or undesirable blue-green algae, shown in red), which were responsible for 50% or more of the total phytoplankton cell counts on each sampling date and averaged 83% of the total cell counts for all of WY 2021. This was less than the average of 85% observed in WY 2020.



Phytoplankton Populations in CCR during WY 2021

However, cyanobacteria only averaged 5% of the total algal biovolume, which was much less than the previous 2 years. Multiple species of cyanobacteria capable of producing toxins were observed during sampling in Cherry Creek Reservoir in WY 2021, but none were present in very high numbers or biovolumes and there were no blooms that required closures.

Chlorophyta (green algae, shown in green) and Bacillariophyta (diatoms, shown in blue), which tend to be considered “good” algae, were also present in relatively high numbers, making up 9% and 2% of the total algal populations, respectively. Based on their large size, diatoms contributed 27% and green algae made up 19% of the relative biovolume for WY 2021.

Cyanophytes, Bacillariophytes, Chlorophytes, and members of the Cryptophyte group (cryptomonads, shown in yellow) were often present at levels of 1,000 or more cells/mL, which is a concentration associated with eutrophic, or imbalanced aquatic ecosystems. The cryptomonads averaged 1% of the total cell count and 7% of the relative biovolume during WY 2021.

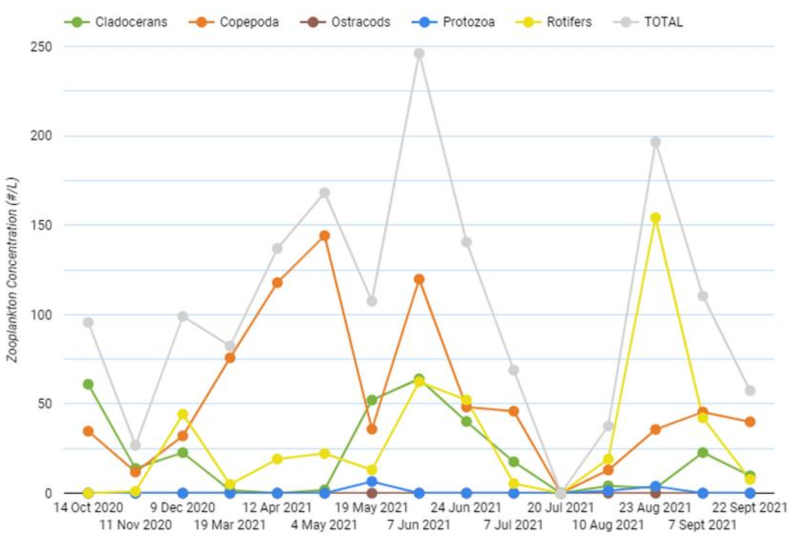
An unusual chrysophyte (golden-brown algae, shown in brown) bloom was observed in March 2021, when *Ochromonas* sp. accounted for 28% of the total algal cell counts on that date, but accounted for 4% of the total algal cell counts and 39% of the total algal biovolume for all of WY 2021. This bloom was also responsible for the highest chl α values seen in WY 2021.

Haptophytes (golden algae, shown in orange) 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 2021 on most dates.

Zooplankton

Most freshwater zooplankton are part of only three phyla: Arthropoda, which includes cladocerans, copepods, and ostracods; 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 2021 were both low compared to phytoplankton, which is typical in most lakes/ reservoirs.



Copepods were typically the zooplankton present in the highest numbers, averaging 51% of the total population during WY 2021 and 12% of the biomass.

Cladocerans frequently comprised over half of the zooplankton biomass, averaging 20% of the zooplankton population and 87% of the total biomass for WY 2021.

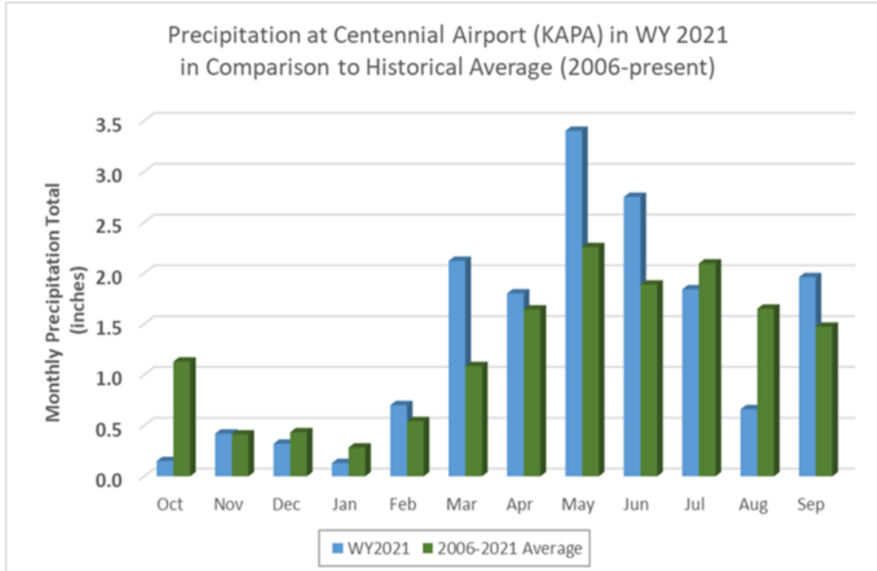
Daphnia lumholtzi, an invasive species that is less palatable to fish, was first identified in Colorado in 2008 and in Cherry Creek Reservoir in 2011. *Daphnia lumholtzi* is a cladoceran that was again present in Cherry Creek Reservoir during WY 2021, with a significant bloom in October 2020 that accounted for 96% of the total zooplankton biomass for that date and 45% of the total zooplankton biomass in WY 2021.

WATERSHED HIGHLIGHTS

Precipitation

Precipitation measured at the National Ocean and Atmospheric Administration (NOAA) at the Centennial Airport Station (KAPA site was above average during the 2021 Water Year. The historical data from the site, indicated the area received 113% of the historical average precipitation from 2007-2021.

The watershed as a whole appears to have received 68-183% average precipitation, based on the 30-year Parameter-elevation Regression on Independent Slopes Model (PRISM) average.



Precipitation at Centennial Aprt (KAPA) - Historical Avg/WY 2021

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 1,469 ft^3/s (cubic feet per second) or 2913.2 Acre Feet (AF) with an annual daily mean of 4.02 cfs (7.98 AF) for WY 2021, which is approximately 44.9% of the annual mean discharge calculated from WY 1940-2021.

The yearly summary for the USGS gauge, Cherry Creek Near Parker, CO, listed a provisional total annual flow of 4,125 ft^3/s (8,180 AF) and an annual daily mean of 11.3 cfs (22.4 AF), which is equal to the annual mean discharge calculated from WY 1992-2021.

It is noteworthy that the headwater flows of Cherry Creek in Castlewood Canyon were 55% lower than average, but flows were equal to the historical 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 just upstream of the Reservoir to measure water levels and flows are calculated from stage discharge relationships based on measured flows or weir calculations. The estimated WY 2021 flow at the CC-10 monitoring site totals 16,773 AF with an average daily discharge of 45.95 AF. The estimated WY 2021 flow at the CT-2 monitoring site total 4,517 AF with an average daily discharge of 12.4 AF.

Cherry Creek

Water quality data is collected on Cherry Creek during base and storm flows all year long. During two monitoring events in WY 2021, data were collected from the USGS Cherry Creek Near Franktown, CO site all the way down Cherry Creek just upstream of the Reservoir (CC-10) and below. Conductivity and pH were monitored as surface water moves from the upper basin downstream to the Reservoir.

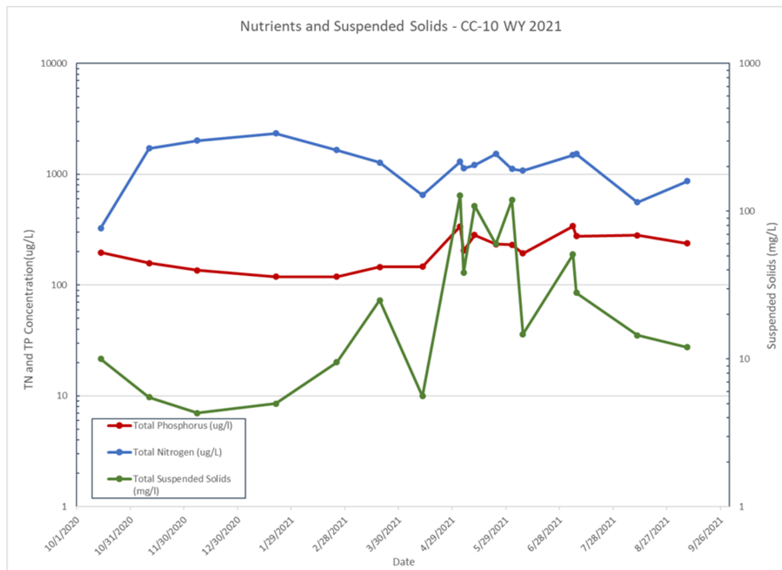
Both upstream to downstream monitoring events indicated limited variability of pH values that ranged from approximately 7.2 to 8.6 through the basin. However, the conductivity was much more variable and was almost

3.3 times higher just upstream of the Reservoir relative to the furthest upstream site. In addition, conductivity data shows an increasing trend since monitoring started in 1992.

During comprehensive upstream to downstream sampling in WY 2021, the TP concentrations had some variability but remained within the same range. TP averaged 129 µg/L in November 2020 and 237 µg/L in May 2021. However, total nitrogen (TN) increased from the USGS Cherry Creek near Franktown site downstream to the USGS Cherry Creek near Parker site, then leveled out near the middle of the watershed and then decreased all the way to the Reservoir and outflow. TN concentrations averaged 2.31mg/L in November 2020 and 2.21 mg/L in May 2021. 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. Increases in conductivity indicate higher levels of dissolved solids in the water such as salts or other inorganic chemicals found in urban landscapes.

Data collected at CC-10 during base and storm flows in WY2021 demonstrates the values and relationships between Total Phosphorus (red), Total Nitrogen (blue), and Total Suspended Solids (TSS) concentrations (green). TP concentrations for both storm and base flow samples ranged between 119 and 340 µg/L during the year. TN concentrations ranged between 327 and 2,340 µg/L during WY 2021. Values of TSS ranged between 4 and 128 mg/L. The mean and median concentrations of TP, TN, and TSS were all higher during the storm events than in base flow conditions on Cherry Creek.



WY 2021 Water Quality at Cherry Creek at CC-10

During WY 2021, 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 2021, the water quality in Cottonwood Creek is monitored during base and storm flows. the pH of water in Cottonwood Creek before it entered the Reservoir at CT-2 ranged from 7.4 to 8.2. The conductivity, or specific conductance, which represents dissolved solids in the water, ranged between 814 µS/cm and 4,507 µS/cm, with a median value of 2,087 µS/ cm at CT-2. The conductivity at CT-2 was higher than the median at CC-10 which was 1,197 µS/cm for WY 2021.

The TP concentrations at CT-2 ranged between 30 and 117 µg/L during the year. The TN concentrations at CT-2 ranged between 590 and 5,300 µg/L during WY 2021. The TSS concentrations ranged between 5 and 19 mg/L.

Overall, Cottonwood Creek TP concentrations were much lower than Cherry Creek just upstream of the Reservoir, but TN concentrations were much higher. Both had elevated concentrations of both nutrients and suspended solids during storm events.

POLLUTION REDUCTION FACILITIES (PRF) HIGHLIGHTS

During WY 2021, samples from 5 complete storm event with the level-based sampling equipment set at all 7 sites with storm sampling equipment were collected. Table B summarizes the changes seen in the various water quality parameters upstream to downstream through each of the different PRFs.

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 2021 in base flow and performed more effectively in storm flows. The other parameters had more variability in measurable changes. The Perimeter Pond showed the highest levels of dissolved nutrient reductions in base and storm flow. In WY 2021, all nutrients were reduced upstream to downstream between MCM-1 and MCM-2 on McMurdo Gulch during base flows.

Table B. Summary of Reductions in Nutrient and Suspended Solids in CCBWQA PRFs, WY 2021. *

PRF	Cottonwood Treatment Train		Peoria Pond		Perimeter Pond		Cottonwood Creek btw Ponds		McMurdo Gulch
Analyte	Base	Storm	Base	Storm	Base	Storm	Base	Storm	Base
Total Phosphorus	◌	●	◌	●	◌	●			○
Soluble Reactive Phosphorus			◌				◌		○
Total Dissolved Phosphorus		◌		◌	○	○	○		○
Total Nitrogen		◌		◌	◌	○			○
Nitrate+ Nitrite					◌	○			●
Ammonia									◌
Total Suspended Solids	○	●		●	○	●			
Volatile Suspended Solids	○	●		●	◌	●			

**Note:* ◌ - reductions of less than 20%, ○ - reductions between 25-50%, ● - reductions of >50%, blank cells indicate no reduction or an increase upstream to downstream

During the last few years, there has been increased effort in evaluating the effectiveness of the individual PRFs to determine statistical significance of changes in concentrations of each parameter at PRF sites. In order to see a snapshot of the potential results that can be generated, the PRF Statistics Tool (https://www.ccbwqportal.org/prf-statistics-tool) was applied to analyze if median downstream concentrations are statistical lower that upstream PRF concentrations using a 10 year timeframe.

The Cottonwood Treatment Train as a whole, showed statistically significant removal efficiencies of TP and TSS showed that it was statistically significant from 2011-2021. Peoria Pond also showed similar significance of removal of TP and TSS upstream to downstream in storm flow conditions over the same time period. The Perimeter Pond PRF demonstrated significant median reductions in TP, TN, and TSS concentrations in base and storm flow conditions during 2011-2021. The McMurdo Gulch analysis demonstrated a statistically significant reduction of TP and TP from 2012 (when monitoring started at that site) through 2021.

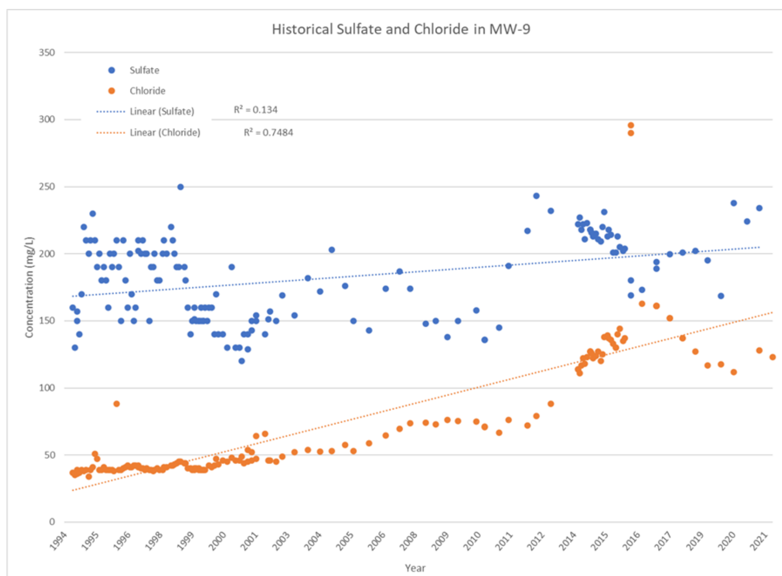
GROUNDWATER HIGHLIGHTS

The groundwater and alluvium of Cherry Creek plays a role in nutrient dynamics as water moves down the watershed and the inflows into the Reservoir. TP concentrations in groundwater (GW) samples collected from the three monitoring wells upstream and one site downstream of the Reservoir, had significant variability but had a mean values of 0.52 mg/L on the two monitoring dates in WY 2021. 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. TN in groundwater averaged 2.6mg/L in WY 2021.

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 for the most part.

During both sampling events in WY 2021 GW chloride concentrations averaged 139 mg/L and sulfate concentrations averaged 133 mg/L. The pH remained relatively constant, and the conductivity seemed to follow the trend of the concentrations of chloride and sulfate.

During WY 2021, the pH values from the monitoring wells ranged between 6.5 and 7.4, with an historical mean value of near neutral at 7.1. The historical values suggest that the pH at MW-9 are remaining relatively constant 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 2021.



Analysis of the historical data for MW-9 from 1994-2021 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 over time, with an annual mean of 256 µg/L in WY 2021.

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 2020 and in May 2021 were 2.5 mg/L, which is slightly lower than the long-term average of 3.2 mg/L from 2014-2021. 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 2021 are:

- Cherry Creek: 16,773 AF
- Cottonwood Creek: 4,517 AF

The estimated evaporative losses from the Reservoir were 3,241 AF during WY 2021, or approximately 40.4 inches (3.37 feet) per acre at the median surface area of 801 acres.

The USGS measured outflows for WY 2021 at Station 06713000, Cherry Creek below Cherry Creek Lake, CO, totaled 16,979 AF, which were used for nutrient balance calculations.

The Reservoir WY 2021 water balance is summarized in Table C. The Reservoir change in storage in WY 2021 was reported by the U.S. Army Corps of Engineers (USACE) was 121 AF (account for rounding errors). The net ungauged inflows(+)/outflows(-) were mathematically calculated in conjunction with the known inflows and outflows to equal the USACE change in storage values. The ungauged flows include ungauged surface water inflows into the Reservoir, GW seepage from the Reservoir through the dam, and measurement uncertainties. Net ungauged outflows for WY 2021 were -4,262 AF which were apportioned between the Cherry Creek and Cottonwood Creek inflows to calculate nutrient loading (see next section). Cherry Creek contributed 78.8% of the combined inflow and Cottonwood Creek contributed 21.2%, based on the 15-minute data obtained from the ISCO samplers.

Table C. WY 2021 Water Balance

Water Source	Water Volume (AF)
Inflows	
Cherry Creek (CC-10)	16,773
Cottonwood Creek (CT-2)	4,517
Precipitation	1,113
Alluvial groundwater	2,200
Total Inflows	**24,603**
Outflows	
Evaporation	-3,241
Reservoir releases	-16,979
Total Outflows	**-20,220**
Net Ungauged Inflows/Outflows	
Calculation	**-4,262**
WY 2021 Change in Storage	121

NUTRIENT BALANCE HIGHLIGHTS

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 2021 flow-weighted TP concentration of all inflows was 176 µg/L, which is slightly higher than WY 2020 (173 µg/L), but 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 WY 2021 flow weighted TN inflow concentration of 1,423 µg/L is lower than WY 2020 (1,491 µg/L), 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 2021 are summarized in Table D.

The Reservoir inflows (nutrient loads) considered in the WY 2021 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 were calculated for WY 2021 based on the nutrient calculations for inflow and releases. The WY 2021 TP and TN mass balances are summarized in Table E. The difference between the inflow and the outflow loads indicate that a net 4,697 pounds of phosphorus and 32,614 pounds of nitrogen were retained in the Reservoir in WY 2021.

Table D. Flow-weighted Nutrient Concentrations to Cherry Creek Reservoir WY 2021.

		Source				
	Nutrient	Cherry Creek	Cottonwood Creek	Alluvial Groundwater	Precipitation	Weighted Total
Inflow Concentration (µg/L)	Total Phosphorus	133	12	25	5	176
	Total Nitrogen	916	342	61	104	1,423
% of Total Inflow		**65.7%**	**18%**	**10.8%**	**5.5%**	**100%**

The calculated total phosphorus and nitrogen loads in WY 2021 were slightly higher than WY 2020 but lower than the long-term historical mean from 1993-2021.

Table E. Nutrient Mass Balance for WY 2021

Water Source	Total Phosphorus (lbs) Mass (pounds)	Total Nitrogen (lbs) Mass (pounds)
Inflows		
Cherry Creek (CC-10)	7,544	51,841
Cottonwood Creek (CT-2)	679	19,410
Precipitation	266	5,888
Alluvial groundwater	1,418	3,428
Total Inflows	**9,907**	**80,567**
Outflows		
Evaporation	0	0
Reservoir releases	-5,210	-47,953
Total Outflows	**-5,210**	**-47,953**
WY 2021 Change in Storage	**4,697**	**32,614**

CONCLUSIONS AND RECOMENDATIONS

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 contribute to phytoplankton productivity and higher chl α concentrations. Cherry Creek Reservoir continues to remain in the eutrophic to hypereutrophic range based on total phosphorus, chl α and water transparency. Although there were no closures due to dense algal blooms in WY 2021, cyanobacteria continue to be present at high numbers within the Reservoir and historically have been present at higher density when nitrogen limitation was present.

Surface water flows are the main contributor of nutrient concentrations in the inflows and nutrient loading of the reservoir. Weather and precipitation in the watershed, directly impact the water quantity and quality entering the Reservoir, internal dynamics and the overall exchange rate.

There continues to be a significant difference in water quality between Cherry Creek and Cottonwood Creek. Cherry Creek has much higher concentrations of phosphorus, but Cottonwood Creek has higher concentrations of nitrogen. These streams show differences in the stream channel morphology, flow patterns, wetlands, vegetation growth patterns, variability from storm events, watershed development, number of permitted WWTP discharge outfalls, and differences in runoff from the watersheds. All of these factors, as well as PRFs and water quality controls of our partners, affect the concentrations of nutrients and solids in the water.

The Cherry Creek watershed has seen significant increases in population and both residential and commercial construction over time. Up-basin MS4 permittees have developed BMPs to treat urban storm water and runoff from impervious areas and minimize negative water quality impacts. Authority implemented PRF projects have also been completed in order to minimize potential negative water quality impacts of these changes in the Cherry Creek Basin. Overall, the constructed wetland PRF ponds on Cottonwood Creek function effectively by reducing total phosphorus and suspended solids in storm flows on an annual and long-term basis.

4,697 lbs of Phosphorus and 32,614 lbs of Nitrogen were calculated to be stored in the Reservoir in WY 2021. The total nutrient mass storage in Cherry Creek Reservoir was more than in WY 2020 but less than the historical mean from 1993-2020.

The following recommendations, which are based on sampling and data analysis in WY 2021 and previous years, 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.

- The continued monitoring of individual TDS components will help determine what is leading to the increased conductivity in Cottonwood Creek, Cherry Creek and the Reservoir. Individual analyses for Chloride, Sulfate, Magnesium, Sodium, Potassium, Calcium, and Alkalinity are being completed to determine what components may be having the largest impacts.
- Efforts have been made to increase accuracy of level and flow gauging on Cherry Creek upstream of the Reservoir to capture information from flows during large storm events that may bypass the current gauging station. This will allow for determination of when the stage discharge relationship generated from stream flow measurements will be used and when modeled flows from the new level gauge at Lakeview drive should be used to estimate high flows which will be completed with a full year of data in 2022.
- Assessment of the differences in water quality or statistically significant changes through the PRFs on Cottonwood Creek during specific time periods will help determine scale and frequency of maintenance

of the wetland plants and sediment removal necessary to maintain storage capacity and reduce organic accumulation. The development of the PRF Statistics Tool on the portal can be used complete these calculations based on the question and specific time frames for individual activities or projects.

- During Fall 2021, a pilot wetland harvesting project was completed along the Cottonwood Creek stream corridor and the shoreline of the Perimeter wetland pond PRF. The wetland plants in the project areas were collected to determine density and the plant material was analyzed for nutrient content. The results of this study will inform the mass of nutrients removed during this project and the potential for future similar efforts to be used to remove Nitrogen and Phosphorus from the watershed.
- 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.
- The sediment nutrient concentration samples that were collected in WY 2021 and will be reported in WY 2022 will help indicate what role internal nutrient loading may play in Reservoir dynamics and provide additional information if 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 and *Daphnia lumholtzi,* known as a spiny water flea, may pose direct and indirect impacts to the fishery.
- As build-out and development continues, it may be necessary to add additional monitoring sites or equipment upstream in Cherry Creek and on its tributaries to determine to changes in water quality and to evaluate efforts to mitigate negative effects.

Cherry Creek Reservoir and its tributaries are important assets to all users. Recreational boaters and other water users, 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 and other warm water aquatic life, water supplies, and agriculture to achieve and maintain current water quality standards. CCBWQA 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 CCBWQA Board consists of representatives from two counties, eight cities, one representative from the seven 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 contains 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 for the purpose of flood control. In 1951, the State Parks Board leased Cherry Creek recreation area from the USACE and created the state's first park which was opened in 1959. 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, primary contact, and aquatic habitat.

The Water Quality Control Commission (WQCC) adopted use classifications and water quality standards, most recently effective August 9, 2021. 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. The CCBWQA focuses on improving, protecting, and preserving the water quality of Cherry Creek and Cherry Creek Reservoir, and on achieving and maintaining the existing water quality standards.

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 reductions in nutrient concentrations, and calculate and document compliance with associated water quality standards. In addition, these data are used to update Reservoir and Watershed models.

The *Cherry Creek Basin Water Quality Monitoring Report - Water Year 2021* describes the Authority monitoring program, data collected during the 2021 water year, and an evaluation of the results.

The WY 2021 monitoring program review includes assessment of data and results from the Reservoir and watershed sampling and analysis, 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 including the cumulative effect of BMPs implementation in the basin.

The specific objectives of the SAP/QAPP are to provide means and methods 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 (PRFs).
- Provide data for CCBWQA's Internet Data Portal to facilitate more comprehensive data analysis

The program has also supported other complementary Authority activities over the years, such as calibration of the Reservoir water quality model, 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 2021 Water Year (WY) was completed by SOLitude Lake Management from October 1st, 2020 to September 30, 2021. The 2021 Monitoring Program was conducted in accordance with the 2021 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.

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

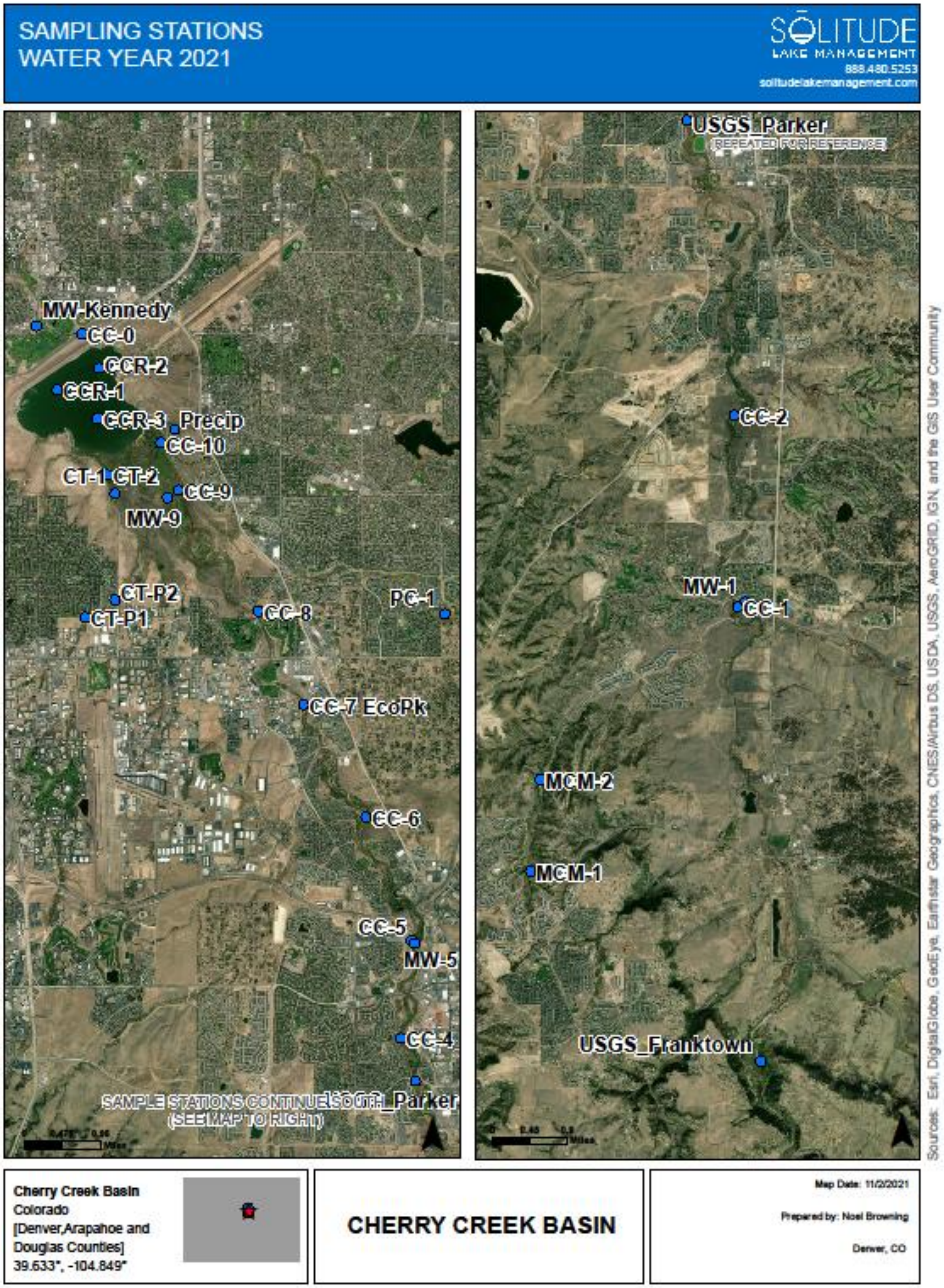


Figure 2. Cherry Creek Basin Monitoring Site Locations

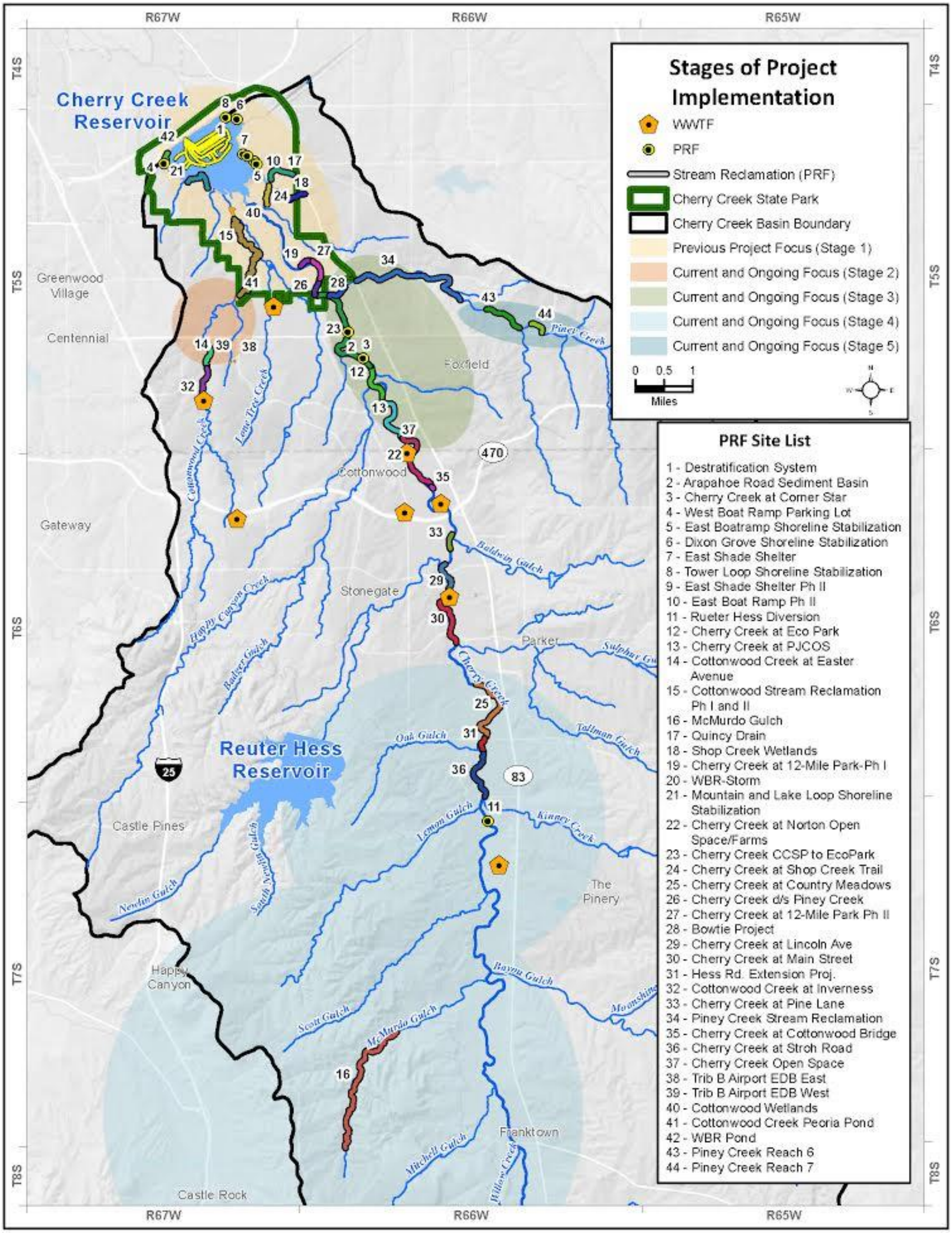


Figure 3. CCBWQA Water Quality Improvement Projects and Pollutant Reduction Facilities

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**
Total Dissolved Solids Components (Ca, Mg, Na, K, $SO_4^{=}$, Cl^-, Alkalinity)		Mar/Sept	7m only Mar/ Sept	
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 7 sites (CC-0, CC-10, CC-7, CT-P1, CT-P2, CT-1, CT-2, PC-1)	Every Other Month Surface Water Samples 2 Sites (MCM-1, MCM-2,)	Storm Event Surface Water ISCO Samples 5 sites (CC-10, CC-7, CT-2, CT-P1, PC-1)	Bi-annual Surface Water Samples 9 sites (USGS Cherry Creek @ Franktown, USGS Cherry Creek @ Parker, CC-1, CC-2, CC-4, CC-5, CC-6, CC-8, CC-9)	Bi-annual Groundwater Samples 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		
Total Dissolved Solids Components (Ca, Mg, Na, K, $SO_4^{=}$, Cl^-, Alkalinity)	X (CC-10, CT-P1, CT-2) March/ Sept				

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 uses." 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 a 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 reactions 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 as concentration (mg/L) or as 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. The disk is slowly lowered into the water column and the depth at which it is no longer visible becomes the Secchi depth. 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 is greater clarity or 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 both an ambient and an 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 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, operationally referred to as soluble reactive phosphorus. Inorganic 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. Organic phosphates are phosphorus forms found in the cells of plants and other organisms and are considered to be biologically unavailable. 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.

Total 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 algal 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 (nitrate, nitrite, and ammonia) to soluble reactive phosphorus (TIN:SRP) can sometimes be more indicative of phytoplankton growth potential since these are the nutrient 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 assign numerical values to trophic state based on multiple water quality parameters. The following are typical characteristics of various trophic states:

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 play a role in conductivity, and 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.

