CHERRY CREEK BASIN WATER QUALITY AUTHORITY MONITORING REPORT - WATER YEAR 2022

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ACRONYMS/ABBREVIATIONS

Acronym	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
CCSP	Cherry Creek State Park
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 (for 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

Acronym	Definition
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	Wastewater Treatment Plant

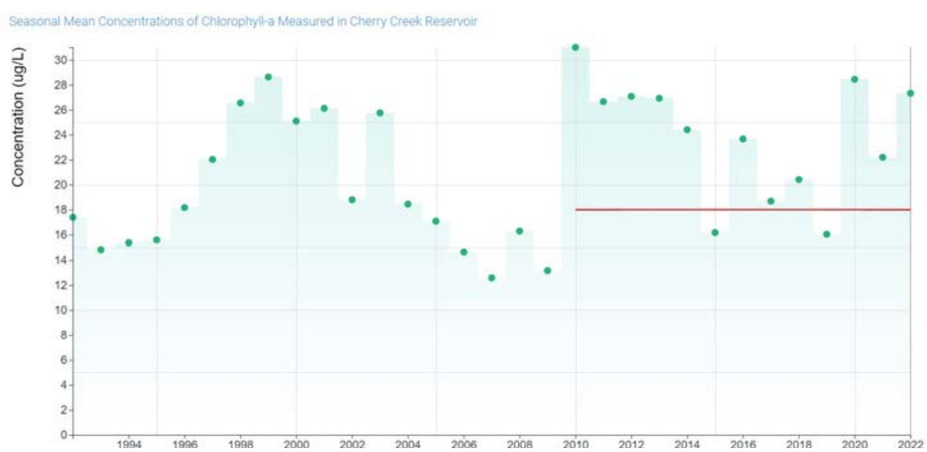
EXECUTIVE SUMMARY

The *Cherry Creek Basin Water Quality Monitoring Report – Water Year 2022* 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 2022 Water Year (WY 2022) between October 1, 2021 and September 30, 2022. The Reservoir and watershed monitoring programs are completed in accordance with the Cherry Creek Sampling and Analysis Plan (SAP), Quality Assurance Project Plan (QAPP), and regulatory requirements. The data were collected to evaluate how successful the requirements specified in Cherry Creek Reservoir Control Regulation 72 (CR 72) are at achieving the chlorophyll-α (chl α) water quality standard and the water quality standards for associated parameters as outlined in Water Quality Control Commission (WQCC) Regulation No. 31 (Reg 31) and Regulation No. 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 2022 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/.

RESERVOIR HIGHLIGHTS

Chlorophyll α

Cherry Creek Reservoir has a seasonal chl α standard of 18 μg/L as set by Reg 38. During each sampling event of WY 2022, chl αlevels were measured from composite samples collected from 0, 1, 2, and 3 m at all three monitoring sites in the reservoir.



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

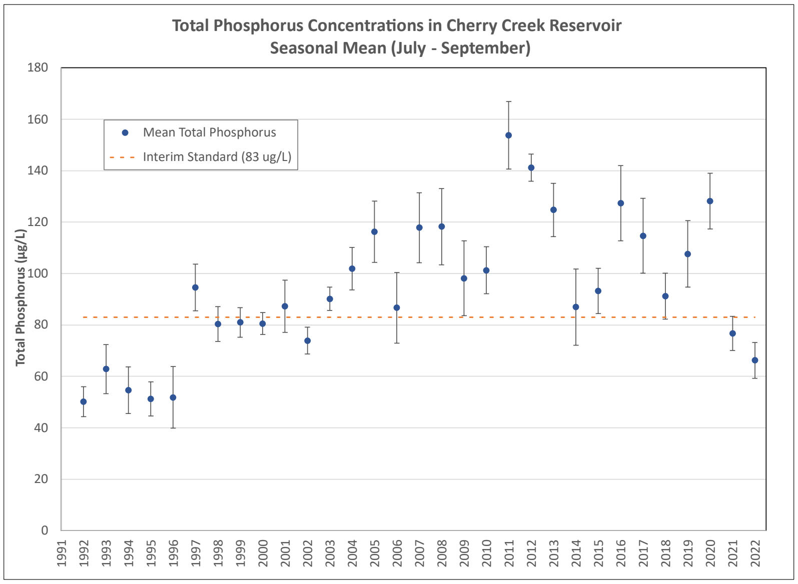
The seasonal (July through September) chl α concentration through the WY 2022 growing season was 27.3 μg/L, which does not meet the standard. The measured chl α concentrations ranged between 2.1 μg/L and 83 μg/L, with a mean of 25.9 μg/L for all of WY 2022. The highest values were observed in early June and the lowest in late August, which followed the major storm event in mid-August. The WY 2022 seasonal mean was higher than WY 2021 (22.2 μg/L) but lower than WY 2020 (28.4 μg/L). 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 (algae growth) and other inorganic and organic suspended solids in the water. The seasonal mean (July–September) Secchi depth during WY 2022 was 1.1 m, ranging between 0.6 m and 1.9 m, with an annual mean of 1.0 m for the year. The Secchi depths were comparable for all three sites. The WY 2022 Secchi depths for Cherry Creek Reservoir followed similar seasonal trends when compared to previous years and are low which indicates eutrophic conditions.

The depth of 1% light transmittance into the water column, which is considered the photic zone, ranged between 1.9 and 4.6 meters. The depth of 1% light transmittance has a strong correlation to the Secchi depth, and ranged between 1.4 and 4.7 times the Secchi depth but averaged approximately 3.2 times the Secchi depth.

Nutrients



Seasonal Total Phosphorus in Cherry Creek Reservoir.

Nutrients in Cherry Creek Reservoir are monitored since they directly impact algal growth and chl α concentrations. The WY 2022 total phosphorus seasonal mean (July through Sept) of 66.2 µg/L is lower than the WY 2021 (76.7 µg/L), WY 2020 (128.2 µg/L), WY 2019 (107.2 µg/L), and the long-term mean 93.9 µg/L measured from 1992-present. The seasonal mean values for TP have considerable annual variability on a long-term scale. Although there is no site-specific standard, 2 of the last 5 years have been below the seasonal interim nutrient value for TP of 83 µg/L in Reg 31.

During WY 2022, the annual monthly mean TP concentrations in the photic zone ranged between 63 µg/L in July and August 2022 and 88 µg/L in October 2021. The WY 2022 data suggests that although the TP concentrations in the Reservoir were lower than in some recent years, the high levels throughout the year contribute to the eutrophic and productive conditions in the Reservoir.

The WY 2022 total nitrogen seasonal mean in Cherry Creek of 984 µg/L is higher than WY 2021 (861 µg/L) and the long-term average of 896 µg/L calculated from 1992-present. Although there is currently no TN standard for the Reservoir, 3 of the last 5 years have been below the seasonal interim nutrient value for TN of 910 µg/L in Reg 31.

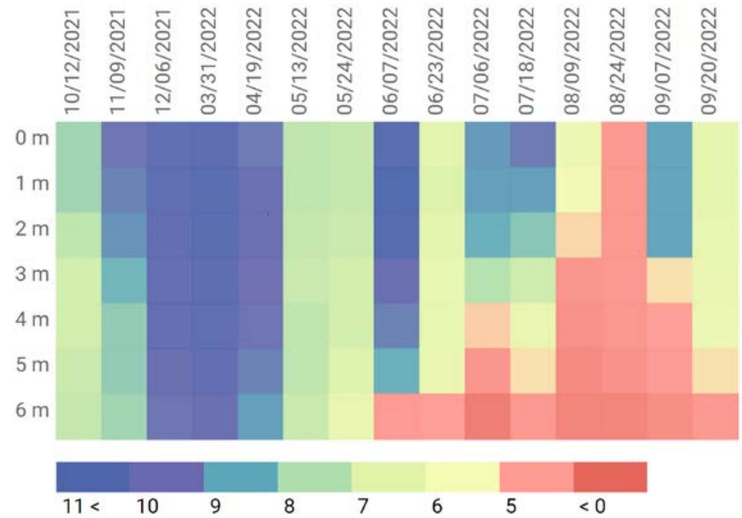
During WY 2022, annual monthly TN concentrations ranged between 589 µg/L and 1,187 µg/L, with a mean value of 959 µg/L. The highest TN values were present in July 2022 and the lowest in June.

Temperature and Dissolved Oxygen

The Class I Warm Water Aquatic Life classification established by Reg 38 for Cherry Creek Reservoir has a Maximum Weekly Average Temperature (MWAT) of and Daily Maximum (DM) of 29.3 ˚C. 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 ˚C (78.8 ^{o}F) at the surface on August 10, 2022, which does not exceed the daily or weekly maximum. The temperature data indicated the maximum temperature change from top to bottom was 6.7˚ C in mid-June. However, the mean difference was only 2˚ C indicating that for the most part the Reservoir did not develop consistent significant thermal stratification and this data supports that the Reservoir is polymictic (Lewis, 1983) which may also be affected by the operation of the Reservoir Destratification System (RDS).

Reg 38 assigns a minimum chronic dissolved oxygen standard of 5.0 mg/L to the Reservoir. The standard requires dissolved oxygen to be at least 5.0 mg/L in the upper portion of a lake or reservoir and that if DO is below 5.0mg/L, adequate refuge for aquatic life (with DO above 5.0mg/L) needs to be available at other depths or locations in the Reservoir at the same time period.

DO meets criteria at all depths during October through May. During June through September, low oxygen is present at lower depths, with upper depths meeting oxygen criteria, with the exception of the sampling event on August 24th, 2022.



Dissolved Oxygen Concentrations (mg/L) in CCR at CCR-2 in 2022.

pH and Conductivity

Reg 38 assigns minimum and maximum pH standards of 6.5 and 9.0, respectively, for the Reservoir. During WY 2022, the mean pH in Cherry Creek Reservoir was 8.3. The pH ranged from 7.5 to 8.5 at CCR-1, 7.6 to 8.9 at CCR-2, and 7.8 to 10.2 at CCR-3.

The higher pH values corresponded with higher productivity and elevated chl α in the Reservoir, especially the values observed at CCR-3 which coincided with the highest chl α concentration measured on July 6th (83 µg/L). In contrast, the lowest chl α concentrations were seen on August 24th, which was when the lowest pH values were also recorded through the water column. Higher pH values are usually correlated with higher productivity and elevated chl α concentrations in the Reservoir.

The specific conductance (hereafter referred to as “conductivity” in this document) indicating dissolved solids (i.e., salts minerals, etc.) in Cherry Creek Reservoir ranged from 1,270 µS/cm to 1,372 µS/cm during WY 2022. There was limited variability in conductivity from top to bottom of the Reservoir and among the three monitoring sites, but conductivity demonstrated higher values during the summer months than the rest of the year.

Trophic State Analysis

The Trophic State Index (TSI) is a relative expression of the biological productivity of a lake using total phosphorus, chl α, and transparency. 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, which are associated with increased

Table A. Cherry Creek Reservoir Trophic State Characteristics.

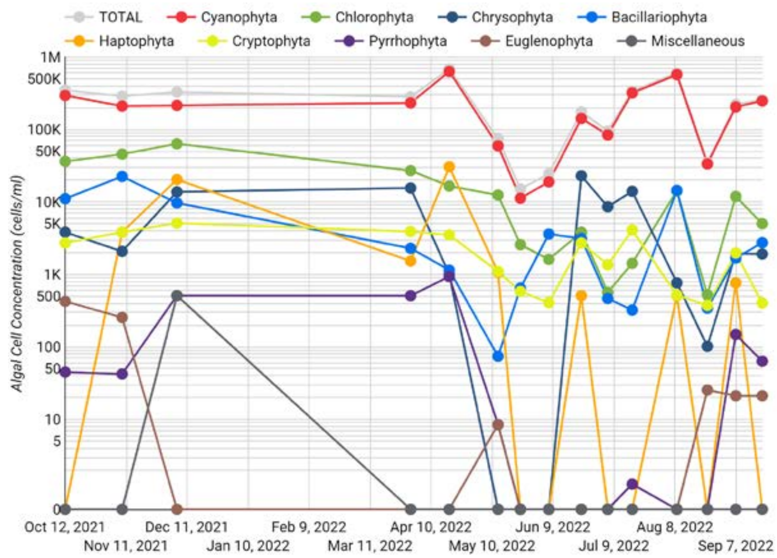
Trophic State	Characteristic			
	Total P (mg/L)	Chlorophyll *a* (µg/L)	Secchi Depth (m)	Relative Productivity
Oligotrophic	< 0.005	< 2.0	> 8	Low
Mesotrophic	0.005 -0.030	2.0 - 6.0	4 – 8	Moderate
Eutrophic	***0.030 - 0.100***	***6.0 - 40.0***	2 – 4	**High**
Hypereutrophic	> 0.100	> 40.0	***< 2***	**Excessive**
Cherry Creek Reservoir	**0.068**	**22.8**	**1.12**	**High-Excessive**

probabilities of encountering nuisance conditions, such as algal scums. The WY 2022 trophic state indices for Cherry Creek Reservoir for total phosphorus is 67, Secchi depth is 58, and chl α is 61, indicating that Cherry Creek Reservoir was eutrophic during WY 2022 (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 2022 to EPA trophic state criteria (from May through September) also indicates that Cherry Creek Reservoir was eutrophic-hypereutrophic in WY 2022 (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, 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 2022 indicate high productivity and high species diversity, with an average of 33 phytoplankton species, and a range of 14-53 species present for the 15 sampling dates, which is slightly less than the last few years. Cell counts were dominated by the Cyanophytes (cyanobacteria or undesirable blue-green algae, shown in red), which were responsible for 65% or more of the total phytoplankton cell counts on each sampling date and averaged 87% of the total cell counts for all of WY 2022.



Phytoplankton Populations in CCR during WY 2022.

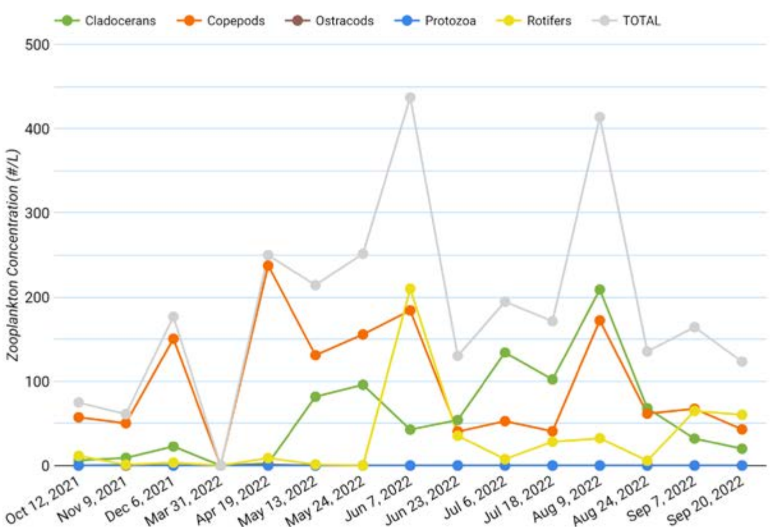
However, cyanobacteria only averaged 34% of the total algal biovolume for WY 2022 and multiple species of cyanobacteria capable of producing toxins were observed during sampling in Cherry Creek Reservoir. Monitoring and testing completed by CPW resulted in multiple caution notifications based on presence of toxin-producing cyanobacteria and one bloom, which tested above the threshold for recreation, required a closure to contact for 4 days in late June. Although there was a severe bloom in July, CPW did not detect toxin during sampling and closure was not required.

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 45% and green algae made up 12% of the relative biovolume for WY 2022. Chlorophytes, Bacillariophytes, Cyanophytes, and members of the Cryptophyte group (cryptomonads, shown in yellow) were often present at levels associated with eutrophic, or imbalanced aquatic ecosystems.

Haptophytes (golden algae, shown in orange) can be found in freshwater systems with higher salinities and are of 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.

Zooplankton

Monitoring zooplankton in Cherry Creek Reservoir is important since many zooplankton feed on phytoplankton. 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, while ostracods are omnivores and eat both small phytoplankton and other organic material. 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 Populations in CCR during WY 2022.

Zooplankton numbers and diversity from samples collected from Cherry Creek Reservoir during WY 2022 were both low compared to phytoplankton, which is typical in most lakes/reservoirs.

Copepods were typically the zooplankton present in the highest numbers, averaging 52% of the total population during WY 2021 and 10% of the biomass.

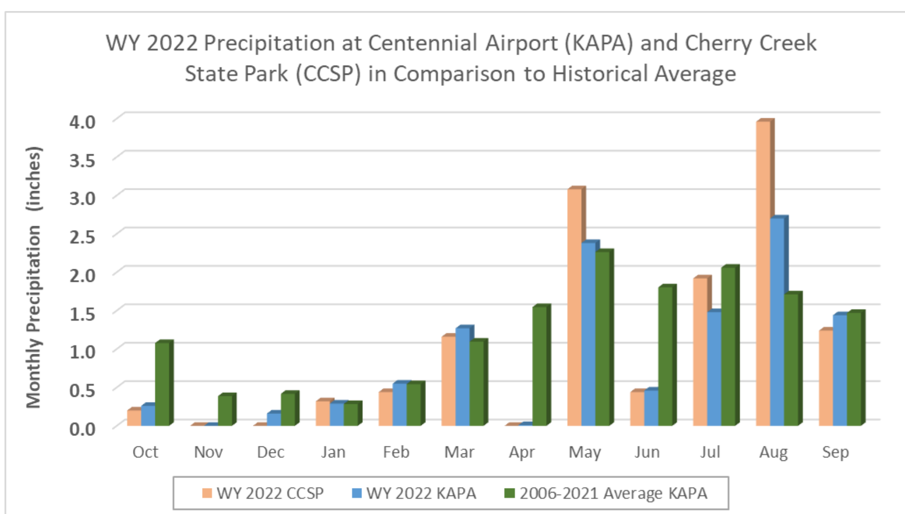
Cladocerans in Cherry Creek Reservoir typically do not include the large-bodied daphnia that serve as a major food source for fish in most reservoirs. However, cladocerans frequently comprised over half of the zooplankton biomass, averaging 31% of the zooplankton population and 86% of the total biomass for WY 2022.

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 2022, accounting for 44% of the total zooplankton biomass in WY 2022.

WATERSHED HIGHLIGHTS

Precipitation

Precipitation plays a large role in water quality in the Cherry Creek basin and Reservoir. The WY 2022 conditions of low inflows to the Reservoir from below average Cherry Creek flows and precipitation resulted in low water level, elevated water temperatures, and longer residence time, which increased the potential for algae growth, cyanobacteria blooms, and high chl α concentrations.



Precipitation at CCSP and KAPA - Historical Average and WY 2022.

In WY 2022, precipitation was measured at the new Cherry Creek State Park meteorological station in addition to National Ocean and Atmospheric Administration's (NOAA) Centennial Airport Station (KAPA) which received 12.76 and 11 inches of precipitation, respectively. The historical data from the KAPA site indicated the area received 78% of the historical average precipitation from 2007 to present.

Different areas within the watershed received 73-126% average precipitation, based on the 30-year Parameter-elevation Regression on Independent Slopes Model (PRISM) average.

Stream Flows

There are two USGS gauging stations in the Cherry Creek Basin that are demonstrate the changes in flow on Cherry Creek upstream to downstream and over time. 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 2,005 acre-feet (AF) with an annual daily mean of 2.8 cfs (5.5 AF) for WY 2022, which is approximately 37% of the mean discharge from WY 1992-2022.

The USGS WY 2022 summary statistics for the USGS Cherry Creek near Parker site provides a total annual flow of 7,061 AF with an annual daily mean flow rate of 9.9 cfs (19.7 AF/day). This rate was approximately 87% to the annual mean discharge of 11.2 AF calculated from the same 3 year period (WY 1992 -WY 2022).

It is noteworthy that the headwater flows of Cherry Creek in Castlewood Canyon were 79% lower than the long term average (entire POR), but flows were only 13% below 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 to calculate flows. In addition, the gauging station at Lakeview Drive estimates high flow events that bypass the CC-10 monitoring station adding to the total flow in to the Reservoir from Cherry Creek. The estimated WY 2022 inflow from Cherry Creek into the Reservoir was 4,892 AF measured at the CC-10 monitoring station, plus an additional 2,307 AF that bypassed the monitoring station at Lakeview Drive. The total flow of 19.7 AF/day from Cherry Creek was approximately 45% of average of the last 5 years. The estimated WY 2022 flow for Cottonwood Creek at the CT-2 monitoring site totaled 3,757 AF, with an average daily discharge of 10.3 AF, which is within 4% of the 5-year average at this site.