Dissolved Solids - Calcium, Magnesium, Sodium, Potassium, Alkalinity

Other dissolved solids such as Calcium, Magnesium, Sodium, Potassium, and Alkalinity (typically expressed as mg/L $CaCO_3$) can also indicate pollutants entering a watershed such as de-icing products, treated wastewater discharge, stormwater runoff, etc. Since these dissolved ions also impact conductivity, these parameters were included in the data analysis for one reservoir site and 3 surface water sites twice during the year. However, due to laboratory error, these parameters were not analyzed as specified and detailed comparisons were not able to be completed in 2021. However, this analysis will be completed in future monitoring efforts.

Suspended Solids

Total Suspended Solids (TSS) is a quantification of concentrations of suspended sediment and other particulates 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. Suspended solids in the water can indirectly impact chl α concentrations by reducing the opportunity for algae to photosynthesize.

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 2021, 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 additional 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 Latitude (Lat) 39.56°N, Longitude (Long) 104.85°W, and an elevation of 5,869 ft. This station measured a total of 16.25 inches of precipitation in WY 2021, approximately 113% of the historical average since precipitation data has been measured at this weather station from 2006 to present Figure 4). In WY 2021, March, May, and June had significantly above average precipitation measuring 195%, 150% and 146%, respectively, based on the historical monthly averages. October, July and August had well below average precipitation measuring 13%, 87% and 40%, respectively, based on the historical monthly averages of the same period.

Additionally, when looking at NOAA's annual precipitation information, the various areas of the watershed received precipitation ranging between approximately 68 to 183 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 southern area of the watershed received significantly above average precipitation and the central and northern parts received closer to the average based on the 30 PRISM normals.

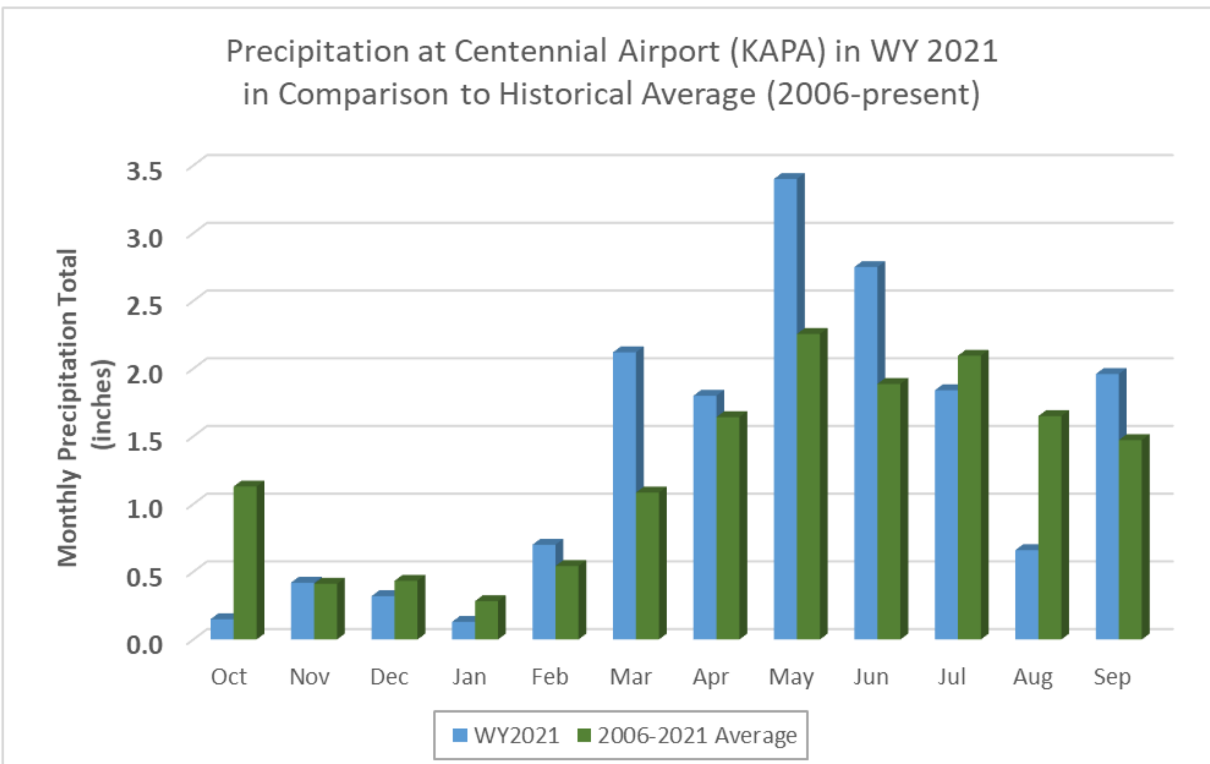


Figure 4. Monthly Precipitation in WY 2021 compared to Historical (2006-2021) average.

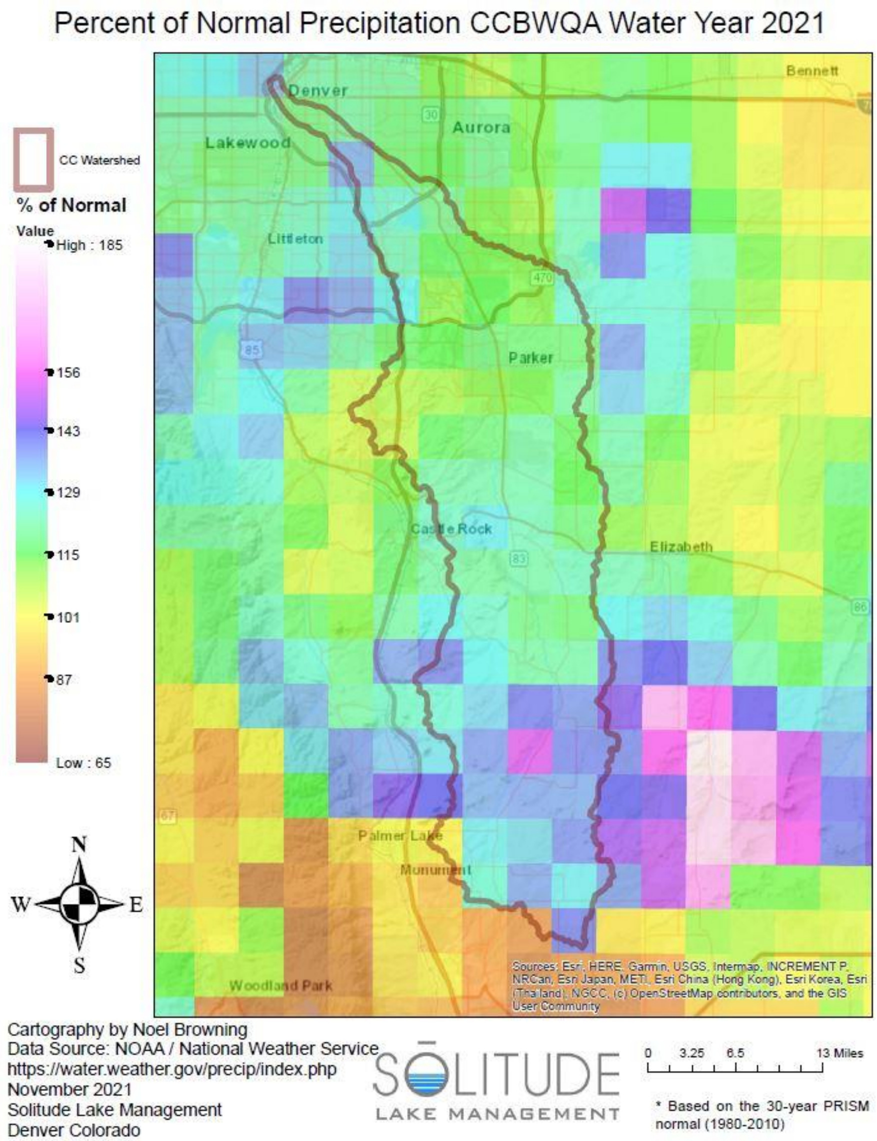


Figure 5. Percent of Normal Precipitation in the Cherry Creek Basin based on 30-year PRISM normal (1981-2010).

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 2021 summary statistics list a total annual flow of 1,469 ft^3 (2,913.2 AF) with an annual daily mean flow rate of 4.02 cfs (7.98 AF/day). This rate was approximately 44.9 % of the annual mean discharge of 8.96 cfs calculated from WY 1940-WY 2021. Figure 6 shows the estimated daily discharge along with the historical daily mean from the last 81 years.

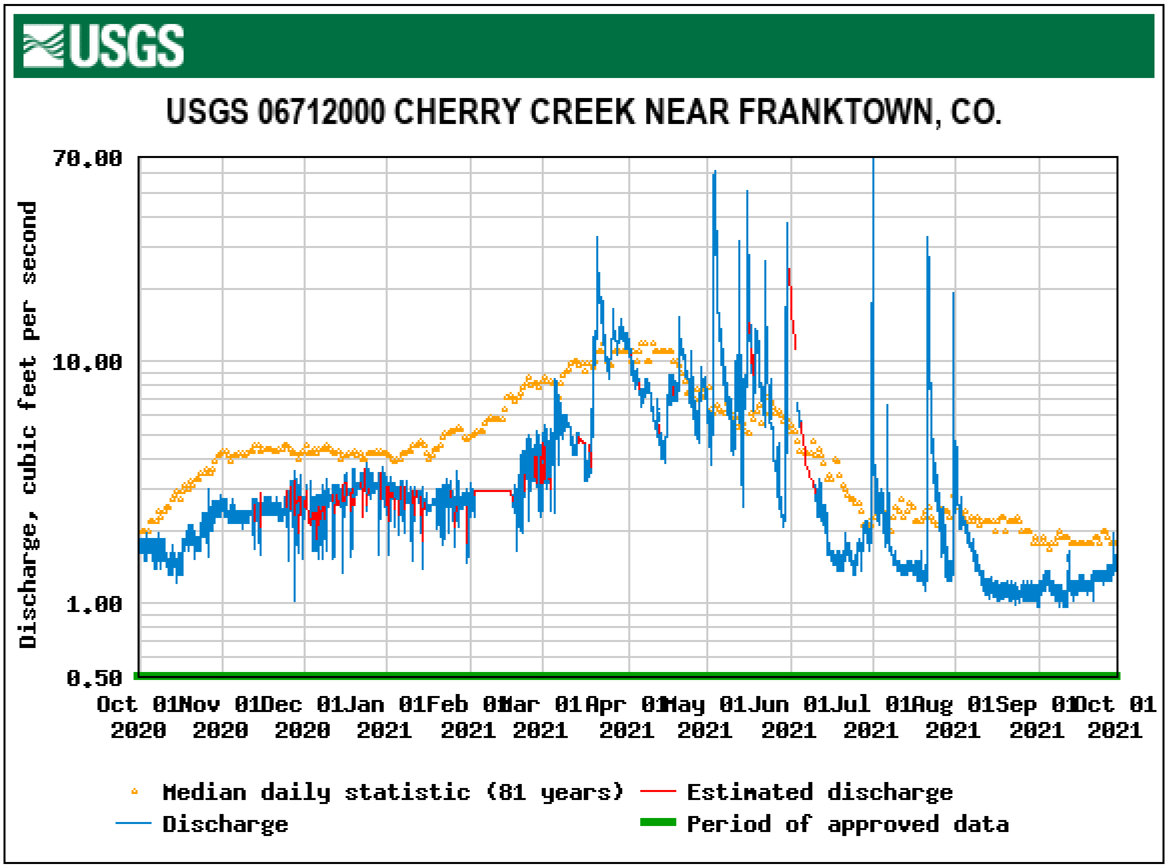


Figure 6. WY 2021 Daily Mean Discharge and Historical Median Flows for USGS Gauge near Franktown (https://nwis.waterdata.usgs.gov/)

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 2021 summary statistics list a total annual flow of 4,125 ft^3 (8,180 AF) with an annual daily mean flow rate of 11.3 cfs (22.4 AF/day). This rate was approximately 100% or equal to the annual mean discharge of 11.3 AF calculated from WY 1992 -WY 2021. Figure 7 shows the estimated daily discharge along with the median daily statistic from the last 29 years.

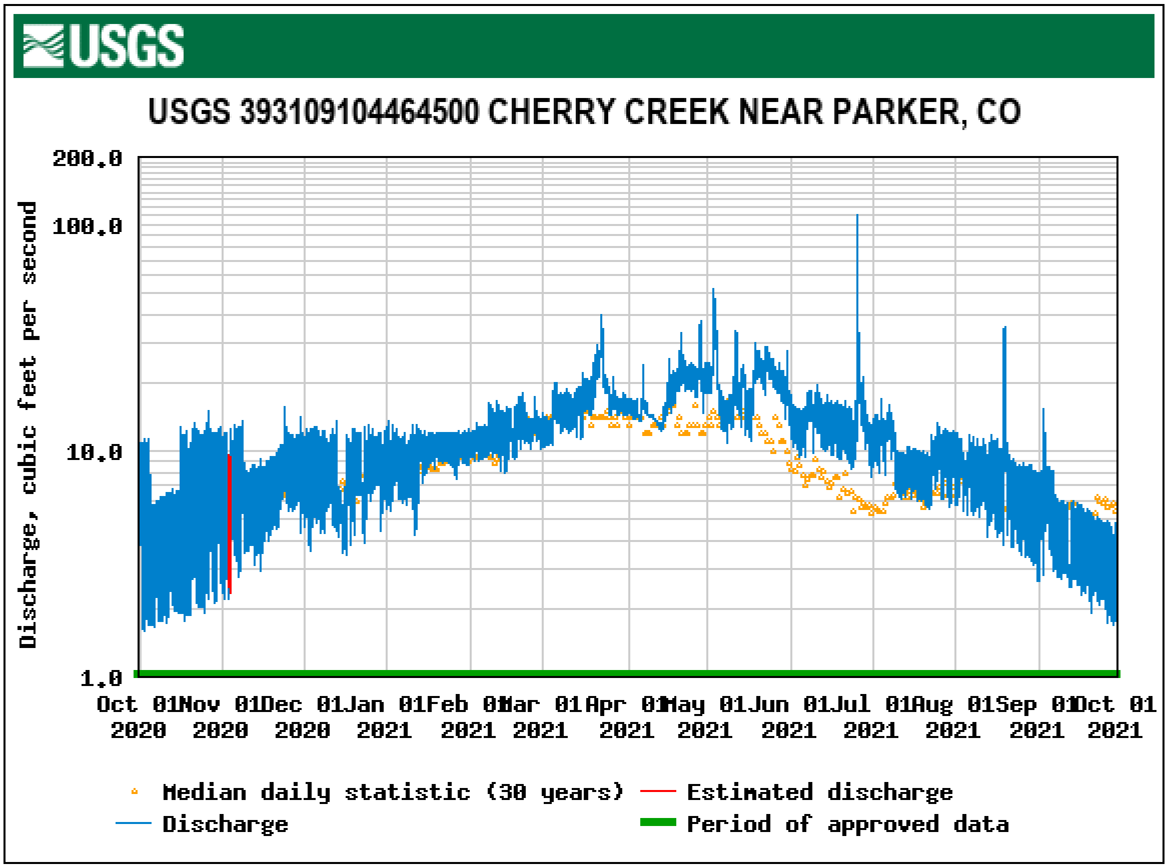


Figure 7. WY 2021 Daily Mean Discharge and Historical Median Flows for USGS Gage near Parker. (https://nwis.waterdata.usgs.gov/)

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. The CCBWQA provides Arapahoe County Water & Wastewater Authority flow data for site CT-1 for Regulation 85 compliance. 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). No ISCO measurements were available for Station CT-2 from February 13 to February 20, 2021, due to instrument and telemetry failure. Daily depths for the missing dates were interpolated to estimate flows for the affected dates. The raw data for the levels and flows are available on the CCBWQA data portal.

The Cherry Creek sub basin is the largest in the watershed and the Cottonwood Creek sub basin makes u only approximately 4% of the total. The estimated WY 2021 flow at the CC-10 monitoring site, on Cherry Creek just upstream of the Reservoir, totals 16,773 AF with an average daily discharge of 46.0 AF. The estimated WY 2021 flow at the CT-2 monitoring site, on Cottonwood Creek Just upstream of the Reservoir, totals 4,517 AF with an average daily discharge of 12.4 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 2021 daily inflow estimates are included in Appendix A.

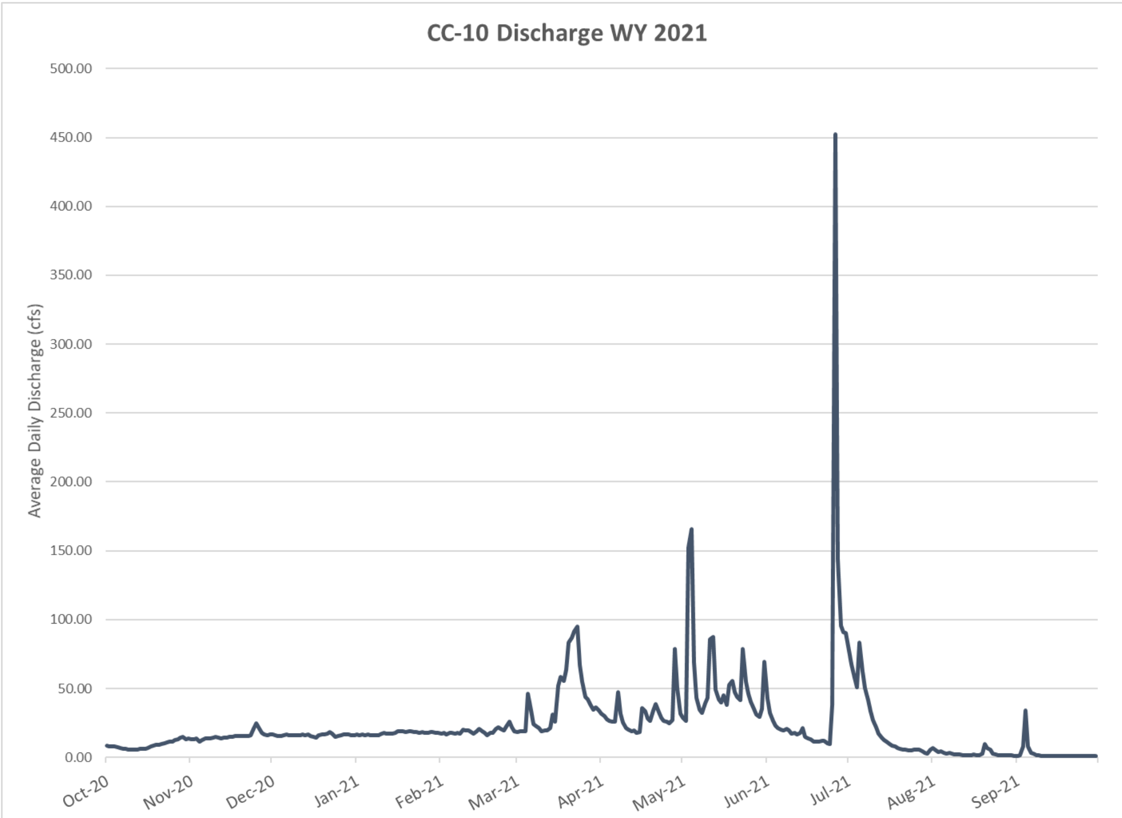


Figure 8. Daily Discharge Rates at CC-10 during WY 2021.

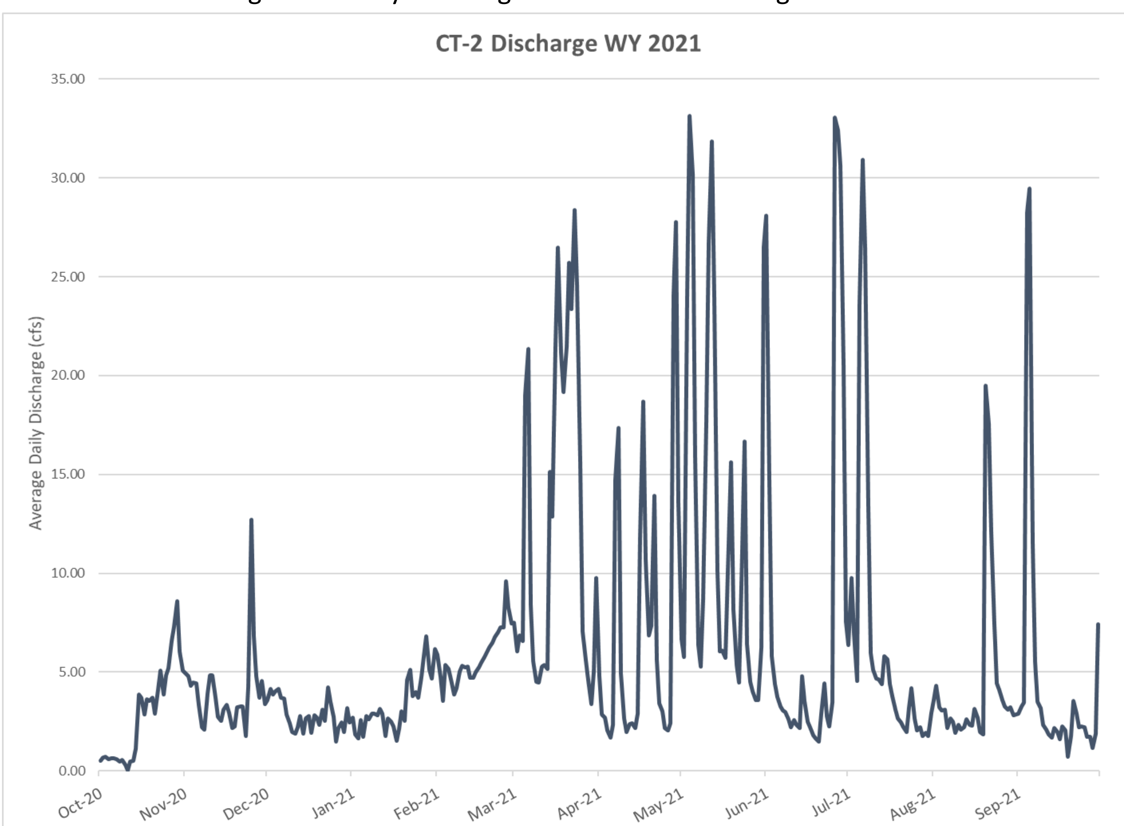


Figure 9. Average Daily Discharge at CT-2 during WY 2021.

3.3 CHERRY CREEK SURFACE WATER QUALITY

Chery Creek flows from south to north to the Reservoir through a 234,000-acre drainage basin. The basin includes various types of land use, including agriculture in the upper basin and higher density 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.

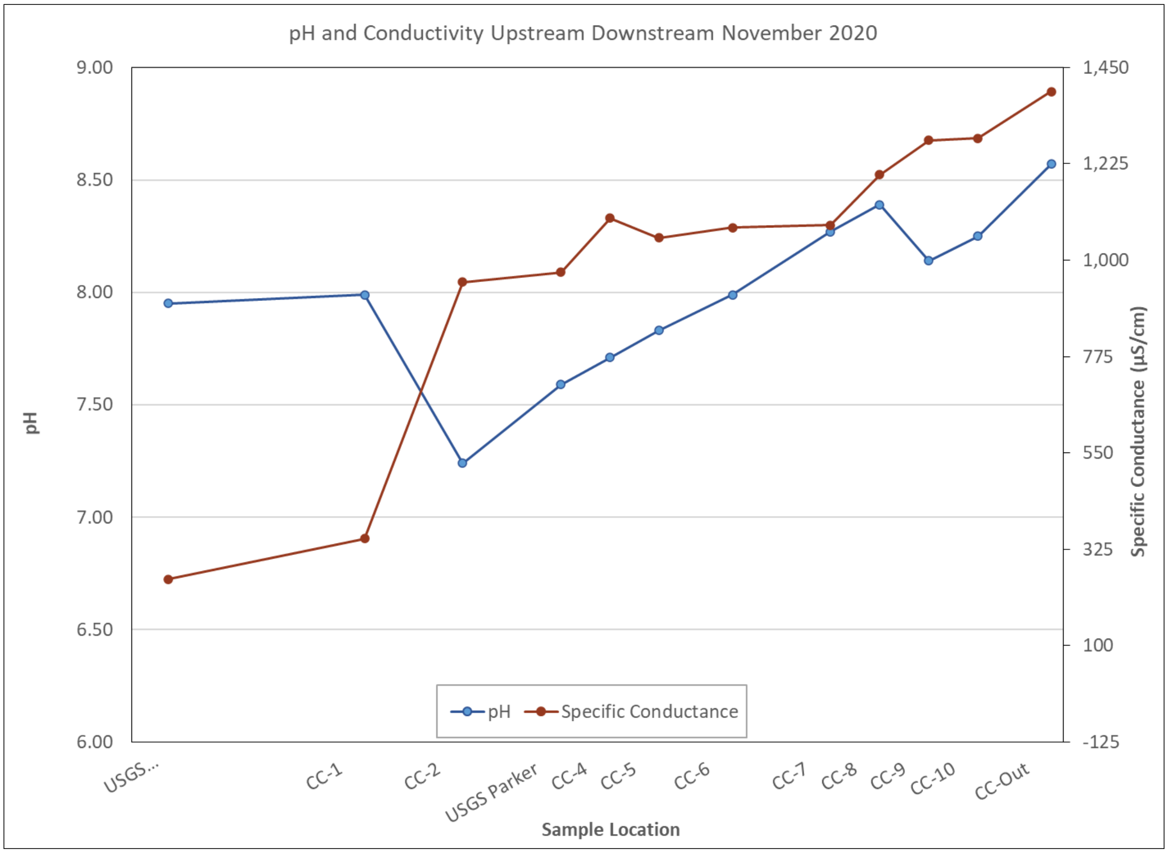


Figure 10. pH and Conductivity Upstream to Downstream on Cherry Creek, November 2020.

The specific conductance (conductivity) and pH were monitored from the surface water sites from the upper basin downstream to the Reservoir in November 2020 and May 2021 (Figure 11 and Figure 11. pH and Conductivity Upstream to Downstream on Cherry Creek, May 2021.). The conductivity increased by a factor of 3.7 from the furthest upstream site (USGS Franktown) to just above where Cherry Creek enters the Reservoir (CC-10) and by a factor of 5.5 at the outlet (CC-O) in Nov 2020. When compared to the furthest upstream site monitored on Cherry Creek, conductivity values were 3.3 times higher in Cherry Creek near the inlet to the Reservoir and 4.8 times higher at the outlet of the Reservoir in May 2021. The increasing conductivity in the upstream to downstream samples during both events indicate increased dissolved solids, such as salts, in the water, as it moves towards and out of the Reservoir. In addition, evaporation and concentration of these dissolved ions could play a role in the increasing conductivity trend downstream, 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 7.2 to 8.6 throughout the basin. The drop in pH between CC-1 and USGS Parker (Figure 10 and Figure 11) could be due to discharges into Cherry Creek between these sites.

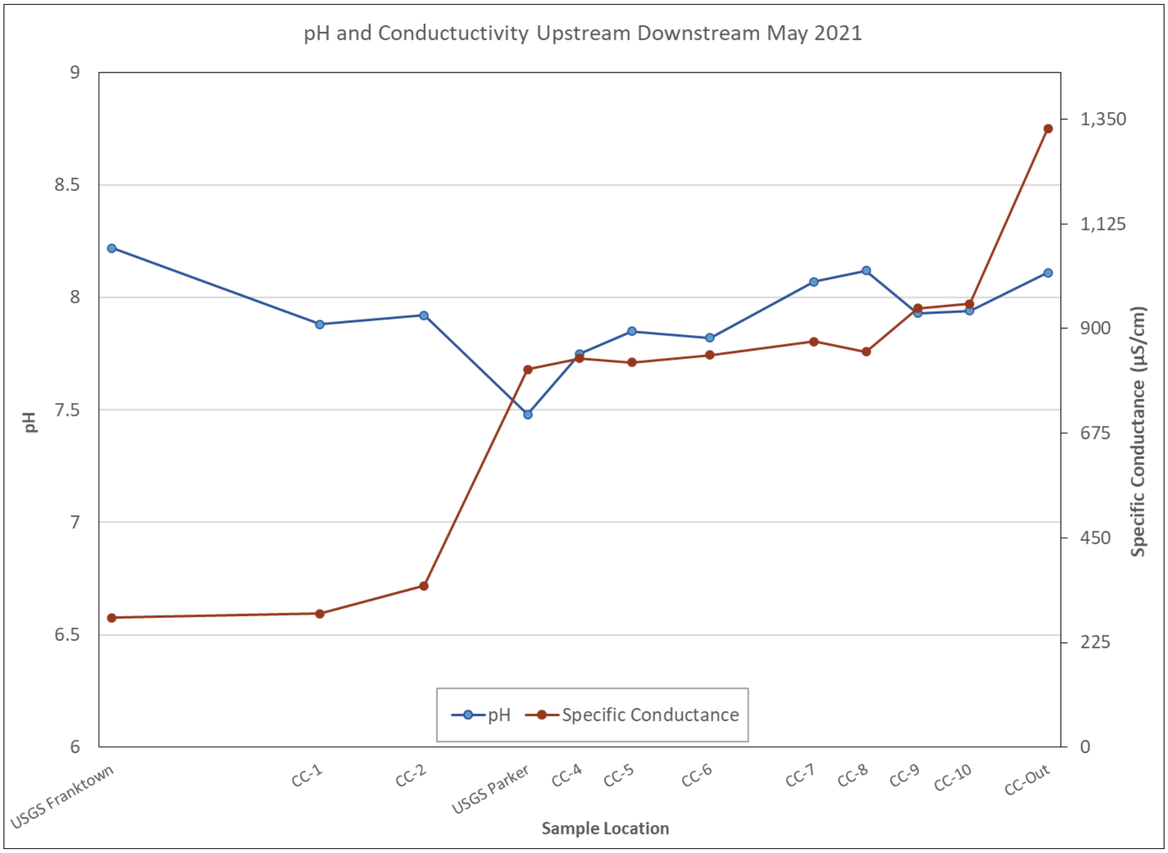


Figure 11. pH and Conductivity Upstream to Downstream on Cherry Creek, May 2021.

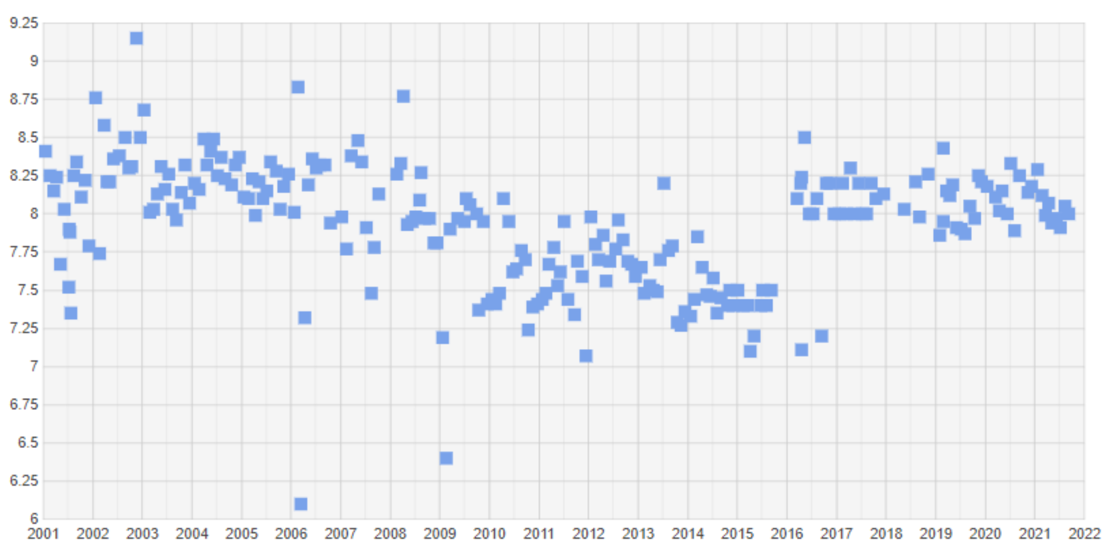


Figure 12. Historical pH Values at CC-10 through WY2021 (X-axis) and pH (Y-axis)

The historical pH values measured at CC-10 appear to have slightly decreased between 2009 and 2016 but have shown higher values since 2017 (Figure 12). In WY 2021, 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 2021, the specific conductance values sampled at CC-10 ranged from 916 to 1,623 µS/cm. The mean specific conductance in Cherry Creek of 1,197 µS/cm during WY 2021 is significantly lower than the mean in Cottonwood Creek, which was 2,087 µS/cm during WY 2021. Cottonwood Creek also had more seasonal variability than Cherry Creek. Figure 18 in Section 3.4 displays the historical trends in conductivity at both sites.

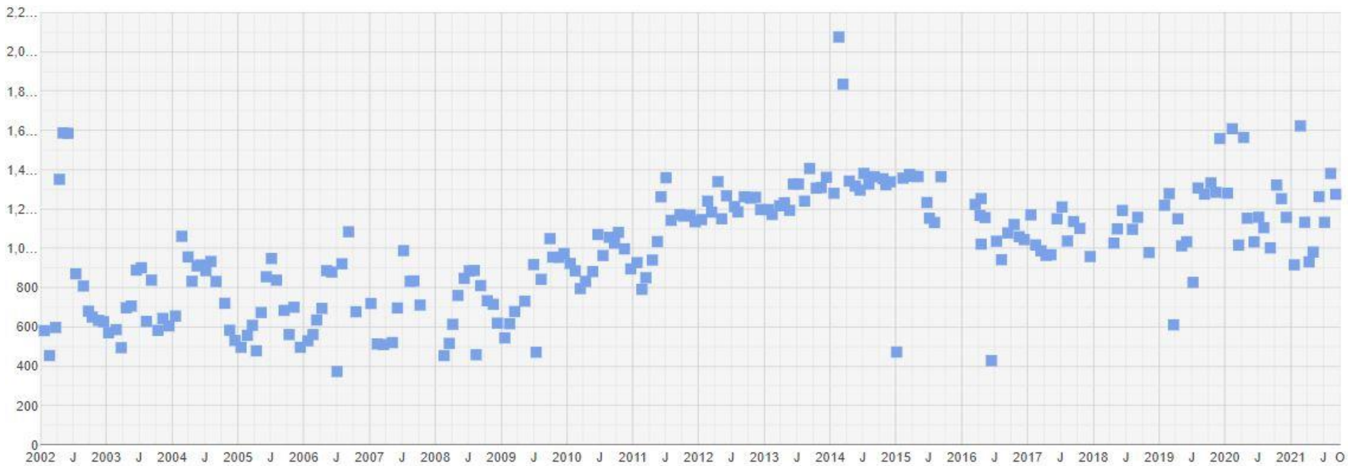


Figure 13. Historic Conductivity at CC-10 through WY 2021. Specific Conductance µS/cm (Y-axis)

During both comprehensive upstream to downstream sampling events, the level of TP had limited variability, but the average concentrations were lower in November 2020 (129 µg/L) than May 2020 (237 µg/L). During both monitoring events, 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). TN concentrations averaged 2.31mg/L in November 2020 and 2.21 mg/L in May 2021.