Cherry Creek

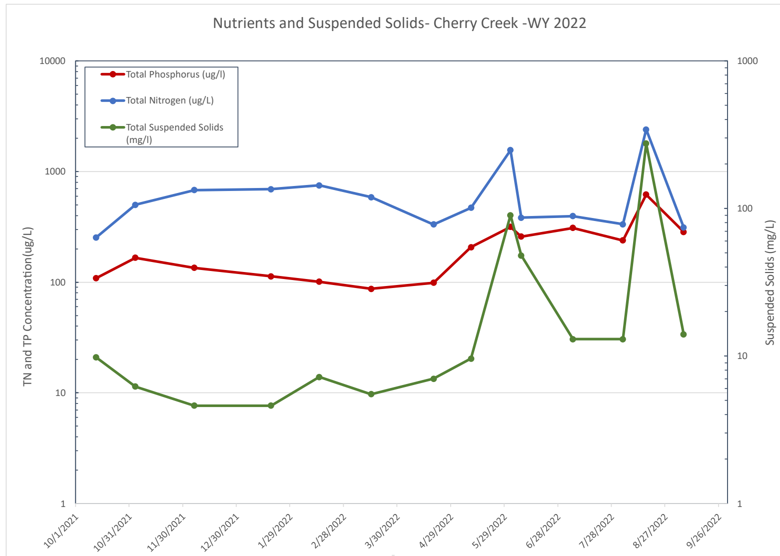
Water quality data are collected on Cherry Creek monthly during base and storm flow events throughout the year. In addition, during WY 2022, samples were collected from the USGS Cherry Creek Near Franktown, CO site all the way down Cherry Creek just upstream of the Reservoir (CC-10) and below during the two comprehensive watershed monitoring events to characterize changes in water quality upstream to downstream.

Both upstream to downstream monitoring events indicated limited variability of pH values that ranged from approximately 7.5 to 8.5 through the basin. 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.

In contrast, conductivity was much more variable and was ≥ 3 times higher just upstream of the Reservoir relative to the furthest upstream site. In addition, conductivity has demonstrated an increasing trend since monitoring started in 1992. 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 and reclaimed water.

During the two comprehensive (upstream to downstream) watershed monitoring events, the TP concentrations ranged from 80 µg/L to 232 µg/L. Average concentrations were lower in November 2021 (116 µg/L) than in May 2022 (146 µg/L). TN concentrations had much greater variability and ranged between 211 µg/L and 5,501 µg/L during the two events. TN averaged 2,225 µg/L in November 2021 and 1,177 µg/L in May 2022.

The adjacent figure shows results of water quality samples collected at CC-10 during base and storm flows in WY 2022, including total phosphorus (red), total nitrogen (blue), and total suspended solids (TSS) (green). TP concentrations ranged between 87 and 620 µg/L during the year with the lowest concentrations over the winter and early spring months. Mean concentrations were more than 60% higher than baseflow during the two storm events measured in May and August. TN concentrations ranged between 253 and 2,400 µg/L with mean concentrations more than 7% higher during storm samples. 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.



Water Quality at Cherry Creek at CC-10, WY 2022.

During baseflow conditions in WY 2022, mean nutrient and suspended solids concentrations were lower in Piney Creek (a tributary to Cherry Creek located southeast of the Reservoir) than above or below the confluence with Cherry Creek.

Cottonwood Creek

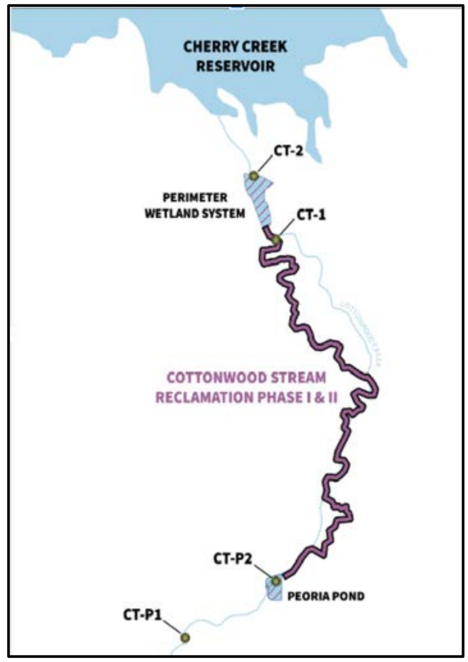
Water quality in Cottonwood Creek was monitored during base and storm flows during WY 2022. The pH of water in Cottonwood Creek before it entered the Reservoir at CT-2 ranged from 7.7 to 8.0 and has remained relatively constant over time. The conductivity, or specific conductance, which represents dissolved solids in the water, ranged between 1,582 µS/cm and 4,467 µS/cm, with a median value of 2,053 µS/ cm at CT-2, which is higher than the median on Cherry Creek (1,201 µS/cm).

The TP concentrations in Cottonwood Creek upstream of the Reservoir ranged between 26 and 240 µg/L during the year. The mean TP concentration for the 5 storm events was almost 250% more than baseflow conditions. The TN concentrations at CT-2 ranged between 744 and 4,250 µg/L during WY 2022. Although the highest concentration was seen during December 2021, the mean TN was 122% higher during storms. The TSS concentrations ranged from a low of 1 mg/L to a high of 44 mg/L which was during the large storm event on August 15th.

Overall, Cottonwood Creek TP concentrations were much lower than Cherry Creek just upstream of the Reservoir; conversely, TN concentrations were much higher in Cottonwood Creek, especially during the winter months. The winter nitrogen increase is hypothesized to be due in part to decomposition of plants in the wetland ponds. Storm-related increases in nutrients and suspended solids occurred for both Cottonwood Creek and Cherry Creek.

POLLUTION REDUCTION FACILITIES (PRF) HIGHLIGHTS

The PRFs in the watershed are monitoring on an ongoing basis to determine effectiveness of water quality benefit annually and over time. During WY 2022, samples from the monitoring sites on Cottonwood Creek were analyzed to determine changes upstream to downstream removal efficiency calculations. In addition to monthly base flow monitoring, samples were collected from 4-7 storm events at monitoring sites with automated sampling equipment at the various Cottonwood Creek sites and during base flows at the two sites on Mc Murdo Gulch. Table B summarizes the percent reduction in concentrations observed in the various water quality parameters upstream to downstream through the different PRFs during WY 2022.



Cottonwood Creek Pollution Reduction Facilities (PRFs)

Based on the water quality 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 storm flows during WY 2022. The other parameters had more variability in measurable changes. The Perimeter Pond demonstrated the highest levels of dissolved nutrient reductions within the Cottonwood Treatment Train. In WY 2022, 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 2022. *

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 25%, ○ - reductions between 25-50%, ● - reductions of >50%, blank cells indicate no reduction or an increase upstream to downstream

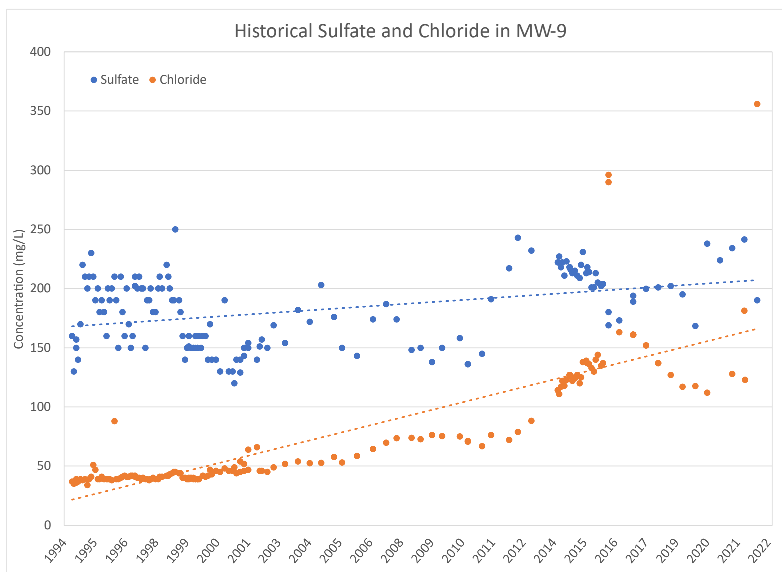
During the last few years, there has been increased effort in evaluating the effectiveness of the individual PRFs in terms of statistical significance in pollutant concentrations at PRF sites. The PRF Statistics Tool (https://www.ccbwqportal.org/prf-statistics-tool) has been developed to support these evaluations and was applied to assess whether median downstream concentrations are statistically lower that upstream PRF concentrations using a 10-year timeframe.

The whole Cottonwood Treatment Train showed significant removal efficiencies of TP and TSS when comparing concentrations downstream to upstream during the last 10 years (2013-2022). Peoria Pond also showed significant removal of TP and TSS upstream to downstream during storm flow conditions over the same time period. The Perimeter Pond PRF demonstrated significant reductions in TP, TN, and TSS concentrations in base and storm flow over the last 10 years. The McMurdo Gulch upstream to downstream concentration analysis demonstrated a statistically significant reduction of TP and TN, since monitoring began at those sites.

GROUNDWATER HIGHLIGHTS

The groundwater and alluvium of Cherry Creek plays a role in nutrient dynamics as water moves down the watershed and flows into the Reservoir. TP concentrations in the groundwater sampled in 2022 demonstrated variability between from the monitoring wells upstream and downstream of the Reservoir. The mean TP concentration was 572 µg/L on the two monitoring dates in WY 2022. TN generally decreased as the wells closer to the Reservoir and were lowest below the dam and averaged 1,898 µg/L in WY 2022.

The data from the comprehensive basin sampling of all Cherry Creek sites suggests surface water TP concentrations were comparable to groundwater soluble reactive phosphorus (SRP) at sites at nearby monitoring locations. SRP is used for long term evaluation since it is the main form found in groundwater, a longer period of record is available, and TP concentrations could be elevated by sediment disturbance during groundwater sampling. SRP concentrations averaged 184 µg/L in WY 2022 which is similar to surface water concentrations. Historical data for SRP in the groundwater upstream of the Reservoir suggest that SRP may also be increasing, with an annual mean of 183 µg/L from 1994-2003 and 199 µg/L from 2004 to 2022.



Sulfate and Chloride in Groundwater, MW-9. 1994-2022

TN concentrations in Cherry Creek were similar or higher than the nearest groundwater sites in November 2021 but were all much lower in May 2022.During both sampling events in WY 2022, groundwater chloride concentrations averaged 170 mg/L and sulfate concentrations averaged 118 mg/L. The pH remained relatively constant, and the conductivity generally followed the trend of the concentrations of chloride and sulfate.

During WY 2022, the pH values from the monitoring wells ranged between 6.5 and 8.2, with slightly higher values closer to the Reservoir and below the dam. The historical pH trend at MW-9 remains relatively constant over time. The historical conductivity values at MW-9 suggest an increasing trend over time with a historical mean from 1994-2022 of 804 µS/cm and a mean value of 1,250 µS/cm from 2017 to 2022.

Analysis of the historical data for MW-9 from 1994-2022 suggests that chloride and sulfate may be increasing over time, although chloride may be less variable and increasing slightly more substantially.

WATER BALANCE HIGHLIGHTS

The water balance in the Reservoir is used as the basis for the nutrient storage calculations. The estimated volumes of surface flow entering the Reservoir from these two surface water sources in WY 2022 are:

- Cherry Creek: 7,199 AF
- Cottonwood Creek: 3,757 AF

The estimated evaporative losses from the Reservoir were 3,197 AF during WY 2022, or approximately 47.9 inches (3.99 feet) per acre at the median surface area of 801.3 acres.

The USGS measured outflows for WY 2022 at Station 06713000, Cherry Creek below Cherry Creek Lake, CO, totaled 13,536 AF, which were used for nutrient balance calculations.

Table C. WY 2022 Water Balance

Water Source	Water Volume (AF)
Inflows	
Cherry Creek (CC-10)	4,892
Cherry Creek (Lakeview Dr)	2,307
Cottonwood Creek (CT-2)	3,757
Precipitation	890
Alluvial groundwater	2,200
Total Inflows	**14,046**
Outflows	
Evaporation	-3,197
Reservoir releases	-13,536
Total Outflows	**-16,733**
Net Ungauged Flows	
Calculation	**1,457**
WY 2022 Change in Storage	-1,230*

The Reservoir WY 2022 water balance is summarized in Table C. The Reservoir change in storage in WY 2022 reported by the U.S. Army Corps of Engineers (USACE) was 1,230 AF. 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, groundwater seepage from the Reservoir through the dam, and measurement uncertainties. Net ungauged outflows for WY 2022 were 1,457 AF which were apportioned between the Cherry Creek and Cottonwood Creek inflows to calculate nutrient loading (see next section). Cherry Creek contributed 66% of the stream inflow and Cottonwood Creek contributed 341%, based on the 15-minute data obtained from the gauging stations.

NUTRIENT BALANCE HIGHLIGHTS

The nutrient concentrations of the inflows and the outflow of Cherry Creek Reservoir are used to calculate the mass storage on an annual basis. The flow-weighted influent phosphorus goal, derived as part of the 2009 Regulation 38 rulemaking process, to achieve the 18 μg/L chl α standard, is 200 μg/L. The WY 2022 flow-weighted TP concentration of 171 μg/L for all inflows is similar to the flow-weighted TP concentration for WY 2021 (176 μg/L) and WY 2020 (173 μg/L), but lower than WY 2019 (188 μg/L), the previous 5-year median from

2017-2021 (188 µg/L), and the long-term historical median from 2000-2016 (208 µg/L) (see Table 27). In contrast, the WY 2022 flow-weighted TN inflow concentration of 1,756 µg/L is higher than WY 2021 (1,420 µg/L), WY 2020 (1,491 µg/L), WY 2019 (1,609 µg/L), the previous 5-year median (1,491 µg/L), and long-term median from 2000-2016 (1,401 µg/L). Flow-weighted nutrient concentrations for WY 2022 are summarized in Table D.

The Reservoir inflows (nutrient loads) considered in the WY 2022 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 2022 based on the nutrient calculations for inflows and releases. The WY 2022 TP and TN mass balances are summarized in Table E. The difference between the inflow and the outflow loads indicates that a net 3,147 pounds of phosphorus and 31,689 pounds of nitrogen were retained in the Reservoir in WY 2022.

Table D. Flow-weighted Nutrient Concentrations to Cherry Creek Reservoir WY 2022.

		Source				
	Nutrient	Cherry Creek	Cottonwood Creek	Alluvial Groundwater	Precipitation	Weighted Total
Inflow Concentration (µg/L)	Total Phosphorus	109	20	36	6	171
	Total Nitrogen	846	669	128	113	1,756
% of Total Inflow		50.4%	29.8%	14.1%	5.7%	100%

The WY 2022 total phosphorus mass storage calculated in Cherry Creek Reservoir was less than the 5-year historical mean (5,278 lbs) and the long term mean from 1993-2012 (5,644 lbs). Nitrogen loads in WY 2022 were slightly lower than WY 2021 and lower than the long-term historical mean from 1993-2021.

Table E. Nutrient Mass Balance for WY 2022

Water Source	Total Phosphorus (lbs) Mass (pounds)	Total Nitrogen (lbs) Mass (pounds)
Inflows		
Cherry Creek (CC-10)	4,673	36,138
Cottonwood Creek (CT-2)	844	28,865
Precipitation	242	4,786
Alluvial groundwater	1,520	5,438
Total Inflows	**7,278**	**75,226**
Outflows		
Evaporation	0	0
Reservoir releases	-4,101	-43,224
Total Outflows	**-4,101**	**-43,224**
WY 2022 Change in Storage	**3,177**	**32,002**

CONCLUSIONS AND RECOMMENDATIONS

Please reference Section 9.0 for conclusions and recommendations for WY 2022.

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 each 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 Colorado's first state 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 2022* describes the CCBWQA's monitoring program, data collected during the 2022 water year, and an evaluation of the results.

The WY 2022 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 2022 Water Year (WY) was completed by SOLitude Lake Management from October 1st, 2021 to December 31st, 2022, and by LRE Water from January 1st, 2022 to September 30th, 2022. The 2022 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:

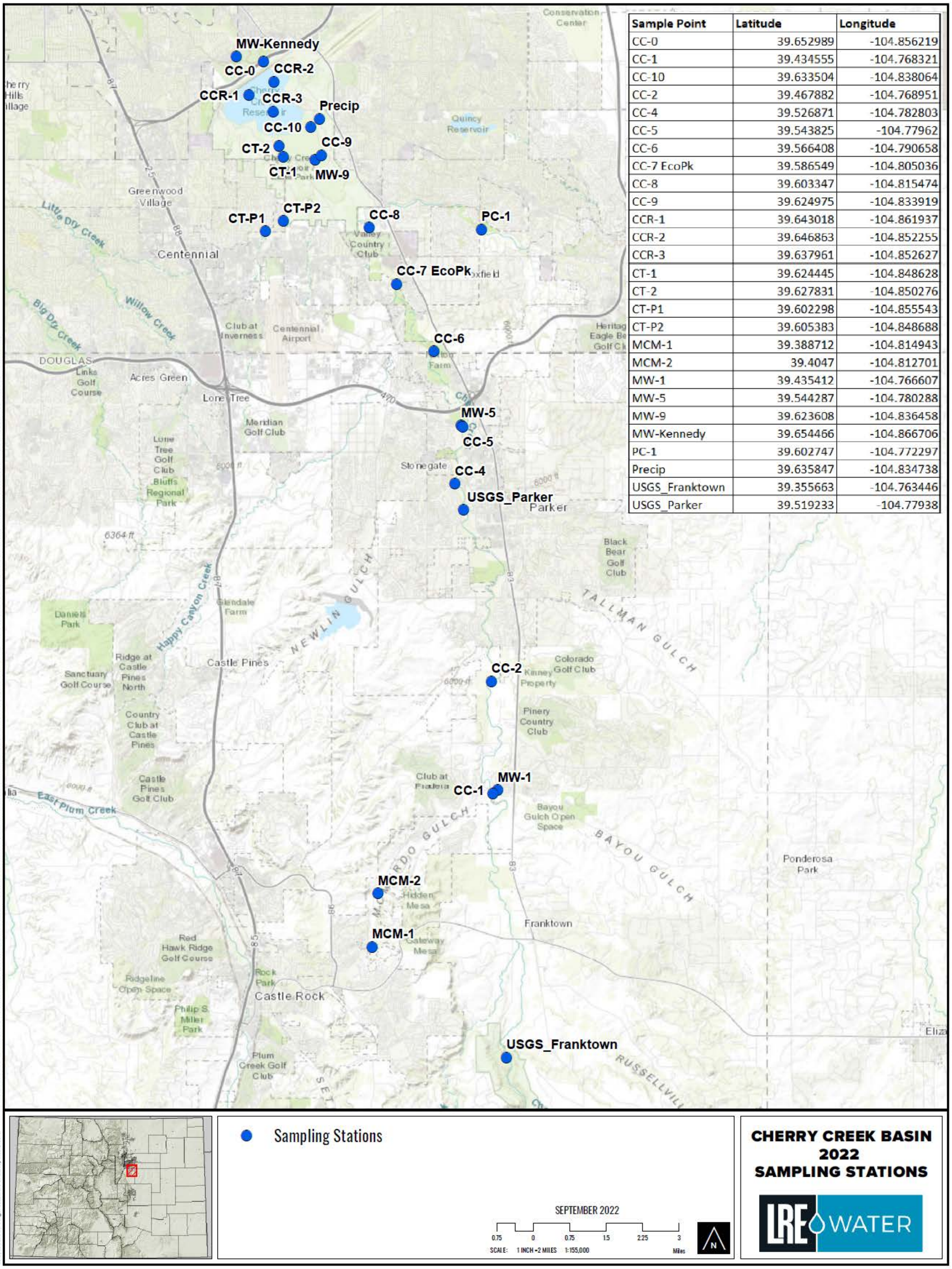
- Quality assurance for accuracy, representativeness, comparability, and completeness of data collected and reported.
- Quality and reproducible field sampling and sample preservation procedures, laboratory processing, and analytical procedures.
- Data verification and reporting including quality control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

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 LRE Water, Solitude Lake Management, Tetra Tech, and GEI Consultants Inc. also served as the Authority's SAP/QAPP Consultant in previous years.



Sample Point	Latitude	Longitude
CC-0	39.652989	-104.856219
CC-1	39.434555	-104.768321
CC-10	39.633504	-104.838064
CC-2	39.467882	-104.768951
CC-4	39.526871	-104.782803
CC-5	39.543825	-104.77962
CC-6	39.566408	-104.790658
CC-7 EcoPk	39.586549	-104.805036
CC-8	39.603347	-104.815474
CC-9	39.624975	-104.833919
CCR-1	39.643018	-104.861937
CCR-2	39.646863	-104.852255
CCR-3	39.637961	-104.852627
CT-1	39.624445	-104.848628
CT-2	39.627831	-104.850276
CT-P1	39.602298	-104.855543
CT-P2	39.605383	-104.848688
MCM-1	39.388712	-104.814943
MCM-2	39.4047	-104.812701
MW-1	39.435412	-104.766607
MW-5	39.544287	-104.780288
MW-9	39.623608	-104.836458
MW-Kennedy	39.654466	-104.866706
PC-1	39.602747	-104.772297
Precip	39.635847	-104.834738
USGS_Franktown	39.355663	-104.763446
USGS_Parker	39.519233	-104.77938

Figure 2. Cherry Creek Basin Monitoring Site Locations

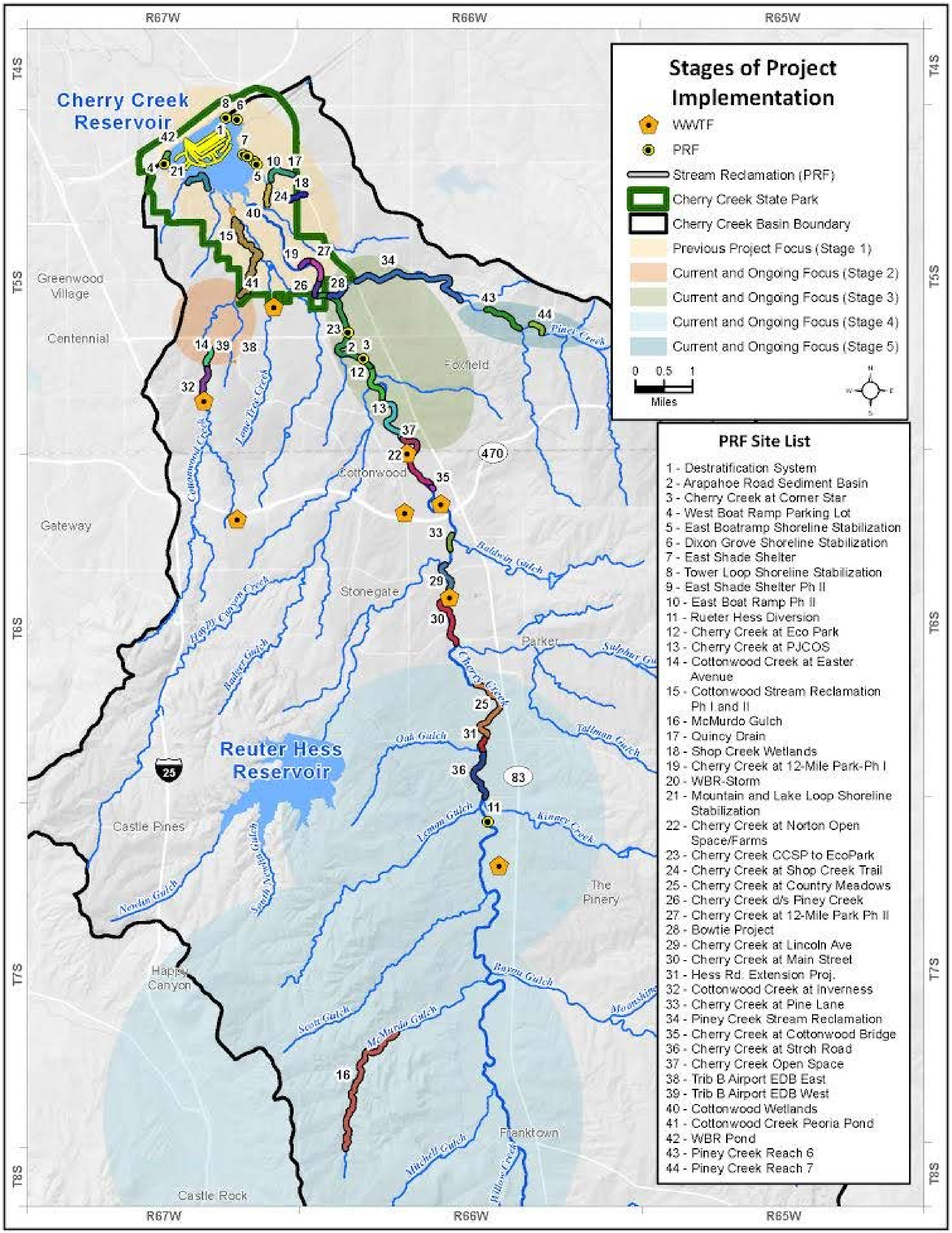


Figure 3. CCBWQA Water Quality Improvement Projects and Pollutant Reduction Facilities

2.2.2 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 (4 m-7 m)	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 CCR-2 only
Dissolved Organic Carbon		X		X CCR-2 only
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	7 m 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	Every Other Month Surface Water Samples	Storm Event Surface Water ISCO Samples	Bi-annual Surface Water Samples	Bi-annual Groundwater Samples
	7 sites (CC-0, CC-10, CC-7, CT-P1, CT-P2, CT-1, CT-2, PC-1)	**2 Sites (MCM-1, MCM-2)**	**5 sites (CC-10, CC-7, CT-2, CT-P1, PC-1)**	**9 sites (USGS Cherry Creek @ Franktown, USGS Cherry Creek @ Parker, CC-1, CC-2, CC-4, CC-5, CC-6, CC-8, CC-9)**	**4 sites (MW-1, MW-5, MW-9, MW-Kennedy)**
Total Nitrogen	X	X	X	X	X
Ammonia as N	X	X	X	X	X
Nitrate + Nitrite as N	X	X	X	X	X
Total Phosphorus	X	X	X	X	X
Total Dissolved Phosphorus	X	X	X	X	X
Soluble Reactive Phosphorus	X	X	X	X	X
Chloride					X
Sulfate					X
Total Organic Carbon	X (CC-10, CT-2)				X
Dissolved Organic Carbon	X (CC-10, CT-2)				X
Volatile Suspended Solids	X	X	X		
Total Suspended Solids	X	X	X		
Total Dissolved Solids Components (Ca, Mg, Na, K, $SO_4^{=}$, Cl^-, Alkalinity)	X (CC-10, CT-P1, CT-2) March/ Sept				

2.2.3 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.

2.2.4 WATER QUALITY METHODS AND ANALYTE DESCRIPTIONS

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 6 m 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 38 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). 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 may become stressed at levels less than 5.0 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 with 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 stream channels is often an important source of phosphorus in aquatic systems. Surface runoff containing phosphorus from fertilizers, wastewater effluent, and decaying organic matter 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 lakes and reservoirs, 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 available for algal uptake.

Ammonia (NH_3-N) 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.

Alkalinity

Alkalinity, expressed as mg $CaCO_3$/L, primarily represents the presence of bicarbonates and carbonates in water and indicates the buffering capacity. A higher buffering capacity can reduce the potential for pH swings during photosynthesis (removing CO_2) primary producers (algae) and plant growth.

Anions: Chloride and Sulfate

Chloride and sulfate are the major anions (negative 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, naturally elevated conditions in groundwater, 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.

Cations: Calcium, Magnesium, Sodium, and Potassium

The major cations (positive ions) that contribute to dissolved solids concentration in water typically are calcium, magnesium, sodium, and potassium. These ions can also indicate pollutants entering a watershed such as de-icing products, treated wastewater discharge, stormwater runoff, etc. These parameters have been included in the data analysis for one reservoir site and 3 surface water sites twice during a year so the major contributions to conductivity can be evaluated when enough data has been collected.

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 of 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 2022, 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 flow 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, aliquots collected by the automatic sampler are 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

Annual precipitation in the watershed and on surface of the Reservoir plays a major role in water quality and overall Reservoir dynamics. 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. The KAPA station measured a total of 11 inches of precipitation in WY 2022, approximately 78% of the historical average precipitation from of 14.14 inches 2006 to 2022 for this weather station (Figure 4).

In June 2021, a new meteorological station, CCSP, was installed at Cherry Creek State Park (CCSP) located at Latitude (Lat) 39.63°N, Longitude (Long) -104.83°W, and an elevation of 5,631 ft. The CCSP station measured a total of 12.76 inches of precipitation in WY 2022. Due to the closer proximity, the new CCSP station should better represent the precipitation on the surface of the Reservoir and will be used in the WY 2022 water balance. However, the KAPA site will continue to be used as a comparison and as a historical reference until a representative period of record can be developed for the new site.

In WY 2022, March, May, and August had higher than normal precipitation at both sites, with the KAPA site representing, 116%, 105%, and 157%, respectively, of the historical average from 2006-2022 for those months. October, November, December, April, and June had well below average precipitation at both sites with the KAPA site respectively representing, 24%, 0%, 38%, 0.06%, and 25% of the historical monthly averages for the same periods.

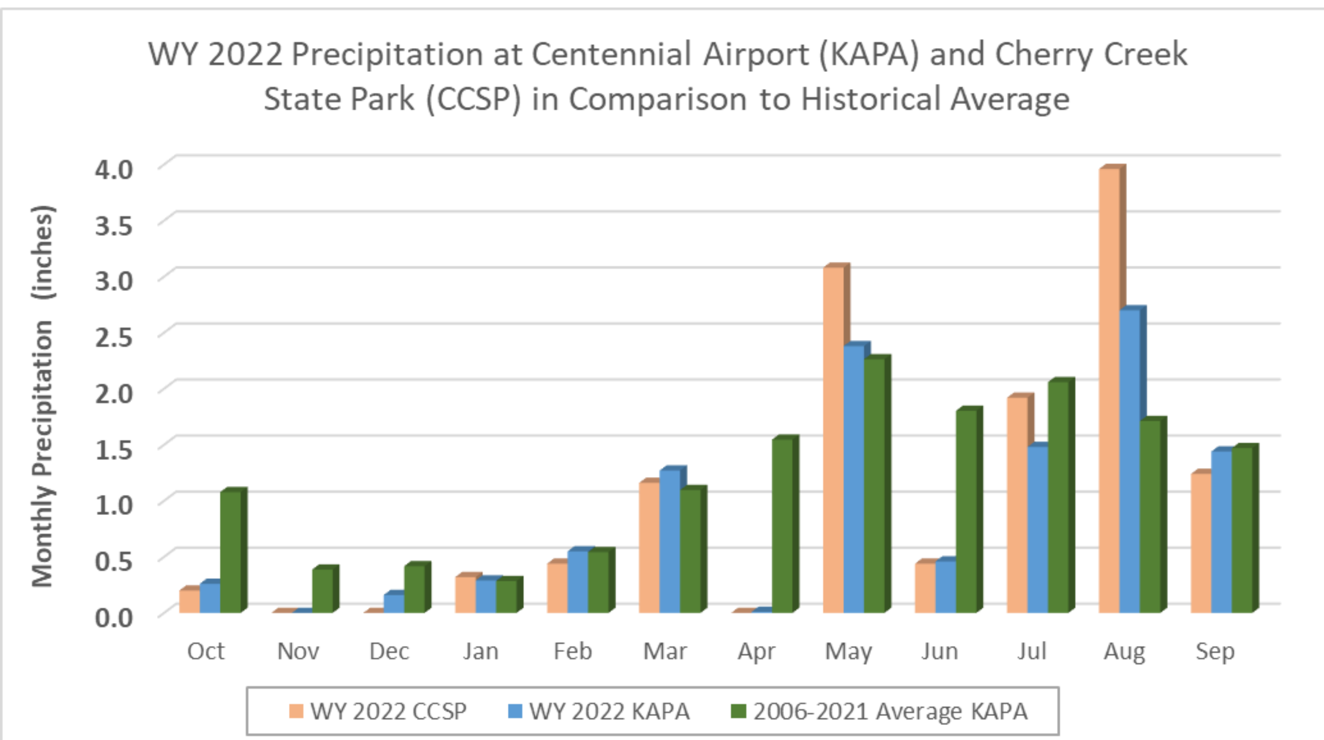


Figure 4. Monthly Precipitation in WY 2022 at KAPA and CCSP compared to Historical (2006-2022) average.

Additionally, when looking at NOAA's annual precipitation information, the various areas of the watershed received precipitation ranging between approximately 73 to 126 percent of normal when compared to the 30-year Parameter-elevation Regression on Independent Slopes Model (PRISM) normal from 1991-2020. The watershed as a whole received approximately 103% of the 30-year average, while areas just above Cherry Creek

Reservoir generally received less than average precipitation. 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 using bilinear interpolation in Figure 5.

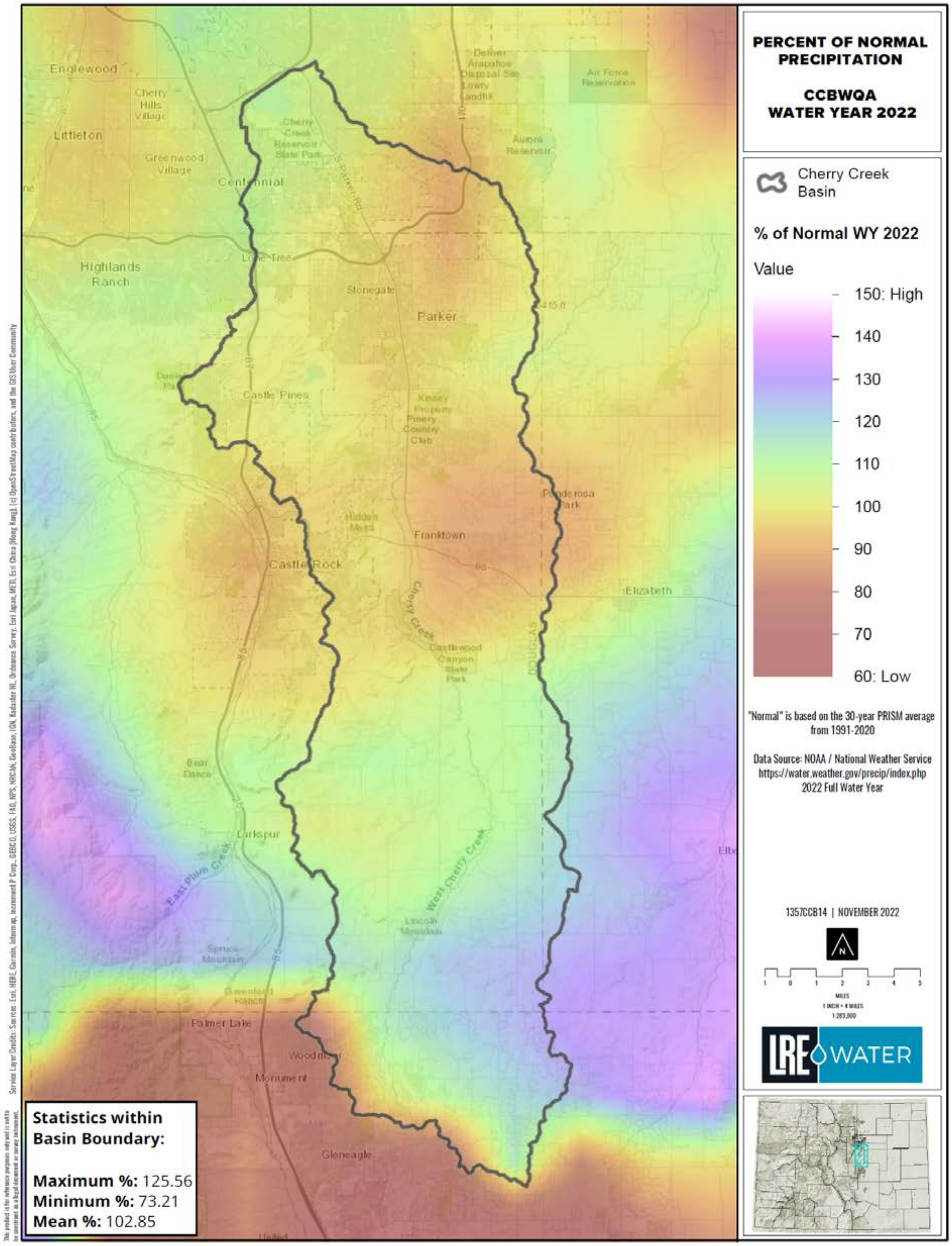


Figure 5. Percent of Normal Precipitation in the Cherry Creek Basin based on 30-year PRISM normal (1991-2020).

3.2 STREAM FLOWS

The U.S. Geological Survey (USGS) operates two gauging 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", 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 2022 summary statistics list a total annual flow of 2,009 AF with an annual daily mean flow rate of 2.8 cfs (5.5 AF/day). This rate was approximately 31.2 % of the annual mean discharge calculated from WY 1940-WY 2022 (since data collection started at the site) and 37% of the mean discharge from WY 1992-2022. Figure 6 shows the estimated daily discharge along with the historical daily mean from the last 82 years.

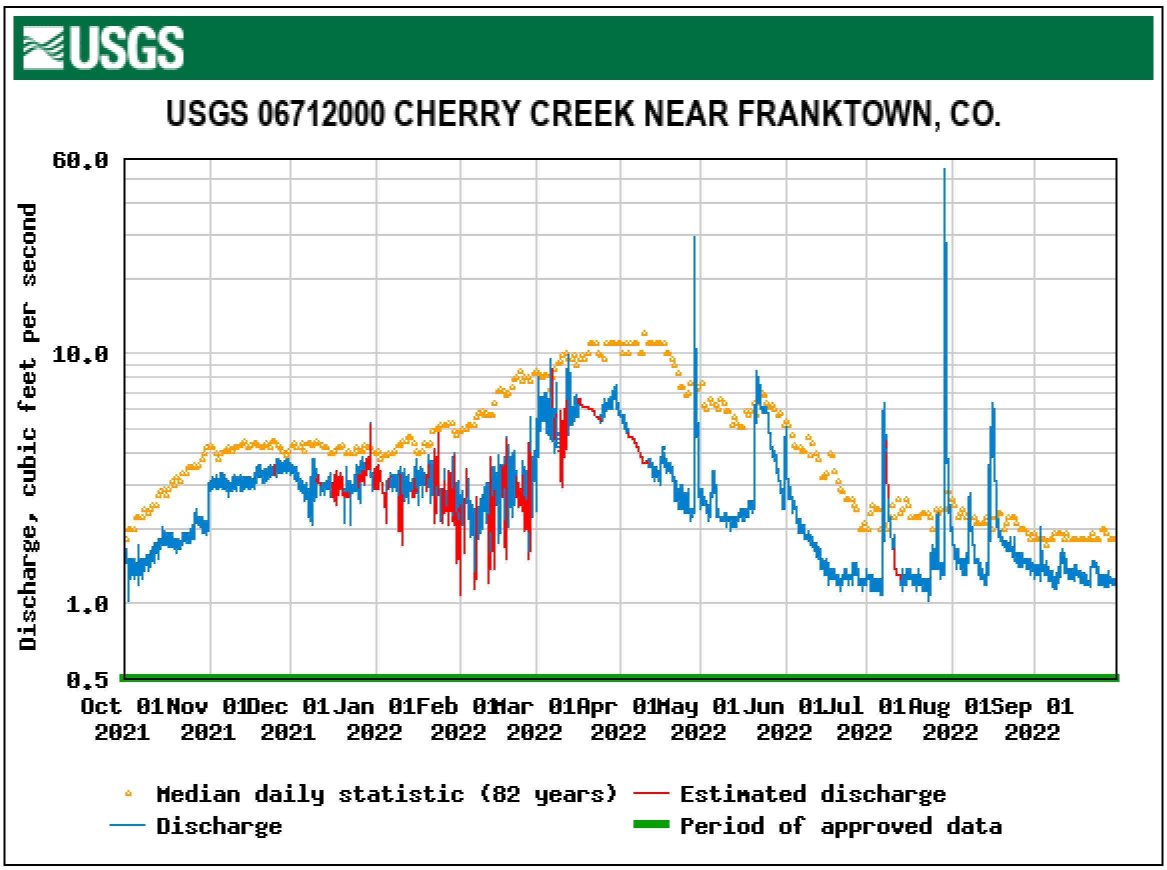


Figure 6. WY 2022 Daily Mean Discharge and Historical Median Flows for USGS Gauge near Franktown.