In November 2020 and May 2021 concentrations of all nutrients were lower below the lake at CC-0 than the sites on Cherry Creek just above the Reservoir, with the exception of ammonia. The concentrations from the bi-annual sampling in WY 2021, 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 2021 are provided in Table 5. Water quality samples from 5 storm events were collected in WY 2021 on May 3rd, 11th, 23rd June 1st and July 7th. The TP concentrations ranged between 87 and 215 µg/L during the water year. The TN concentrations ranged between 328 and 2340 µg/L during WY 2021. The values of TSS ranged between 4.3 and 128 mg/L. Based on the characterization of the 5 storm events that were collected in WY 2021, 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 2021. Typically storm flows increase the suspended sediments in the water, represented by higher values of TSS. During WY 2021, the captured storm events indicated a correlation between storm flows and increases in Phosphorus concentrations and often Nitrogen as well with higher TSS levels (Table 5). These data, along with historical trends, suggest that storm events make a large contribution of the total nutrient and sediment loading to the Reservoir.

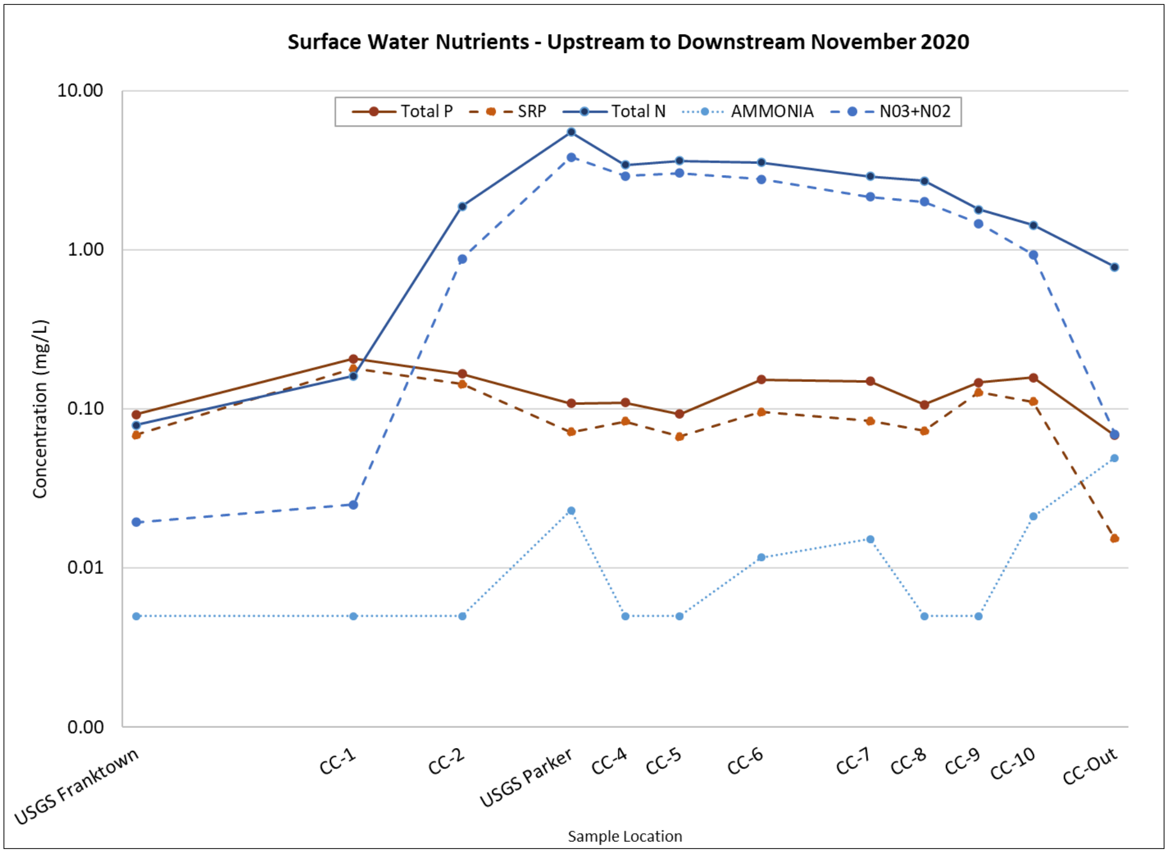


Figure 14. Surface Water Nutrient Sampling of Cherry Creek, November 2020.

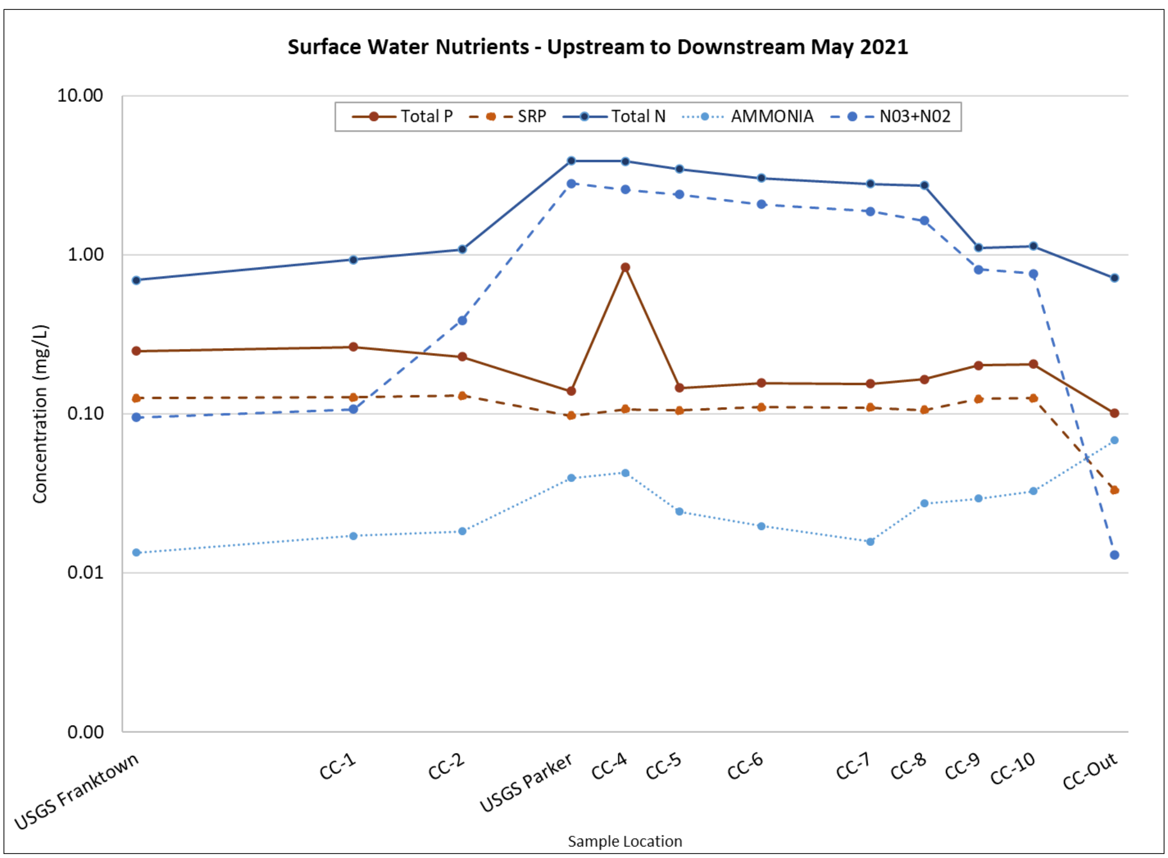


Figure 15. Surface Water Nutrient Sampling of Cherry Creek, May 2021.

Table 5. WY 2021 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	5	-	12	5	-	12	5	-
Minimum	119	232	49%	327	1,120	71%	4	51	92%
Maximum	282	340	17%	2340	1,530	-53%	38	128	70%
Mean	185	286	35%	1263	1,330	5%	14	93	85%
Median	176	283	38%	1205	1,300	7%	11	109	90%

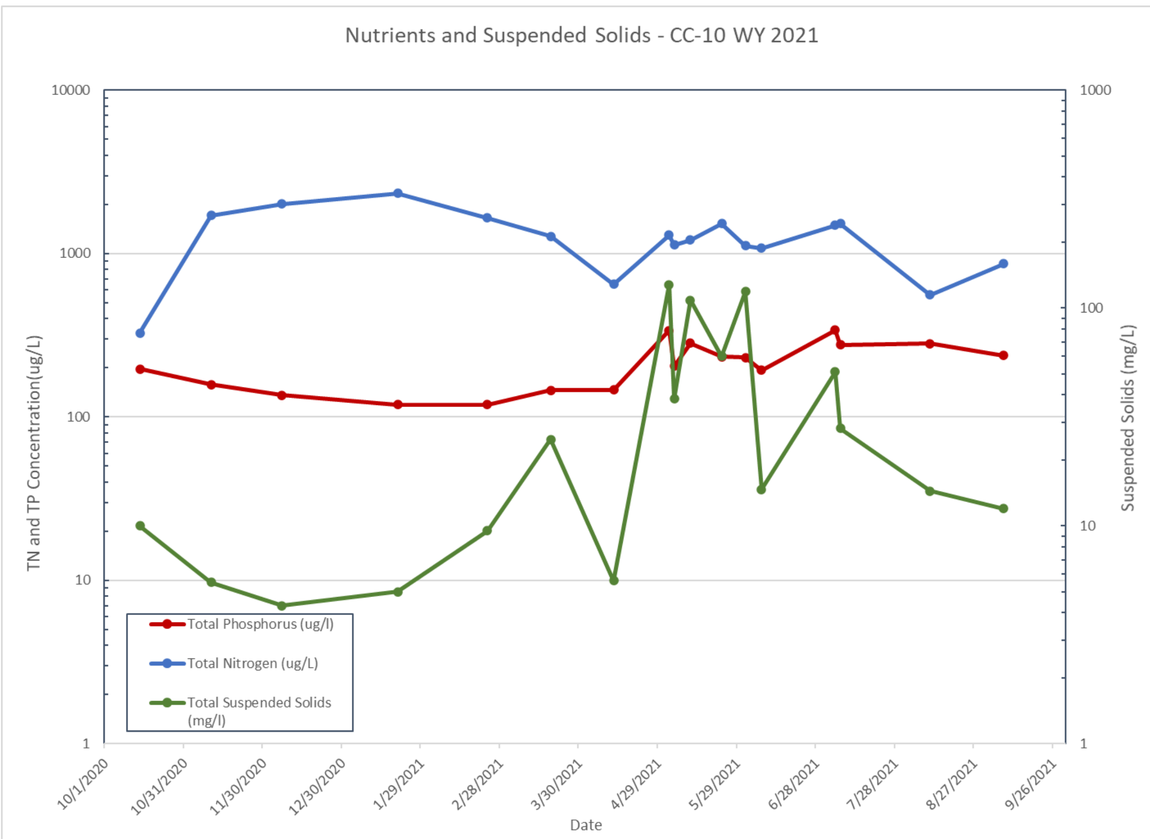


Figure 16. Total Phosphorus, Total Nitrogen and Total Suspended Solids at CC-10, WY 2021.

3.3.1 PINEY CREEK

Piney Creek is one of the primary tributaries which feeds Cherry Creek and is a sub basin of approximately 14,080 acres. This site is monitored to determine baseline data from this sub-basin and potential influence the water quality in Piney Creek may have downstream and on Cherry Creek. Data from PC-1, which is located South of Buckley Rd and East of S Waco St. has been collected since 2018. Summary statistics for total phosphorus, total nitrogen, and TSS concentrations at PC-1 during base and storm flows during WY 2021 are provided in Table 6. Due to the timing of storms and equipment problems in 2021, only three (2 composite, 1 grab) storm samples were collected from this site.

The TP concentrations ranged from 32 and 556 µg/L during the year. The TN concentrations ranged from 333 and 2,380 µg/L. The values of TSS ranged from 1 to 232 mg/L. The mean concentrations of TP, TN and TSS during storm flows were 65%, 48% and 94% higher respectively when compared to base flow conditions.

Table 6. WY 2021 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	3	-	12	3	-	12	3	-
Minimum	32	103	69%	333	902	63%	1.0	11	91%
Maximum	305	556	45%	1680	2380	29%	28.0	232	88%
Mean	121	347	65%	889	1721	48%	9.2	154	94%
Median	110	383	71%	796	1880	58%	5.5	220	98%

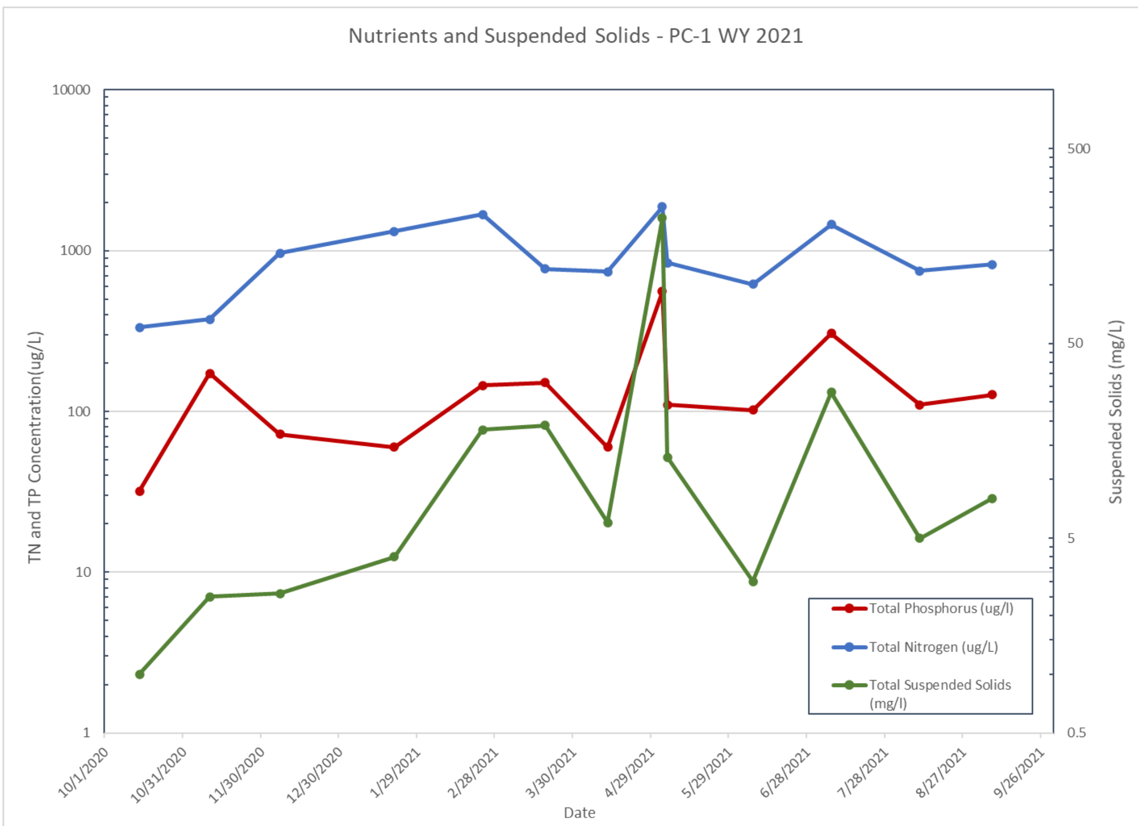


Figure 17. Total Phosphorus, Total Nitrogen and Total Suspended Solids at PC-1, WY 2021.

During WY 2021 the pH values in Piney Creek ranged between 7.94 and 8.44, and the specific conductance values ranged from 906 to 2,393 µS/cm. The mean specific conductance on Piney Creek was 1,731 µS/cm, which is higher than the specific conductance of 1,190 µS/cm in Cherry Creek, but still significantly lower than the mean of 2,390 µS/cm on Cottonwood Creek during WY 2021.

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 are included in Table 7. During WY 2021 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's inflows are not negatively impacting the quality in Cherry Creek during base flow conditions. As more data become available from this site, additional statistical analysis can be completed to compare the water quality upstream and downstream of where Piney Creek enters Cherry Creek.

Table 7. Water Quality in Piney Creek, Upstream, and Downstream of Confluence with Cherry Creek, WY 2021.

Base Flow	Mean Concentration		
N=	12	12	12
	Site		
Analyte	CC-7	PC-1	CC-10
TP, µg/L	136	121	185
SRP, µg/L	85	132	132
TDP, µg/L	98	80	145
TN, µg/L	2,669	889	1,263
NO_3+NO_2-N, µg/L	1,683	297	850
NH_3-N, µg/L	18	21	22
TSS, mg/L	14	9	14
VSS, mg/L	4	3	3

3.4 COTTONWOOD CREEK SURFACE WATER QUALITY

Cottonwood Creek is the second largest surface water input to Cherry Creek Reservoir. Cottonwood Creek has a sub-basin of 9,050 acres, 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 2021, the pH of water in Cottonwood Creek before it entered the Reservoir ranged from 7.4 to 8.2, but it has remained relatively consistent over time.

Conductivity, or specific conductance, at CT-2 ranged between 814.3 µS/cm and 4,507µS/cm with a mean value of 2,087 µS/cm, which is significantly higher than the mean for Cherry Creek (1,197 µS/cm) for WY 2021. Historical conductivity is plotted in Figure 18 and shows an increasing trend with greater variability over time, specifically in Cottonwood Creek.

Summary statistics for total phosphorus, total nitrogen, and TSS concentrations at CT-2 during base and storm flows during WY 2021 are provided in

Table 8. The TP concentrations ranged between 30 and 117 µg/L during the year. The TN concentrations ranged between 590 and 5,300 µg/L during WY 2021. The TSS concentrations ranged between 5 and 19 mg/L. Of the five samples collected to characterize storm flow in WY 2021, the mean and median concentrations of TP were 22% and 6% higher than in the base flow samples. The mean and median TN concentrations at CT-2 were

actually 55% and 16% lower than the maximum concentration during base flow conditions due to the high variability and the very high concentrations seen in December 2020 and Jan 2021. The mean TSS concentrations at CT-2 were 13% higher in storm flows but the median concentrations were actually 29% less due to limited variability among the samples.

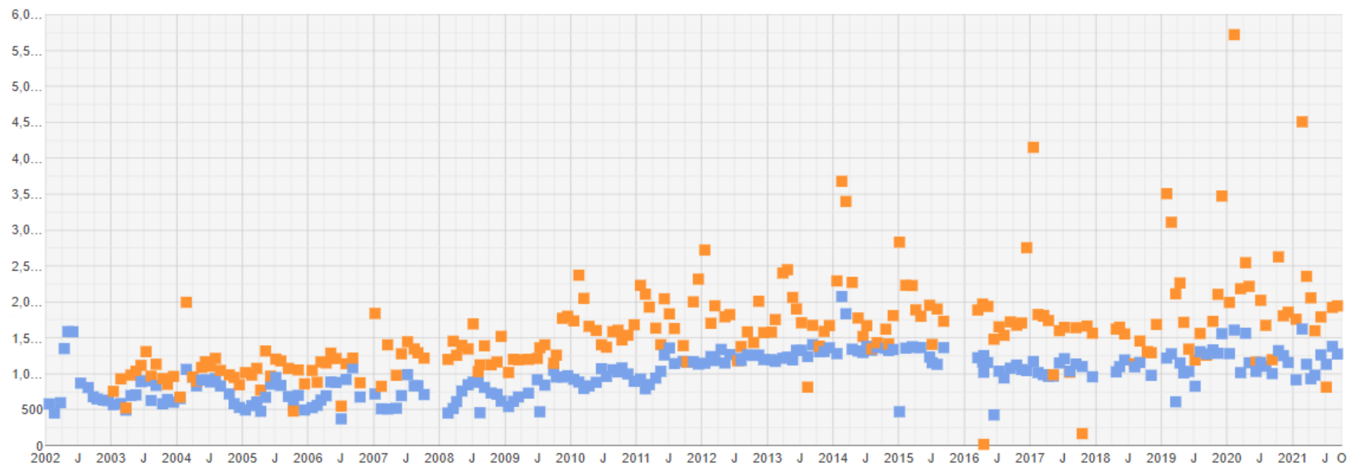


Figure 18. Historic Conductivity at CC-10 and CT-2 through WY 2021. Specific Conductance µS/cm (Y-axis)

CC-10 CT-2

Table 8. Total Phosphorus, Nitrogen and Suspended Solids at CT-2 during Base and Storm Flows, WY 2021.

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	5	-	12	5	-	12	5	-
Minimum	30	50	40%	590	1120	47%	5	5	0%
Maximum	117	109	-7%	5300	1660	-219%	19	22	14%
Mean	59	74.8	22%	2267	1462	-55%	9.5	10.9	13%
Median	57	60	6%	1825	1570	-16%	9	7	-29%

The concentrations of TP and TN measured at CT-2 in WY 2021 are shown in Figure 19 with the TSS values on the second axis as a comparison. As displayed in the graph, a similar positive relationship between nutrients and TSS is present on CT-2, although it appears less significant than seen in Cherry Creek since, overall, the TP concentrations are much higher entering the Reservoir at Cherry Creek than from Cottonwood Creek during WY 2021.

A summary of the mean water quality concentrations at CT-2 during base flow conditions for WY 2021 is provided in Table 9.

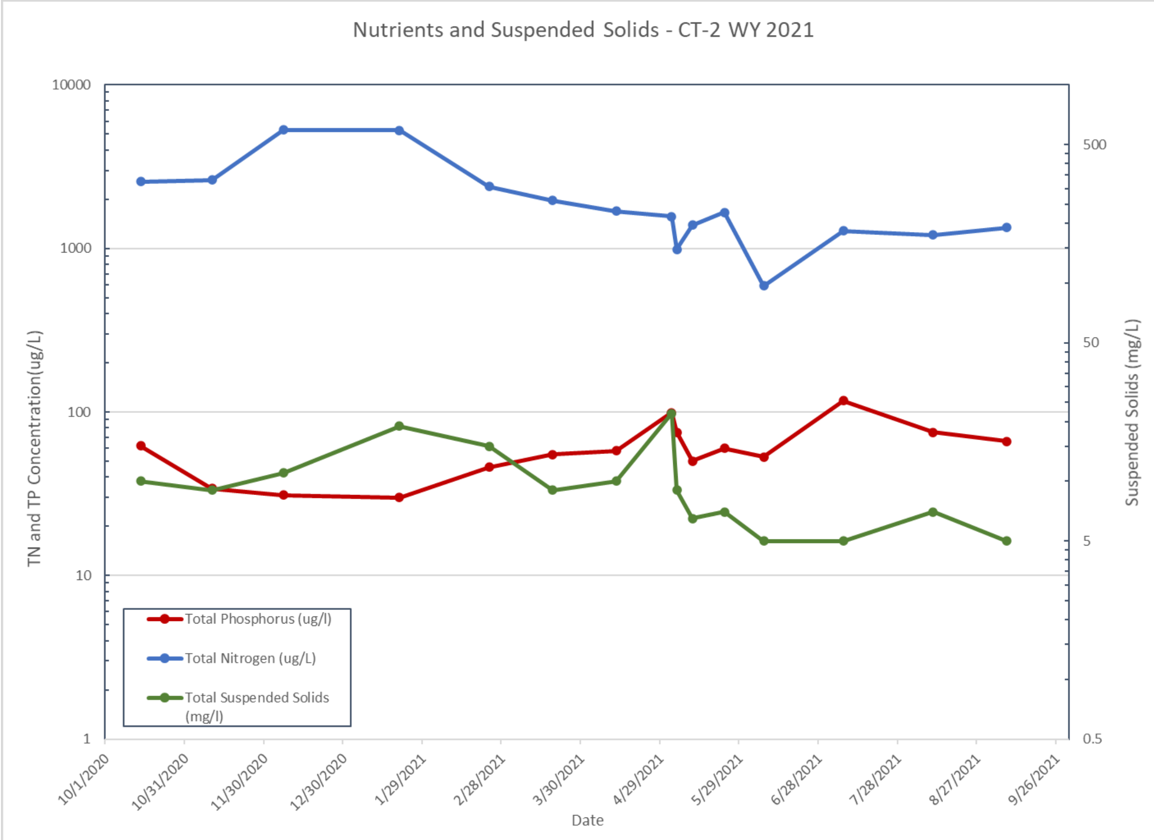


Figure 19. Total Phosphorus, Total Nitrogen and Total Suspended Solids CT-2, WY 2021.

Table 9. Water Quality Summary for CT-2 Base flow conditions WY 2021.

Base Flow	CT-2
Analyte	Mean Concentration
TP, µg/L	59
SRP, µg/L	15
TDP, µg/L	24
TN, µg/L	2,267
NO3+NO2-N, µg/L	1,344
NH3-N, µg/L	57
TSS, mg/L	9.5
VSS, mg/L	3.2

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. Monitoring of PRF's is conducted in accordance with REG 72.8.1(b).

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 - which has been reclaimed as a PRF - between the two ponds is evaluated by looking at the changes in water quality between CT-P2 and CT-1.

During WY 2021, water samples from five storm events with the level-based sampling equipment set at the monitoring sites were captured. While only a few points are not sufficient to complete a statistically significant analysis, calculations were included for annual reference. The PRF statistics tool available on the CCCBWA portal can analyze the effectiveness upstream to downstream and trends over time in more detail. (Section 3.5.1)

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 10. Summary of Reductions in Nutrient and Suspended Solids in CCBWQA PRFs, WY 2021. *

PRF	Cottonwood Treatment Train		Peoria Pond		Perimeter Pond		Cottonwood Creek btw Ponds		McMurdo Gulch
Analyte	**Base**	**Storm**	**Base**	**Storm**	**Base**	**Storm**	**Base**	**Storm**	**Base**
Total Phosphorus	◌	●	◌	●	◌	●			○
Soluble Reactive Phosphorus			◌				◌		○
Total Dissolved Phosphorus		◌		◌	○	○	○		○
Total Nitrogen		◌		◌	◌	○			○
Nitrate+ Nitrite					◌	○			●
Ammonia									◌
Total Suspended Solids	○	●		●	○	●			
Volatile Suspended Solids	○	●		●	◌	●			

Note: ◌ - reductions of less than 20%, ○ - reductions between 25-50%, ● - reductions of >50%, blank cells indicate no reduction or an increase upstream to downstream

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 2021. Tables 11-14 also indicate increases in concentrations upstream to down in orange and decreases in green.

Based upon the data collected in WY 2021, the Cottonwood Treatment Train as a whole (between Peoria Pond and Perimeter Pond), reduced TP concentrations by approximately 12% under base flow conditions and 80% during storm flows (Table 11). Suspended sediment concentrations, measured as TSS, were reduced by approximately 42% under base flow conditions and 94% during storms. Volatile Suspended Solids or VSS concentrations were reduced by 30% under base flows and 85% during storm events. There were low reductions of SRP up to downstream in base flows and TDP and TN in storm flows. The other nutrients showed higher concentrations in downstream, in base and storm flow conditions. Based on the concentrations in base and storm flow events, the PRFs effectively reduced phosphorus and suspended sediment concentrations in downstream flows during WY 2021 but the other parameters displayed more variability.

Table 11. Pollutant Reduction Analysis of the Cottonwood Creek Treatment Train PRF, WY 2021.

	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	67	59	-8	-12	372	75	-297	-80
SRP, µg/L	16	15	-1	-7	6	21	16	269
TDP, µg/L	23	24	2	7	33	31	-1	-4
TN, µg/L	1,110	2,267	1,157	104	1,605	1,462	-143	-9
NO2+NO3,µg/L	431	1,344	913	212	346	642	296	86
NH_3-N, µg/L	47	57	10	22	42	68	26	62
TSS, mg/L	16	10	-7	-42	169	11	-158	-94
TVSS, mg/L	5	3	-1	-30	26	4	-22	-85

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 2021. TP concentrations of the Peoria Pond PRF demonstrated a similar trend as the entire treatment train with approximately 17% reduction in TP upstream to downstream in base flow and approximately 72% reduction in the mean storm flow. SRP concentrations were lower downstream in base flows but actually higher during the storm events. (Table 12).

TP concentrations of the Perimeter Pond PRF had limited to no reduction in TP upstream to downstream in base flow and approximately 78% reduction in the mean storm flow. SRP and NO2+NO3 showed some increase upstream during base flow but all other nutrient and suspended solid concentrations were lower downstream in base flows and significantly lower during the storm events (Table 13).

Table 12. Pollutant Reduction Analysis of the Peoria Pond PRF, WY 2021.

Peoria Pond	Base Flow				Storm Flow			
	Mean Concentration		Upstream to Downstream		Mean Concentration		Upstream to Downstream	
Site	CT-P1	CT-P2	Net	Percent	CT-P1	CT-P2	Net	Percent
Events	12	11	Difference	Difference	5	5	Difference	Difference
Analyte								
TP, µg/L	67	55	-11	-17	372	103	-269	-72
SRP, µg/L	16	13	-3	-19	6	20	14	245
TDP, µg/L	23	40	18	79	33	29	-4	-12
TN, µg/L	1,110	1,265	156	14	1,605	1,373	-232	-15
NO2+NO3, µg/L	431	574	143	33	346	513	167	48
NH_3-N, µg/L	47	38	-9	-19	42	66	24	58
TSS, mg/L	16	11	-5	-32	169	17	-152	-90
TVSS, mg/L	5	4	-1	-20	26	6	-20	-78

Table 13. Pollutant Reduction Analysis of the Perimeter Pond PRF, WY 2021.

Perimeter Pond	Base Flow				Storm Flow			
	Mean Concentration		Upstream to Downstream		Mean Concentration		Upstream to Downstream	
Site	CT-1	CT-2	Net	Percent	CT-1	CT-2	Net	Percent
Events	12	11	Difference	Difference	6	6	Difference	Difference
Analyte								
TP, µg/L	59	59	0	-1	343	75	-268	-78
SRP, µg/L	13	15	2	18	52	21	-30	-59
TDP, µg/L	34	25	-9	-26	62	31	-31	-50
TN, µg/L	2,687	2,267	-420	-16	2,200	1,462	-738	-34
NO2+NO3, µg/L	1,751	1,344	-407	-23	855	642	-213	-25
NH_3-N, µg/L	40	57	17	43	98	68	-31	-31
TSS, mg/L	14	10	-5	-34	164	11	-153	-93
TVSS, mg/L	4	3	-1	-15	18	4	-14	-78

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 2021 with the exception of small reductions in SRP and TDP during base flow only (

Table 14).

Table 14. Pollutant Reduction Analysis of the Treatment Train between the PRF ponds, WY 2021

Cottonwood Creek Treatment Train 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			5	5		
Analyte								
TP, µg/L	55	59	4	7	103	343	239	232
SRP, µg/L	13	13	-1	-4	20	52	32	159
TDP, µg/L	40	22	-19	-46	29	62	33	116
TN, µg/L	1,860	5,690	3,830	206	1,373	2,200	827	60
NO2+NO3, µg/L	574	1751	1,177	205	513	855	342	67
NH_3-N, µg/L	38	40	2	6	66	98	32	48
TSS, mg/L	11	14	3	29	17	164	147	887
TVSS, mg/L	4	4	0	3	6	18	12	217

One of the upper tributaries of Cherry Creek is McMurdo Gulch, which has multiple reclamation projects completed early in the area's urbanization to install a proactive PRF designed to protect the gulch and reduce sediment and nutrient loading into Cherry Creek. In addition, over the last few years, other improvements have been completed in various reaches of the same area to further stabilize the channel. Routine water quality samples only under base fl1ow 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 2021.

Mean Concentration			Upstream to Downstream	
Flow	Base			
Site	MCM-1	MCM-2	Mean Difference	Percent Change
Events	6	6		
Analyte				
TP, µg/L	356	265	-91	-26
SRP, µg/L	287	230	-57	-20
TDP, µg/L	300	224	-76	-25
TN, µg/L	682	517	-165	-24
NO2+NO3, µg/L	374	150	-224	-60

NH_3-N, µg/L	11	9	-1	-12
TSS, mg/L	1	5	3	221
VSS, mg/L	1	1	0	38

In WY 2021, TP, TDP, SRP, and NO_3+NO_2-N, and NH_3-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 higher downstream, 221% and 37.6% respectively.

3.5.1 LONG TERM PRF EVALUATION

During the last few years, there has been increased effort in evaluating the effectiveness of the individual PRFs to determine statistical significance of changes to efficiency of removal of pollutants over time and in response to maintenance activities. During 2020 and 2021, a data analysis tool was developed by LRE Water that allows real time visualization of the concentrations upstream to downstream from individual years or over a specific time period for individual or multiple monitoring sites, or single PRF or the comparison of two PRFs. Based on the data chosen the tool calculated statistical significance that the median downstream concentration is lower than the upstream. Using a Wilcoxon-Rank test, the tool calculates if the p value is less than 0.05, which means that it is statistically significant.

In order to demonstrate the capabilities of this tool,

When evaluating the Cottonwood Treatment Train as a whole, the removal efficiency of TP and TSS showed that it was statistically significant over the last 10 years. Peoria Pond also showed similar significance of removal of TP and TSS upstream to downstream in storm flow conditions over the same time period.

Table 16, Table 17, Table 18, Table 19, and Table 20 show the median concentrations of TP, TN, and TSS upstream to downstream for the period from 2011-2021 and if the reductions are statistically significant during that time. It is important to note that the basis for this analysis was completed in the same manner for each PRF. During the period evaluated, projects, such as implementation of BMPs and maintenance, such as dredging and wetland harvesting, could have affected results. If more detailed analysis is required to evaluate projects, maintenance activities, or other changes in the watershed, specific evaluations can be completed using the PRF statistics tool (https://www.ccbwqportal.org/prf-statistics-tool).

When evaluating the Cottonwood Treatment Train as a whole, the removal efficiency of TP and TSS showed that it was statistically significant over the last 10 years. Peoria Pond also showed similar significance of removal of TP and TSS upstream to downstream in storm flow conditions over the same time period.

Table 16. Pollutant Reduction Analysis of Cottonwood Treatment Train – 2011-2021 Significance

PRF	**Cottonwood Treatment Train**			
Flow Condition	**Base**		**Storm**	
Analyte	**Median Δ**	**Significant**	**Median Δ**	**Significant**
TP, µg/L	3	No	-187	Yes
TN, µg/L	598.5	No	-40	No
TSS, mg/L	1.07	No	-96.35	Yes

Table 17. Pollutant Reduction Analysis of Peoria Pond – 2011-2021 Significance

PRF	Peoria Pond			
Flow Condition	Base		Storm	
Analyte	Median Δ	Significant	Median Δ	Significant
TP, µg/L	-40	No	-120	Yes
TN, µg/L	209.5	No	-6.5	No
TSS, mg/L	1.1	No	-90.2	Yes

The Perimeter Pond PRF demonstrated significant median reductions in TP, TN, and TSS concentrations in base and storm flow conditions during 2011-2021.

Table 18. Pollutant Reduction Analysis of Perimeter Pond – 2011-2021 Significance

PRF	Perimeter Pond			
Flow Condition	Base		Storm	
Analyte	Median Δ	Significant	Median Δ	Significant
TP, µg/L	-11	Yes	15.5	Yes
TN, µg/L	-250.5	Yes	510	Yes
TSS, mg/L	-8	Yes	9.1	Yes

When looking at the upstream to downstream concentrations of TP, TN and TSS on Cottonwood Creek between the ponds between the ponds, there was no significant reductions between 2011 and 2021 in base or storm flow conditions.

Table 19. Pollutant Reduction Analysis of Cottonwood Creek Between Ponds – 2011-2021 Significance

PRF	Cottonwood Creek Between Ponds			
Flow Condition	Base		Storm	
Analyte	Median Δ	Significant	Median Δ	Significant
TP, µg/L	15.5	No	-28	No
TN, µg/L	510	No	243	No
TSS, mg/L	9.1	No	1.9	No

When reviewing the effectiveness of McMurdo Gulch, the upstream to downstream concentrations of TP and TN during base flow conditions demonstrated a statistically significant reduction from 2012, when monitoring started at that site, through 2021.

Table 20. Pollutant Reduction Analysis of McMurdo Gulch – 2012 -2021 Significance

PRF	McMurdo Gulch	
Flow Condition	Base	
Analyte	Median Δ	Significant
TP, µg/L	-100.5	Yes

TN, µg/L	-172	Yes
TSS, mg/L	0.83	No

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.

Due to an equipment error no data was collected between June 9, 2021 and the end of the water year. For the data that was collected, the groundwater level and temperature groundwater in MW-9 displayed some seasonal fluctuation. The temperature ranged from 9.1 to 9.6˚C, with highest temperatures observed in early November, decreasing through late February and stabilizing in the spring. The water levels in MW-9 increased to the highest level of 11.3 m in early May. Overall, the temperature and trend of water depth was similar to 2019 and 2020.

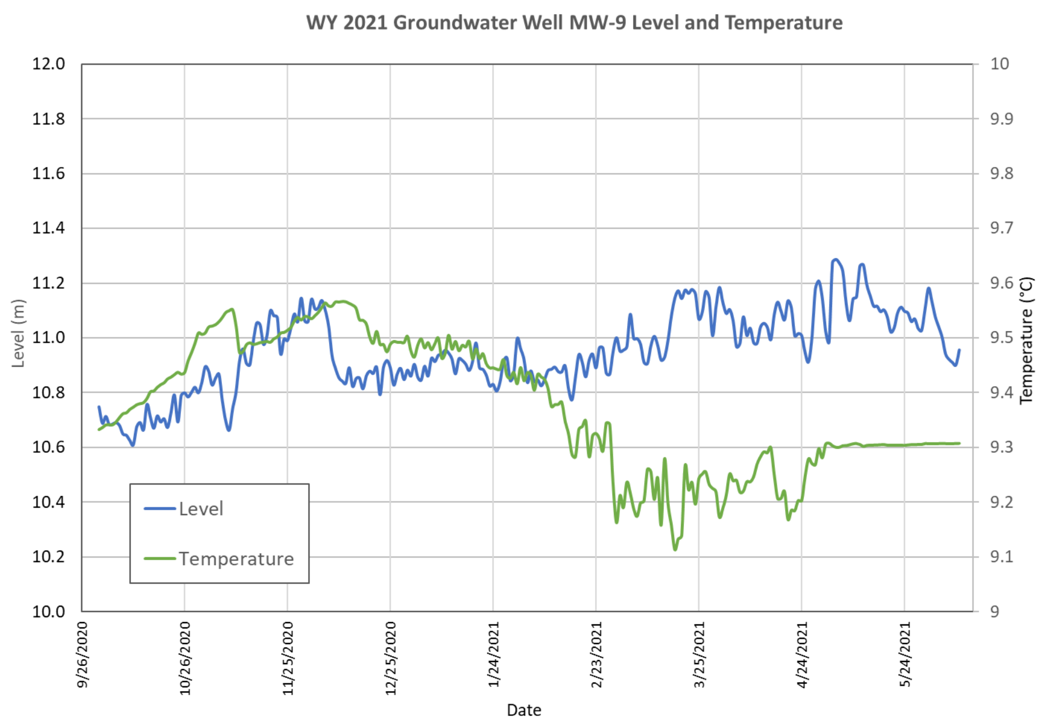


Figure 20. Daily Mean Level and Temperature in Groundwater Well MW-9.

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 Park 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 down gradient from Cherry Creek Reservoir.

The mean concentration of TP (listed in mg/L vs µg/L) from the GW sites during the two monitoring events was 0.52 mg/L, with concentrations averaging 0.6 mg/L in November 2020 and 0.45 mg/L in May 2021. The TP concentrations ranged between 0.27 mg/L and 1.13 mg/L in November 2020, and between 0.24 mg/L and 1.1 mg/L in May 2021. In both November 2020 and May 2021, the TP concentrations were highest at MW-5, less at MW-1, then lowest and similar concentrations at MW-9 and MW-Kennedy, below the Reservoir. (Figure 21 and Figure 22)

The mean concentration of TN (listed in mg/L vs µg/L) from the GW sites during the two monitoring events was 2.6 mg/L, with concentrations averaging 2.15 mg/L in November 2020 and 3.0 mg/L in May 2021. The TN concentrations ranged between 0.23 mg/L and 3.2 mg/L in November 2020, and between 0.19 mg/L and 7.8

mg/L in May 2021. In November 2020, the TN concentrations were similar at MW-5 and MW-3, then decreased at MW-9 and were lowest at MW-Kennedy, below the Reservoir. In May, the TN concentrations were highest at MW-1 and decreased moving towards the Reservoir at MW-5 and MW-9, and the lowest concentrations were seen below the outlet 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 5.3 mg/L was observed in November 2020 from MW-1 and the lowest concentration of 0.2mg/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 2020 and May 2021, the TP concentrations furthest upstream were lower at MW-1, increased to MW-5 then decreased at MW-9 just upstream of the Reservoir, and were again lower at the monitoring well below the reservoir (MW-Kennedy). During November 2020 TN concentrations were slightly higher at MW-5 than MW-1 but then decreased just above and below the Reservoir. In May TN concentrations decreased all the way from the upstream MW-1 to below the Reservoir.

In November 2020 the TP concentrations in the nearby surface water sites represented on the graphs in Figure 21 were lower than the nearby GW sites at all 4 locations. In May 2021 the TP was slightly higher at CC-1 than MW-1 but the rest of the GW sites has higher concentrations than the nearby monitoring wells (Figure 22). TN concentrations were much lower at the surface water site CC-1 than the nearest groundwater site MW-1, similar in the nearby SW and GW sites MW-5/CC-5 and MW-9/ CC-9, and higher in the SW site CC-0 below the Reservoir in both November 2020 and May 2021.

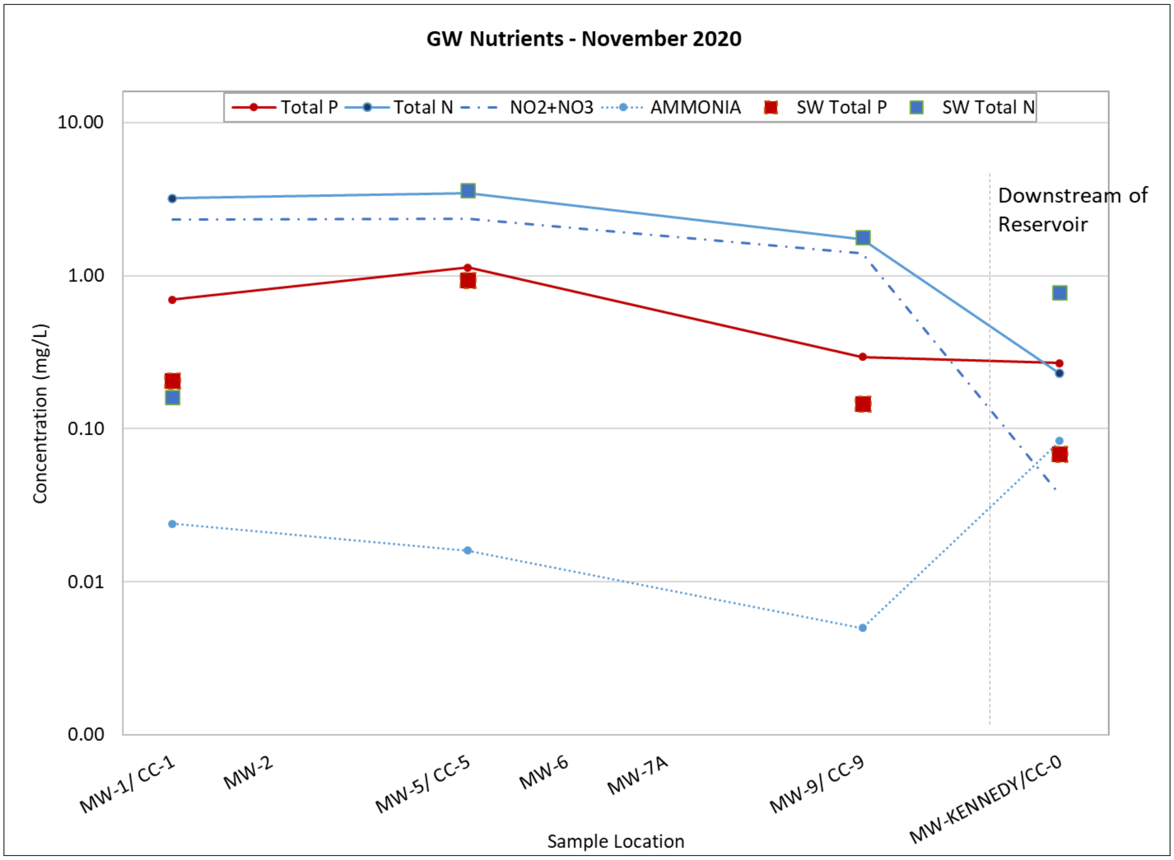


Figure 21. Groundwater Nutrients in Monitoring Well Samples in November 2020.

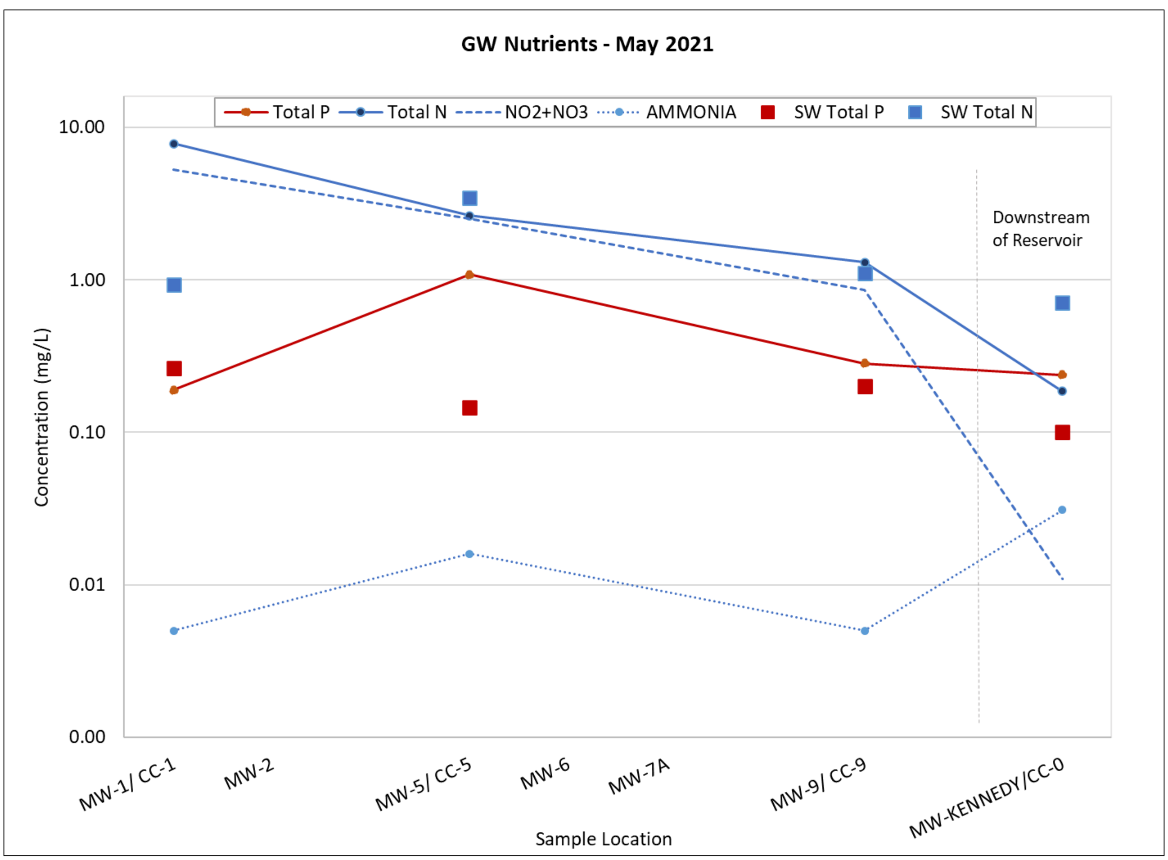


Figure 22. Groundwater Nutrients in Monitoring Well Samples in May 2021.

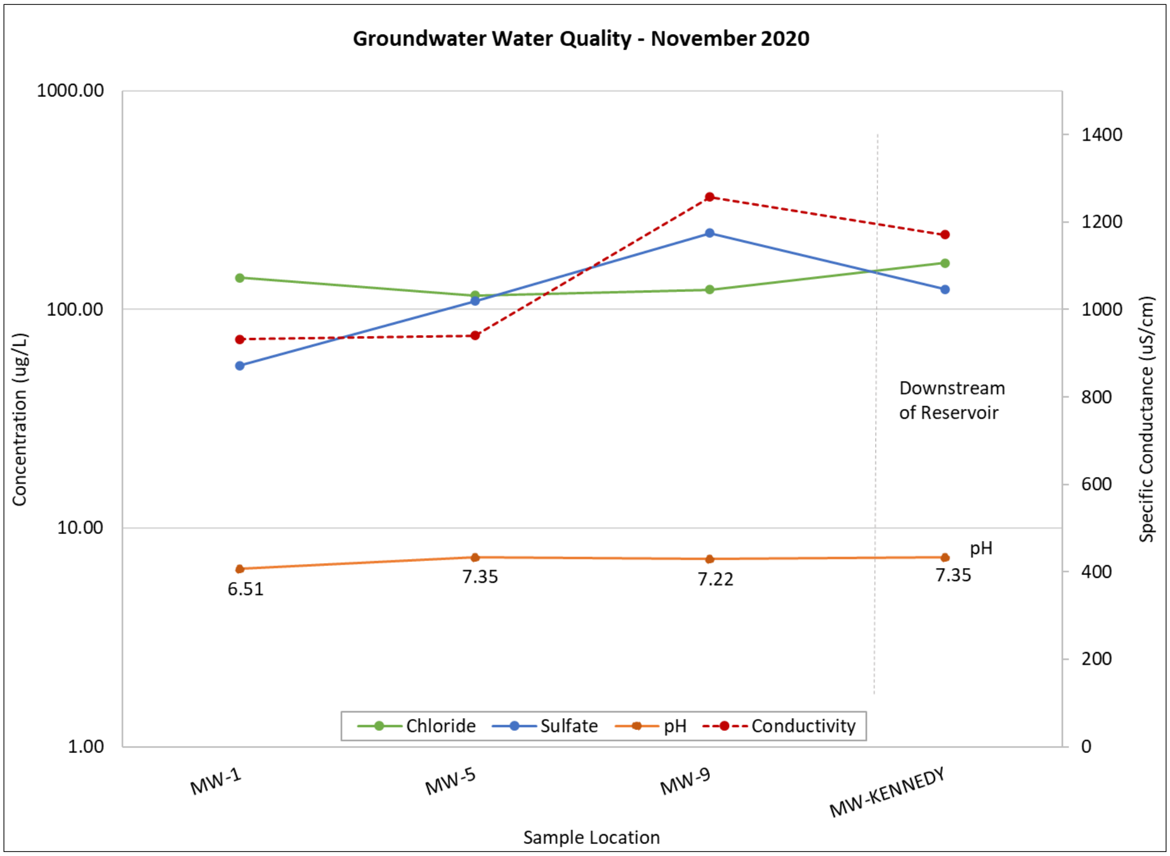


Figure 23. Groundwater Levels of Sulfate, Chloride, Specific Conductance, and pH, November 2020.

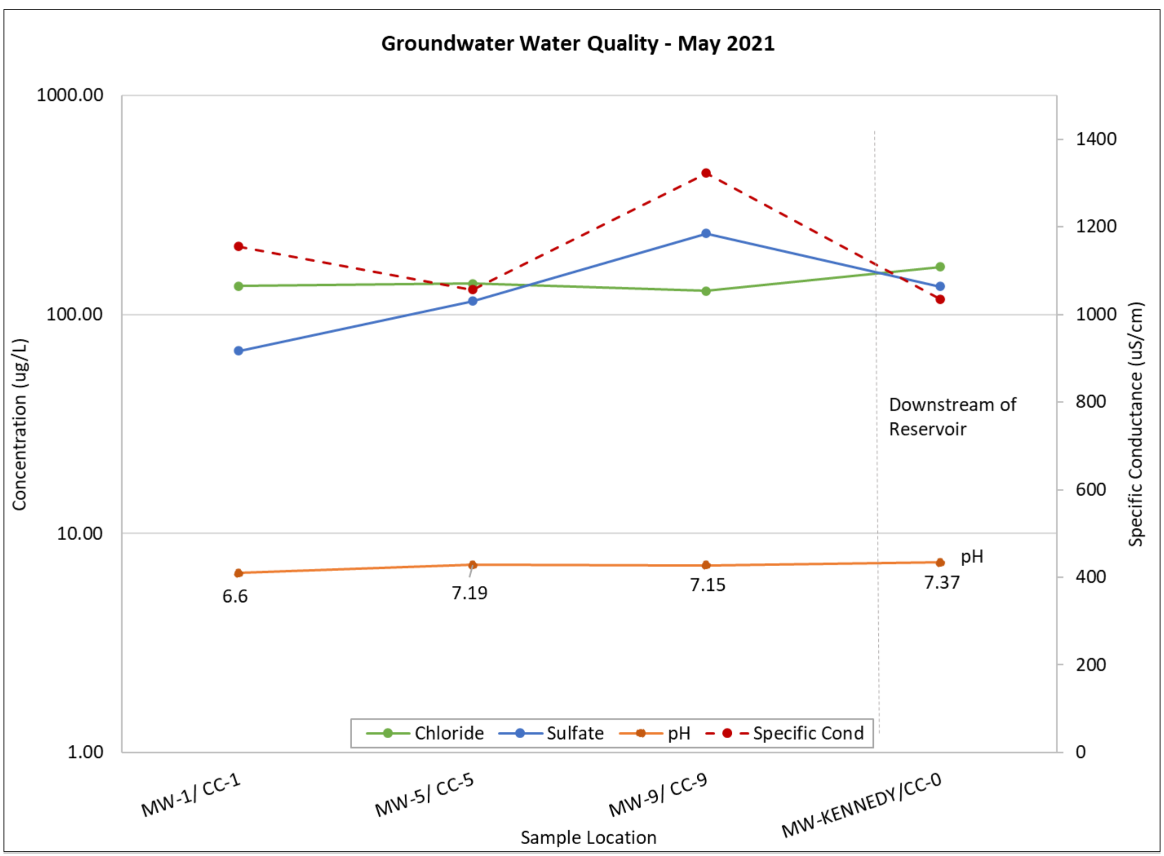


Figure 24. Groundwater Levels of Sulfate, Chloride, Specific Conductance, and pH, May 2021.

As shown in Figure 23 and Figure 24, data from both sampling events during WY 2021 indicated groundwater concentrations of chloride averaged 139 mg/L and sulfate averaged 133 mg/L. Concentrations during both events varied slightly, sulfate was lowest at the furthest upstream site at MW-1, increased slightly at MW-5 and were higher overall at the wells just upstream (MW-9) than downstream of the Reservoir (MW-Kennedy). 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 6.5 to 7.4 and a mean of 7.1, but increased slightly in the wells closer to the Reservoir. The conductivity was highest at the MW-9 site in both November 2020 and in May 2021, with mean concentrations of 1108.5µS/cm for the two events.

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 7.22 in November 2020 and 7.15 in May 2021. The historical pH values from MW-9 from 1994-2021 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.

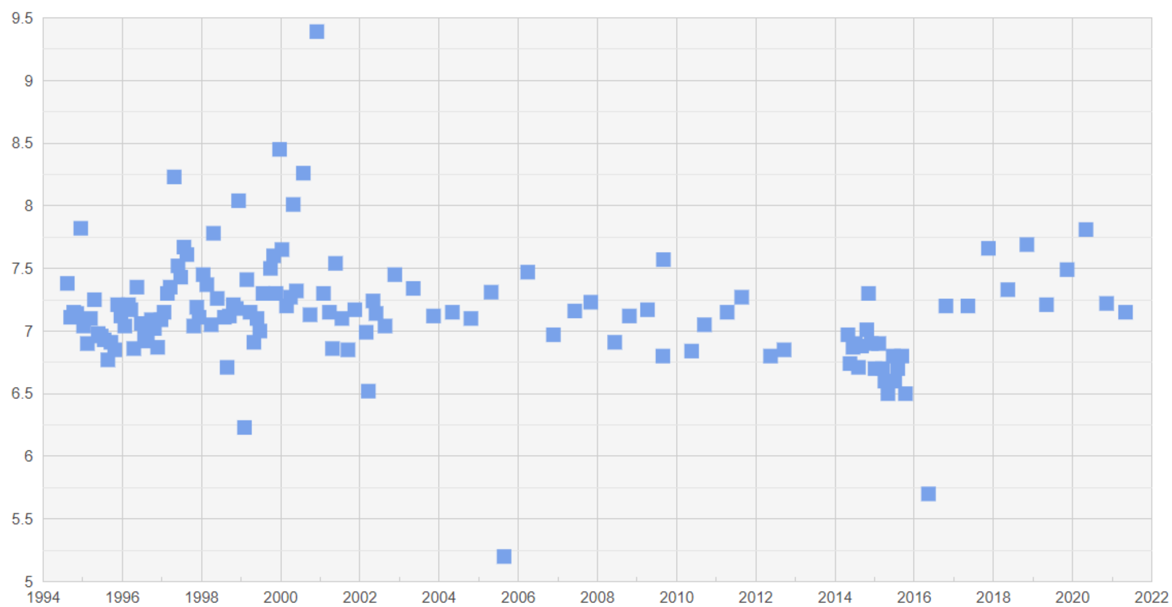


Figure 25. Historic pH Values in Well MW-9, 1994-2021. (http://ccbwqportal.org/)

The conductivity at MW-9 was 1,257 µS/cm in November 2020 and 1,323 µS/cm in May 2021. 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 2021. (Figure 26.)

Figure 27 illustrates the historical chloride and sulfate concentrations from 1994-2021. 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.

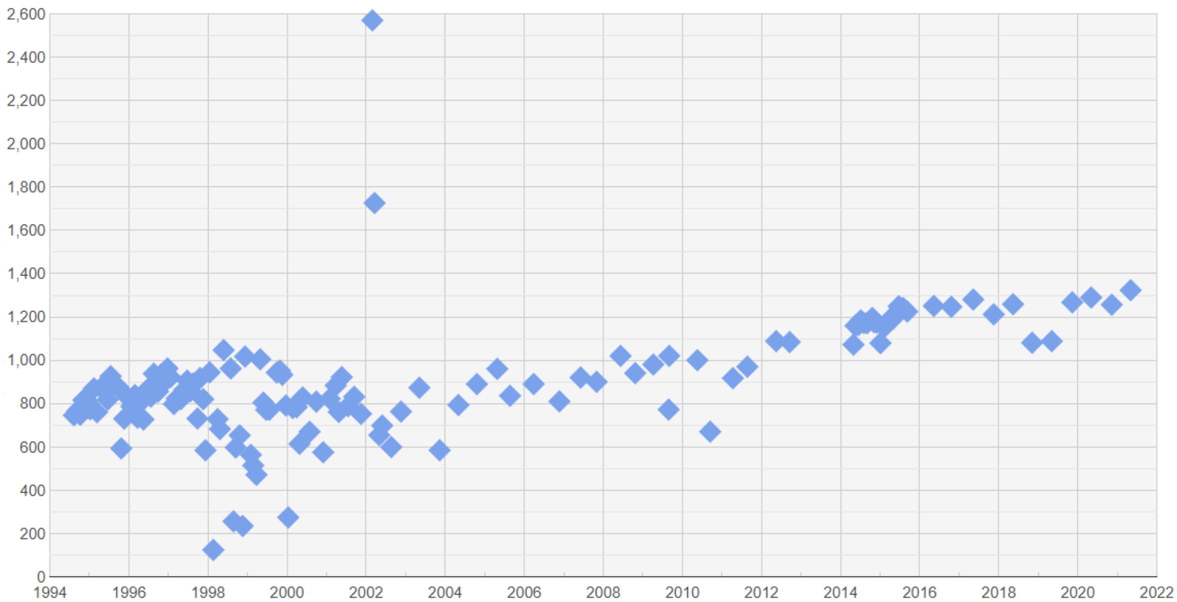


Figure 26. Historic Specific Conductance (µS/cm) Concentration at MW-9, 1994-2021. (http://ccbwqportal.org/)

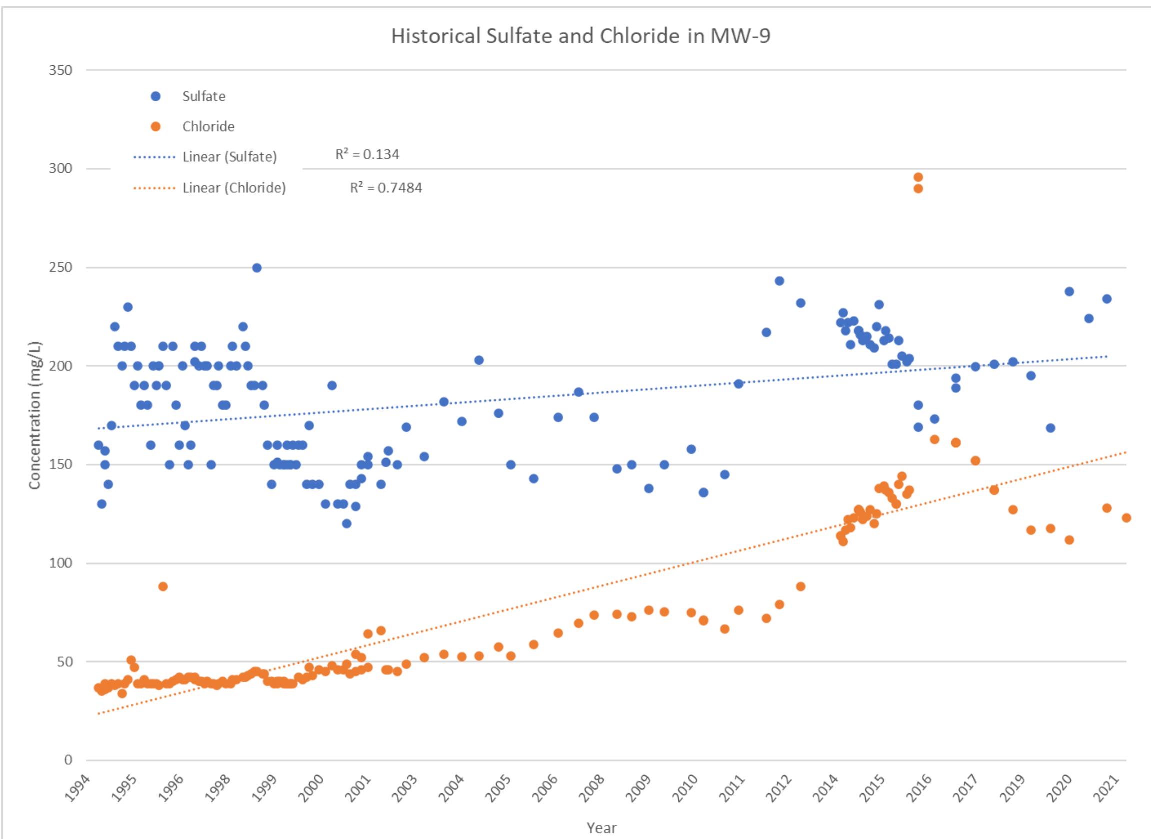


Figure 27. Historical Sulfate and Chloride (mg/L) at MW-9, 1994-2021.

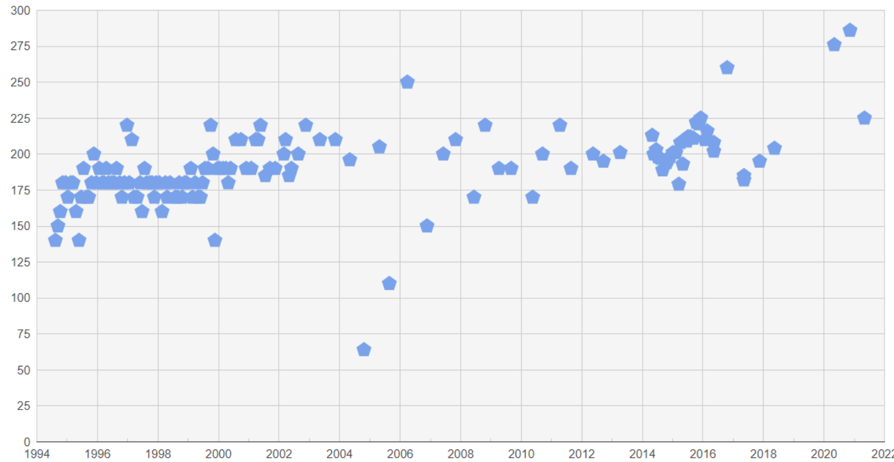


Figure 28. Historic SRP (µg/L) Concentrations at Groundwater MW-9 (1994–2021). (http://ccbwqportal.org/)

Historically, the concentration of SRP in the groundwater upstream of the Reservoir at MW-9 also appears to be slightly increasing over time with the values in WY2021 averaging 256µg/L (Figure 28).

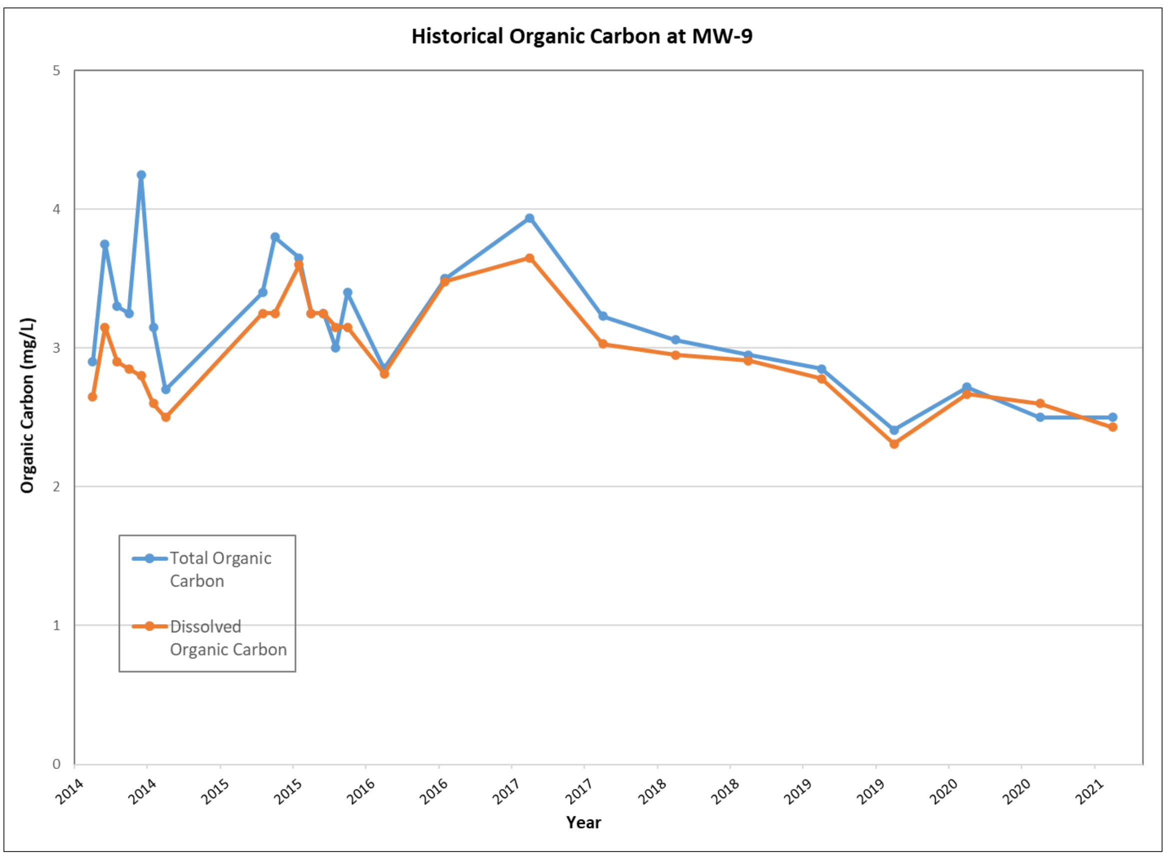


Figure 29. Total and Dissolved Organic Carbon Data from MW-9, 2014-2021.

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 were 2.5 mg/L and in November 2020 and May 2021, which are both slightly lower than the long-term average of 3.2 mg/L from 2014-2021. 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 25, 2021, at 2:30 pm the dam began releasing at 50 cfs, then beginning at 9:00 am on Wednesday May 26 and continuing through 12:30 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 with a maximum of 250 cfs.

4.2 TRANSPARENCY

Transparency is used an indicator for primary productivity and turbidity of the water column and can be a good reference point for the abundance of phytoplankton (algae) and 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 Reservoir sites during each monitoring event.

The Secchi depth measurements represent reduced clarity and eutrophic-hypereutrophic conditions through the year, with one date in mid-May being the only one with clarity above 2 m. The Secchi depths were very similar between CCR-1, 2, and 3, with the highest variance of 15% but an average of approximately 6% variance between the sites. The measured Secchi depth ranged between 0.55 and 2.1 m, with an annual mean of 0.98 m.