The USGS Cherry Creek near Parker station is located at Lat 39°31'09", Long 104°46'45", 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 mi^2.

The USGS WY 2022 summary statistics for the USGS Cherry Creek near Parker site provides a total annual flow of 7,189 AF with an annual daily mean flow rate of 9.9 cfs (19.7 AF/day). This rate was approximately 87% of the historical mean discharge of 11.2 AF calculated from WY 1992 -WY 2022. Figure 7 shows the estimated daily discharge along with the median daily statistic from the last 30 years.

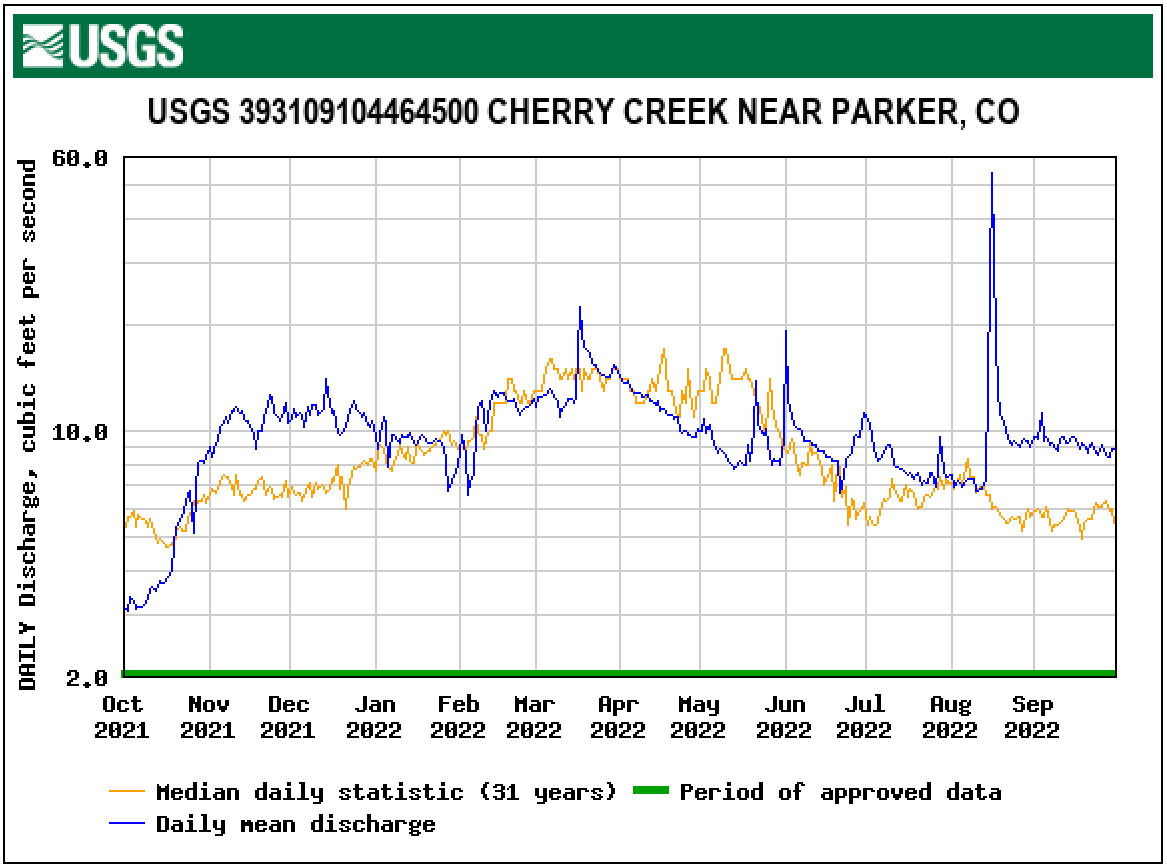


Figure 7. WY 2022 Daily Mean Discharge and Historical Median Flows for USGS Gage near Parker.

CCBWQA owns and operates equipment that continuously monitors water levels so annual flows can be calculated at multiple sites along Cherry Creek and Cottonwood Creek. The two recording stations on Cherry Creek are CC-7 (Eco Park) and CC-10, and monitoring stations on Cottonwood Creek are CT-1, CT-2, CT-P1 and CT-P2. The CCBWQA provides Arapahoe County Water & Wastewater Authority flow data for site CT-1 for Reg 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. In addition to CC-10, the Lakeview Dr. gauging station was added during 2021 to estimate large flow events that would allow flow to bypass the CC-10 monitoring station, often overtopping the road. These three sites are used to calculate inflows and nutrient loading into the Reservoir (Figure 8 and Figure 9).

Due to equipment failure at CC-10, ISCO stage values were unavailable from 2/3/22 to 8/3/22. During this period, stage values from the Sutron Constant Flow Bubbler (CFB) were substituted. The values were adjusted based on the average difference between the ISCO and CFB values (<3%) when data was available during WY 2022.

During the 2022 wetland harvesting project, the gate at CT-2 was opened intermittently to reduce the water level in the wetland ponds to improve access for operations. ISCO level data was not available when the gate was open since water flow bypassed the pressure transducer. In order to provide the best estimate based on available data, TS1 was used to interpolate the flow during the time that no data was available. Each missing period was filled independently with the starting point of the interpolation defined as the last valid flow record and the ending point of the interpolation defined as the next valid flow record greater than or equal to the starting point. This interpolation is a conservative estimate of the 15-minute observed flow but is more representative of the daily average flow and the total flow volume observed at the site.

The Cherry Creek sub-basin is the largest in the watershed and the Cottonwood Creek sub-basin makes up only approximately 4% of the total land area. The estimated WY 2022 flow at the CC-10 monitoring site on Cherry Creek just upstream of the Reservoir totals 4,892 AF with an average daily discharge of 13.4 AF. There were 12 days that included high flow events bypassing the CC-10 monitoring station at Lakeview Drive which accounted for an additional 2,307 AF that entered the Reservoir through Cherry Creek (Figure 8). These high flow events were responsible for almost 32% of the total inflows from Cherry Creek to the Reservoir for WY 2022. The total flow from Cherry Creek into the Reservoir was approximately 45% of the previous 5- year average.

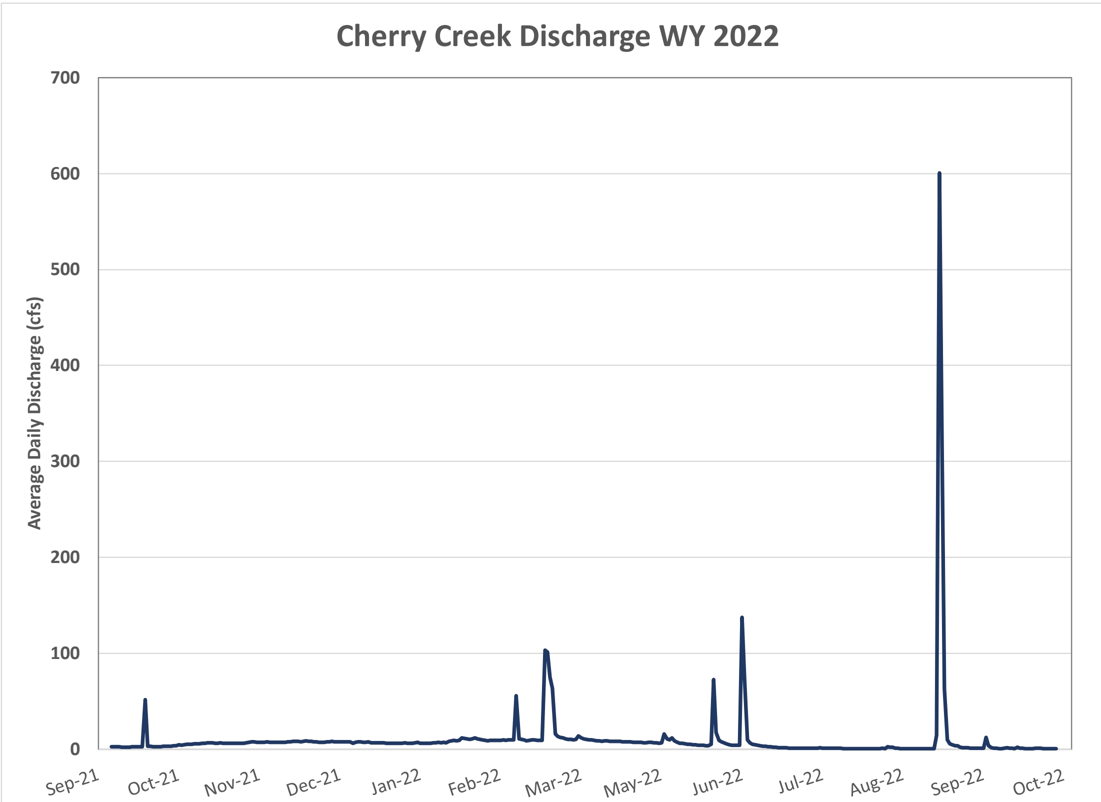


Figure 8. Cherry Creek Daily Discharge Rates (CC-10 and Lakeview Dr), WY 2022.

The estimated WY 2022 flow at the CT-2 monitoring site on Cottonwood Creek Just upstream of the Reservoir totals 3,757 AF with an average daily discharge of 10.3 AF/day (Figure 9) which is within 4% of the 5-year average at this site.

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 2022 daily inflow estimates are included in Appendix A.

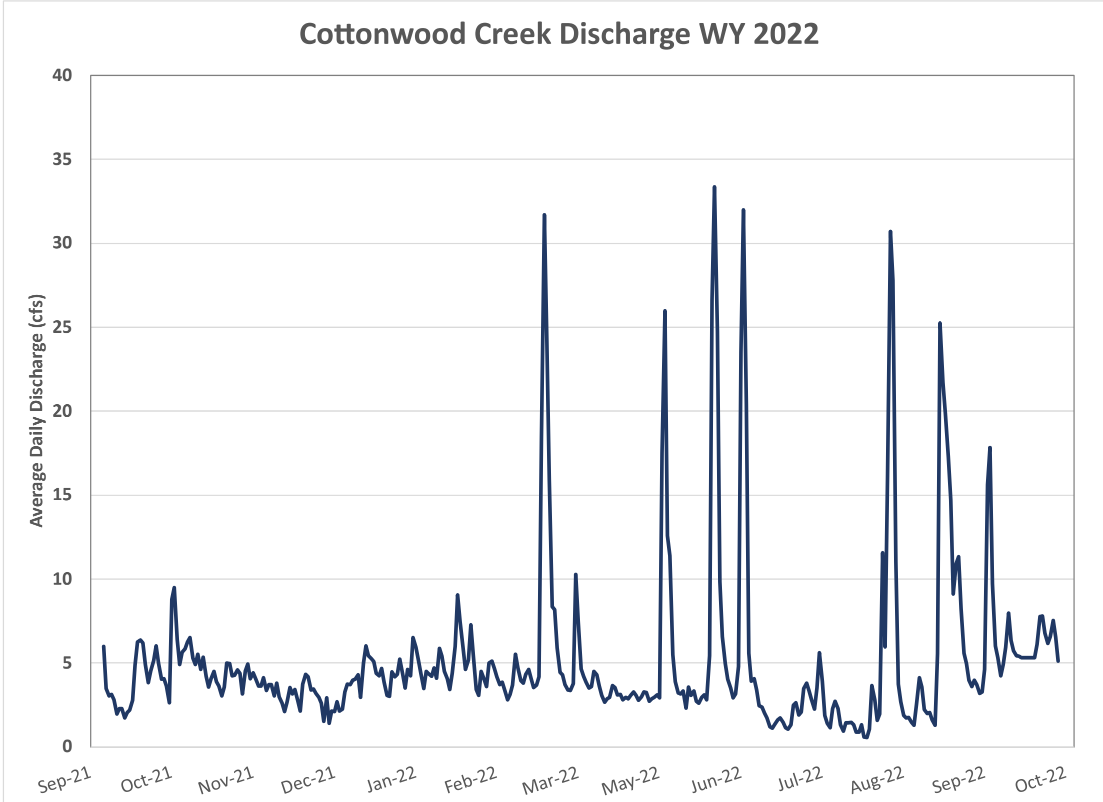


Figure 9. Average Daily Discharge at CT-2 during WY 2022.

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) and continue downstream towards the Reservoir and at the outlet.

Conductivity and pH

The specific conductance (conductivity) and pH were monitored from the surface water sites from the upper basin downstream to the Reservoir in November 2021 and May 2022 (Figure 10 and Figure 11). The conductivity increased by a factor of 3.2 from the furthest upstream site (USGS Franktown) to just above where Cherry Creek enters the Reservoir (CC-10) and was almost 5 times higher at the outlet (CC-Out) in Nov 2021. When compared to the furthest upstream site monitored on Cherry Creek, conductivity values were 3 times higher in Cherry Creek near the inlet to the Reservoir and 5.2 times higher at the outlet of the Reservoir in May 2022. The increase in conductivity from upstream to downstream sites during both events indicates increased dissolved solids, such as salts, in the water, as it moves downstream and through the Reservoir. Evaporation and concentration of these dissolved ions could also play a role in the increasing conductivity, especially in the Reservoir and below. The pH has some minimal variability but remained within the range of 7.5 to 8.5 throughout the basin and a had mean value of 8.0 on both sampling events. There is a notable increase in pH from CC-5 to CC-8 and then a decrease in pH and increase in conductivity between CC-8 and CC-9 (Figure 10 and Figure 11).

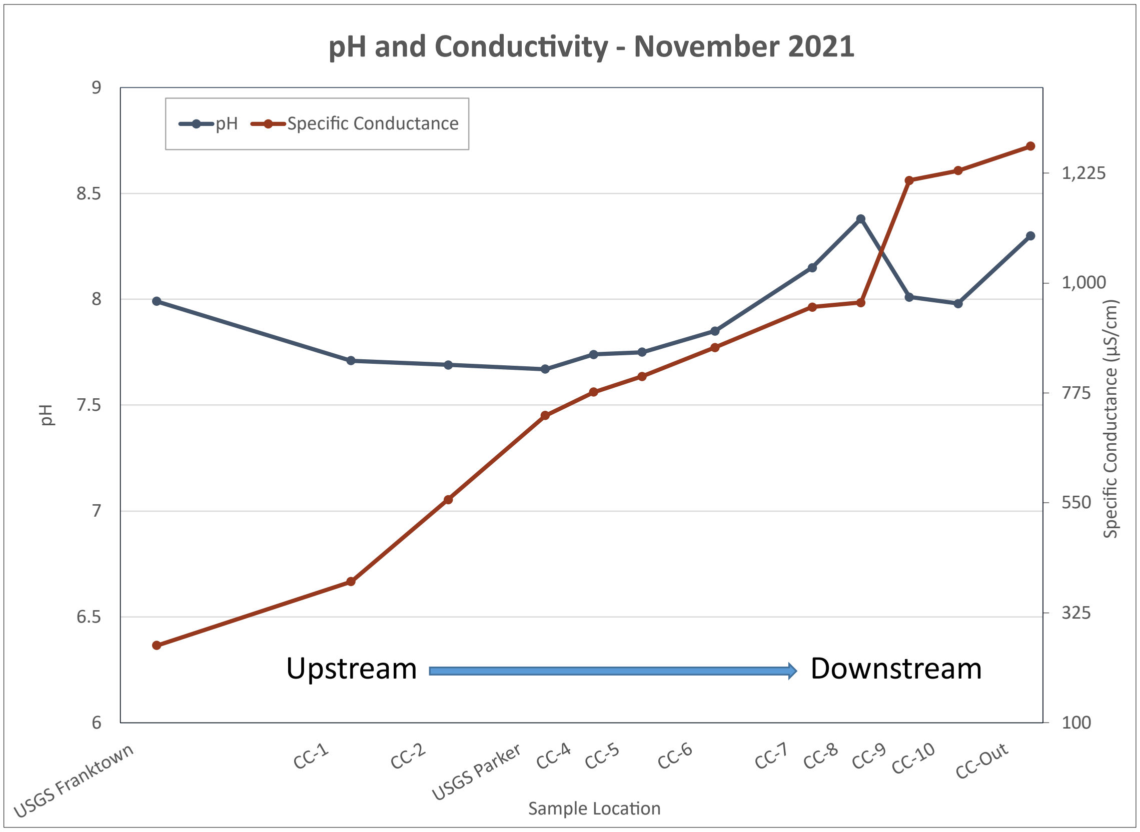


Figure 10. pH and Conductivity Upstream to Downstream on Cherry Creek, November 2021.

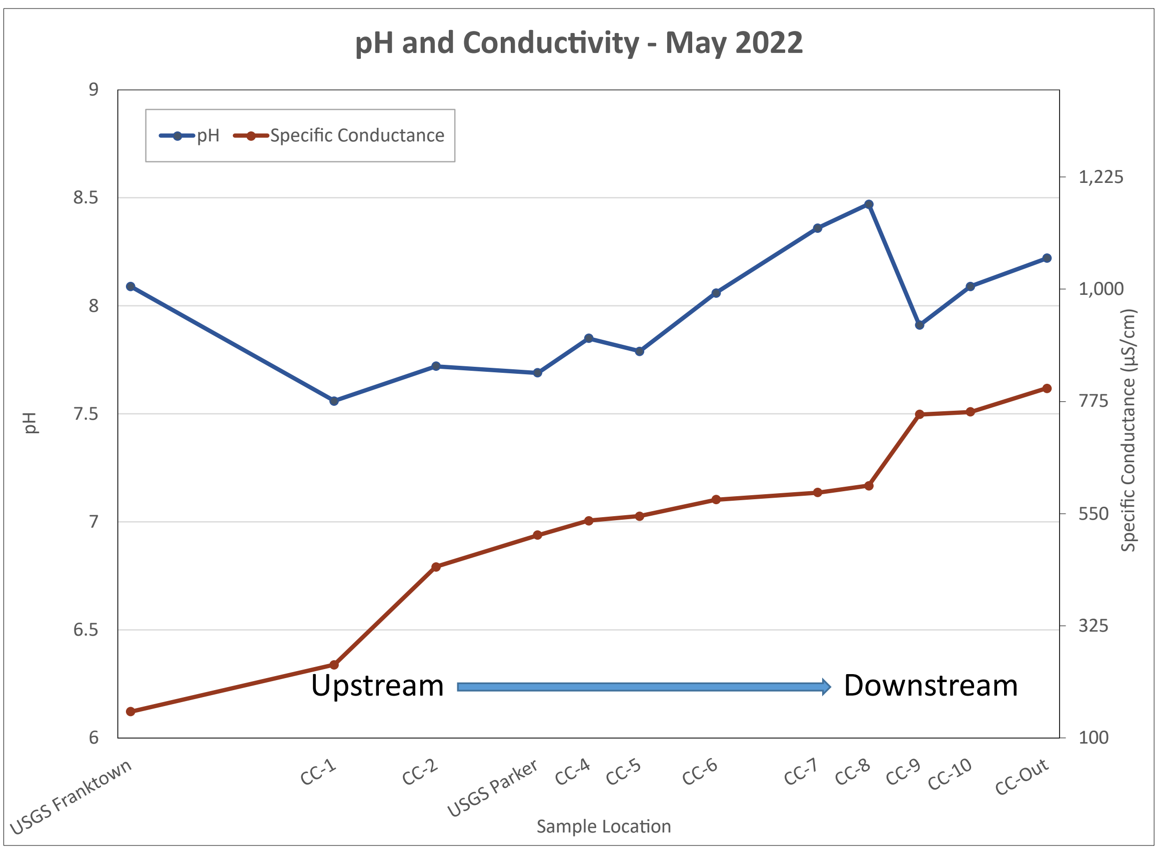


Figure 11. pH and Conductivity Upstream to Downstream on Cherry Creek, May 2022.