Figure 30 depicts the Secchi depth measurements from the three sites during each sampling event in WY 2021.

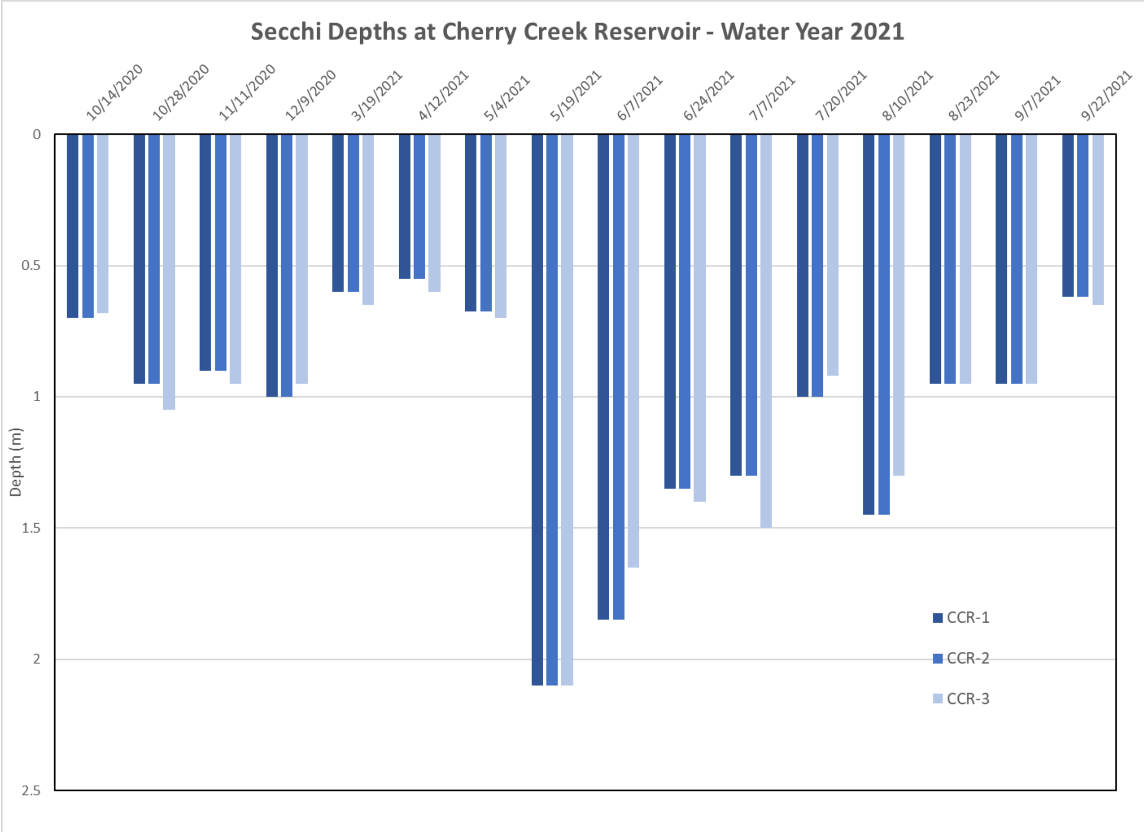


Figure 30. Secchi Depths in Cherry Creek Reservoir, Stations CCR-1, CCR-2 and CCR-3 during WY 2021.

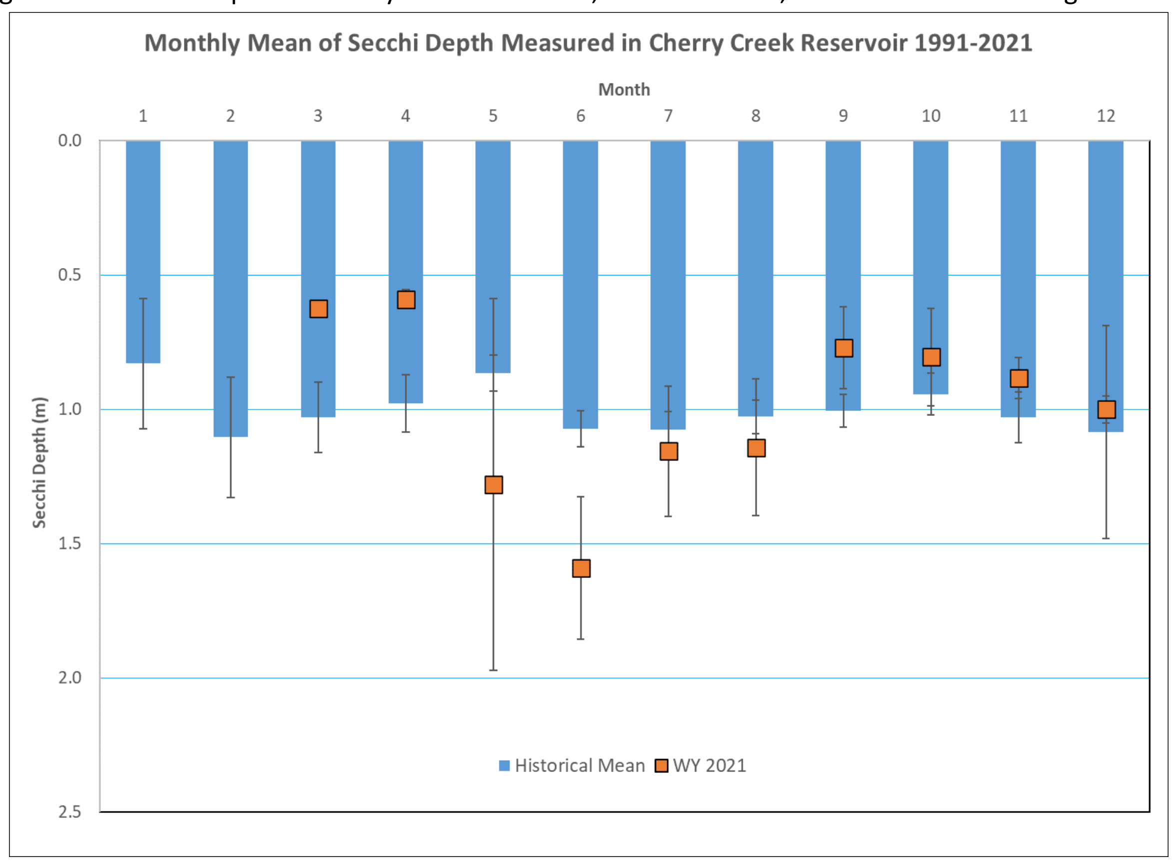


Figure 31. Historical and Monthly Mean Secchi Depth in Cherry Creek Reservoir from 1992- 2021.

Figure 31 shows the historical monthly mean Secchi depth and the WY 2021 monthly mean values with the standard deviations for both values. The seasonal mean was 1.02 m during the months of July to September. In WY 2021 the Secchi depth followed somewhat similar seasonal trends when compared to the historical monthly values, with the exception of the higher-than-average transparency seen in mid-May and early June. 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.

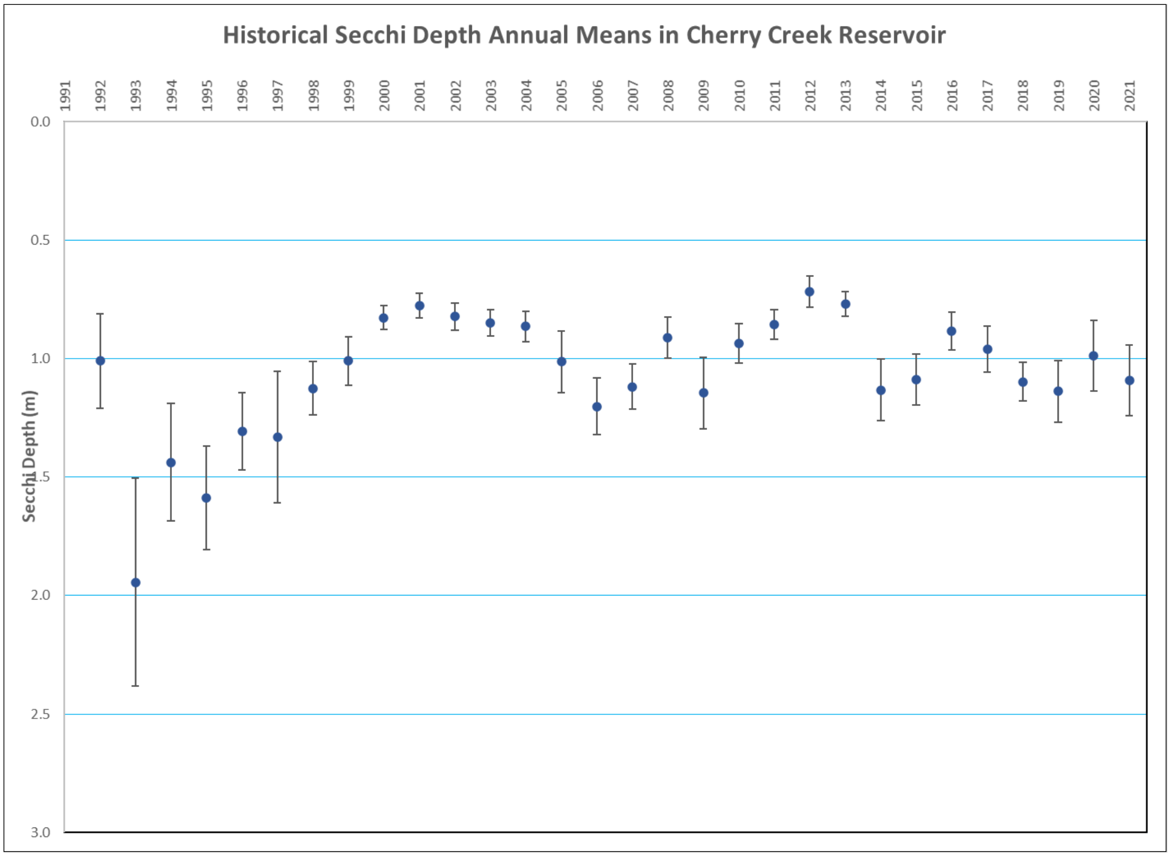


Figure 32. Annual Mean of Secchi Depth in Cherry Creek Reservoir from 1992- 2021.

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, with all annual means less than 2 m. The lowest values were observed in 1999-2004 and again in 2011-2013 but over time does demonstrate a trend of decreasing values.

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 1.95 m to 5.35 m during WY 2021. The lowest values were observed in early spring and late summer and the maximum depth was observed in mid-May through mid-July. There is a clear relationship between Secchi depth and depth of 99% light attenuation (Figure 32).

In WY 2021, the depth of 1% light transmittance ranged between 2.1 and 3.9 times the Secchi depth, but on average was approximately 3.2 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 +2.4 with a Pearson correlation coefficient of 0.86.

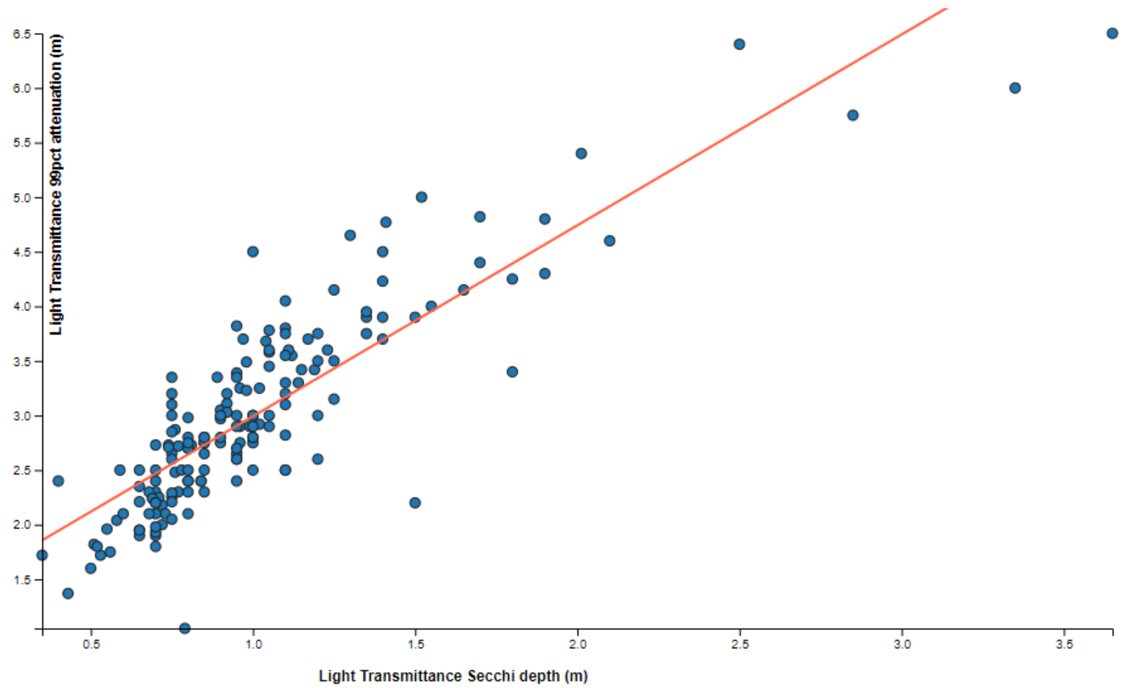


Figure 33. Relationship between Secchi Depth and Depth of 1% Light Transmittance at CCR-2.
(http://ccbwqportal.org/)

4.3 CHLOROPHYLL A

Cherry Creek Reservoir has a seasonal chl α standard of 18 µg/L as set by WQCC Regulation No. 38 (REG 38). During each sampling event of WY 2021 chl α levels were measured from composite samples collected from 0, 1, 2, and 3 meters at all three monitoring sites in the Reservoir. The chl α concentrations ranged between 4.8 µg/L and 67.8 µg/L, with an average annual value of 25.2 µg/L in WY 2021 (Figure 34). The highest values were observed in March, April and November, and the lowest in October and late May through late July.

The seasonal chl α concentration for WY 2021 through the growing season (July through September) concentration was 22.2 µg/L, which is slightly lower than 2020 (Figure 35). Only one of the mean values during the six sampling events during the season (July 1-September 30), which was 12.7 in early July, was at or below the standard of 18 µg/L.

The seasonal mean for WY 2021 did not meet the growing season average REG 38 standard 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.

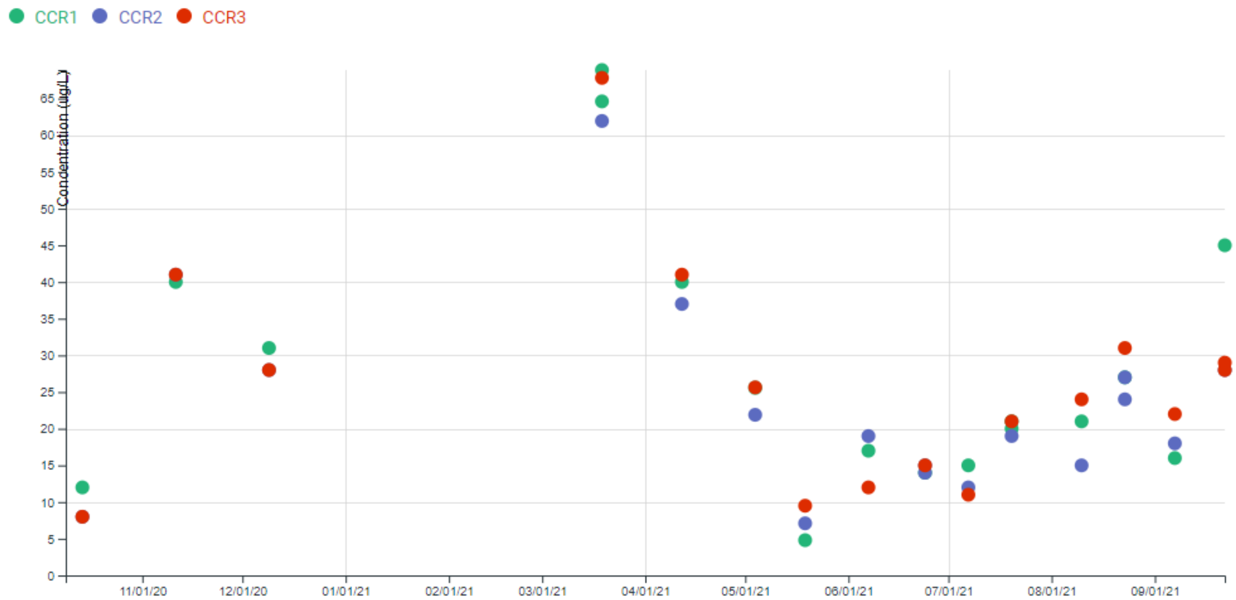


Figure 34. Monthly Chlorophyll *α* (µg/L) Concentrations in Cherry Creek Reservoir during WY 2021. (http://ccbwqportal.org/)

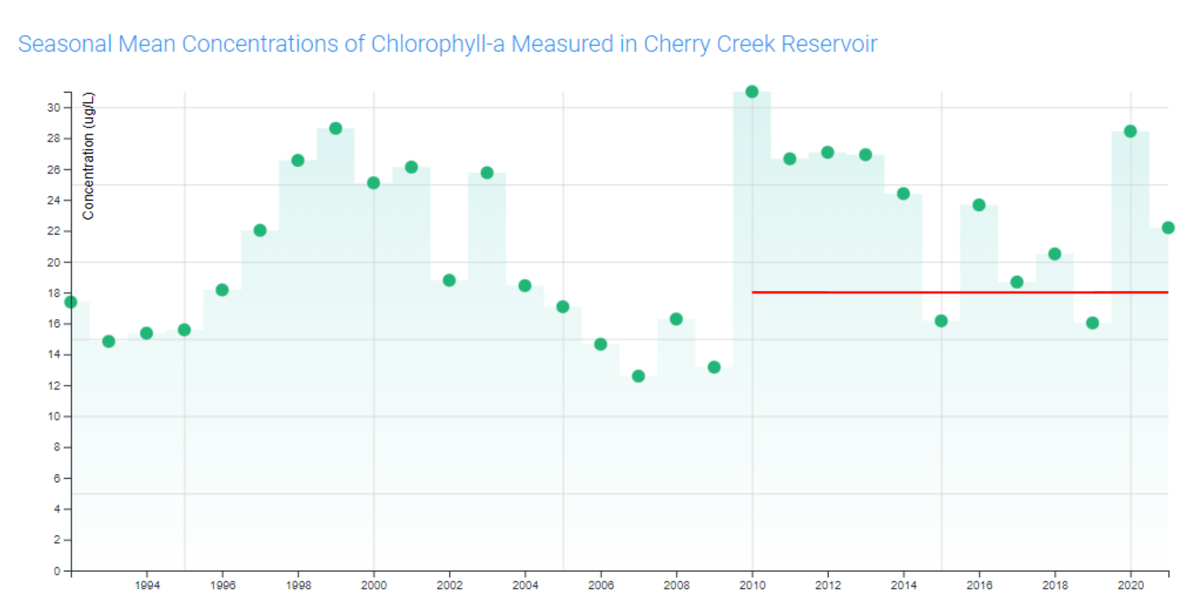


Figure 35. Historical Seasonal Mean of Chlorophyll *α* in Cherry Creek Reservoir WY 1991-2021.

(Red line --- indicates the 18.0 µg/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 21) to describe perceptions of water quality by typical lake users.

Table 21. 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 2021 was 9.33 µg/L in October 2020. The maximum monthly average was 65.5 µg/L in March 2021. The highest mean concentrations for the 3 sites during the growing season were 39.3 µg/L in April and 23.2 µg/L in August. This would indicate that some algal scums or nuisance conditions were present that could affect lake use. However, during WY 2021, there were no blooms that were identified to be toxin producing cyanobacteria at any of the public areas monitored by Colorado Parks and Wildlife.

4.4 TEMPERATURE

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

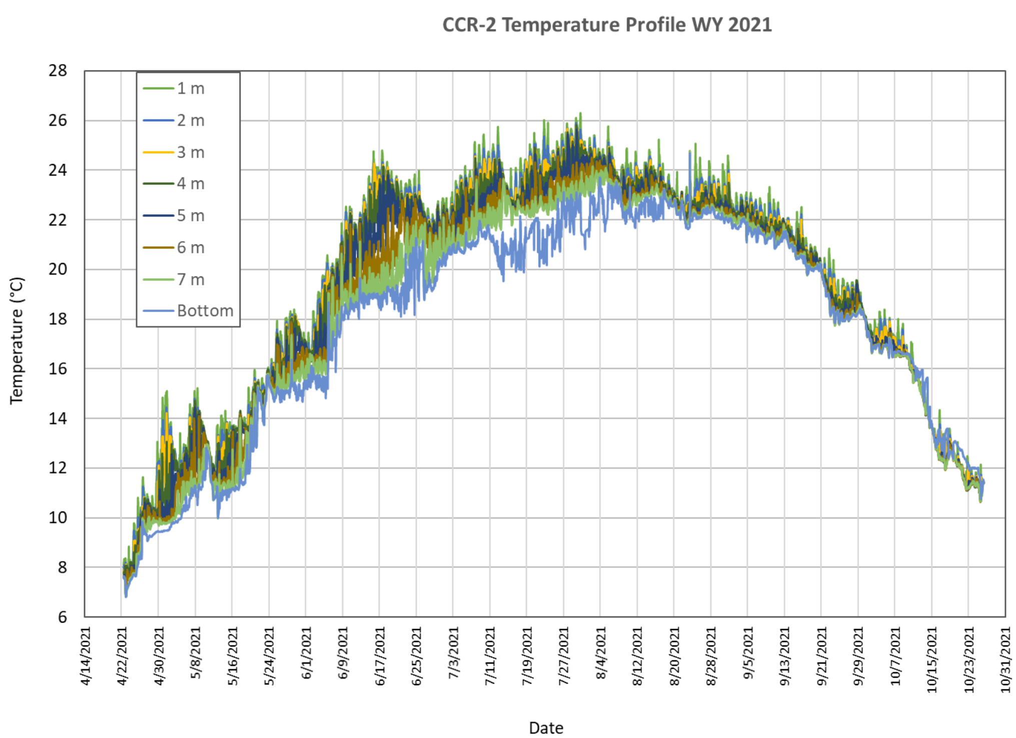


Figure 36. 2021 Temperature Profile of CCR-2 in Cherry Creek Reservoir.

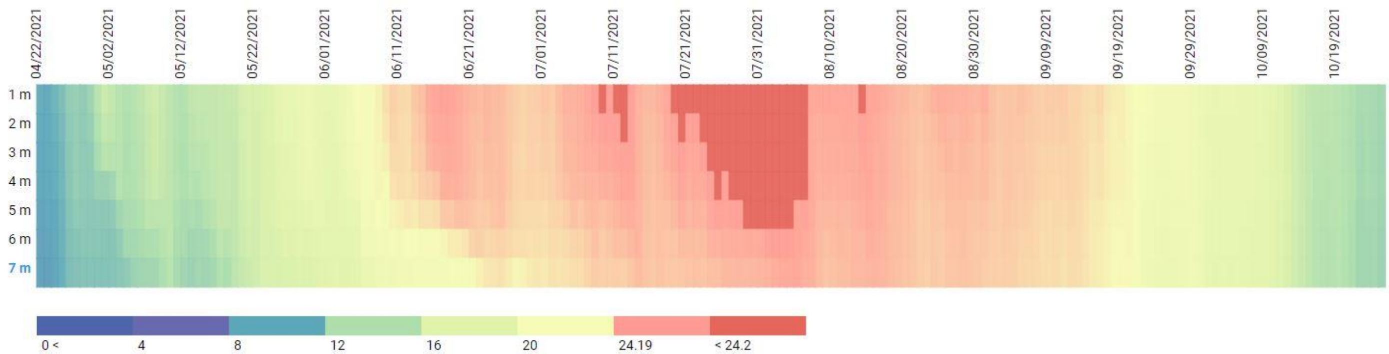


Figure 37. 15-min Temperature Profile at CCR-2, WY 2021.

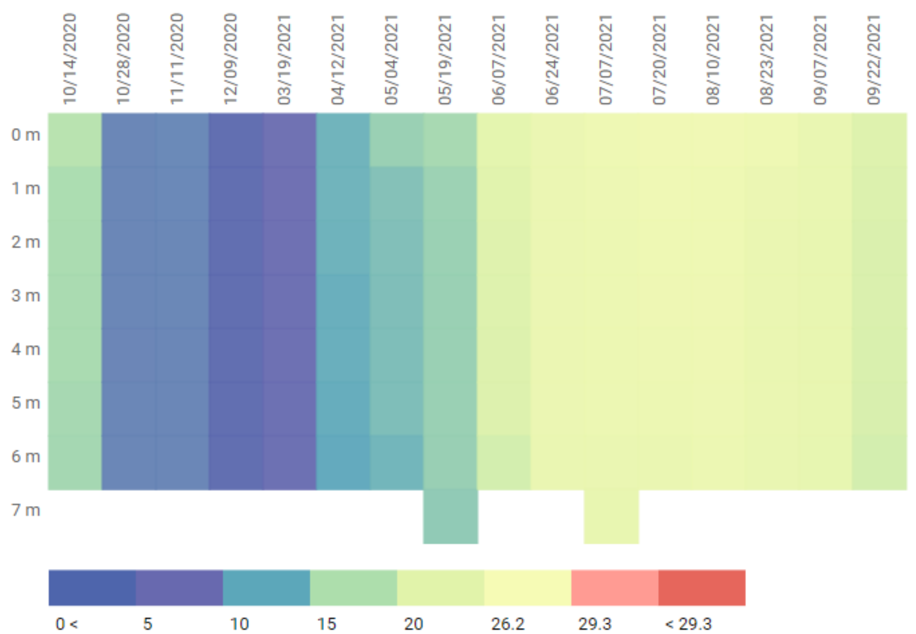


Figure 38. WY 2021 Temperature (˚C) Profile in Cherry Creek Reservoir at CCR-2. (http://ccbwqportal.org/)

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 WY 2021 is plotted in Figure 36 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 2021.

The maximum temperature measured in the surface during the reservoir monitoring events was 24.2˚C (75.6 ^{o}F) on August 10, 2021 and on the continuous monitoring thermistors was 26.3 ˚C on July 30, 2021 which was recorded for a period of 15 minutes.

The biggest temperature range measured in the vertical profiles during the monitoring events was 2.5˚C on May 5, 2021 from 13.5˚C (56.3^{o}F) to 11.0˚C (51.8^{o}F). The largest temperature difference logged by the thermistors was approximately 6.1˚C on June 17, 2021 from top to bottom but the mean difference for the year was only 1.75˚C. 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 (Figure 38).

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 2021, DO levels were below 5.0 mg/L at 6 m meters or below at CCR-2 in early-July through early August.

From May through Sept, there were events at CCR-1 where DO concentrations were below 5.0 mg/L at variable depths from 5 m and the bottom at CCR-1. At site CCR-3, the DO was at or below 5.0 mg/L at depths between 4-5 m to the bottom from late June through August.

During WY 2021, there were events when measured DO concentrations of the Reservoir were below 5.0 mg/L at depth. However, during the same time period, the DO concentrations in the upper part of the reservoir (from 3-5 m to the surface) were greater than 5.0 mg/L at all 3 monitoring sites, 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 39 and the profiles from the other two sites are available on the data portal.

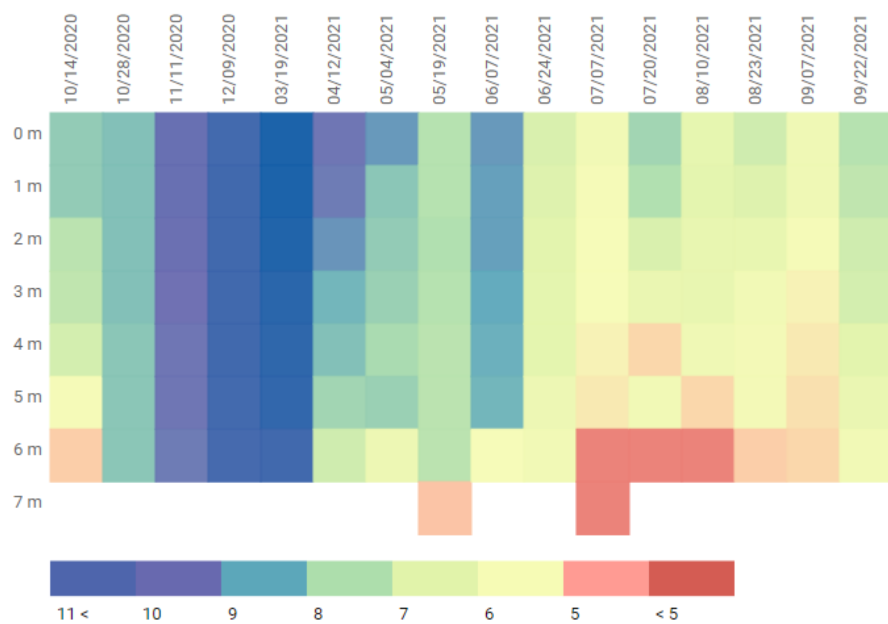


Figure 39. WY 2021 Dissolved Oxygen (mg/L) Profile in Cherry Creek Reservoir at CCR-2.
(http://ccbwqportal.org/)

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 2021 ranged from 7.9 to 8.8. The lowest values in the water column (7.7-7.9) were recorded at the bottom of the Reservoir in July through early August and on the surface in early August and early September (8.2). The highest values (8.8) were seen at the Reservoir's surface in March and at the bottom in October/ November 2020 and March/April 2021 (8.5-8.7). 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. The highest monthly chl α concentrations were found in March 2021 which also coincided with the highest pH values through the entire water column. In contrast, the lowest chl α concentrations were seen on May 19th which was when the lowest pH values were also recorded through the water column. Higher pH values usually correlated with higher productivity and elevated chl α concentrations in the Reservoir.

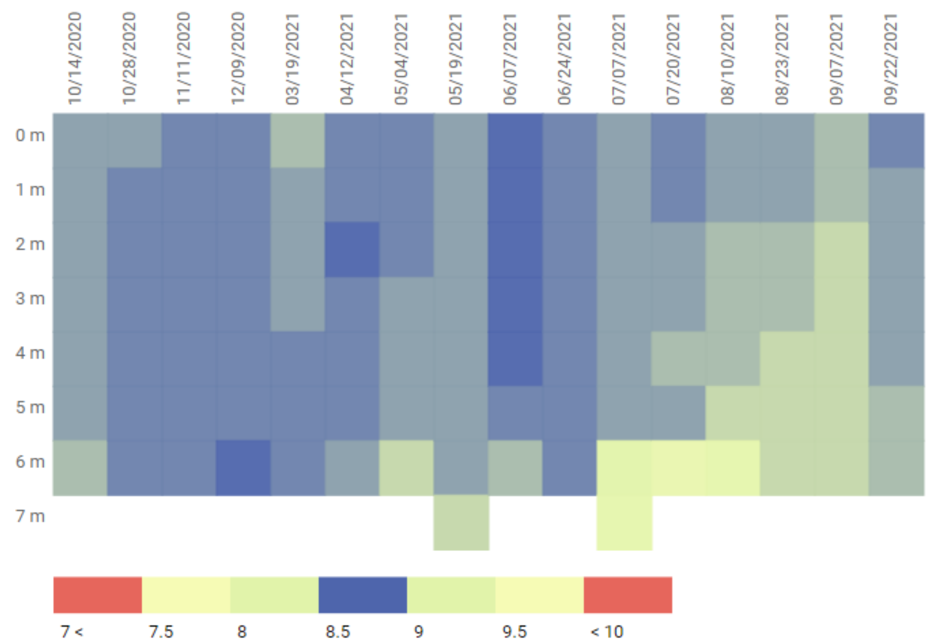


Figure 40. WY 2021 pH Profile from CCR-2 in Cherry Creek Reservoir. (http://ccbwqportal.org/)

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 in Figure 41. The ORP in the photic zone ranged from 141 mV in early July 2021 to 264 mV during WY 2021. The ORP in the samples near or at the bottom of the Reservoir ranged from 141 mV in early July to 274 mV in March. The lower ORP values in July and early August, indicate a reducing environment at the bottom of the Reservoir which coincided with the lower DO and lower pH measurements at the bottom of the Reservoir. These trends are typical and an indication of decomposition processes in the sediments and sediment-water interface and seasonal trends normally seen in the Reservoir. Higher ORP values, indicating an oxidative environment, were present during higher DO levels and colder water temperatures.

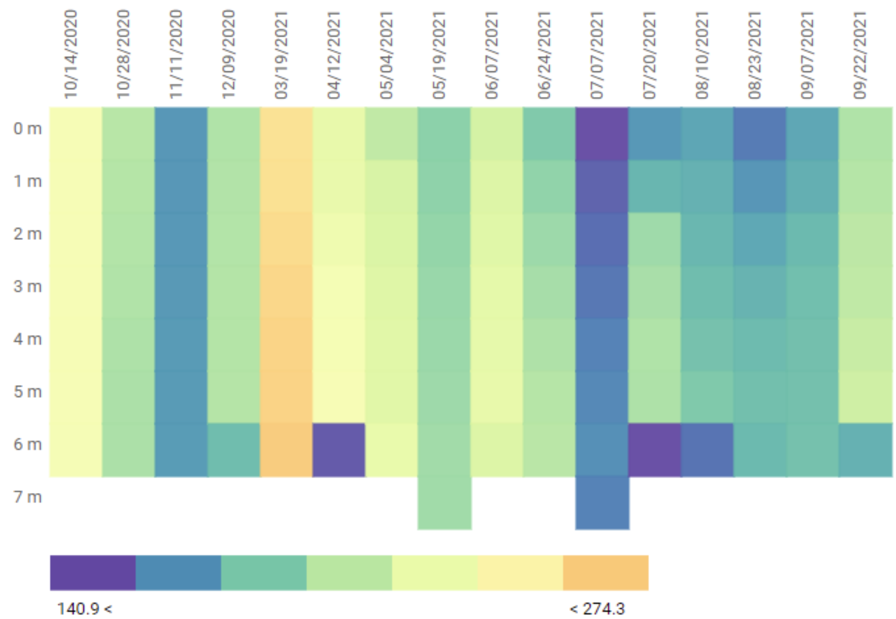


Figure 41. WY 2021 Oxidation Reduction Potential (mV) Profile in Cherry Creek Reservoir at CCR-2. (http://ccbwqportal.org/)

4.8 CONDUCTIVITY

The specific conductance, or conductivity, is a representation of dissolved solids (i.e. salts, minerals, etc.) in Cherry Creek Reservoir. During WY 2021, the specific conductance, ranged from a minimum of 1198 µS/cm to 1436.6 µS/cm. CCR-2 showed a range from 1,213 µS/cm in July 2021 to 1,435 µS/cm during October 2020 (

Figure 42). There was limited variability in conductivity from top to bottom of the Reservoir and between the three monitoring sites. The concentrations were highest in October 2020 and April 2021 and the lowest were in July and again in late September. Overall, the conductivity in the Reservoir was lower than WY 2020 but has demonstrated an increasing trend since monitoring of this parameter started in 1999.

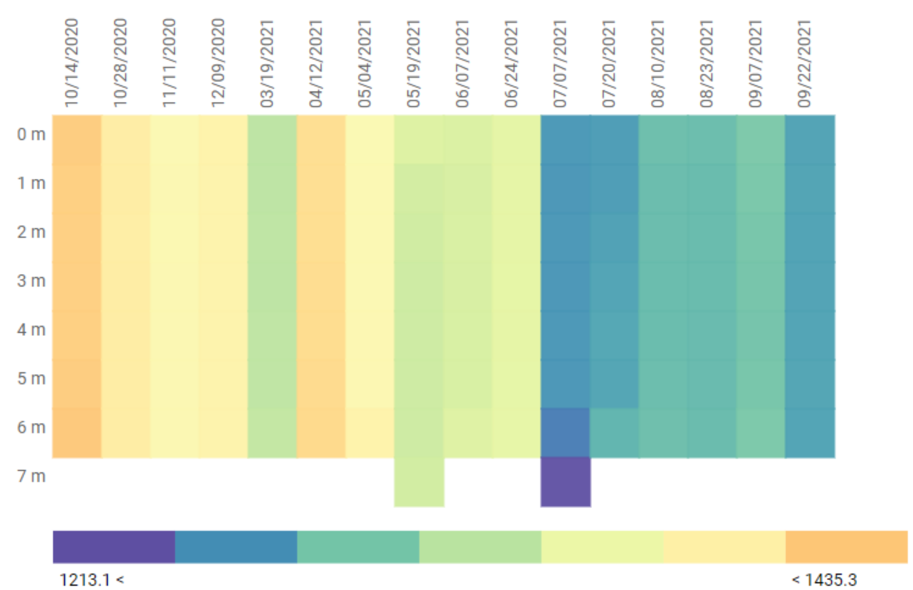


Figure 42. Conductivity (Specific Conductance µS/cm) Profile in Cherry Creek Reservoir at CCR-2, WY 2021. (http://ccbwqportal.org/)

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 (0-3 m). The WY 2021 seasonal mean of 76.7 µg/L was much lower than the previous few years, WY 2020 (128.2 µg/L), 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 2021 seasonal TP mean is also lower than the long-term average of 94.7 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 the historical seasonal phosphorus concentrations in Cherry Creek Reservoir with the interim phosphorus criterion of 83ug/L represented by the orange line. The historical analysis indicates that TP levels in Cherry Creek Reservoir have exceeded 83 µg/L every year since 2003, with the exception of 2021.

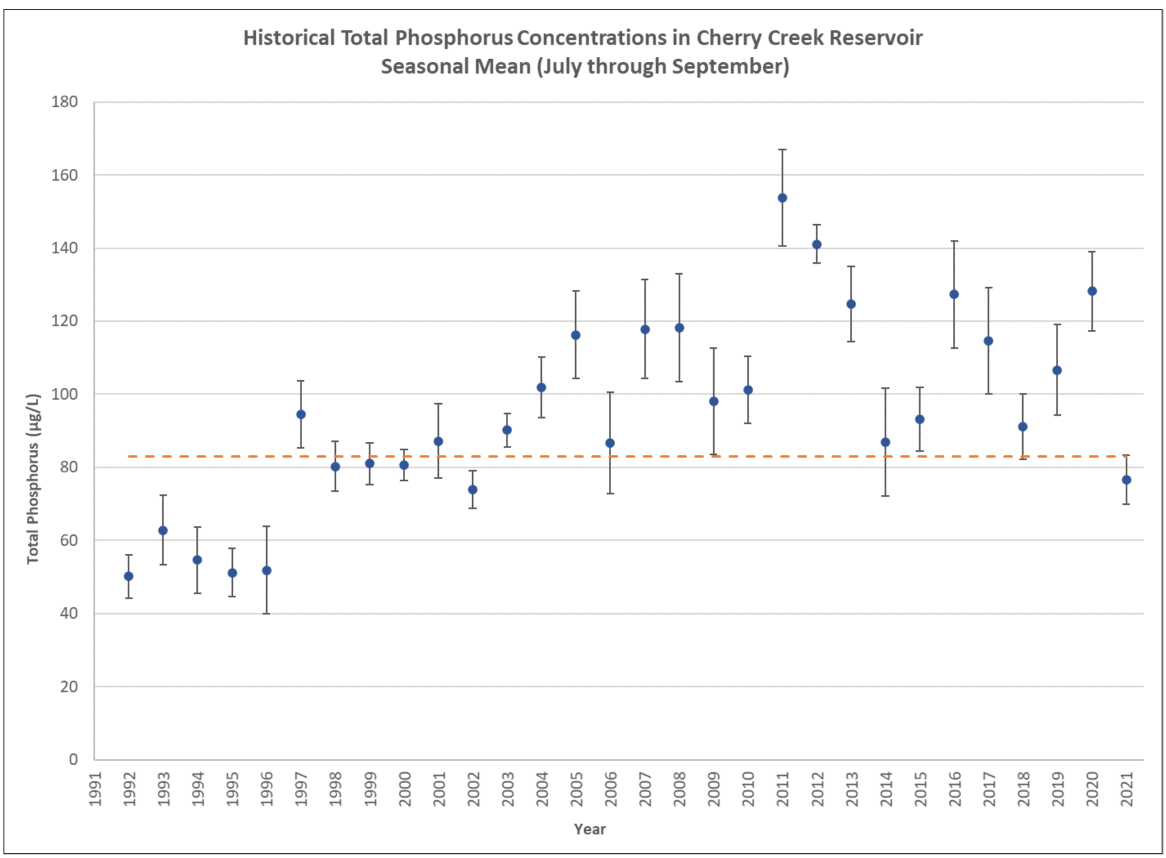


Figure 43. Historical Seasonal Mean TP Concentrations in Photic Zone of Cherry Creek Reservoir 1992-2021.

During WY 2021, the monthly mean TP concentrations ranged between 69 µg/L and 115 µg/L, with a mean value of 87 µg/L (Figure 44). The lowest monthly mean TP was seen in in September and the highest values in April 2021. With the exception of September, all TP levels were above 75 µg/L, but only April and June had monthly mean TP levels above 100 µg/L. The WY 2021 data suggests that there are high levels of TP in the Reservoir throughout the year contributing to eutrophic conditions.

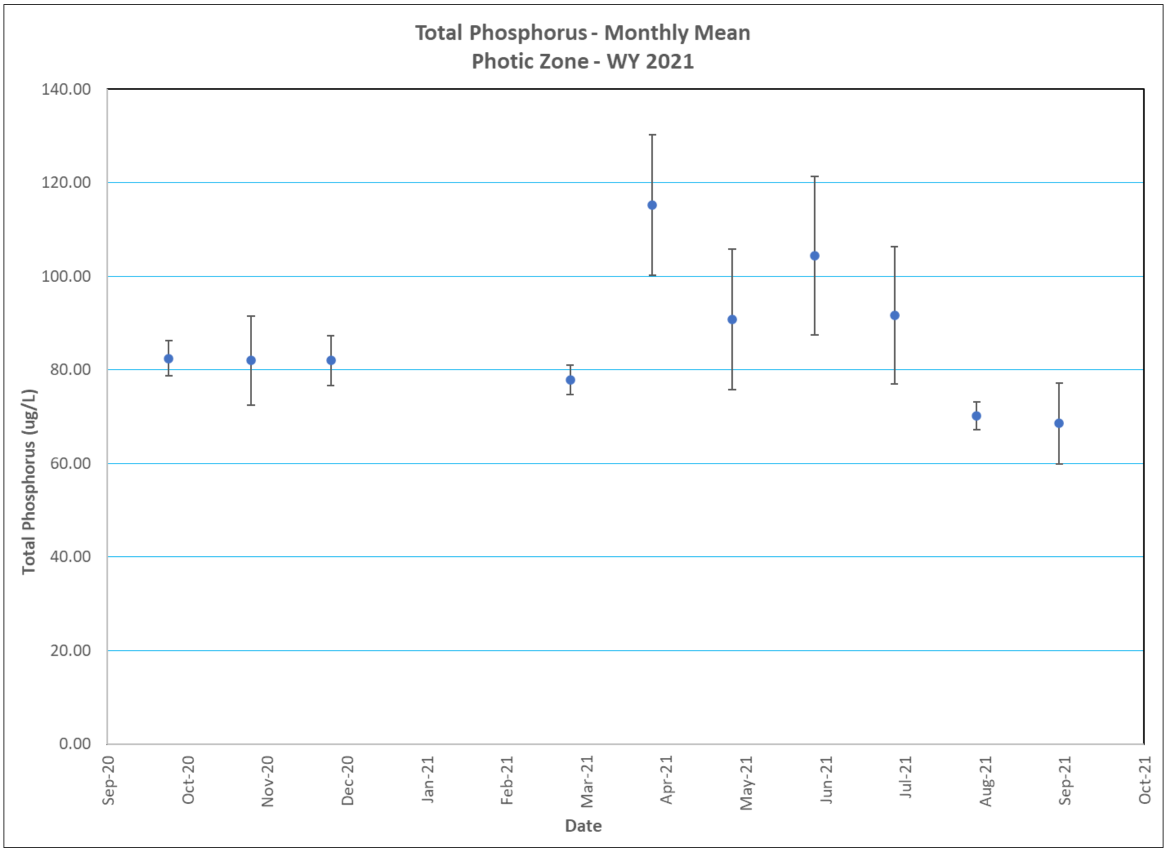


Figure 44. Monthly Average of Total Phosphorus in the Photic Zone, Cherry Creek Reservoir, WY 2021.

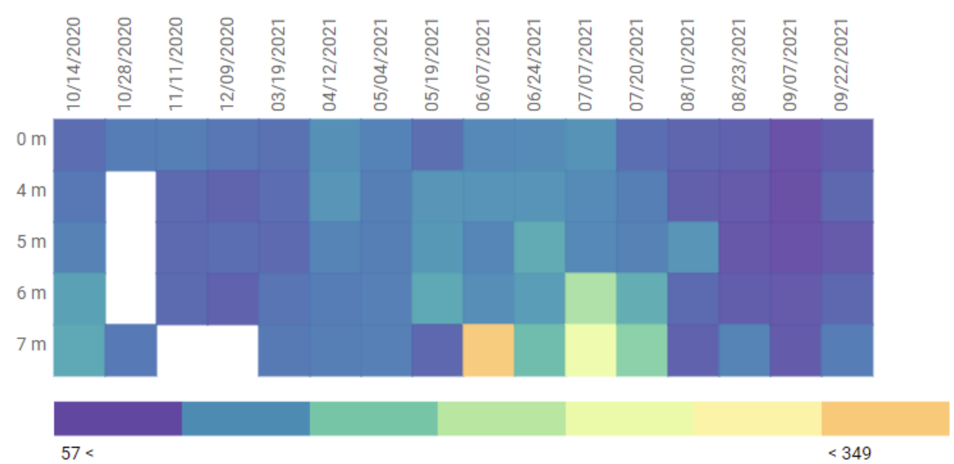


Figure 45. Total Phosphorus (µg/L) Profile at CCR-2 in Cherry Creek Reservoir, WY 2021. (http://ccbwqportal.org/)

Figure 45 displays how TP concentrations increased as the season progressed from spring through early summer and then decreased in August through early fall. The highest concentration in the photic zone was 107 µg/L on July 7, 2021. 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, especially during June and July. TP concentrations at station CCR-2 ranged from 57 µg/L to 349 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.

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 2021.

During WY 2021, it appeared that both TDP and SRP remained relatively constant through late fall and winter 2020-21, but levels throughout the water column 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. Similar to TP, TDP and SRP concentrations increased in May through July. There was a strong correlation of lower levels of TDP and SRP in the photic zone during the events when DO levels were low and pH was 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 June 7th, concentrations of TDP and SRP from the samples collected at 7 m were 240 µg/L and 237 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 which indicates that primary productivity in the photic zone was utilizing the available forms of phosphorus as they were released and mixed through the water column.

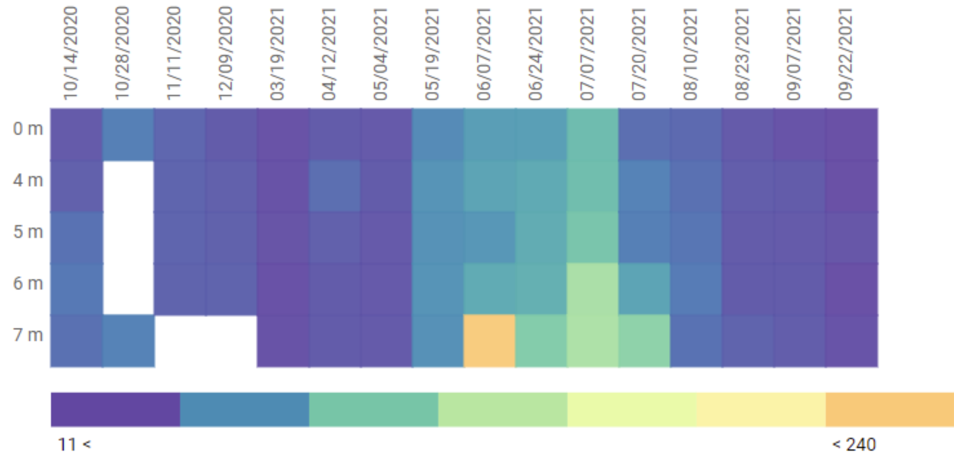


Figure 46. Total Dissolved Phosphorus (µg/L) Profile at CCR-2 in Cherry Creek Reservoir, WY 2021.
(http://ccbwqportal.org/)

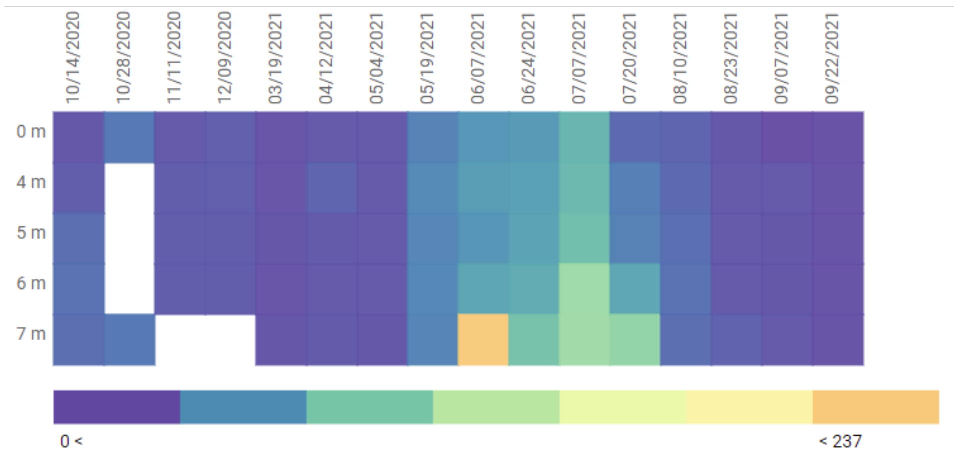


Figure 47. Soluble Reactive Phosphorus (µg/L) Profile at CCR-2 in Cherry Creek Reservoir, WY 2021.
(http://ccbwqportal.org/)

4.11 TOTAL NITROGEN

The seasonal mean (July thorough Sept) of Total Nitrogen (TN) in the Reservoir in WY 2021 of 861 µg/L was lower than WY 2020 (999 µg/L), higher than WY 2019 (689 µg/L), WY 2018 (848 µg/L), and WY 2017 (761 µg/L). The WY 2021 seasonal mean was slightly lower than the long-term average of 896 µg/L calculated from 1992-present. As illustrated by Figure 48, the historical 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 with the large reservoir nitrogen criterion of 910ug/L represented by the orange line.

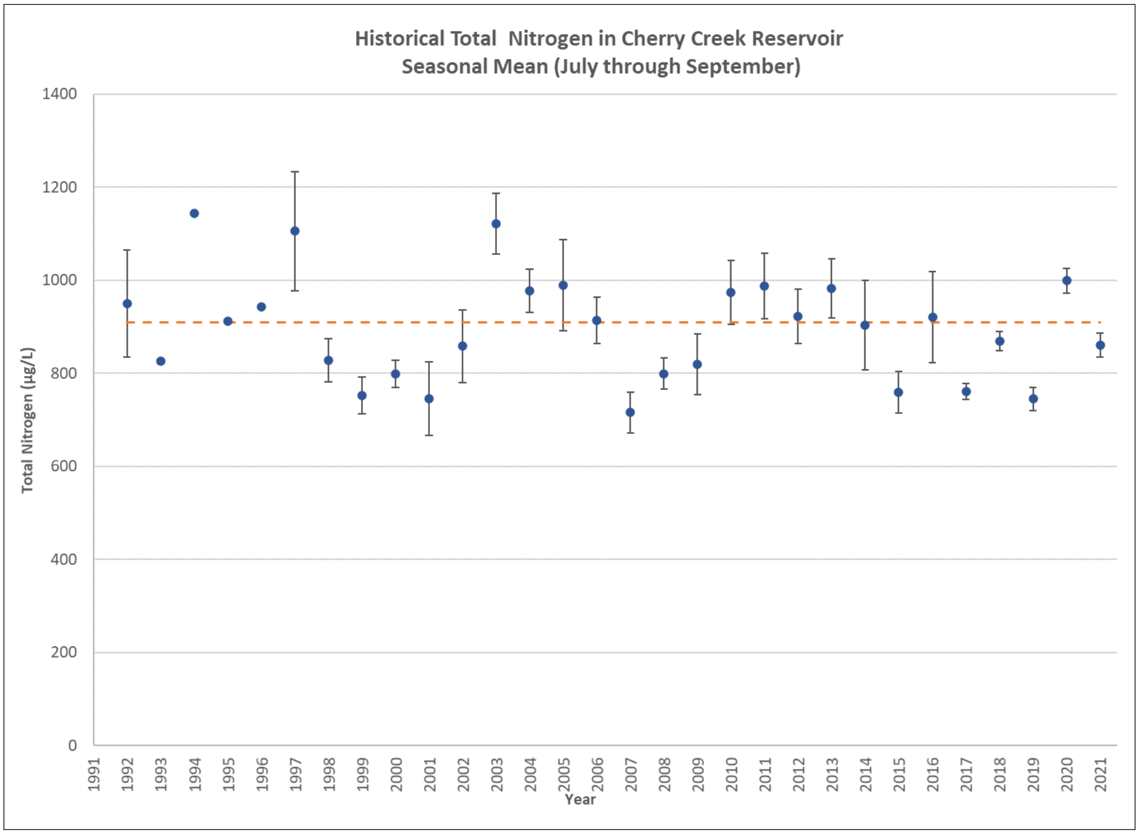


Figure 48. Historical Seasonal Mean TN Concentrations in Photic Zone of Cherry Creek Reservoir 1992-2021.

During WY 2021, monthly TN concentrations in the photic zone from the 3 Reservoir monitoring sites ranged between 605 µg/L and 1,240 µg/L with a mean value of 942 µg/L (Figure 49). The highest TN concentrations were present in November 2020, April 2021 and the lowest in June.

During WY 2021, at CCR-2 TN levels were highest in the photic zone during the November 2020 and March and April 2021 monitoring events (Figure 50). Also, in the July 7th samples, the TN concentrations from the 7 m depth sample at CCR-2 were much higher than other sampling dates at that depth throughout the year. The profiles from the other 2 monitoring sites can be found on the data portal.

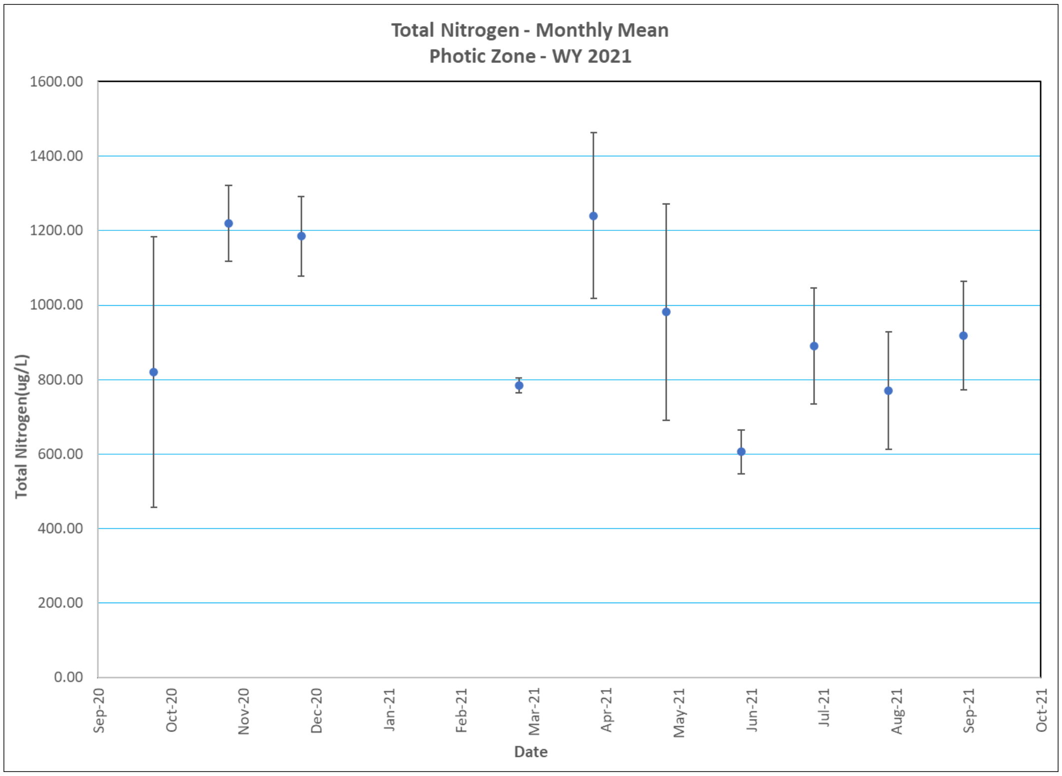


Figure 49. Monthly Average TN Concentrations in Photic Zone, Cherry Creek Reservoir, WY 2021.

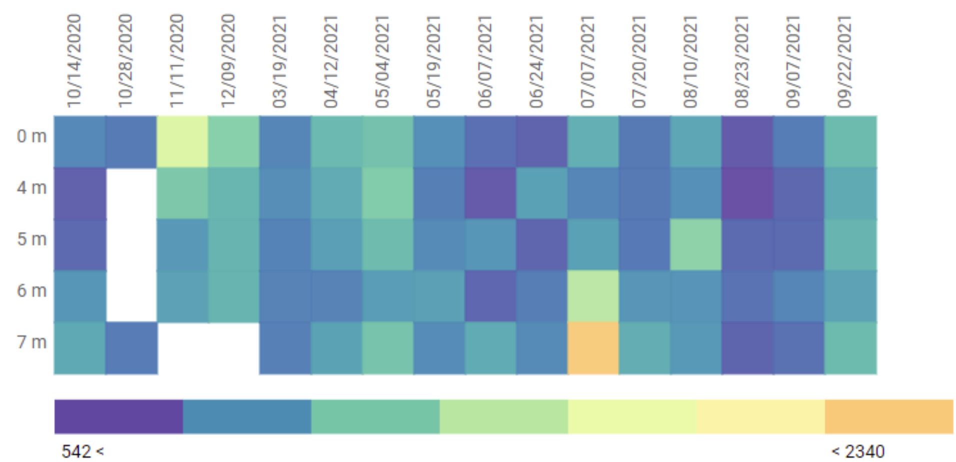


Figure 50. Total Nitrogen (µg/L) Profile at CCR-2 in Cherry Creek Reservoir, WY 2021. (http://ccbwqportal.org/)

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 dominates.

Nitrates were generally low in the photic zone of Cherry Creek Reservoir throughout WY 2021. The highest concentrations among the 3 sites were seen in November 2020 (53 µg/L), and March 2021 (32.2 µg/L). All other mean concentrations were below 25 µg/L. 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 mid-May through July but lower in surface waters overall. This is an indication of a highly productive reservoir. The increases in ammonia concentrations in the deeper layers (6 and 7 m) also correlated to the periods of lower oxygen at the bottom of the Reservoir. NH_3-N was highest in the photic zone In October and November 2020 at 145 µg/L and 133 µg/L respectively and again in late September 2021 at 98µg/L.

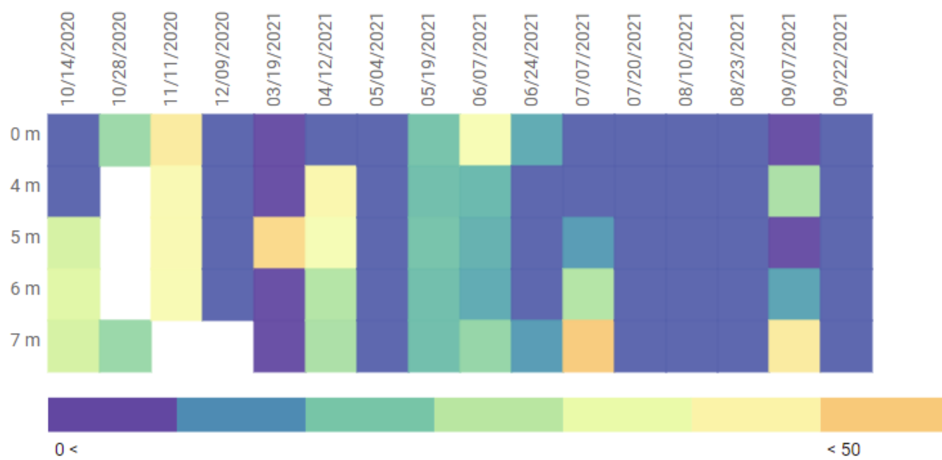


Figure 51. Nitrate/ Nitrite (µg/L) Profile at CCR-2 in Cherry Creek Reservoir, WY 2021. (http://ccbwqportal.org/)

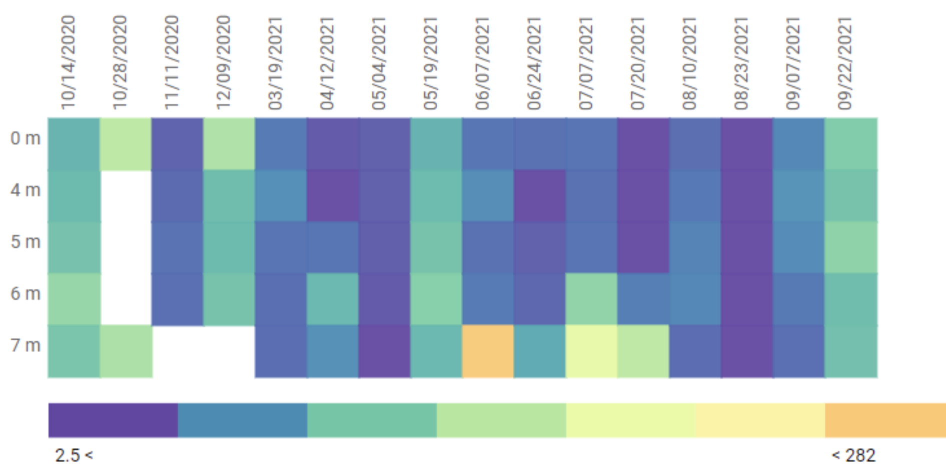


Figure 52. Ammonia (µg/L) Profile at CCR-2 in Cherry Creek Reservoir, WY 2021. (http://ccbwqportal.org/)

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 mass ratios of TN:TP (in blue), TDN:TDP (in green) and TIN: SRP (in orange). 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 in a red dotted line and the point of limitation is the purple dotted line. The TN:TP ratios indicate that TN was limiting during the month of June when values were below the line. The TDN:TDP ratio only neared the point of nitrogen limitation through June and demonstrated phosphorus limitation throughout the year. However, the TIN:SRP ratio indicated that the more biologically available forms of nitrogen were below the line indicating limitation all year, with the exception of early October, November, December 2020, and late September 2021.

Based on the nutrient ratios and the concentrations of chl α at site CCR-2 during WY 2021, it appears that the biologically available forms of nitrogen may have limited algal growth with the exception of March 2021 which represented a significant chrysophyte bloom (See Phytoplankton Section 4.15).

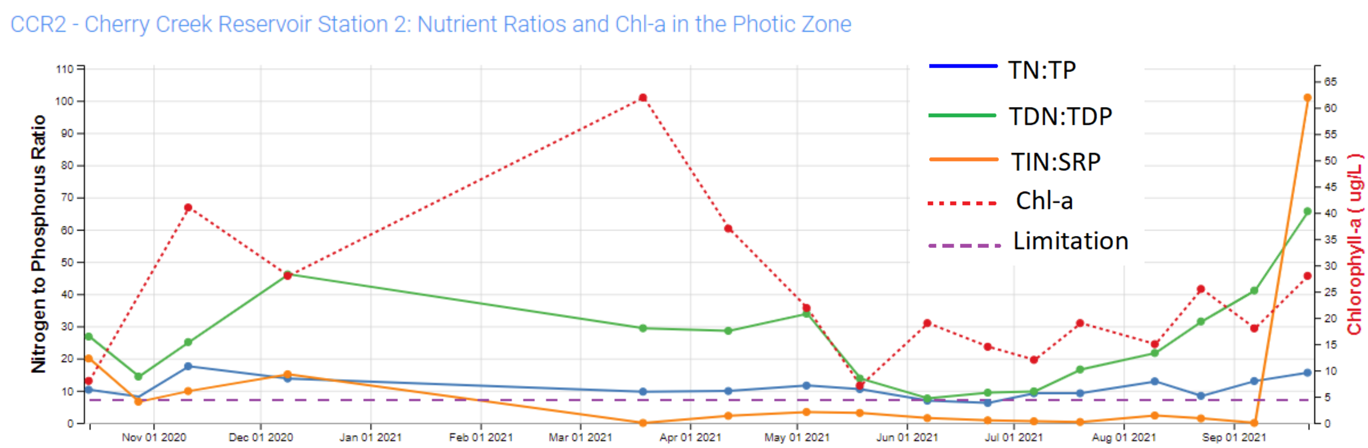


Figure 53. Nutrient Ratios for and Chlorophyll *a* in Cherry Creek Reservoir in WY 2021.

4.14 TROPHIC STATE ANALYSIS

The trophic state of a lake is a relative expression of the biological productivity of a lake. Two approaches to TSI are presented below, one based on the Carlson index and on based on EPA criteria.

Carlson Index

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 is used in 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 from WY 2018 to 2021 are presented in Table 22. 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 2021, concentrations in Cherry Creek Reservoir averaged 87.2 µg/L for TP, 19.8 µg/L for chl α and 1.19 m for the Secchi depth. Based on these values, calculated trophic state indices were 67 for TP, 60 for chl α, and 56 for Secchi depth. These values indicate that Cherry Creek Reservoir is eutrophic in regard to all three TSI indices for WY 2021.

Table 22. Trophic State Indices for Cherry Creek Reservoir WY 2018-2021.

Year	Trophic State Index (TSI)		
	Total P	Secchi Depth	Chlorophyll *a*
2018	69	58	59
2019	71	57	57
2020	73	60	60
2021	67	56	60
Trophic State	**Eutrophic**	**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 2021. 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 over time, the TSI for TP and Secchi depth are lower than the last 3 years. The WY 2021 TSI for chl-α is the same as WY2020 and slightly higher than 2018-2020.

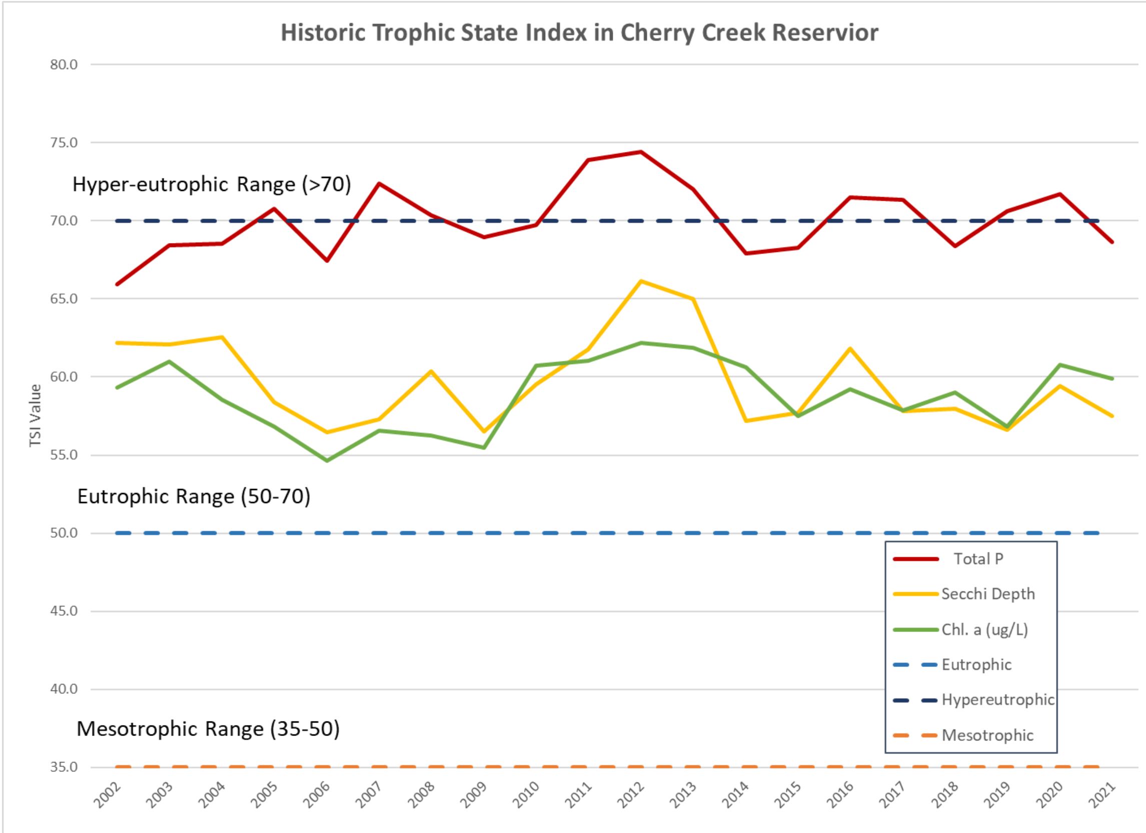


Figure 54. Historical Trophic State Index for Cherry Creek Reservoir (2002-2021).