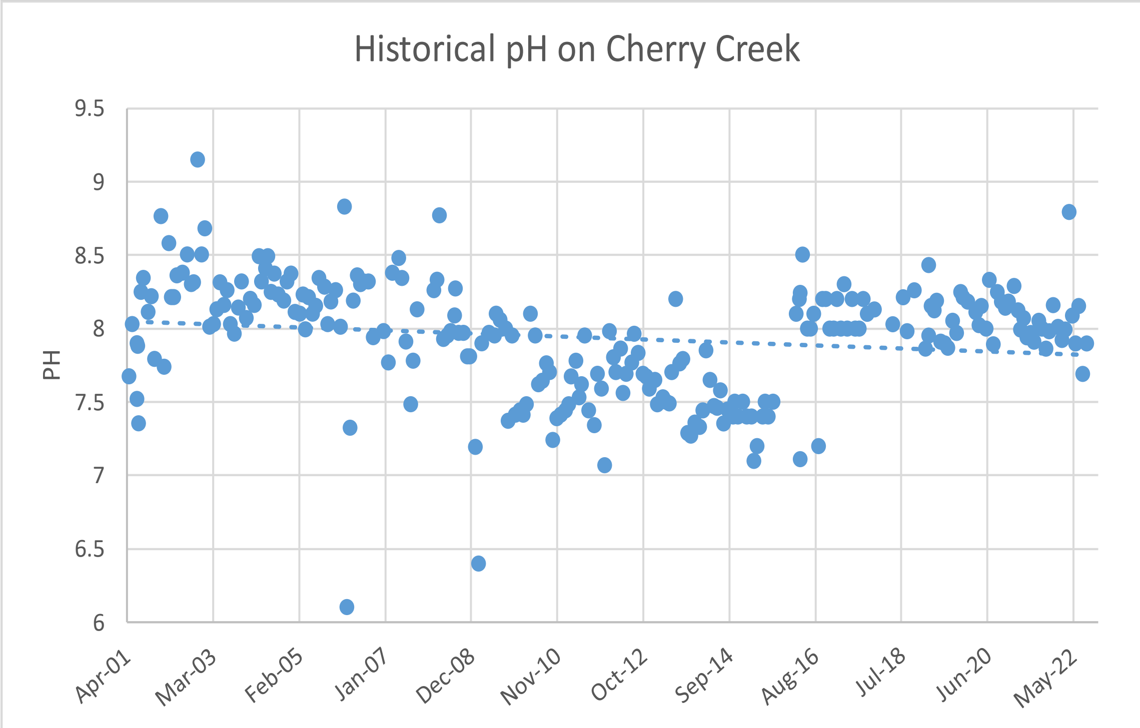


Figure 12. pH, Cherry Creek at CC-10, 2001-2022.

During WY 2022 the pH in Cherry Creek at CC-10 ranged between 7.89 and 8.37, with a mean value of 8.0. The specific conductance values ranged from 953 to 1,691 µS/cm with a WY 2022 mean of 1,201 µS/cm. The historical pH values measured at CC-10 appear to decrease between 2009 and 2016. In 2016, values increased to similar values from 2001 to 2008 and have remained relatively stable since 2017 (Figure 12). In WY 2022, the pH values at CC-10 had a mean value of 8.0, which was similar to the last three years.

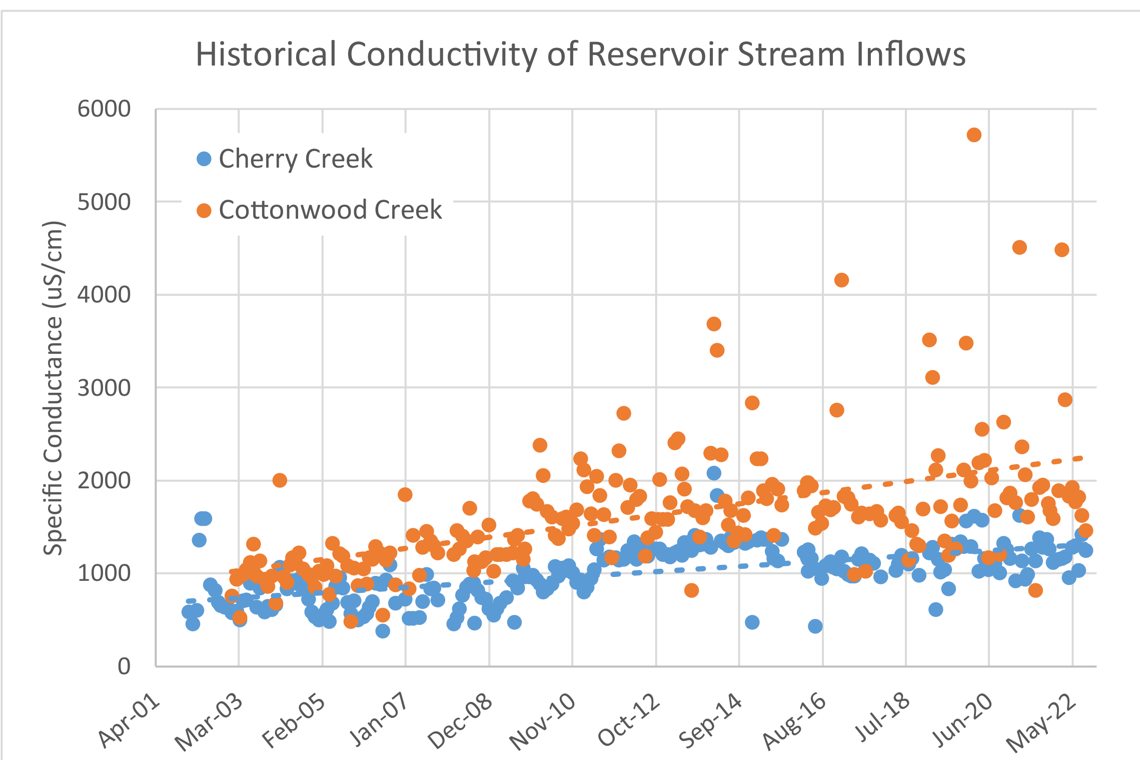


Figure 13. Conductivity in Cherry Creek and Cottonwood Creek, 2021-2022.

Dissolved salts and inorganic compounds increase the conductivity of which poses a concern in many watersheds due to potential negative ecological impacts. Specific conductance values measured at CC-10 (blue dots) 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 2022, the specific conductance values sampled at CC-10 ranged from 953 to 1,417 µS/cm with a mean value of 1,200 µS/cm (compared to a range of 794 to 1,070 µS/cm and a mean value of 943 µS/cm in 2010). The mean WY 2022 specific conductance in Cherry Creek (1,200 µS/cm) is lower than the mean in Cottonwood Creek, which was 2,053 µS/cm during WY 2022. Figure 13 displays the historical trends in conductivity at both sites and shows that Cottonwood Creek has more seasonal variability than Cherry Creek.

Nutrients and Suspended Solids

During both comprehensive upstream to downstream sampling events, TP concentrations ranged between 80 and 232 µg/L; the average concentrations were lower in November 2021 (116 µg/L) than in May 2022 (146 µg/L). In November 2021 TN concentrations ranged between 697 µg/L to 5,501 µg/L and between 211 µg/L and 2,219 µg/L in May. During both events, TN increased from the USGS Franktown site downstream to the highest concentrations at the USGS Parker site then leveled out and decreased all the way to the Reservoir (Figure 14 and Figure 15). However, in November the TN concentrations were lower at CC-4 then increased again at CC-5. In May, the TN concentrations were slightly higher below the Reservoir at the outlet site CC-Out. TN concentrations averaged 2,225 µg/L in November 2021 and 1,177 µg/L in May 2022.

In November 2021 and May 2022 concentrations of all nutrients were lower below the lake at CC-Out than the sites on Cherry Creek just above the Reservoir, with the exception of ammonia in November and TN in May, which were both higher. The concentrations from the bi-annual sampling in WY 2022, 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 2022 are provided in Table 5. Water quality samples from 2 storm events were collected on June 1 and August 16. The TP concentrations ranged between 87 and 620 µg/L, TN concentrations ranged between 253 and 2,400 µg/L, and TSS concentrations ranged between 5 and 275 mg/L. The 2 storm events sampled in WY 2022 had mean TP concentrations 68% higher than during base flows. Mean TN and TSS concentrations were also much higher in the storm samples, 78% and 95% respectively.

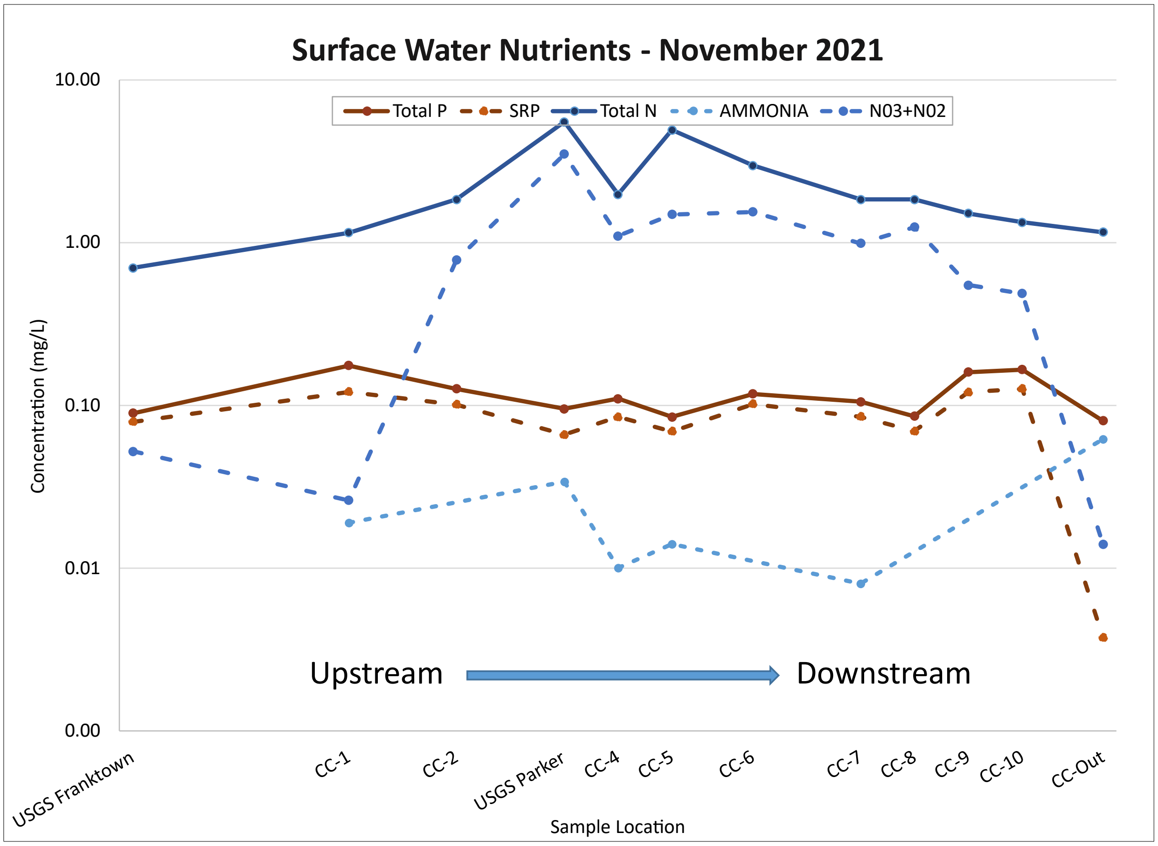


Figure 14. Surface Water Nutrient Sampling of Cherry Creek, November 2021.

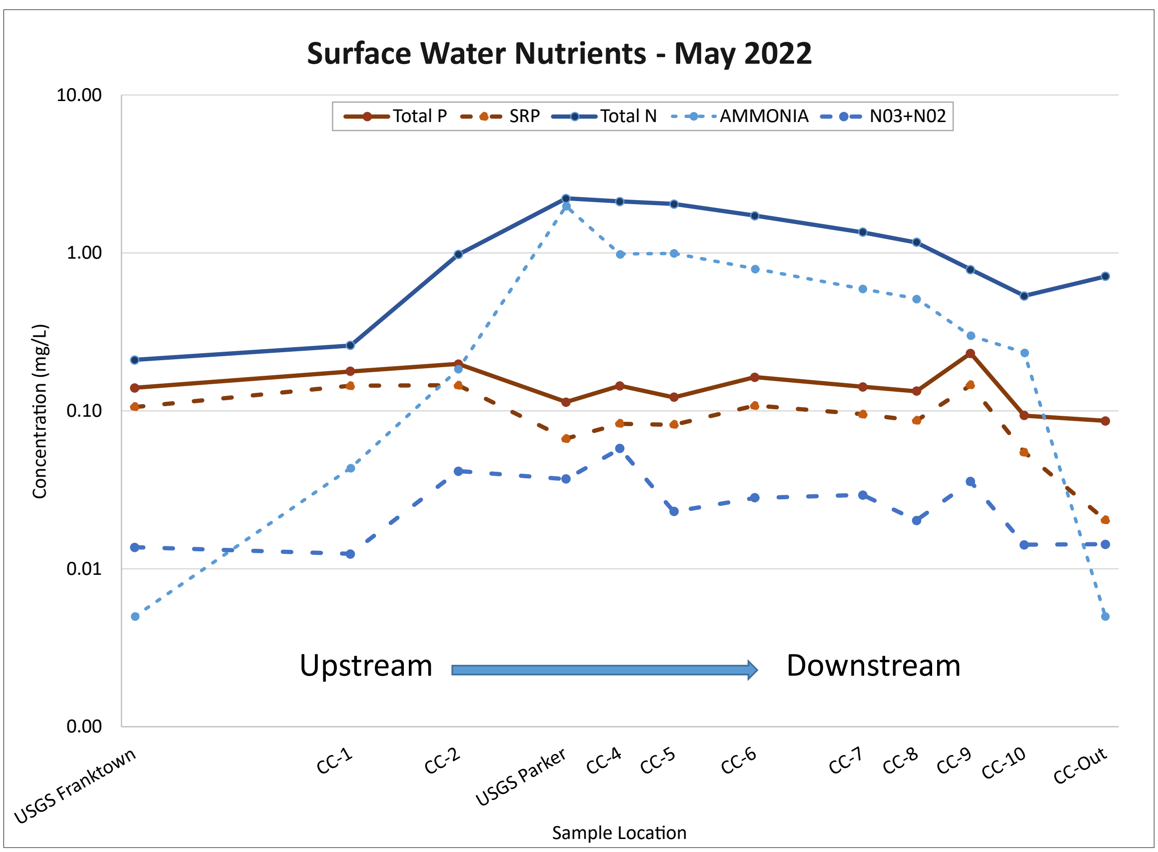


Figure 15. Surface Water Nutrient Sampling of Cherry Creek, May 2022.

The relationship between nutrients and TSS concentrations is also reflected in the water quality of samples collected on Cherry Creek just upstream of the Reservoir at CC-10 during storm and base flow sampling events. Figure 16 illustrates TP, TN, and TSS for each monitoring event during WY 2022. Typically storm flows increase the suspended sediments in the water, represented by higher values of TSS. During WY 2022, the samples that were collected from the storm events indicated a correlation between storm flows and increases in phosphorus, nitrogen and TSS levels (Table 5). WY 2022 sampling results, along with historical data, suggest that storm events are responsible for a large contribution of the total nutrient and sediment loading to the Reservoir.

Table 5. Cherry Creek – Total Phosphorus, Nitrogen, and Suspended Solids, Base and Storm Flows, CC-10, WY 2022.

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	2	-	12	2	-	12	2	-
Minimum	87	316	-	253	1,560	84%	5	90	-
Maximum	310	620	-	749	2,400	69%	48	275	-
Mean	175	468	63%	474	1,980	76%	12	183	93%
Median	150.5	468	68%	433	1,980	78%	8.4	183	95%

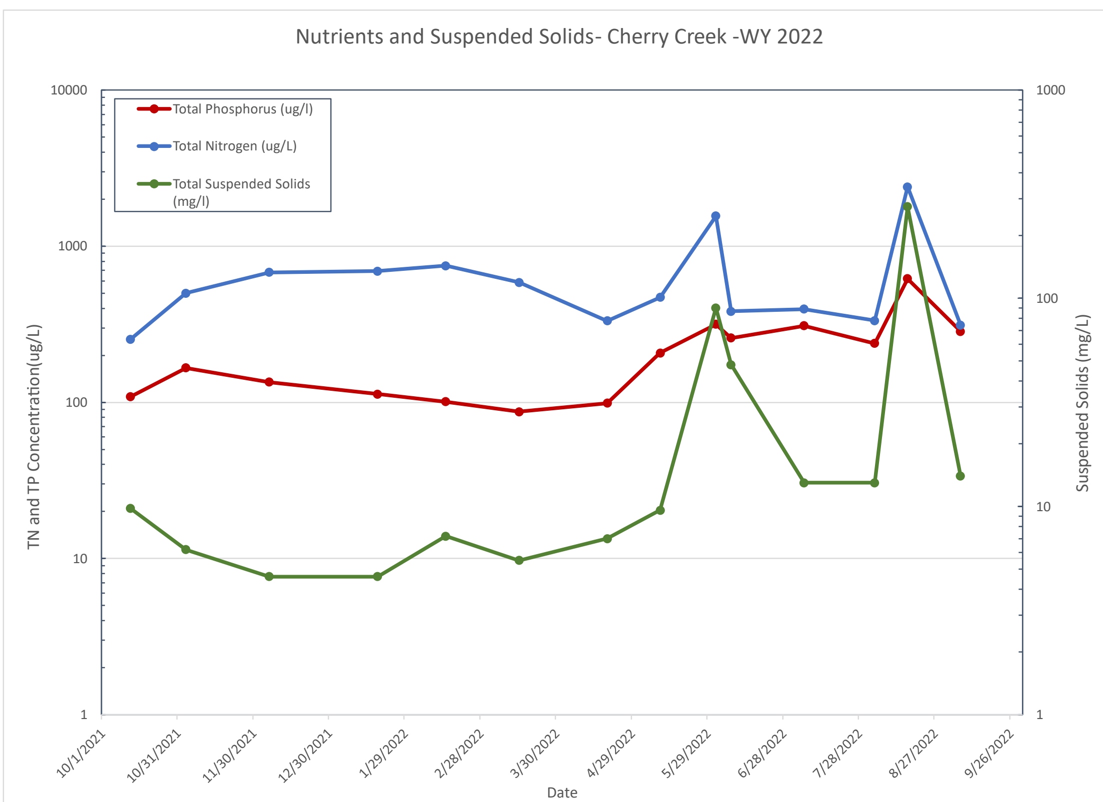


Figure 16. Cherry Creek - Total Phosphorus, Total Nitrogen and Total Suspended Solids, at CC-10 WY 2022.

3.3.1 PINEY CREEK

Piney Creek is one of the primary tributaries that feeds Cherry Creek and is fed by a sub-basin of approximately 14,080 acres. Unlike Cherry Creek and Cottonwood Creek, it has no permitted municipal wastewater treatment plants. Piney Creek is monitored at site PC-1 to determine baseline data from this sub-basin and the potential influence that Piney Creek may have on downstream water quality in Cherry Creek. In 2019, a permanent monitoring station with storm sampling equipment, located off S. Walden Way and south of Tower Rd, was installed at PC-1. Prior to 2019, samples were collected south of Buckley Rd. and east of S Waco St. Summary statistics for total phosphorus, total nitrogen, and TSS concentrations on Piney Creek at PC-1 during base and storm flows during WY 2022 are provided in Table 6. Similar to Cherry Creek, limited storm events meeting the flow threshold along with some equipment errors resulted in only two storm samples collected from the Piney Creek site.

Table 6. Piney Creek - Total Phosphorus, Nitrogen, and Suspended Solids, Base and Storm Flows, at PC-1, WY 2022.

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	12	2	-	12	2	-	12	2	-
Maximum	40	411	-	466	1,770	74%	1	160	-
Mean	119	645	82%	1,680	1,820	8%	12	450	97%
Median	71	528	87%	841	1,795	53%	4	305	99%

The TP In Piney Creek concentrations ranged from 40 to 645 µg/L, TN concentrations ranged from 466 to 1,829 µg/L, and TSS concentrations ranged from 1 to 450 mg/L. The mean concentrations of TP, TN and TSS in storm samples were 87%, 58% and 99% higher respectively when compared to base flow concentrations.

During WY 2022 the pH in Piney Creek ranged between 7.89 and 8.37, with a mean value of 8.1. The specific conductance values ranged from 1856 to 2,580 µS/cm. The mean specific conductance on Piney Creek was 2,010 µS/cm, which is higher than the mean of 1,201 µS/cm in Cherry Creek, but similar to the mean on Cottonwood Creek at CT-2 of 2,053 µS/cm on Cottonwood Creek during WY 2022.

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 for baseflow conditions only. During WY 2022, mean nutrient concentrations were lower in Piney Creek than either the upstream (CC-7) or downstream (CC-10) sites in Cherry Creek, indicating that the Piney Creek inflows are not negatively impacting the quality in Cherry Creek during base flow conditions. This finding is expected during baseflow conditions because there are not WWTP discharges to Piney Creek. All forms of phosphorus (TP, SRP, TDP) on Piney Creek were approximately 60% of upstream concentrations on Cherry Creek and less than 40% of the downstream site near the inlet to the Reservoir. These phosphorus concentrations are much more similar to those seen on Cottonwood Creek. Average TN concentrations were less than 50% of upstream values and less than 75% of downstream. NO3+NO2-N and NH3-N were also much lower on Piney Creek than either site on

Cherry Creek. TSS and VSS concentrations on Piney Creek in WY 2022 were the same as upstream of the confluence on Cherry Creek but lower than those downstream at the CC-10 monitoring location. Although limited monitoring data is available prior to when the major portion of the stream restoration work on Piney Creek was completed prior to 2018, it appears that the Piney Creek watershed is not contributing to degradation, and likely improving, the water quality in Cherry Creek during baseflow conditions.

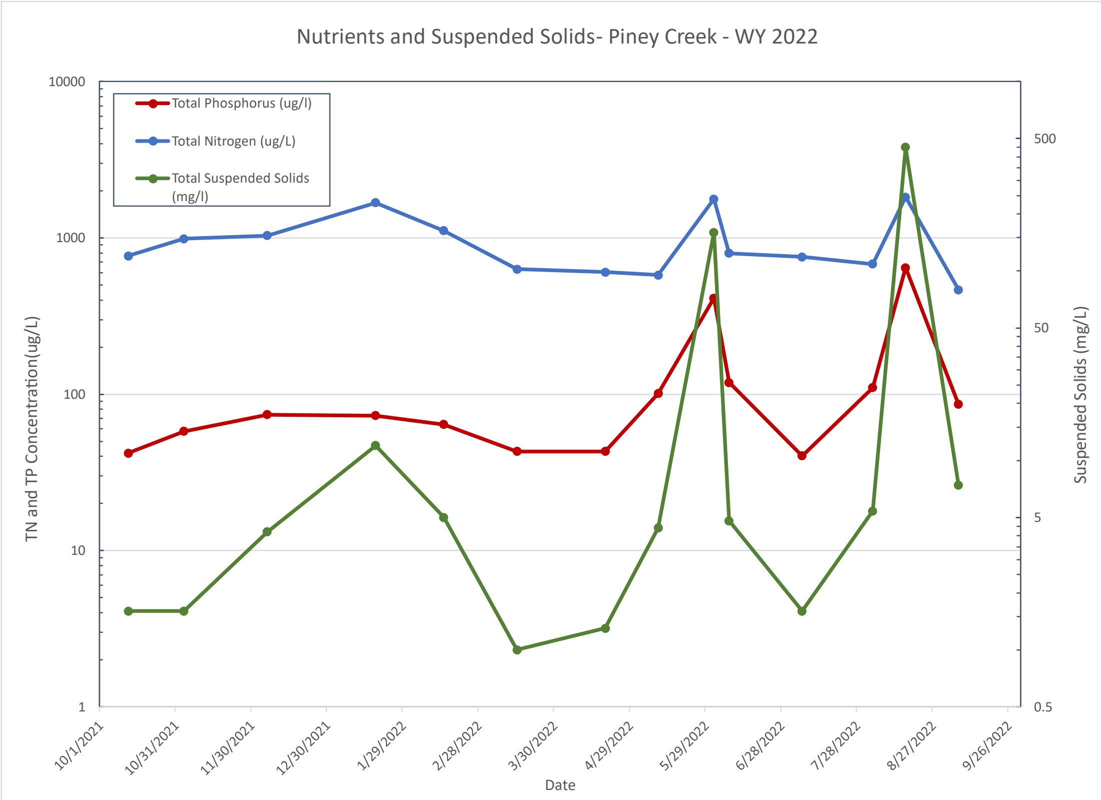


Figure 17. Piney Creek - Total Phosphorus, Total Nitrogen and Total Suspended Solids at PC-1, WY 2022.

Table 7. Water Quality in Piney Creek, Upstream, and Downstream of Confluence with Cherry Creek, Baseflow, WY 2022.

Base Flow		Mean Concentration	
N=	12	12	12
Location	Upstream Cherry Creek	Piney Creek	Downstream Cherry Creek
Analyte	CC-7	PC-1	CC-10
TP, µg/L	113	71	183
SRP, µg/L	80	50	148
TDP, µg/L	88	56	160
TN, µg/L	1776	841	1180
NO_3+NO_2-N, µg/L	926	163	530
NH_3-N, µg/L	16	11	12
TSS, mg/L	4	4	12
VSS, mg/L	1	1	2

3.4 COTTONWOOD CREEK SURFACE WATER QUALITY

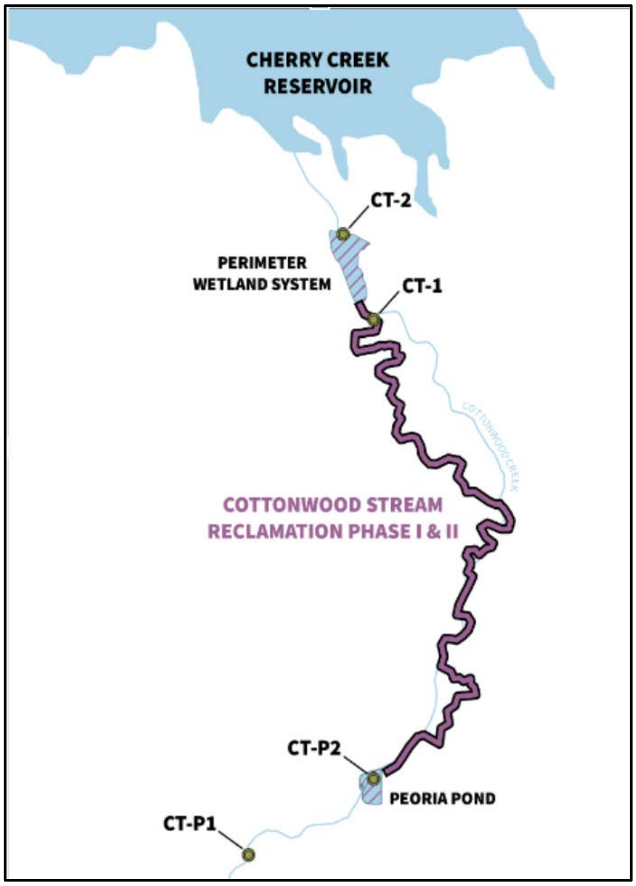


Figure 18. Cottonwood Creek Pollution Reduction Facilities

Cottonwood Creek is the second largest surface water input to Cherry Creek Reservoir. Cottonwood Creek has a sub-basin of 9,050 acres. Compared to Cherry Creek, Cottonwood Creek sub basin has more developed land use, and one permitted wastewater discharge as compared to multiple permitted wastewater discharges. 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 upstream and downstream of the PRF ponds and wetland systems (Figure 18).

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 2022, the pH of water in Cottonwood Creek before it entered the Reservoir ranged from 7.7 to 8.0, and it has remained relatively consistent over time.

Conductivity, or specific conductance, at CT-2 ranged between 1,582 µS/cm and 4,467 µS/cm with a mean value of 2,053 µS/cm, which is much higher than the mean for Cherry Creek (1,201 µS/cm) for WY 2022. Historical conductivity (plotted in Figure 13 above) shows an increasing trend with greater seasonal variability over time, which is more substantial in Cottonwood Creek than Cherry Creek. The conductivity in Cottonwood Creek may be more impacted by road salts and de-icing activities at Centennial Airport during the winter months.

Summary statistics for total phosphorus, total nitrogen, and TSS concentrations at CT-2 during base and storm flows during WY 2022 are provided in Table 8. As shown in Table 8, both TP and TN concentrations are much higher during storm events than baseflow on Cottonwood Creek, with median concentrations nearly doubling for both. Mean and median TSS concentrations were low during baseflow and storm flow events.

The concentrations of TP and TN measured at CT-2 in WY 2022 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 TP and TSS is present on Cottonwood Creek, although it appears less notable than seen in Cherry Creek since, overall, the TP concentrations are much higher entering the Reservoir from Cherry Creek than from Cottonwood Creek during WY 2022. In addition, the TN concentrations were often elevated in storm samples as well.

A summary of the mean water quality concentrations at CT-2 during base flow conditions for WY 2022 is provided in Table 9.

Table 8. Cottonwood Creek - Total Phosphorus, Nitrogen, and Suspended Solids, Base and Storm Flows, WY2022

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	26	71	-	1,455	1,670	-	1	4	-
Maximum	65	240	-	4,254	3,060	-	14	44	-
Mean	48	119	248%	1,931	2,362	122%	7	14	200%
Median	48	92	192%	1,455	2,540	175%	8	8	100%

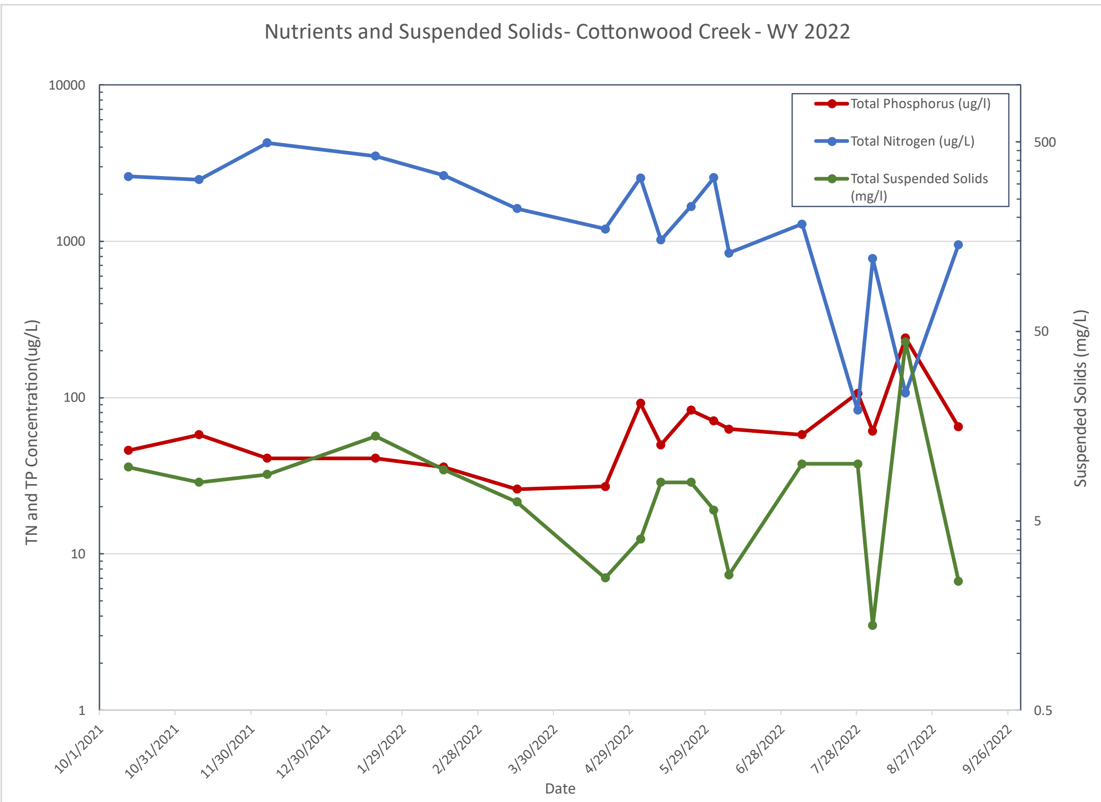


Figure 19. Total Phosphorus, Total Nitrogen and Total Suspended Solids in Cottonwood Creek at CT-2, WY 2022.

Table 9. Water Quality Summary for CT-2 Base flow conditions WY 2022.

Base Flow	CT-2
Analyte	Mean Concentration
TP, µg/L	48
SRP, µg/L	15
TDP, µg/L	24
TN, µg/L	1,931
NO3+NO2-N, µg/L	863
NH3-N, µg/L	58
TSS, mg/L	7
VSS, mg/L	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 PRFs 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 (Figure 18). The monitoring program includes water quality samples during routine base flow sampling, as well as storm conditions above and below these sites.

Table 10. Summary of Reductions in Nutrient and Suspended Solids in CCBWQA PRFs, WY 2022. *

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	○	●		○	◌	●	○		

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

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.

While the limited results from WY 2022 are not sufficient to complete a robust statistical analysis, calculations are 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 in the various water quality parameters in base flow conditions for each PRF during WY 2022 and Tables 11 through 15 summarize the change in mean concentrations and the percent difference upstream to downstream. Since percent reduction is influenced by influent concentration, negligible percent reductions are shown for baseflow conditions when inflow (or upstream) concentrations are low.

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 2022. Tables 11 through 14 also indicate increases in concentrations upstream to down in orange and reductions in **green**. These differences are not necessarily statistically significant; instead, they represent simple comparisons of the mean values.

The mean monthly base and storm flow concentrations from upstream to downstream samples from the Cottonwood Treatment Train as a whole (from upstream of Peoria Pond to below Perimeter Pond) demonstrated reductions in TP concentrations by approximately 73% during storm flows (Table 11). Suspended sediment concentrations, measured as TSS, were 24% lower downstream during base flow conditions and 95% lower downstream during storms. Mean volatile suspended solids, or VSS, concentrations were 21% lower downstream during base flows and 87% lower downstream during storm events. The other nutrients showed more variability resulting in higher mean concentrations in downstream, baseflow and storm flow conditions. Overall, the Cottonwood Treatment Train worked as designed to effectively reduce phosphorus and suspended sediment concentrations during storm events during WY 2022. Dissolved nutrient forms are typically harder to remove than particulate forms, which is supported by the Cottonwood Creek PRF data.

Table 11. Pollutant Reduction Analysis, Cottonwood Creek Treatment Train PRF, WY 2022.

Cottonwood Treatment Train	Base Flow				Storm Flow			
Site	CT-P1	CT-2	Upstream to Downstream		CT-P1	CT-2	Upstream to Downstream	
Events (n)	12	12			4	5		
Analyte	Mean Concentration		Net Difference	Percent Difference	Mean Concentration		Net Difference	Percent Difference
TP, µg/L	43	48	5	12%	467	125	-341	-73%
SRP, µg/L	9	15	6	76%	7	38	31	439%
TDP, µg/L	15	24	9	61%	15	52	38	254%
TN, µg/L	1,065	1,931	867	81%	1,868	2,318	450	24%
NO_2+NO_3,µg/L	292	863	571	196%	485	885	400	82%
NH_3-N, µg/L	36	58	22	60%	69	126	57	81%
TSS, mg/L	9	7	-2	-24%	313	17	-296	-95%
VSS, mg/L	2	2	0	-21%	37	5	-33	-87%

When evaluating the two sections individually (Peoria Pond and Perimeter Pond Wetland Systems shown in Table 12 and Table 13), TP, TSS, and VSS concentrations were both lower downstream during storm events although the Perimeter Pond also saw reduced mean concentrations or TSS and VSS during base flows. The mean TP concentrations were between 230 to 246 µg/L lower downstream of the ponds during storms, but most nutrient concentrations were within 10 µg/L upstream to downstream during base flows.

There were limited changes in mean concentrations of TP, SRP and TDP upstream to downstream of the Peoria Pond during base flow conditions; however, mean TP demonstrated an almost 50% reduction in downstream concentrations during storm flows. Mean TN and NO_2+NO_3 concentrations increased from upstream to downstream in all flow conditions. Mean TSS concentrations were lower downstream in both base flows (30%) and storm events (62%) (Table 12).

Table 12. Pollutant Reduction Analysis, Peoria Pond PRF, WY 2022.

Peoria Pond	Base Flow				Storm Flow			
Site	CT-P1	CT-2	Upstream to Downstream		CT-P1	CT-2	Upstream to Downstream	
Events	12	12			4	5		
Analyte	Mean Concentration		Net Difference	Percent Difference	Mean Concentration		Net Difference	Percent Difference
TP, µg/L	43	47	4	10%	467	237	-230	-49%
SRP, µg/L	9	5	-3	-39%	7	43	36	507%
TDP, µg/L	15	10	-5	-31%	15	57	42	286%
TN, µg/L	1,065	1,276	212	20%	1,868	2,168	300	16%
NO_2+NO_3, µg/L	292	458	166	57%	485	708	223	46%
NH_3-N, µg/L	36	30	-6	-17%	69	256	186	268%
TSS, mg/L	9	12	3	30%	313	118	-196	-62%
VSS, mg/L	2	3	1	32%	37	32	-5	-13%

Table 13. Pollutant Reduction Analysis, Perimeter Pond PRF, WY 2022.

Perimeter Pond	Base Flow				Storm Flow			
Site	CT-1	CT-2	Upstream to Downstream		CT-1	CT-2	Upstream to Downstream	
Events	12	12			6	5		
Analyte	Mean Concentration		Net Difference	Percent Difference	Mean Concentration		Net Difference	Percent Difference
TP, µg/L	46	48	2	4%	364	119	-246	-67%
SRP, µg/L	8	15	7	99%	12	35	23	197%
TDP, µg/L	15	24	8	55%	22	49	27	124%
TN, µg/L	2,261	1,931	-330	-15%	2,576	2,362	-214	-8%
NO_2+NO_3, µg/L	1,104	863	-241	-22%	761	889	128	17%
NH_3-N, µg/L	28	58	30	109%	56	118	62	110%
TSS, mg/L	11	7	-5	-40%	196	14	-182	-93%
VSS, mg/L	3	2	-1	-29%	32	4	-28	-87%

During WY 2022, the Perimeter Pond PRF had no reduction in TP upstream to downstream in base flow conditions but concentrations were approximately 67% lower downstream during storm flow samples collected (Table 13). TN concentrations were 15% lower downstream in base flows and 8% lower in the storm samples collected. NO_2+NO_3 concentrations were 22% lower downstream of the Perimeter Pond in base flows but 17% higher during storms. Mean SRP, TDP, and NH_3-N concentrations were slightly higher downstream during base flow and storm flow. Mean TSS concentrations were lower downstream in base flows (5%) and significantly lower (182%) during the storm events (Table 13).

When evaluating the Cottonwood treatment train between the two ponds (Table 14), mean concentrations of TP, SRP, TDP, and NH_3-N and suspended solids in the upstream samples (CT-P2) were similar to the downstream samples (CT-1) during base flows conditions WY 2022. However, mean concentrations of TP, TSS, and VSS were higher downstream during storm flows. TN and NO_2+NO_3 both demonstrated increased mean concentrations downstream in base and storm flow conditions. During WY 2022 mean SRP, TDP, and NH_3-N concentrations were lower in the storm flow samples collected downstream.

Table 14. Pollutant Reduction Analysis, Cottonwood Treatment Train between the PRF ponds, WY 2022

Cottonwood Ck between PRF Ponds	Base Flow				Storm Flow			
Site	CT-P2	CT-1	Upstream to Downstream		CT-P2	CT-1	Upstream to Downstream	
Events (n)	12	12			7	4		
Analyte	Mean Concentration		Net Difference	Percent Difference	Mean Concentration		Net Difference	Percent Difference
TP, µg/L	47	46	-1	-2%	239	357	118	49%
SRP, µg/L	5	8	2	44%	41	11	-30	-73%
TDP, µg/L	10	15	5	51%	56	22	-34	-60%
TN, µg/L	1,276	2,261	985	77%	2,455	2,823	367	15%
NO_2+NO_3, µg/L	458	1,104	646	141%	716	763	47	7%
NH_3-N, µg/L	30	28	-2	-8%	298	63	-235	-79%
TSS, mg/L	12	11	-0.3	-3%	100	185	85	85%
VSS, mg/L	3	3	-0.5	-15%	28	30	3	10%

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 were collected every other month only under base fl1ow conditions from monitoring site MCM-1, upstream of the stream reclamation project area, and MCM-2, downstream.

In WY 2022, the TP, TDP, SRP, and NO_2+NO_3, NH_3-N, and TSS concentrations were all lower downstream of the McMurdo stream reclamation project (Table 15) when compared to the upstream site. Although VSS was slightly higher it was an insignificant difference since the mean concentrations were so low overall.

Table 15. Pollutant Reduction Analysis, McMurdo Gulch, WY 2022.