EPA Trophic State Criteria

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 23 presents a comparison of Cherry Creek Reservoir monitoring data from WY 2021 to EPA trophic state criteria. Values for the various parameters were the same averages used to calculate the trophic state indices.

Table 23. Comparison of Cherry Creek Reservoir Monitoring Data to EPA Trophic State Criteria WY 2021.

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	**.087**	**19.8**	**1.2**	**High**

The trophic state criteria in Table 23, 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 for TP and chl α concentrations. The trophic state criteria for Secchi depth was in the hypereutrophic range according to the EPA criteria during WY 2021. 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.

Although these two methods use slightly different calculations and ranges, both the Carson Index and EPA criteria indicate eutrophic to hypereutrophic conditions of Cherry Creek Reservoir for each of the individual parameters evaluated.

4.15 PLANKTON SAMPLES

Analyses of phytoplankton and zooplankton samples were used to assess biological conditions in Cherry Creek Reservoir during WY 2021. 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.

4.15.1 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 2021 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 27 on May 19, 2021, and the maximum number was 66 on August 23, 2021. These results were nearly the same as WY 2019 and WY 2020, when the average numbers of species present were 41 and 40, respectively. The minimum number of species present was 28 in both WY 2019 and WY 2020, and the maximum number of species present was 60 in WY 2019 and 57 in WY 2020. The lowest number of species present is generally lowest in late summer and early spring, with species diversity increasing in late summer and early fall as water temperatures warm.

Chlorophytes (green algae) had the highest number of different species on each sampling date, peaking at 30 different species on August 23, 2021. The chlorophytes provided 50% or more of the total number of phytoplankton species on most sampling dates, with an average of 18 and a range of 11-30 species present. Bacillariophytes (diatoms) and cyanophytes (blue-green algae) also had high diversities, with averages of 6.6 and 8.6 species, respectively, per sampling date. Chrysophytes (golden-brown algae) and cryptophytes (cryptomonds) were the only other groups of algae that were present on each sampling date, with averages of

1.7 and 2.6 species per sampling event. The haptophyte, *Chrysochromulina parva*, was present on all except one date and was the only golden algal species present in WY 2021. The remaining groups, euglenophytes (9 dates, 1-3 species), pyrrhophytes (8 dates, 1-4 species), and miscellaneous microflagellates (2 dates, unknown species) were less common and averaged less than two species per sampling event.

Cyanophytes are probably responsible for the majority of nuisance algal blooms that occur in freshwater ecosystems and some species are also capable of producing algal toxins. Cyanophytes have the ability to use atmospheric nitrogen as a nutrient source and they can also 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.

Several species of cyanobacteria are capable of producing toxins. These include *Dolichospermum* sp. and *Aphanizomenon flos-aquae*, the two species that contributed to the severe blooms found at Cherry Creek Reservoir during July 2020. These two species were still present but less common during WY 2021, and two other cyanophytes that are capable of toxin production were also present. *Microcystis aeruginosa* (June through August) and *Pseudoanabaena limnetica* (November and December 2020 and July through September 2021) were observed during WY 2021 but were present in relatively low concentrations.

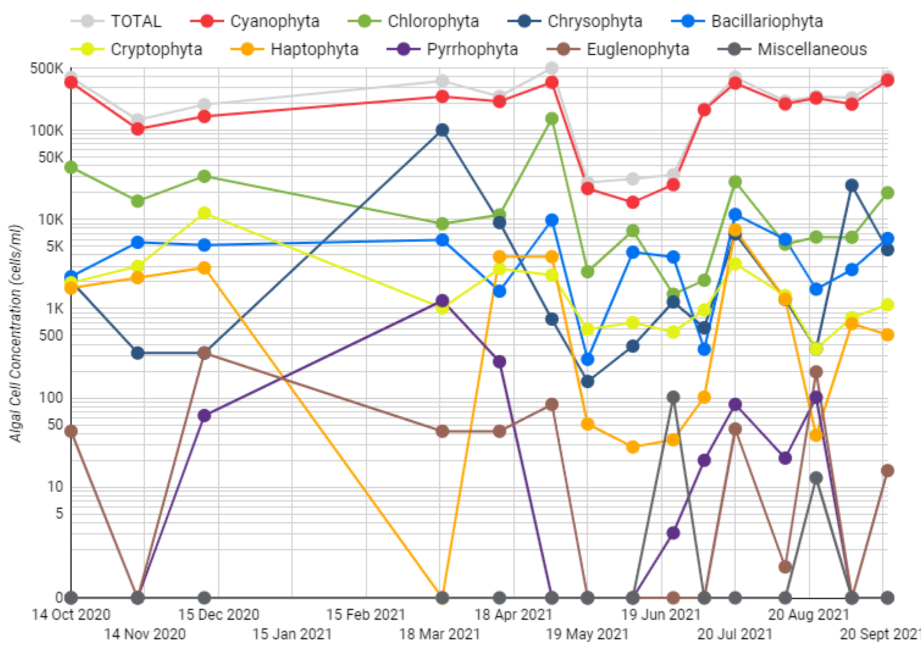


Figure 55. Phytoplankton Concentrations in Cherry Creek Reservoir, WY 2021.

As in previous years, 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). Cyanophyte concentrations averaged 196,034 cells/mL during WY 2021, with a minimum observed cyanophyte cell count of 15,609 cells/mL on June 7, 2021, and a maximum of 363,778 cells/mL on September 22, 2021, which comprised almost 92% of the total algal cell count on that date. In general, cyanophyte cell counts were lower in WY 2021 than in WY 2020, but higher than in WY 2019. Relative concentrations followed the same pattern. The cyanophytes were responsible for 50% or more of the total phytoplankton population on each sampling date and averaged 80% of the algal cell counts on each sampling date and 83% of the total algal cell counts for all of WY 2020 (Figure 56). For comparison, cyanophytes averaged 85% of the total algal cell counts in WY 2020 and 74% of the total algal cell counts in WY 2019.

The most common cyanophytes were *Chroococcaceae* spp. and *Synechococcus* sp. 1, both small (<1 µm) species that were each present on all sampling dates. *Chroococcaceae* spp. concentrations peaked at 179,102 cells/mL on April 12, 2021 and concentrations averaged 101,339 cells/mL for all of WY 2021. *Synechococcus* sp. 1 peaked at 76,539 cells/mL on July 20, 2021, and averaged 36,394 cells/mL for all of WY 2021. These two species combined for 70% of all cyanobacteria counts and over 58% of the total algal cell counts for WY 2021.

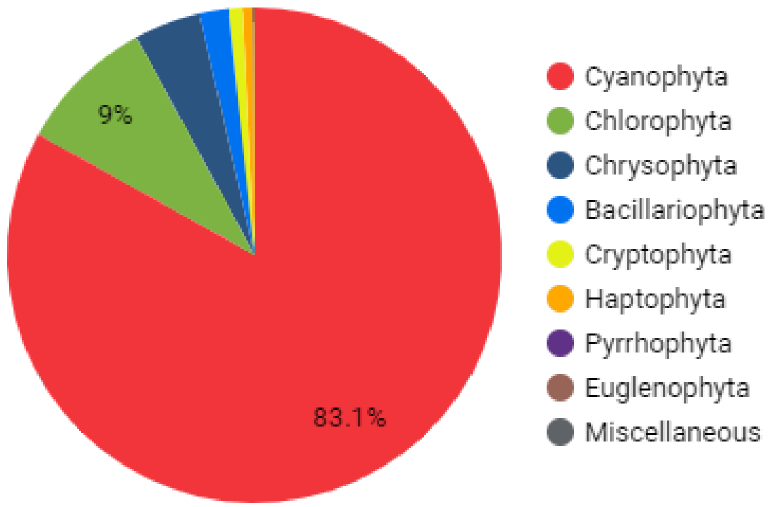


Figure 56. Relative Phytoplankton Concentration, WY 2021.

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 4.7% of the total algal biovolume in WY 2021. 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 less than 25% of the cyanophyte biovolume and only 1.2% of the total algal biovolume for WY 2021.

The relative cyanophyte biovolume of 4.7% of the total algal biovolume in WY 2021 was much less than the averages of 21.6% in WY 2019 and 18.1% of the total algal biovolume in WY 2020. These lower percentages were due to large blooms of some of the other groups.

When looking at the total cyanobacteria population and biovolume in more detail a few key factors are apparent. Although the small cyanobacteria *Chrooococcaceae* accounted for a large percentage of the total algal and cyanobacteria population cell counts, they did not contribute a large percentage of the overall biovolume at any sampling event during the year and only 25.8% for the whole year due to their small size (Figure 57). The potential toxin-producing cyanobacteria, such as *Dolichospermum* and *Aphanizomenon,* which were responsible for the severe blooms in 2020, were present in WY 2021 but only accounted for less than 1% of the total biovolume for the year.

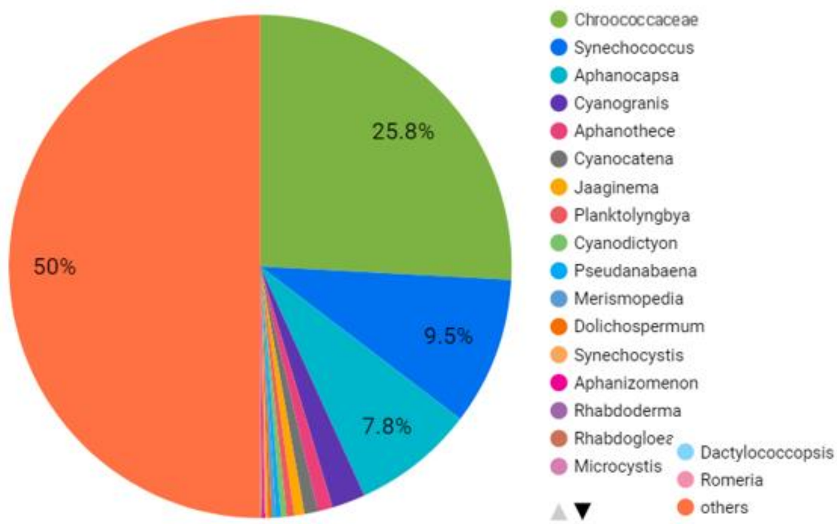


Figure 57. Annual Relative Biovolumes of Cyanobacteria Populations in WY 2021

Chlorophytes were present in high numbers throughout the year, and chlorophyte cell concentrations were second only to the cyanophytes on all dates except March 19, 2021. Chlorophyte concentrations averaged 21,222 cells/mL for each samples date, for a total of 9.0% of the total cell counts in WY 2021. This was less than the 10.1% in WY 2019, but greater than the 8.6% the total cell counts in WY 2020 (Figure 56). *Chlamydomonas* sp. was the only chlorophyte present on all sampling dates, and it exceeded the 1,000 cells/mL threshold generally accepted as causing bloom conditions on six of those dates. *Monoraphidium capricornutum* and *Monoraphidium arcuatum* were each present on 12 sampling dates and *Monoraphidium griffithii* was present on 11 sampling dates. Those three species exceeded 1,000 cells/mL on a combined 11 occasions, with *Monoraphidium griffithii* reaching the highest concentration of 18,369 cells/mL on May 4, 2021. *Mucidosphaerium pulchellum* was the green alga present at the highest concentrations in WY 2021, with a cell count of 42,862 cells/mL, also on May 4, 2021, where that species accounted for 8.6% of the total algal population. *Oocystis parva* was present on 13 sampling dates and exceeded the 1,000 cells/mL threshold on four of those dates.

Many chlorophyte species are fairly large, and most are larger than the cyanophytes. Green algae made up 18.6% of the total algal biovolume in WY 2021, which was slightly lower than the 19.8% in WY 2019 and 22.8% of the total algal biovolume in WY 2020 (Figures 56 and 57). *Pyramichlamys dissecta*, a very large species, was present on 10 sampling dates and had biovolumes exceeding 100,000 μm^3/mL on 6 of those dates. *Pyramichlamys dissecta* had the highest biovolume of any chlorophyte in WY 2021, peaking at 1,196,169 μm^3/mL on September 22, 2021, which was 59% of the total biovolume on that date. *Chlamydomonas* sp. and *Oocystis parva* were other large chlorophytes with biovolumes of over 100,000 μm^3/mL on several dates.

Bacillariophytes (diatoms) can also be responsible for nuisance blooms, but those relate mainly to taste and odor problems in drinking water supplies, and those issues are not as common as nuisance cyanobacteria blooms. Diatom blooms tend to be most common during the spring or fall months when water temperatures are relatively low; however, diatom counts in Cherry Creek Reservoir peaked at 11,380 cells/mL on July 20, 2021, which was 2.9% of the total cell count on that date. *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 also 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 1.9% of total phytoplankton cell counts in WY 2021, which was lower than the 2.9% of cell counts in WY 2019 and 2.2% of the relative phytoplankton cell counts during WY 2020. *Cyclotella atomus*, with a cell count of 6,123 cells/mL on May 4, 2021, was the diatom with the highest concentration during WY 2021, but that represented only 1.2% of the total algal cell count on that date.

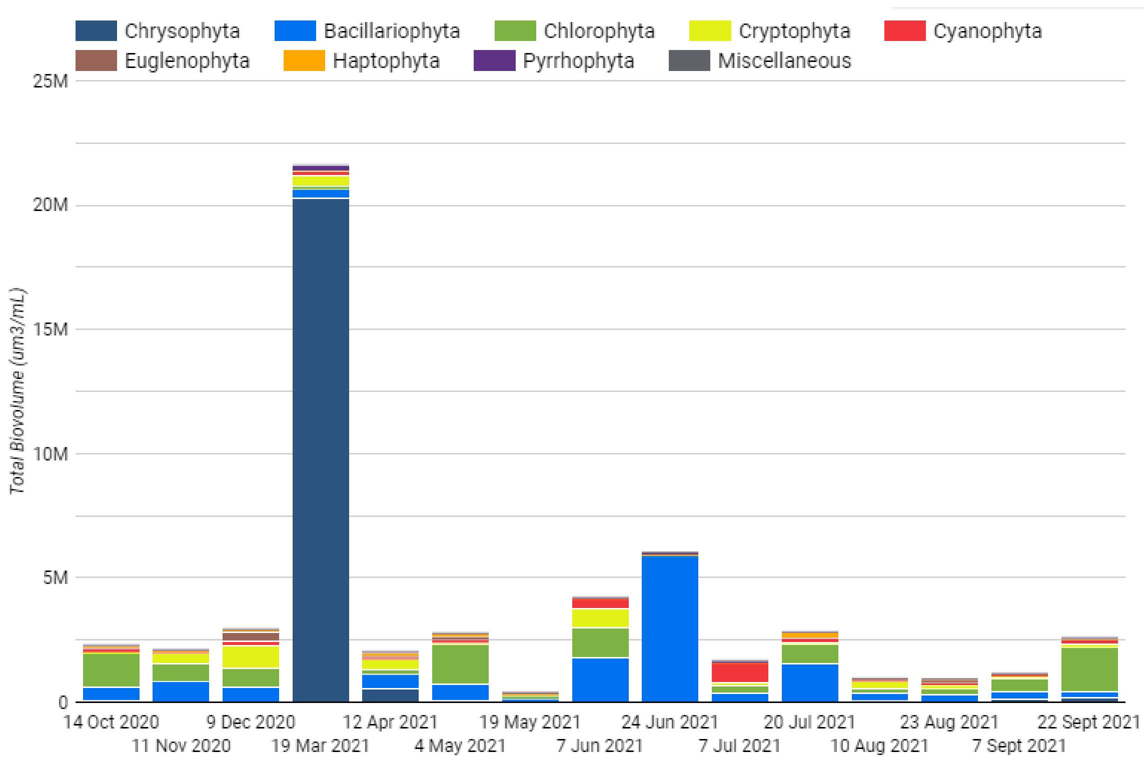


Figure 58. Phytoplankton Biovolumes in Cherry Creek Reservoir in WY 2021.

Because of their relatively large size, diatoms contributed 26.5% of the relative algal biovolume in WY 2021 (Figure 58). That was greater than the 21.6% of the relative algal biovolume in WY 2019, but much less than the 37.8% of the relative algal biovolume in WY 2020. Diatoms made up 97.3% of the relative diatom biovolume on June 24, 2021. *Aulacoseira granulata* was the diatom with the highest biovolume on that date (5.76×10^6 μm^3/mL), which represented 95.2% of the total algal biovolume. That was also the highest diatom biovolume for WY 2021.

An unusual chrysophyte (golden-brown algae) bloom was observed on March 19, 2021, when *Ochromonas* sp. reached a concentration of 101,032 cells/mL. That accounted for 28.3% of the total algal cell counts on that date, as well as 66% of the chrysophyte counts and 4.3% of the total algal cell counts for all of WY 2021 (Figures 56 and 58). The WY 2021 chrysophyte count of 153,305 cells/mL was behind only the cyanophyte and chlorophyte counts, and was much higher than the relative chrysophyte counts of 0.51% of total cell counts for WY 2019 and 0.52% of total cell counts for WY 2020. *Ochromonas* sp. only reached bloom conditions on one other date and chrysophytes of the class Chrysophyceae occurred at concentrations of greater than 1,000 cells/mL on an additional four occasions.

Some chrysophytes are relatively large and, mainly because of the March *Ochromonas* sp. bloom, chrysophytes made up 39% of the total algal biovolume in WY 2021 (Figure 60), more than any other group. This bloom had a biovolume of 20.3 x 10^6 µm^3/mL, which was 94% of the total algal biovolume for the date and 37% of the total algal volume for all of WY 2021. This was far higher than the relative chrysophyte biovolumes of 0.78% for WY 2019 and 0.88% for WY 2020.

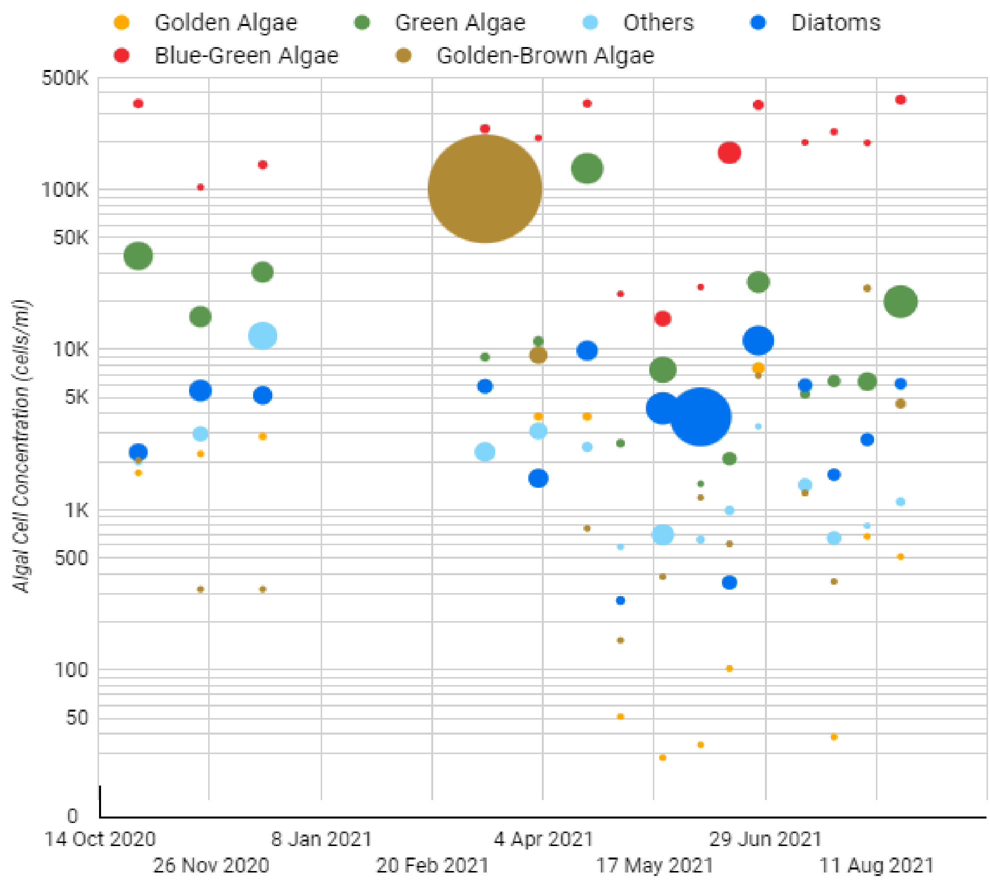


Figure 59. Phytoplankton Population (y-axis) and Biovolume (bubble size) in Cherry Creek Reservoir in WY 2021.

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. Cryptophytes were present at that level on 10 occasions and on all but four sampling dates in WY 2021 (

Figure 55). Only six species of cryptomonads were identified in Cherry Creek Reservoir during WY 2021, but *Cryptomonas erosa* was present on each sampling date and *Plagioselmis* (formerly *Rhodomonas*) *minuta nannoplnctica* was present on all but one sampling date. *Plagioselmis minuta nannoplnctica* was usually the cyptomonad present in the highest numbers, peaking at 6,566 cells/mL on July 20, 2021, which was only 1.7% of the total cell count on that date. The cryptomonads contributed only 0.9% to the total cell count in WY 2021 (Figure 60), compared to 3.5% in WY 2019 and 1.5% in WY 2020.

The cryptomonads are typically relatively large algae and often made up a significant portion of the relative phytoplankton biovolume, averaging 7.2% of the relative algal biovolume for WY 2021 (**Error! Reference source not found.**60). This compared to 14.0% in WY 2019 and 9.3% of the relative algal biovolume in WY 2020. The large species, *Cryptomonas erosa*, was the cryptomonad species with the highest biovolume on most sampling dates. The biovolume for this species peaked at 763,860 µm^3/mL on June 7, 2021, when it comprised 18.3% of the total algal biovolume. The cryptomonads reached their highest relative biovolume during WY 2021 of 31.3% on August 21, 2021; overall cell counts and biovolumes were relatively low on that date (Figures 55 and 58).

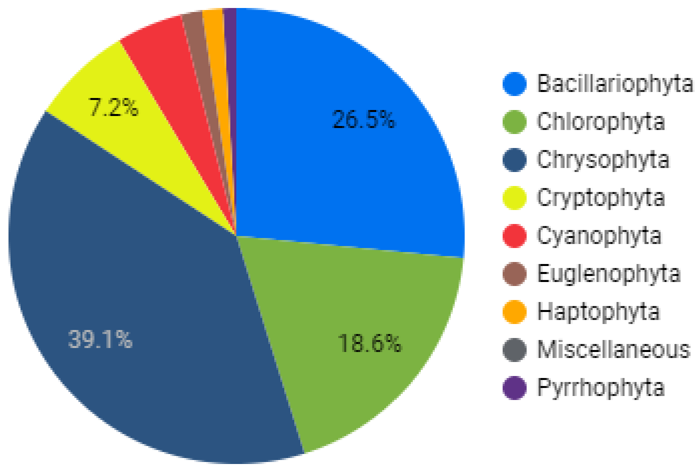


Figure 60. Relative Phytoplankton Biovolume during WY 2021

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. *Chrysochromulina parva* was the only haptophyte present during WY 2021, and it occurred on every sampling date except March 19, 2021 (Figure 55).

Chrysochromulina parva made up 0.7% of the total alga cell counts and 1.5% of the total algal biovolume in Cherry Creek Reservoir in WY 2021 (Figure 56 and 60). These figures for the haptophytes are less than the 3.4% of cell counts and 5.5% of algal biovolumes observed in WY 2019 and the 2.2% of the alga cell counts and 4.9% of the total algal biovolume in Cherry Creek Reservoir in WY 2020. Concentrations of *Chrysochromulina parva* were variable throughout the year (

Figure 55 and 59), reaching a peak concentration of 7,654 cells/mL and biovolume of 246,329 μm^3/mL on July 20, 2021. These numbers accounted for only 1.9% of the total algal population and 0.7% of the total algal biovolume on that date.

Other groups present at various times during the year included the phyrrhophytes (dinoflagellates), euglenophytes, and miscellaneous microflagellates. The phyrrhophytes and euglenophytes include some large species, but concentrations never reached bloom conditions in WY 2021 and those two groups contributed less than 0.05% and 0.02%, respectively, of the total cell counts (Figure 56). Because of their relatively large size, the phyrrhophytes and euglenophytes contributed 0.95% and 1.9%, respectively, to the total algal biovolume for WY 2021 (Figure 60).

The miscellaneous microflagellates were only present on June 24, 2021, and August 23, 2021, and only at very low concentrations. The miscellaneous microflagellates contributed less than 0.01% of the total cell counts and total algal biovolume for WY 2021.

4.15.2 ZOOPLANKTON

Zooplankton are microscopic animals that consume algae and bacteria in the water column. Some types of zooplankton feed on algae, some 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 cladocerans, copepods, and ostracods; *Rotifera*; and *Protozoa*. Cladocerans, copepods, and ostracods are microscopic crustaceans that feed primarily on phytoplankton. Larger organisms in these groups 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 2021 were 0-4 cladocerans, 1-5 copepods, 0-8 rotifers, and either 0 or 1 protozoa present on each date, with an average of 9.5 species, including immature forms, present on each sampling date. This is slightly lower than the 11.6 species per date in WY 2019 and 10.8 zooplankton species per sampling date in WY 2020.

Copepods were typically the zooplankton present in the highest numbers in Cherry Creek Reservoir during WY 2021 (Figure 61), averaging 51% of the total zooplankton population. This is similar to the averages of 54% for WY 2019 and 51% of the total zooplankton population in WY 2020. Relative copepod concentrations during WY 2021 ranged from 18% on August 23 to 92% on March 19, 2021. Unidentified, immature copepods were the only zooplankton present on each sampling date, with immature cyclopoid copepods present on all but two dates. These two forms plus immature calanoid copepods accounted for 48% of the total zooplankton population present during WY 2021. Unidentified, immature copepods reached the highest number of any copepod with 91.9 organisms/L on June 7, 2021, which was 37% of the total zooplankton population on that date.

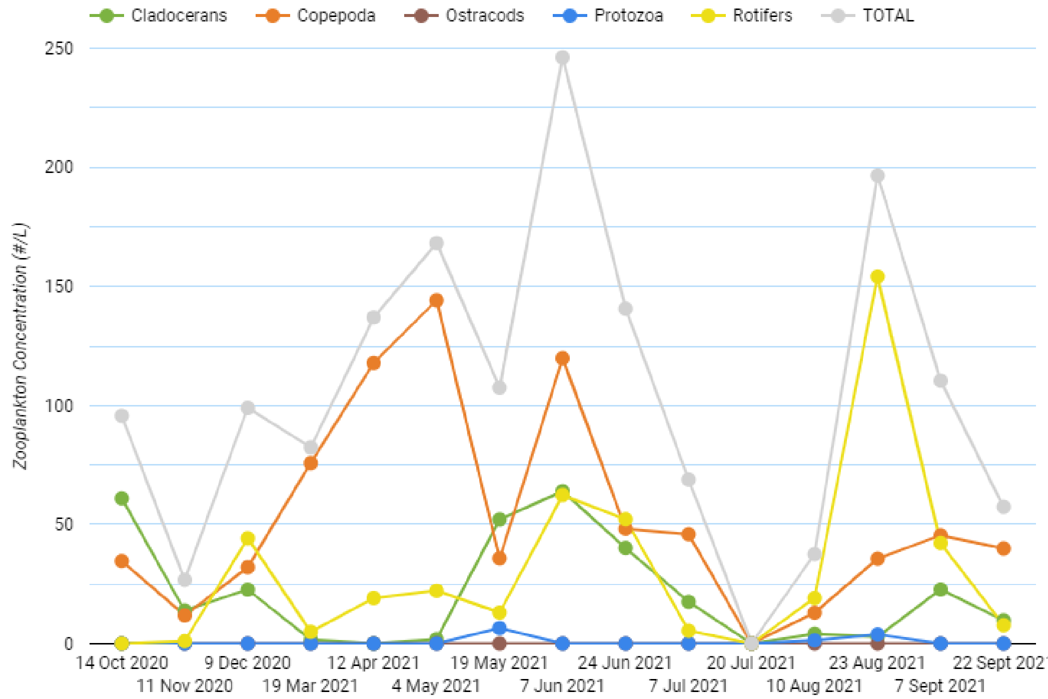


Figure 61. Total Zooplankton Concentrations – WY 2021.

Only five adult species of copepods were present in Cherry Creek Reservoir during WY 2021. *Leptodiaptomus ashlandi*, present on six dates, and *Diachyclops thomasi*, present on five sampling dates, were the most common adult species. *Diachyclops thomasi* was the adult form reaching the highest concentration during the year, with 14.8 organisms/L present on March 19, 2021. That represented 18% 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 generally smaller than the cladocerans. Total copepod biomass during WY 2021 was 672 µg/L, which was only 12% of the total zooplankton biomass. Relative copepod biomass ranged from less 2.5% on October 14, 2020, to 99.3% on April 12, 2021 (Figure 633 and 64). The relative copepod biomass in WY 2021 was much lower than the 34% observed in WY 2019 and the 43% observed in WY 2020. *Acanthocyclops vernalis* had the highest biomass of any copepod during the year, with a concentration of 78.4 µg/L on May 19, 2021. That value was 22.8% of total zooplankton biomass on that date.

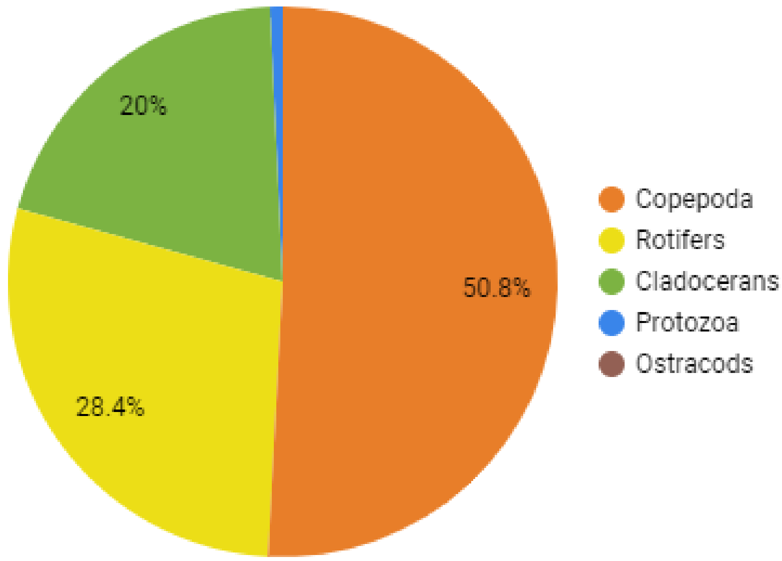


Figure 62. Relative Zooplankton Concentrations in WY 2021, Percent of Total.

The cladoceran species present in Cherry Creek Reservoir typically do not include the large-bodied Daphnia which 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).

Cladocerans were present in Cherry Creek Reservoir on all sampling dates during WY 2021, except for April 12, 2021. The average cladoceran concentration was 21 organisms/L (Figure 61 and Figure 62, but only five species of cladocerans were present during the year. Cladoceran populations during WY 2021 averaged 20% of the total zooplankton population, which was less than the relative populations of 29% of the total zooplankton population during WY 2019 and 31% during WY 2020. The highest relative cladoceran population was 64% of the total zooplankton population on October 14, 2020. *Bosmina longirostris* was the most prevalent cladoceran, being present on 13 of the 15 sampling dates. *Daphnia ambigua* was only present on three sampling dates from May through July, but it was the cladoceran with the highest individual population in WY 2021, with 62.4 organisms/L on June 7, 2021. That figure comprised 25% of the total zooplankton population on that date.

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 only one sampling date during WY 2020. *Daphnia lumholtzi* was again common in WY 2021 and was present on six sampling dates from October-December 2020 and again in August and September 2021.

Cladocerans comprised over half of the total zooplankton biomass on 11 of the 15 sampling dates during WY 2021 and over 90% of the zooplankton biomass on 6 dates (Figure 633 andFigure 64). Cladoceran biomass averaged 61% of the zooplankton biomass for the individual sampling dates, with a range of 0% (April 12, 2021) to 97.5% (October 14, 2020) for the 15 sampling dates. The average relative zooplankton biomass in WY 2021 was lower than the 65% observed in WY 2019 and higher than the 54% for WY 2020.

When looking at overall zooplankton biomass for WY 2021 as a whole, cladocerans comprised 87.4% of the total, primarily due to an exceptional bloom of *Daphnia lumholtzi*, on October 14, 2020. *Daphnia lumholtzi* had a biomass of 2,464 µg/L, on that date, which represented 96% of the zooplankton biomass for that date and 45% of the total zooplankton biomass for all of WY 2021.

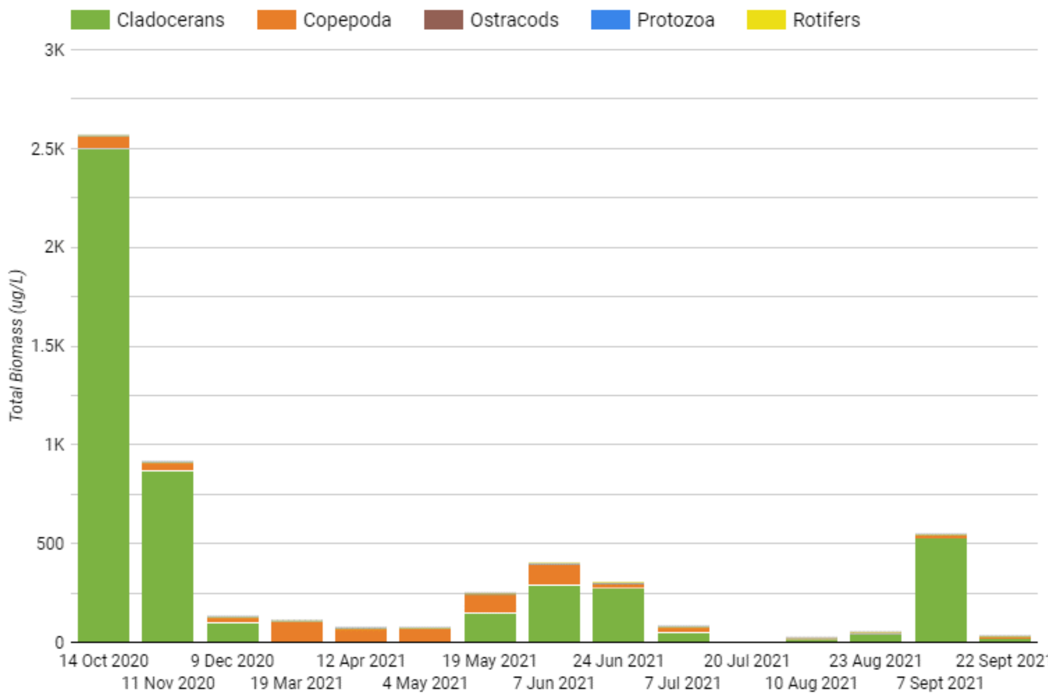


Figure 63. Total Zooplankton Biomass (µg/L) in WY 2021.

Rotifers had a diverse population in Cherry Creek Reservoir during WY 2021, with 13 different species present. Rotifers averaged 28.4% of the total zooplankton population during WY 2021, which was higher than averages of 15.5% for WY 2019 and 17.6% for WY 2020. The maximum relative rotifer population was 78.4% of the total on August 23, 2021, and no rotifers were present October 14, 2021. Rotifer populations reached a maximum of 154 organisms/L on August 23, 2021. *Brachionus angularis* contributed 150 organisms/L to this total, which represented 98% of the rotifer population and 76% of the total zooplankton population on that date (Figure 61 and Figure 62). *Keratella cochlearis*, present on 13 dates, was the only rotifer present on at least half of the sampling dates during WY 2021.

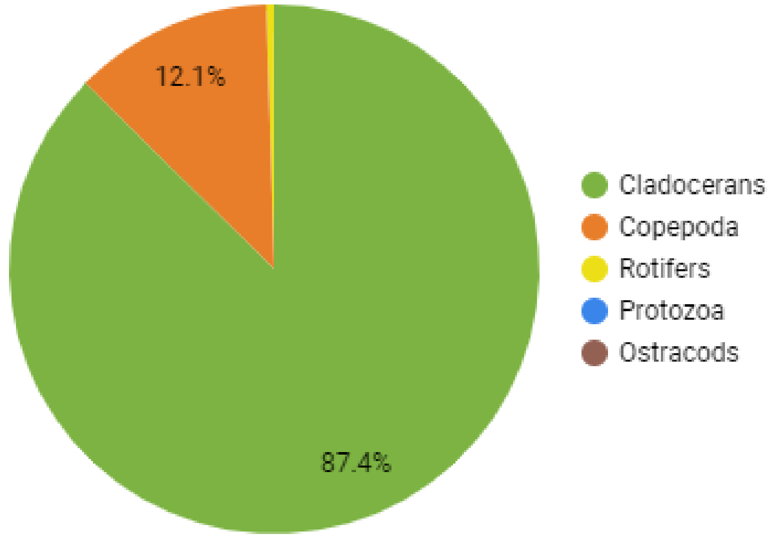


Figure 64. Relative Zooplankton Biomass in Cherry Creek Reservoir in WY 2021.

Due to their small size, rotifer biomass averaged only 1.7 µg/L, which was only 0.47% of the total zooplankton biomass for the year. This similar to the 1.6 µg/L observed during WY 2019 but lower than the 4.7 µg/L observed in WY 2020. The maximum rotifer biomass was only 4.9 µg/L on June 7, 2021, which was only 1.2% of the total relative zooplankton biomass on that date. The maximum relative rotifer biomass was 3.2 µg/L or 4.1% of the total zooplankton biomass on July 7, 2021, when the total zooplankton biomass was 78.1 µg/L. The rotifer with the highest biomass was *Keratella quadrata*, which had a biomass of 6.05 µg/L on June 24, 2021. That comprised 96% of the rotifer biomass but only 2.0% of the total zooplankton biomass on that date.

Protozoa and ostracods made only minor contributions to the zooplankton community in Cherry Creek Reservoir during WY 2021. Protozoans were present on only four sampling dates during WY 2021 and only two species, *Centropyxis* sp. and *Difflugia* sp., were present. *Centropyxis* sp. was present on July 20, 2021, and August 10, 2021, while *Difflugia* sp. was present on May 19, 2021, and August 23, 2021. The protozoans averaged only 3.9% of the total zooplankton population and 0.33% of the total zooplankton biomass on the dates when they were present (Figures 61-64).

An ostracod of the subclass Podocopa was present only on July 20, 2021, with a concentration of 0.0002 organisms/mL and a biomass of 0.0093 µg/L. Those numbers represented 0.50% of the total zooplankton concentration and 0.67% of the total zooplankton biomass for that date, but only because very few zooplankton were present then (Figures 61 and 63).

5.0 WATER BALANCE

The WY 2021 water balance for Cherry Creek Reservoir was calculated from the following equation:

Ending $Storage_{9/30/2021}$ + ∑Reservoir Inflows – ∑Reservoir Outflows - Starting $Storage_{10/1/2020}$ = Δ 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 5548.54 ft and 11,367 AF on October 1, 2020, and 5548.7 ft and 11,497 AF on September 30, 2021. This results in a gain in storage of 121 AF (Δ Storage) during WY 2021.

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 16.25 inches (1.35 feet) of precipitation was recorded at the KAPA weather station during WY 2021. This marked the first year since 2016 that annual precipitation was above the 10-year average of 14.32 inches from 2009-2020 (Figure 5). Based on these calculations, precipitation contributed an estimated 1,113 AF of water to the Reservoir during WY 2021.

The surface area of Cherry Creek Reservoir during WY 2021 varied between 783 acres on November 15, 2020, and 888 acres on June 30, 2020, with a median value of 801 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 CT-2 from February 15 to February 23, 2021 as a result of equipment 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 2021 are:

- Cherry Creek: 16,773 AF
- Cottonwood Creek: 4,517 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 3,241 AF during WY 2021, or approximately 3.37 feet (40.4 inches) per acre at the median surface area of 801 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 65). 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 2021 flows at the USGS gauge below the Reservoir averaged 46.52 AF/day for an annual total of 16,979 AF. The 2021 outflow is 222% of the long-term average from 1950-2021, but only 86% of the average for the previous 5 years (2016-2020).

The Reservoir WY 2021 water balance is summarized in Table 24. Following methods developed by TetraTech (2018), the net ungauged inflow(+)/outflow(-) was mathematically calculated to result in the Reservoir gain in storage of 120 ac-ft reported by the USACE for WY 2021 (Appendix A). Components included in this calculated term include data from the USACE, as well as, 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 24 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 2021 were -4,262 AF.

It is hard to determine what may be overestimating inflows into the Reservoir. The stage discharge relationship at CC-10 is continuously being updated and evaluated based on the changes in the channel but it only demonstrates small differences from year to year. In 2021, a detailed survey was completed and new equipment was installed at Lakeview Dr. to estimate the flows that may bypass the monitoring station at CC-10 during high flows. In 2022, when a full year of data is available, the rating curve for this site and at CC-10 will be evaluated in more detail to determine at what stage which calculations should be used. However, this will likely increase the flow calculated at CC-10 and could cause the ungauged flows to be higher.

Based on previous practice, the ungauged inflows (outflows in WY2021) were apportioned between the Cherry Creek and Cottonwood Creek inflows to calculate nutrient loading (Section 6). For WY 2021, Cherry Creek contributed 78.8% of the combined inflow and Cottonwood Creek contributed 21.2%, 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 3,407 AF for Cherry Creek and 855 AF for Cottonwood Creek. The adjusted inflows were 13,366 AF for Cherry Creek and 3,662 AF for Cottonwood Creek.

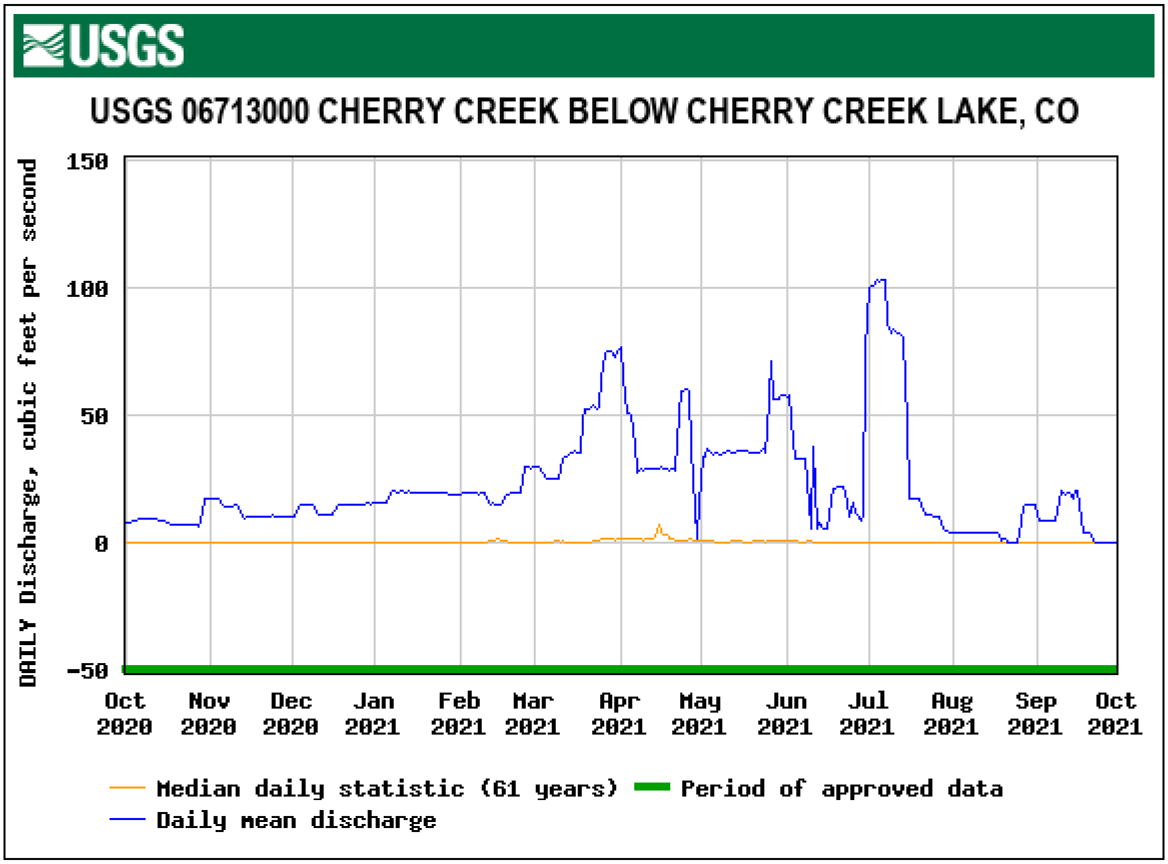


Figure 65. WY 2021 Hydrograph and Historical Median Flows for USGS Site Cherry Creek below Cherry Creek Lake.

Table 24. Cherry Creek Reservoir WY 2021 Water Balance

Water Source	Water Volume (AF)
Inflows	
Cherry Creek (CC-10)	16,773
Cottonwood Creek (CT-2)	4,517
Precipitation	1,113
Alluvial groundwater	2,200
Total Inflows	**24,603**
Outflows	
Evaporation	-3,241
Reservoir releases	-16,979
Total Outflows	**-20,220**
Net Ungauged Inflows/Outflows	
Calculation	**-4,262**
WY 2021 Change in Storage	121

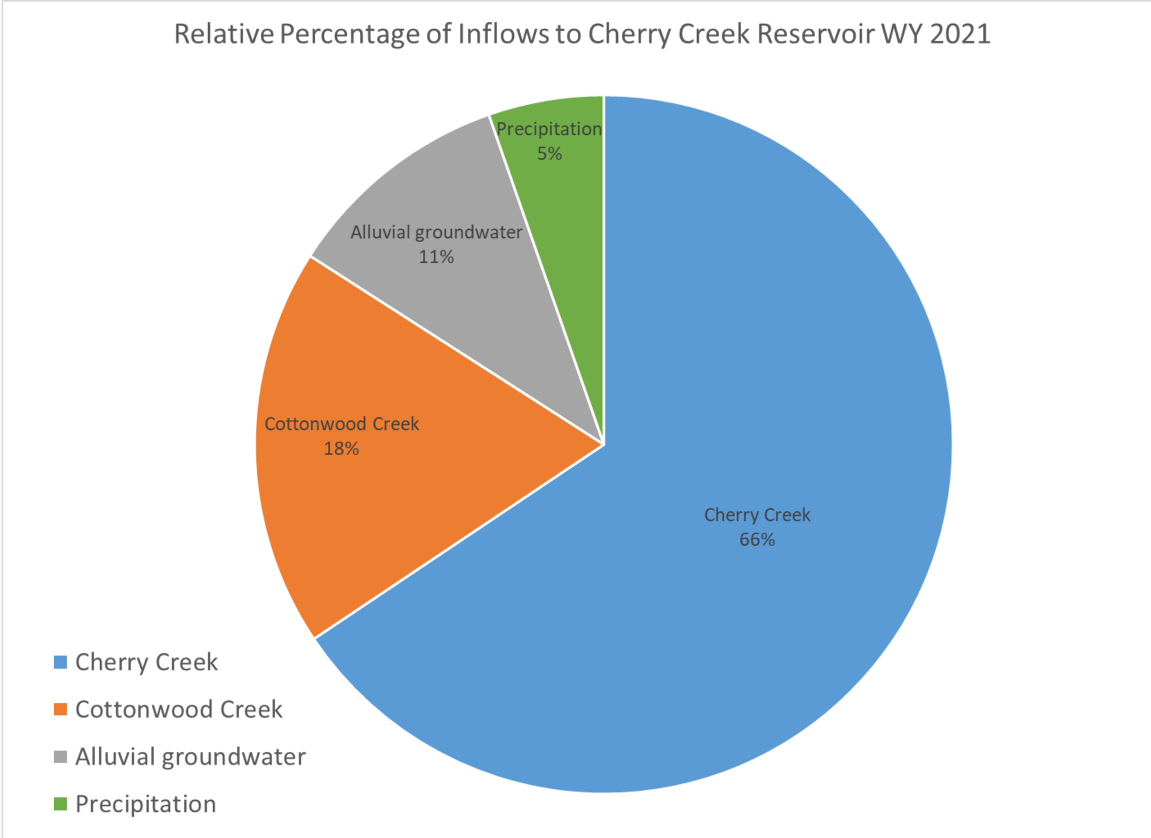


Figure 66. Relative Inflows to Reservoir Water Balance in WY 2021.

The relative inflows to the Reservoir from Cherry Creek, Cottonwood Creek, groundwater, and precipitation are pictured in Figure 66.

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 2021 as well as the concentrations from previous years are outlined in Table 25.

The WY 2021 flow-weighted TP concentration for Cherry Creek Station CC-10 was 203 µg/L was higher than the WY 2020 188 µg/L, which was lower than WY 2019 concentration of 222 µg/L and the average 2011 – 2029 flow-weighted total phosphorus concentration of 244 µg/L (Table 25). The WY 2021 flow-weighted TN concentration of 1,396 µg/L for station CC-10 was lower than the WY 2020 (1,500 µg/L), WY 2019 (1,565 µg/L), but higher than the 2011 – 2020 average flow-weighted total nitrogen concentration of 1,352 µg/L.

The WY 2021 flow-weighted TP concentration for Cottonwood Creek Station CT-2 was 65 µg/L which was higher than WY 2020 (53 µg/L), WY 2019 (49 µg/L), but lower than the average 2011 – 2020 total phosphorus concentration of 70 µg/L. The WY 2021 flow-weighted TN concentration for Station CT-2 of 1,856 µg/L was much lower than WY 2020 (2,479 µg/L), WY 2019 (2,427 µg/L) and slightly lower than the 2011 – 2020 average total nitrogen concentration of 1,878 µg/L.

Similar to the averages for the past 10 years, the flow-weighted total phosphorus concentrations for WY 2021 were much higher for Station CC-10 than for Station CT-2 (Table 25). In contrast, the WY 2021, WY 2020 and WY 2011--2020 average flow-weighted total nitrogen concentrations were all higher for Station CT-2 than for Station CC-10.

Table 25. 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 2011-2020	244	1,352	70	1,868
WY 2020	188	1,500	53	2,479
WY 2021	**203**	**1,396**	**65**	**1,856**

The median groundwater concentrations of 237 µg/L of total phosphorus and 573 µg/L of total nitrogen for the period 2015-2021 were used in the calculation of flow-weighted nutrient concentrations in groundwater for WY 2021. The median nutrient concentrations in precipitation samples for the period of 2001-2021 of 88 µg/L of total phosphorus and 1,946 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 2021 are summarized in Table 26.

Table 26. Flow-Weighted Inflow Concentrations of TN and TP, WY 2021

		Source				
	Nutrient	**Cherry Creek**	**Cottonwood Creek**	**Alluvial Groundwater**	**Precipitation**	**Weighted Total**
Inflow Concentration (µg/L)	Total Phosphorus	134	12	26	5	176
	Total Nitrogen	918	335	62	105	1,420
% of Total Inflow		**65.7%**	**18.0%**	**10.8%**	**5.5%**	**100%**

The WY 2021 flow-weighted TP concentration of all inflows of 176 µg/L is similar to WY 2020 but is lower the historical median from 2011-2020 (Table 27). The flow weighted TP concentration limit set by the Cherry Creek Reservoir Control Regulation 72 (REG72) is 200 µg/L. In contrast, the WY 2021 flow-weighted TN inflow concentration of 1,420 µg/L is slightly lower than WY 2020 concentrations, but higher than the 2015-2020 median.

Table 27. Flow-Weighted Nutrient Concentrations for Surface Water Inflows to Cherry Creek Reservoir.

Water Year	Total Flow-Weighted Nutrient Concentrations (µg/L)	
Median	Total Phosphorus	Total Nitrogen
WY 2011-2020 (*2015)	200	1,344*
WY 2020	173	1,491
WY 2021	**176**	**1,420**

**Note: Flow weighted nutrient concentrations for nitrogen were not calculated prior to 2015 so the historical median is calculated from 2015-2020.*

In addition to the above inflow sources, both phosphorus and nitrogen can be added to Cherry Creek Reservoir through internal nutrient loading from the bottom sediment and dry deposition. No current estimates for dry deposition or internal nitrogen loading are available, but Nurnberg and LaZerte (2008) provided estimates for internal phosphorus loading for the 1992-2006 period of 1,895 lbs/yr (average) and 1,383 lbs/yr (median). More detail is provided in Section 8.0 below.

In addition, nitrogen and phosphorus can be added to the Reservoir due to dry deposition and 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 and can, therefore, be excluded from mass balance and flow weighted calculations.

The flow-weighted nutrient concentrations for Reservoir outflows (losses) during WY 2021 are shown in Table 28. Water leaves the Reservoir through the outlet at the Cherry Creek Reservoir dam and surface evaporation.

Table 28. Flow-Weighted TP and TN Concentrations at CC-0 and Evaporation, WY 2021

Nutrient	Concentration (µg/L)	
	Cherry Creek Outflow	**Evaporation**
Total Phosphorus	113	0
Total Nitrogen	1,037	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 under anaerobic conditions. Since nitrate concentrations in Cherry Creek Reservoir are very low, these losses are considered negligible.

7.0 NUTRIENT BALANCE

The calculated WY 2021 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 2021 nutrient balance are:

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

The only physical release mechanism considered from the Reservoir in the WY 2021 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 24 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 2021 are summarized in Table 25 and Table 26. Nutrient concentrations in were combined with the WY 2021 daily flows to calculate annual total phosphorus and total nitrogen loads for the surface water inflows and outflows (releases) to/from the reservoir (Table 29). The Cherry Creek and Cottonwood Creek loads presented in Table 30 were adjusted to apportion the ungauged inflows as discussed in Section 5.0.

Table 29. Surface Water Nutrient Loads to Cherry Creek Reservoir, WY 2021.

	WY 2021 Nutrient Loading	
Site	**Total Phosphorus (Pounds)**	**Total Nitrogen (Pounds)**
Inflows		
Cherry Creek @ CC-10	7,544	51,841
Cottonwood Creek @ CT-2	679	19,410
Releases		
USGS Gage & CC-Out	-5,210	-47,953

7.2 PRECIPITATION LOADS

In WY 2021, TP and TN were measured at the PRECIP site located in Cherry Creek State Park during storm sampling events. Samples were collected from five storm events during WY 2021 which were analyzed for total phosphorus and total nitrogen concentrations. These values represent atmospheric loading and dry deposition. Table 30 lists nutrient concentrations in the precipitation sample collected in WY 2021 and the updated historical mean values which were used to calculate the total loading from precipitation during WY 2021.

Table 30. Cherry Creek Reservoir WY 2021 Precipitation Nutrient Loads

	WY 2021 Nutrient Loading	
PRECIP	**Total Phosphorus**	**Total Nitrogen**
Maximum (µg/L)	552	6,150
Minimum (µg/L)	18	692
Median Concentration (µg/L)	40	1,945
Updated Historical Median(µg/l)	88	1,946
Inflow WY 2021 (AF)	1,113	1,113
Total (lbs)	**266**	**5,888**

- The median total phosphorus concentration in the WY 2021 of 40 µg/L was lower than WY 2020 (50 µg/L and the historical median of 88 µg/L (1991-2021).
- The median total nitrogen concentration in the WY 2021 of 1,946 µg/L was lower than WY 2020 (1,031 µg/L), but and the same as the historical median value of 1,946 µg/L (1991-2021).

Nutrient loads from precipitation were calculated by multiplying the 1991 - 2021 median nutrient concentrations due to significant variability in concentrations and limited measurements collected annually. Daily precipitation loads were calculated by multiplying the lake surface area on each day with measurable precipitation by the amount of precipitation. The total precipitation volume falling on the reservoir surface during WY 2021 was 1,113 AF. The calculated precipitation loads for WY 2021 were:

- Total Phosphorus: 266 pounds
- Total Nitrogen: 5,888 pounds

The nutrient loads from precipitation during WY 2021 were lower the historical mean of 362 lbs of phosphorus and 6,277 lbs of nitrogen calculated from 2006-2021.

7.3 ALLUVIAL GROUNDWATER LOADS

Water samples from monitoring well MW-9 were collected in November 2020 and May 2021 during WY 2021 and analyzed for total phosphorus and total nitrogen. The results are summarized in Table 31.

The median TP concentration from MW-9 for WY 2021 was 306 µg/L which was similar to WY 2020 (312 µg/L), but 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 2021 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 237 µg/L.

The median TN from MW-9 for WY 2021 WY 2020 was 1,510 µg/L was higher than the median from WY 2020 (1,155 µg/L), 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 573 µg/L. Nutrient loads from groundwater were calculated using the historical median values due to significant variability in concentrations and limited measurements collected annually.

Table 31. Cherry Creek Reservoir WY 2021 Groundwater Loading

	WY 2021 Nutrient Load	
MW-9	**Total Phosphorus**	**Total Nitrogen**
Maximum (µg/L)	328	1,720
Minimum (µg/L)	284	1,300
Median (µg/L)	306	1,510
Updated Historical Median (µg/L)	237	573
Inflow WY20 (AF)	2,200	2,200
Total (lbs)	**1,413**	**3,428**

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 2021.

- Total Phosphorus: 1,413 pounds
- Total Nitrogen: 3,428 pounds

8.0 NUTRIENT MASS BALANCES

As summarized in Table 32, 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 29 through Table 31.

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 32. The difference between the inflow and the outflow loads (Δ Storage$_{Nutrients}$) indicate that a net 4,697 pounds of phosphorus and 32,614 pounds of nitrogen were retained in the reservoir in WY 2021.

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 32. Internal phosphorus loading in WY 2021 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 32. Total Phosphorus and Nitrogen Mass Balance in Cherry Creek Reservoir WY 2021

Water Source	Total Phosphorus Mass (pounds)	Total Nitrogen Mass (pounds)
Inflows		
Cherry Creek (CC-10)	7,544	51,841
Cottonwood Creek (CT-2)	679	19,410
Precipitation	266	5,888
Alluvial groundwater	1,418	3,428
Total Inflows	**9,907**	**80,567**
Outflows		
Evaporation	0	0
Reservoir releases	-5,210	-47,953
Total Outflows	**-5,210**	**-47,953**
WY 2021 Change in Storage	**4,697**	**32,614**

The relative contributions of the inflow sources of phosphorus and nitrogen loading to the Reservoir in WY 2021 are represented in Figure 67.

Table 33 presents the current total nutrient mass loads, outflows and resulting storage in Cherry Creek Reservoir in comparison to previous years and the long term average and Figure 68 shows a graphical representation. The calculated total phosphorus loads were higher than 2020 but lower than 2019 and 2018 and the historical mean from 1993-2020. The total nitrogen loads were slightly higher than WY 2020 but lower than the 2018 and 2019 and the long-term historical mean from 1993-2020.

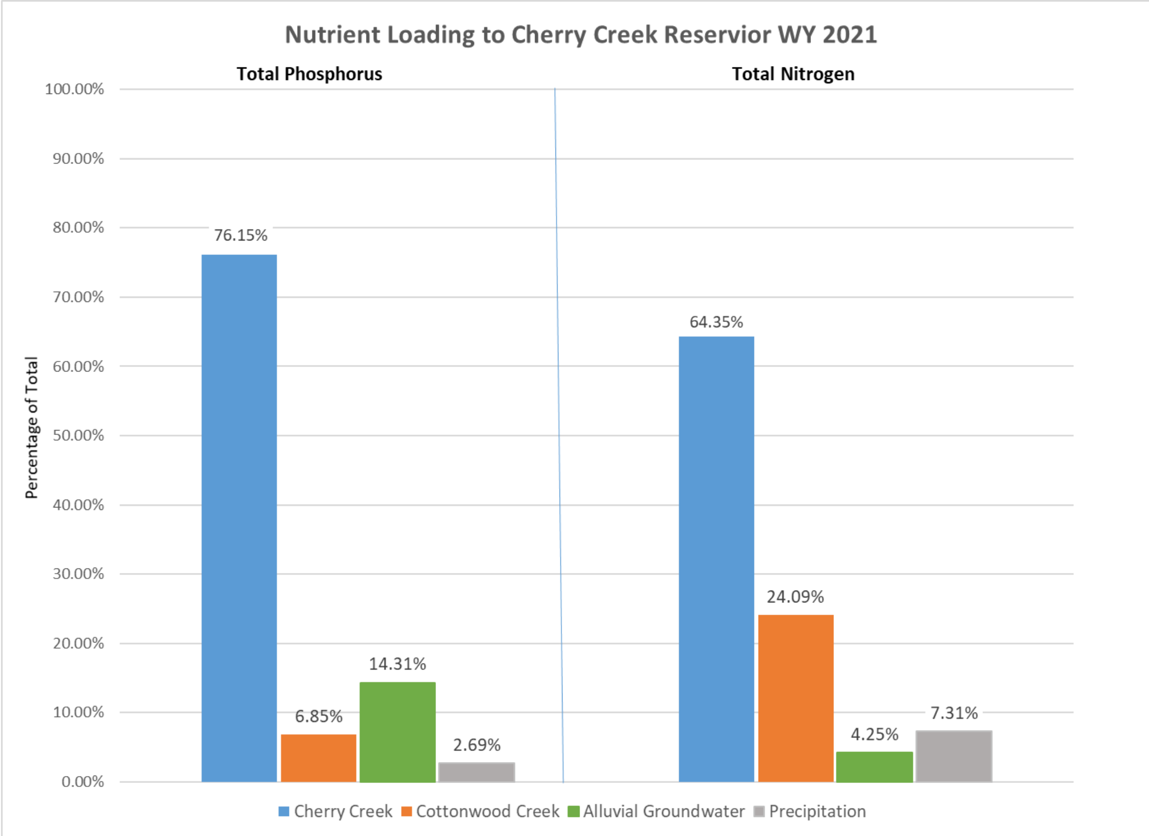


Figure 67. Nutrient Loading Percentages by Source to Cherry Creek Reservoir, WY 2021.

Table 33. Historical Comparison of Total Phosphorus and Nitrogen Loading to Cherry Creek Reservoir.

Analyte	Period Mean	Inflows (pounds)				Outflow (pounds)	Δ Storage (pounds)
		Surface Water	Alluvial Groundwater	Precipitation	Total		
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 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
Phosphorus	**WY 2021**	**8,223**	**1,418**	**266**	**9,907**	**-5,210**	**4,697**
Nitrogen		**71,251**	**3,428**	**5,888**	**80,567**	**-47,953**	**32,614**

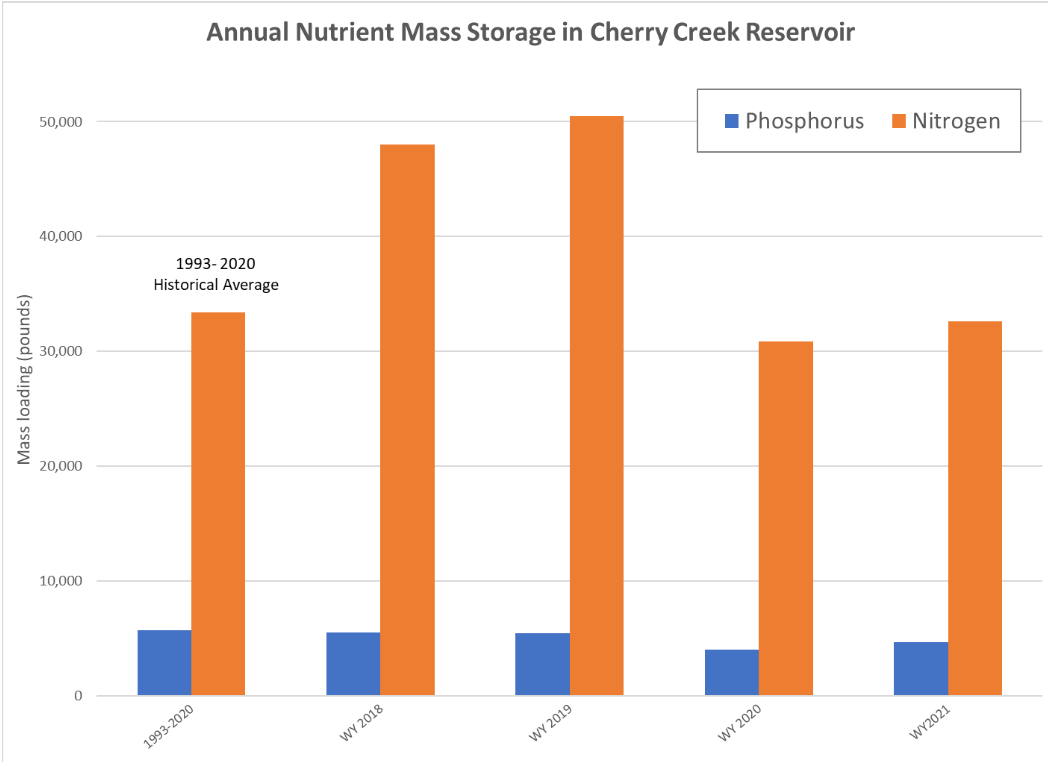


Figure 68. Current and Historical Total Phosphorus and Nitrogen Loading to Cherry Creek Reservoir.

(Historical mean from 1993-2020, WY 2018, 2019, 2020 and 2021)

9.0 2021 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. Cherry Creek Reservoir continues to remain in the eutrophic to hypereutrophic in regard to total phosphorus, chl α, and transparency of the water. Although there were no closures due to dense blooms and algal toxins in 2021, cyanobacteria continue to be present at high numbers within the Reservoir and historically have been present at higher density when nitrogen limitation was present.

Surface water flows are the main contributor of nutrient concentrations in the inflows and nutrient loading of the reservoir. Weather and precipitation in the watershed directly impact the water quantity and quality of Reservoir inflows, internal Reservoir dynamics, and the overall exchange rate.

There continues to be a significant difference in water quality between Cherry Creek and Cottonwood Creek. Cherry Creek has much higher concentrations of phosphorus, but Cottonwood Creek has higher concentrations of nitrogen. These streams show differences in the stream channel morphology, flow patterns, wetlands, vegetation growth patterns, variability from storm events, watershed development, number of permitted WWTP discharge outfalls, and differences in runoff from the watersheds. All of these factors 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 MS4 permittees have developed advanced BMPs to treat regulated storm water in urban areas. Authority implemented PRF projects have also been completed in order to reduce water quality impacts of these changes in the Cherry Creek Basin. 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 reduce negative water quality impacts from these changes in the watershed. In addition, other watershed and PRF projects have been completed in order to decrease negative water quality impacts of these land use activities and changes. Overall, the constructed wetland PRF ponds on Cottonwood Creek function effectively by reducing total phosphorus and suspended solids in storm flows on an annual and long-term basis.

Based on calculations, 4,697 lbs of Phosphorus and 32,614 lbs of Nitrogen were added to the stored loads in the Reservoir in WY 2021. The increase in total nutrient mass storage in Cherry Creek Reservoir was more than 2020 but less than this historical mean of 5,678 lbs of Phosphorus and 33,407 lbs of Nitrogen.

The monitoring and data analysis efforts during and prior to WY 2021 brought to light recommendations for improvement and enhancement to the sampling program or other analysis of the Cherry Creek watershed or Reservoir. 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.

- The continued monitoring of individual TDS components will help determine what is leading to the increased conductivity in Cottonwood Creek, Cherry Creek and the Reservoir. Although full analyses were not completed in 2021, individual analyses for Chloride, Sulfate, Magnesium, Sodium, Potassium, Calcium, and Alkalinity will continue to help determine what constituents may have the largest impacts.
- During 2021 efforts were made to increase accuracy of level and flow gauging on Cherry Creek upstream of the Reservoir to capture information from flows during large storm events that may bypass the current gauging station. In spring 2021, a detailed site survey was completed and a level sensor was installed. This will allow for determination of when the stage discharge relationship generated from stream flow measurements will be used and when modeled flows from the survey should be used to estimate high flows. Since the measurement equipment wasn't installed until May 2021 a brief comparison of the measurements was completed but results for a full water year using the measurements at both sites will be completed in 2022.
- Assessment of the differences in water quality or statistically significant changes through the PRFs on Cottonwood Creek during specific time periods will help determine scale and frequency of maintenance of the wetland plants and sediment removal necessary to maintain storage capacity and reduce organic accumulation. The development of the PRF Statistics Tool on the portal can complete these calculations based on the question and specific time frame requested.
- During Fall 2021, a pilot wetland harvesting project was completed along the Cottonwood Creek stream corridor and the shoreline of the Perimeter wetland pond PRF. The wetland plants in the project areas were collected to determine density and the plant material was analyzed for nutrient content. The

results of this study will inform the mass of nutrients removed during this project and the potential for future similar efforts to be used to remove Nitrogen and Phosphorus from the watershed.

- 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, or other viable options will help reduce chlorophyll α to meet the standard and help maintain the beneficial uses of the Reservoir.
- The sediment nutrient concentration samples that were collected in WY 2021 will be reported in WY 2022 and will help indicate what role internal nutrient loading may play and provide additional information when in-reservoir options are being considered.
- There may be potential negative impacts to beneficial uses that may occur due to the presence of aquatic nuisance species (ANS) present in Cherry Creek Reservoir. Golden algae 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 impacts of an imbalance in high quality forage available to support the fishery.
- 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 and other water users, 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 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 2021