McMurdo Gulch	Base Flow			
Site	MCM-1	MCM-2	Upstream to Downstream	
Events	6	6		
Analyte	Mean Concentration		Net Difference	Percent Difference
TP, µg/L	363	262	-101	-28%
SRP, µg/L	587	239	-348	-59%
TDP, µg/L	329	250	-80	-24%
TN, µg/L	888	514	-374	-42%
NO_2+NO_3,µg/L	350	70	-280	-80%
NH_3-N, µg/L	18	6	-12	-68%
TSS, mg/L	3	2	-1	-42%
VSS, mg/L	0.5	1	0.5	124%

3.5.1 LONG TERM PRF EVALUATION

During the last few years, there has been increased effort towards 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. Recently, a data analysis tool was developed that allows for 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. The tool uses a non-parametric Wilcoxon signed rank test to assess whether differences are present between two data sets, with statistically significant differences indicated by p values less than 0.05.

In order to demonstrate the capabilities of this tool, an analysis of upstream to downstream concentrations over the last 10 water years (WY 2013-2022) was completed to assess changes (Δ) in median concentrations during baseflow and storm flow conditions. Cottonwood Treatment Train as a whole (Table 16), Peoria Pond (Table 17) and Perimeter Pond (Table 18) all showed statistically significant reductions of TP and TSS during storm flow conditions. Additionally, the Perimeter Pond PRF demonstrated statistically significant reductions in median TP, TN, and TSS concentrations in base flow conditions as well. Activities such as implementation of BMPs and maintenance (e.g., dredging and wetland harvesting) may affect results during various time periods. 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).

Table 16. Pollutant Reduction Analysis of Cottonwood Treatment Train (2013-2022).

PRF	Cottonwood Treatment Train			
Flow Condition	Base		Storm	
Analyte	Median Δ	Significant	Median Δ	Significant
TP, µg/L	2.5	No	-156.5	Yes
TN, µg/L	518	No	90	No
TSS, mg/L	-0.05	No	-93	Yes

Table 17. Pollutant Reduction Analysis of Peoria Pond (2013-2022).

PRF	Peoria Pond			
Flow Condition	Base		Storm	
Analyte	Median Δ	Significant	Median Δ	Significant
TP, µg/L	3	No	-114.5	Yes
TN, µg/L	213	No	-6.5	No
TSS, mg/L	1	No	-72.25	Yes

Table 18. Pollutant Reduction Analysis of Perimeter Pond – (2013-2022).

PRF	Perimeter Pond			
Flow Condition	Base		Storm	
Analyte	Median Δ	Significant	Median Δ	Significant
TP, µg/L	-10	Yes	-83	Yes
TN, µg/L	-276	Yes	-170	Yes
TSS, mg/L	-7	Yes	-45	Yes

When looking at the upstream to downstream concentrations of TP, TN and TSS on Cottonwood Creek, between the ponds during WY 2013-2022, there was no significant difference in base or storm flow concentrations (Table 19).

Table 19. Pollutant Reduction Analysis of Cottonwood Creek Between Ponds – (2013-2022).

PRF	Cottonwood Creek Between Ponds			
Flow Condition	Base		Storm	
Analyte	Median Δ	Significant	Median Δ	Significant
TP, µg/L	10	No	66	No
TN, µg/L	760	No	243	No
TSS, mg/L	7	No	12	No

For the McMurdo Gulch PRF during WY 2013-2022 (Table 20), the upstream to downstream concentrations of TP and TN during base flow conditions demonstrated a statistically significant reduction. Statistically significant changes during baseflow conditions were not present for TSS; however, TSS concentrations were extremely low during baseflows.

Table 20. Pollutant Reduction Analysis of McMurdo Gulch – 2013*-2022 Significance.

PRF	McMurdo Gulch	
Flow Condition	Base	
Analyte	Median Δ	Significant
TP, µg/L	-94	Yes
TN, µg/L	-166	Yes
TSS, mg/L	1	No

. *Note: Monitoring of McMurdo Gulch did not begin until 2013.

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 depth of water above the pressure transducer and temperature every 15 minutes. The daily mean water level above the transducer and temperature values measured in MW-9 can be found in Figure 20.

The groundwater level and temperature in MW-9 displayed some seasonal fluctuation through WY 2022 (Figure 20). The temperatures ranged from 9.5 to 10.3˚C, with temperatures increasing from July through November. Water level increased from a low of 10.6 m on August 13th, to 11.2 m by August 17th, a few days after the major storm on August 15th, 2022. Groundwater temperature also increased following this storm. Overall, this monitoring typically does not experience major changes to in water depth or temperature unless there are significant storms events nearby and even then, levels return to normal in a few days.

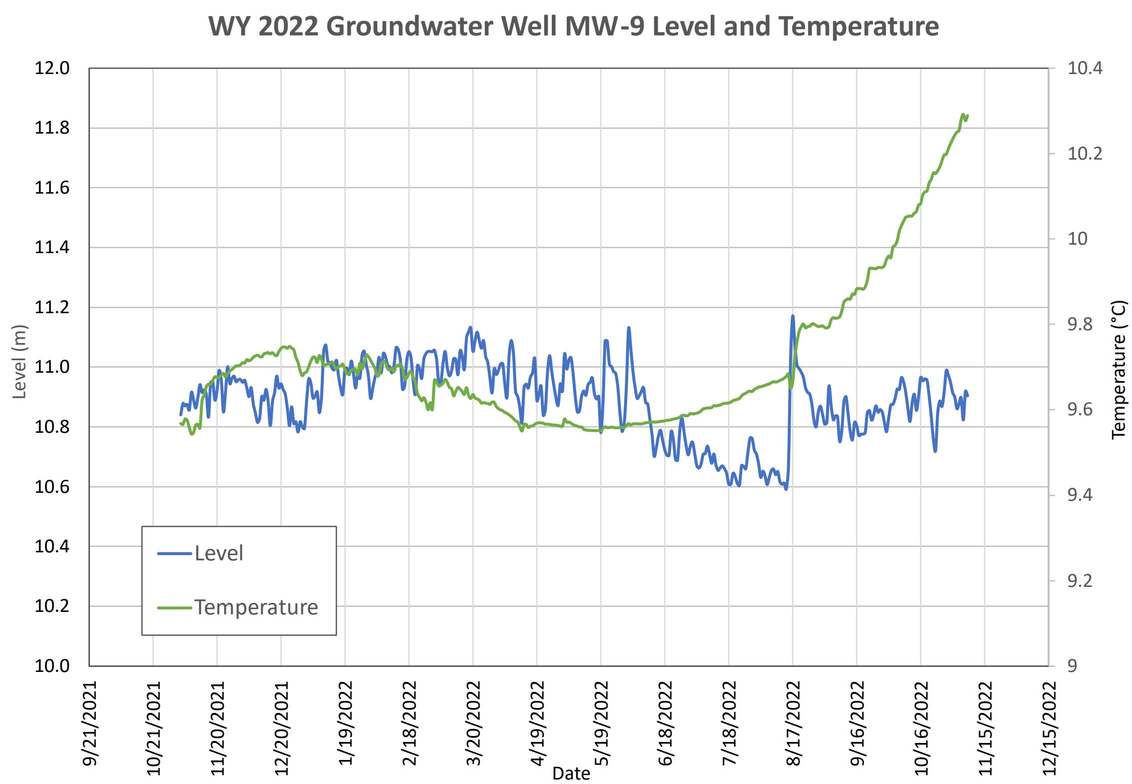


Figure 20. Daily Mean Level and Temperature in Groundwater Well MW-9, Upstream of Cherry Creek Reservoir.

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.

Water quality samples and measurements are collected from the monitoring wells twice annually. During WY 2022 monitoring was completed in November 2021 and May 2022.

The mean concentration of total phosphorus (TP) from the groundwater sites during the two monitoring events was 572 µg/L, with concentrations averaging 939 µg/L in November and 205 µg/L in May. (Figure 21 and Figure 22) The TP concentrations ranged between 190 µg/L and 1,932 µg/L in November, and between 140 µg/L and 254 µg/L in May. In November the TP concentrations were elevated at MW-1 and MW-5 and it appeared they could have been affected by sample collection. Manual well bailing is completed to remove 3 casing volumes prior to sample collection but these activities can cause an increase in suspended sediments and associated particulate phosphorus.

The SRP concentrations observed in the groundwater at both of these sites are more useful to compare based on a longer period of record than TP which has been inconsistently analyzed. Sample collection was modified in 2022 to use a well pump to limit disturbance caused by manual bailing so TP concentrations are more accurately represented beginning in May 2022, but a few more years of data are required to complete a meaningful analysis.

The mean concentration of TN from the groundwater sites during the two monitoring events was 1,898 µg/L, with concentrations averaging 1,546 µg/L in November and 2,249 µg/L in May. (Figure 21 and Figure 22) The TN concentrations ranged between 420 µg/L and 3,256 µg/L in November 2021, and between 267 µg/L and 3,070 µg/L in May 2022. The TN concentrations were highest at MW-5 in November 2021 but were more similar between MW-1, MW-5 and MW-9. During both monitoring events, the TN was lowest at MW-Kennedy, below the Reservoir.

The mean concentration of NO_2+NO_3 from the groundwater sites during the two monitoring events was 992 µg/L, with concentrations averaging 735 µg/L in November 2021 and 1,249 µg/L in May 2022. The highest concentration was collected in May 2022 from the sample from well MW-1, the furthest upstream monitoring well. Concentrations of NO_2+NO_3 were highest at MW-9 (1,650 µg/L) in November 2021 but were highest at MW-1 (2,160 µg/L) in May 2022 and demonstrated a decreasing trend downstream and below the Reservoir. The lowest concentration measured during WY 2022 at MW-Kennedy was 25 µg/L on the same date. The state drinking water standard for nitrate is 10 mg/L (10,000 µg/L) (5 CCR 1002-41.8).

The mean concentration of ammonia (NH_3-N) was below the detection limit at all sites except at MW-1 in November 2021 (12µg/L) and MW-Kennedy below the Reservoir (93 and 88 in November 2021 and May 2022 respectively).

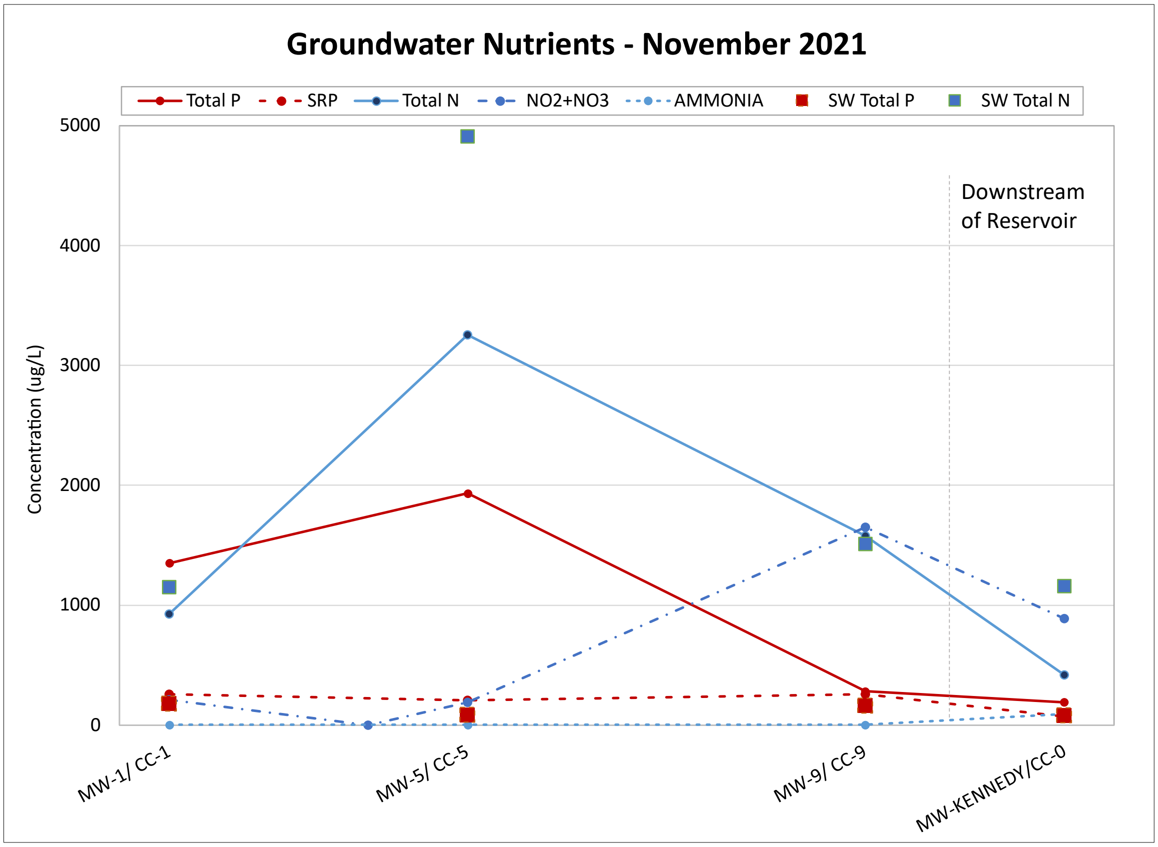


Figure 21. Groundwater Nutrients (Monitoring Wells) - November 2021.

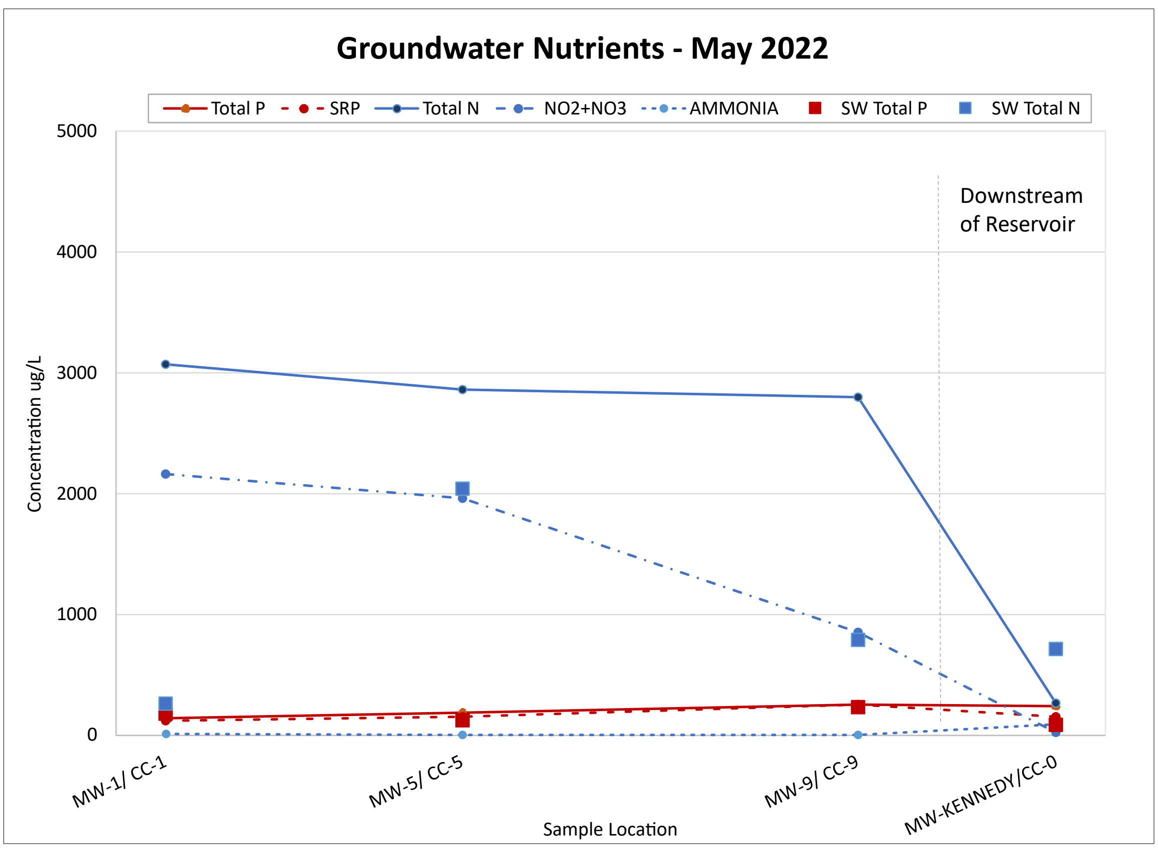


Figure 22. Groundwater Nutrients (Monitoring Wells) - May 2022.

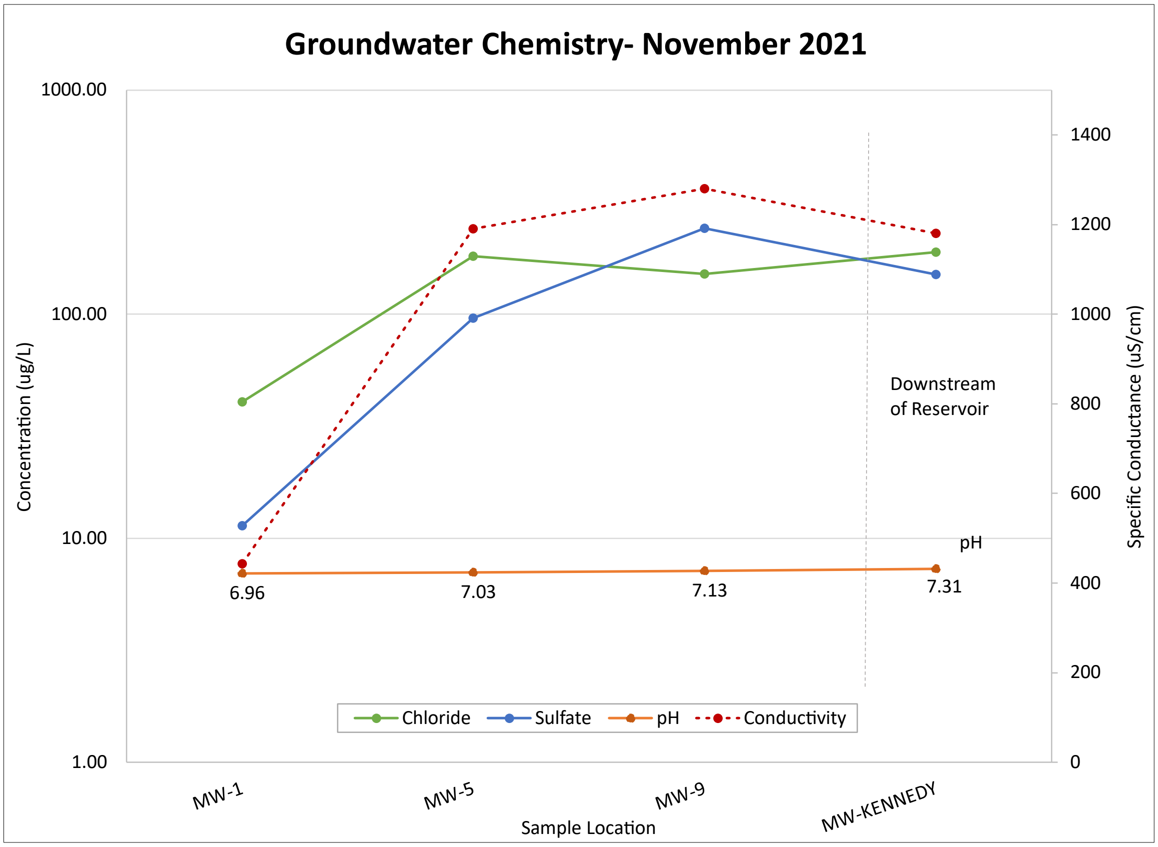


Figure 23. Groundwater Levels of Sulfate, Chloride, Specific Conductance, and pH, November 2021.

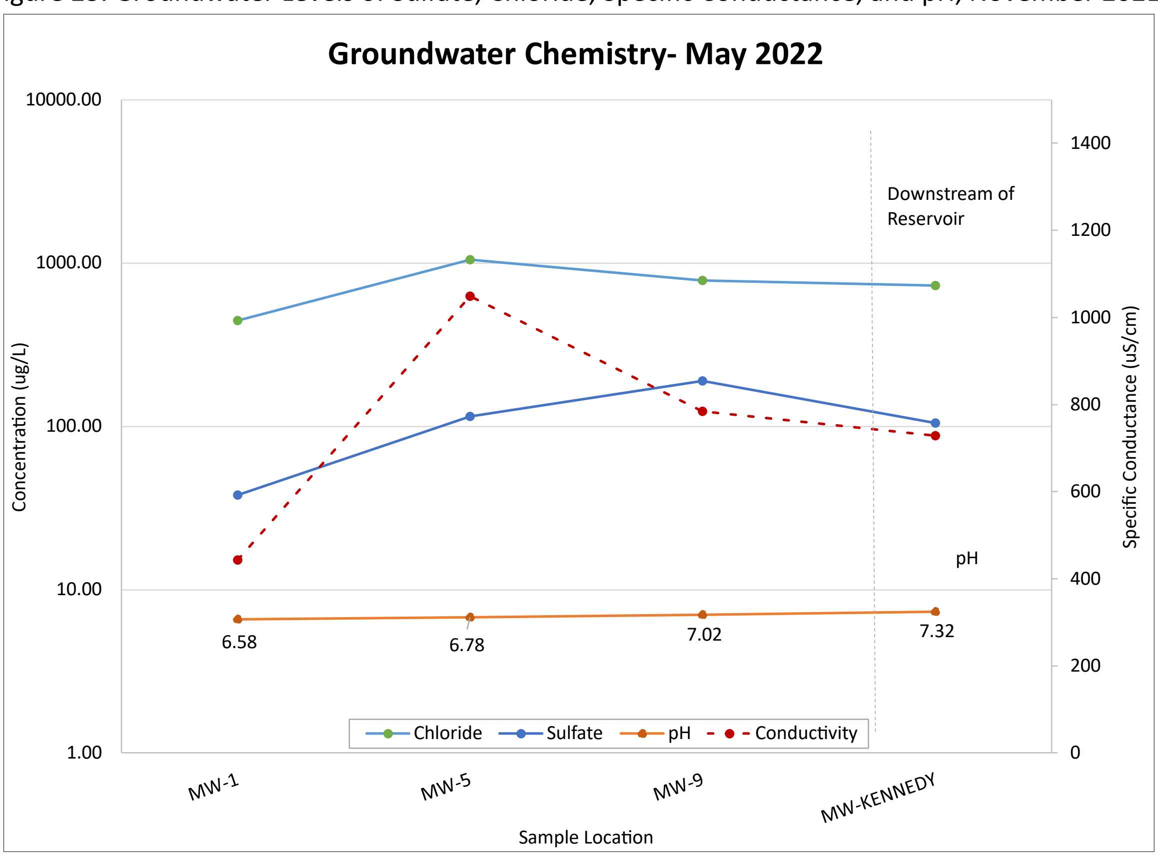


Figure 24. Groundwater Levels of Sulfate, Chloride, Specific Conductance, and pH, May 2022.

During both monitoring events, surface water TP concentrations were similar to the SRP concentrations in the nearby monitoring well (Figure 21 and Figure 22). TN concentrations in Cherry Creek were similar or higher than the nearest groundwater sites in November 2021 but were all much lower in May 2022, except for MW-Kennedy, which was lower than the outlet of the Reservoir.

As shown in Figure 23 and Figure 24, data from both sampling events during WY 2022 indicated groundwater concentrations of chloride averaged 170 mg/L and sulfate averaged 118 mg/L. During both events, sulfate was lowest at the furthest upstream well, MW-1, increased at MW-5, then was lower at MW-9 and similar downstream of the Reservoir (MW-Kennedy). The chloride at MW-1 and MW-5 was much higher in May 2022 than November 2021, with the highest concentrations at MW-5 in November 2021 (356 mg/L). 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 7.3 and a mean of 7.0, but increased slightly in the wells closer to the Reservoir and below. The conductivity was highest at the MW-5 site in November 2021, with a mean of 1,023 µS/cm, and the MW-9 well in May 2022, with a mean of 751 µS/cm. The mean conductivity for the two events was 887 µS/cm.

3.6.3 GROUNDWATER UPSTREAM OF RESERVOIR AT MONITORING WELL MW-9

The MW-9 site is monitored to indicate the groundwater conditions just upstream of the Reservoir and water quality concentrations at this site are used to calculate nutrient loading from groundwater sources. The pH at MW-9 was 7.13 in November 2021 and 7.02 in May 2022 (Figure 25). Figure 26 illustrates the historical pH from MW-9 from 1994-2022. Although values vary slightly, pH has remained relatively stable during this period, ranging between 6.5 and 8.2. The historical mean from 1994-2022 is 7.1, which is slightly lower than the mean of 7.3 from 2017-2022.

The conductivity at MW-9 was 1,344 µS/cm in November 2021 and 1,350 µS/cm in May 2022. The historical conductivity values at MW-9 suggest an increasing trend over time with a historical mean from 1994-2022 of 804 µS/cm and a mean value of 1,250 µS/cm from 2017 to 2022 (Figure 25).

Figure 26 illustrates the historical chloride and sulfate concentrations from 1994-2022, which both appear to be increasing over time, although chloride may be less variable and increasing slightly more.

Historically, the concentration of SRP in the groundwater upstream of the Reservoir at MW-9 also appears to be slightly increasing over time with historic concentrations from 1994-2003 averaging 183 µg/L and from 2004 to 2022 averaging 199 µg/L (Figure 27).

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 28). The TOC concentrations were 2.8 mg/L in both November 2021 and May 2022, which are both slightly lower than the long-term average of 3.2 mg/L from 2014-2022. Historically, the dissolved fraction of the TOC in well MW-9 has a long-term average of 93% of the total.

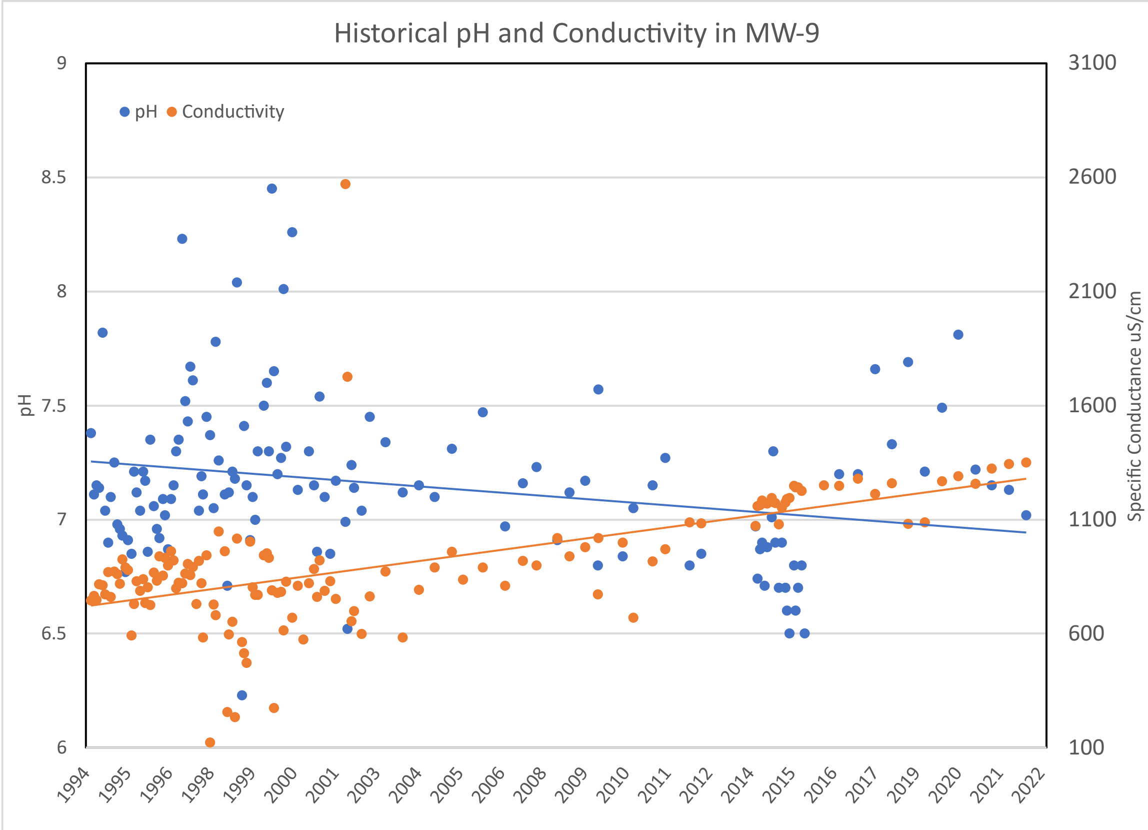


Figure 25. pH and Conductivity, Monitoring Well 9, 1994-2022.

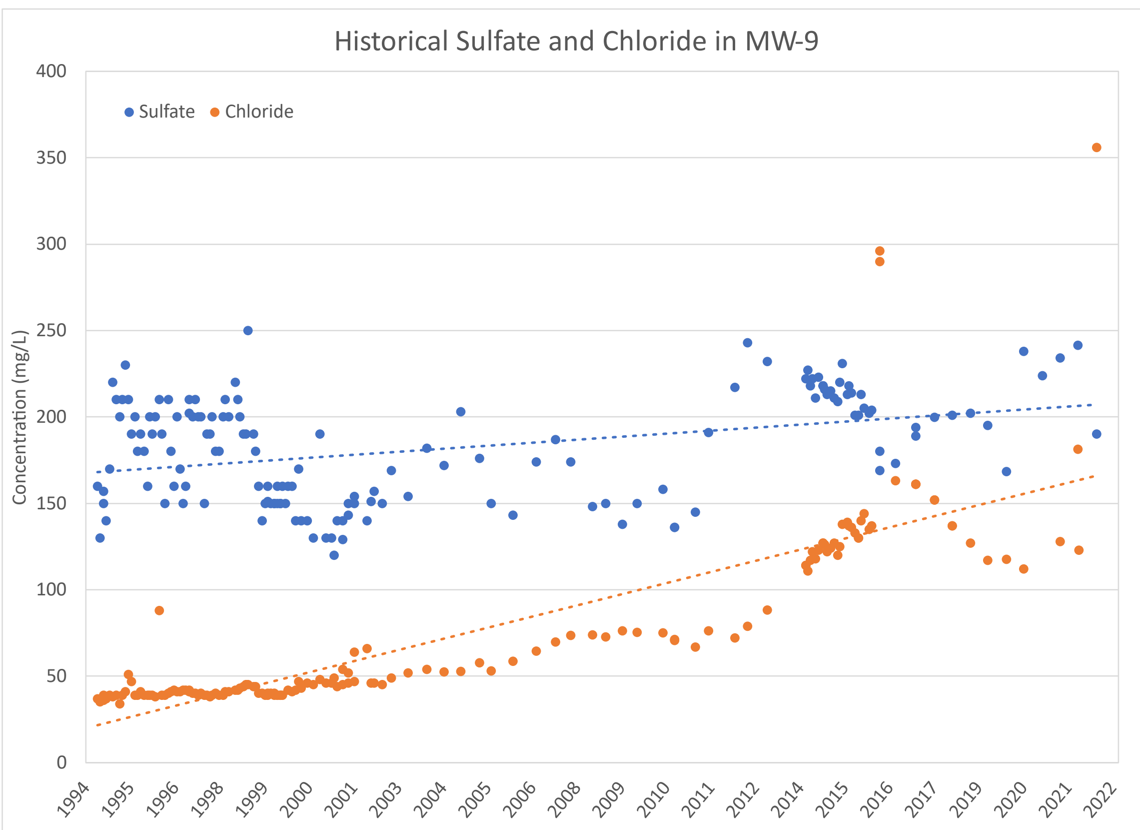


Figure 26. Sulfate and Chloride (mg/L) at MW-9, 1994-2022.

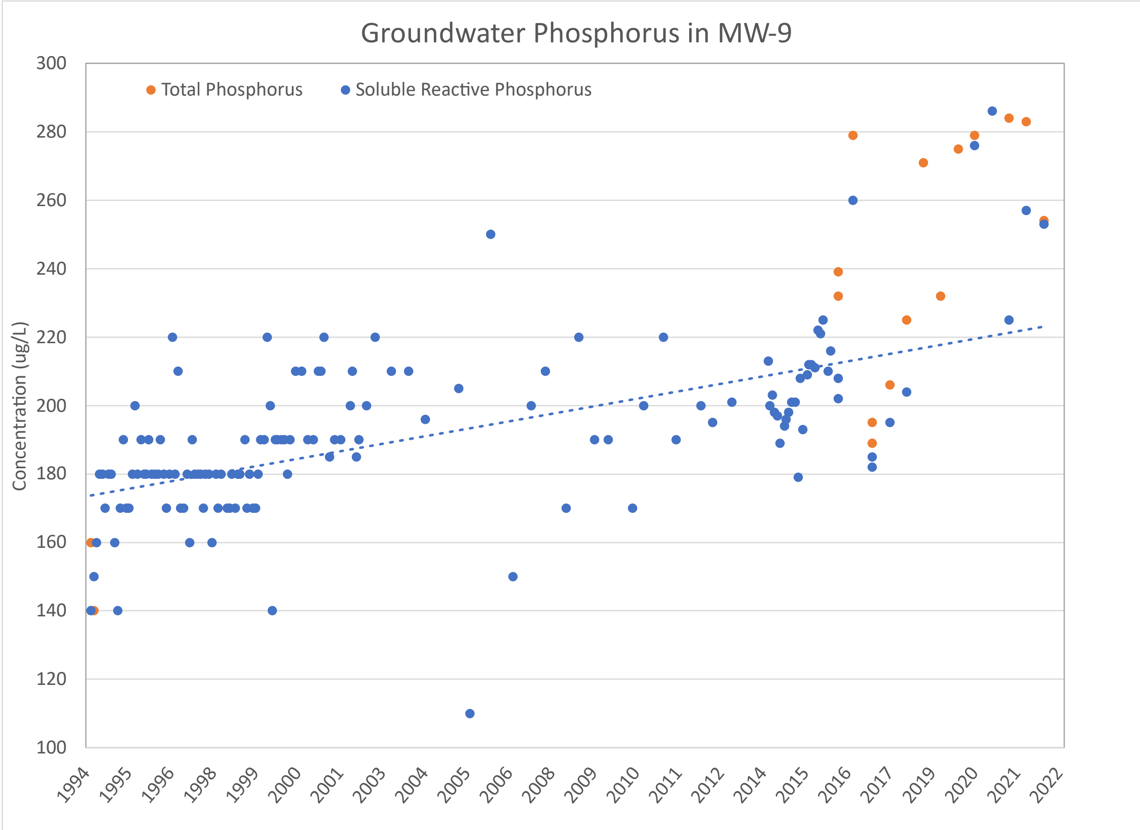


Figure 27. SRP and Total Phosphorus in Groundwater MW-9, 1994–2022.

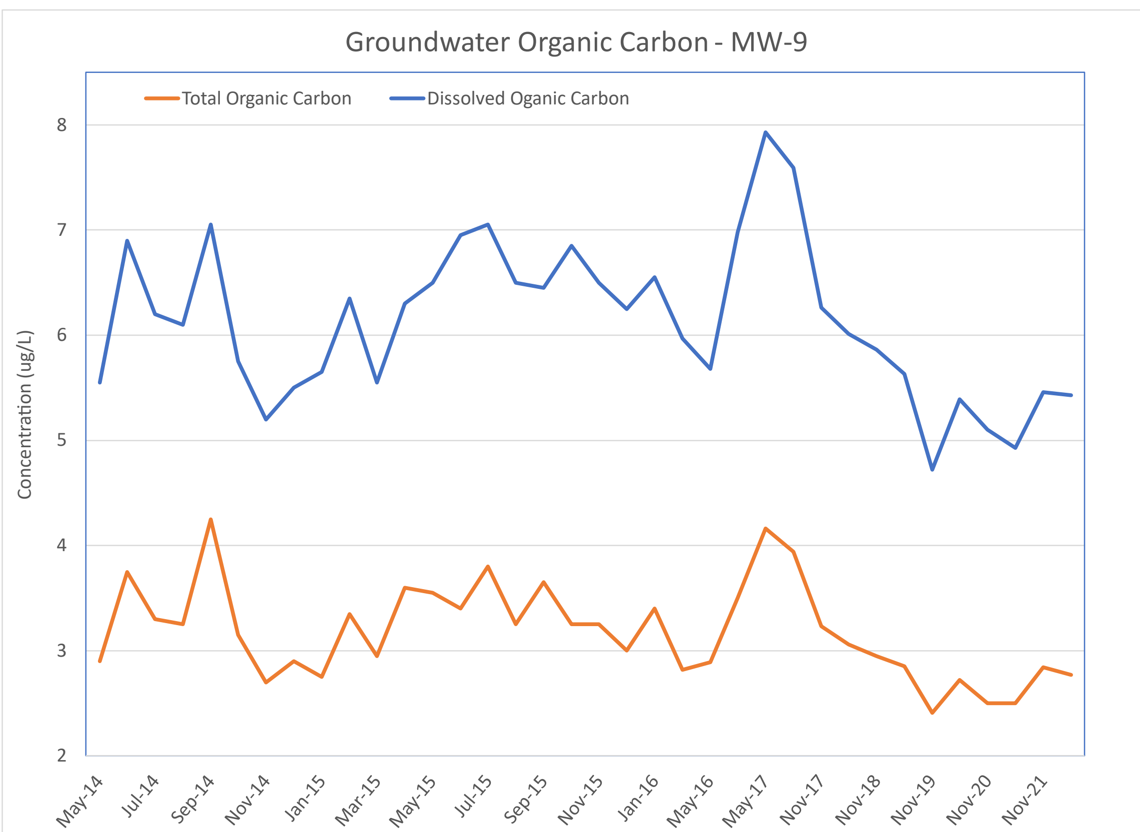


Figure 28. Total and Dissolved Organic Carbon Data from MW-9, 2014-2022.

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 and Reservoir outlet. 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. The sampling program includes monthly monitoring events from March through December, with additional bi-monthly monitoring events from May through September. Water quality samples are collected from the photic zone (0-3 m composite) at each site and from 4 m to the bottom at CCR-2. Physical parameters are measured at 1 m increments from the surface (0 m) to the bottom, which varied during WY 2022. However, due to low water levels in the Reservoir no measurements were collected at 7 m or below, so values from 6 m and the bottom were averaged for graphical representation on the data portal and graphs shown in Sections 4.4 through 4.8.

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 monthly 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 GATE EXERCISE ACTIVITY

The USACE completed the annual gate operation activity at the Cherry Creek Reservoir dam from 9:00 am through 1:05 pm on Tuesday May 24th. The USACE performs this exercise to verify the proper operation of the outlet gates. The USACE individually operated gates 1-5 with various flows from 150 cfs to 1300 cfs. The exercise varies from year to year with larger releases on even years and smaller releases on odd years. It is assumed that this flushing exercise may release some of the nutrient rich water and sediments from the bottom of the reservoir.

Tue May 24, 2022

Est. Time (MDT)	Activity
8:55	**Dam Low-flow gates closed, 0 cfs.**
9:00	Gate 3 release 150 cfs for 30 minutes.
9:30	Gate 3 release 1300 cfs for 10 minutes.
9:40	Gate 3 release 150 cfs for 40 minutes.
10:20	Gate 3 closed, 0 cfs.
10:25	Operation notes: Shut Security Gate#3,
10:35	Gate 2 release 1300 cfs for 10 minutes.
11:15	Gate 2 release 150 cfs for 40 minutes.
11:20	Gate 2 closed, 0 cfs. Operation notes:
11:30	Gate 4 release 1300 cfs for 10 minutes.
12:10	Gate 4 release 150 cfs for 40 minutes.
12:15	Gate 4 closed, 0 cfs. Operation notes:
12:25	Gate 5 release 1300 cfs for 10 minutes.
13:05	Gate 5 release 150 cfs for 40 minutes..
13:10	**Cherry Creek Dam outflow amount re-set to routine Colorado Engineer-directed releases.**

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.

Secchi depth measurements represent reduced clarity and eutrophic-hypereutrophic conditions through WY 2022. The Secchi depth ranged between 0.6 and 1.9 m, with an annual mean of 1.0 m and a seasonal mean (July-Sept) of 1.1 m. The highest Secchi depths were recorded in early June and late August following significant storm events which increased flows into the Reservoir. The highest mean Secchi depth occurred in late August and coincided with the lowest chl α concentrations of the year as well. Storm events are responsible for increasing inflows to the reservoir, reducing temperature, and likely assisting with mixing, all of which reduce the potential for algae growth.

The Secchi depths were relatively similar between CCR-1, 2, and 3 (3-33% variability), with the exception of the severe algae bloom in July 2022 when there was an approximately 50% difference between the sites due to the variation in the density of algal cells.

Figure 29 depicts the variability between Secchi depth measurements at the three monitoring locations, and the mean depth during each sampling event in WY 2022.

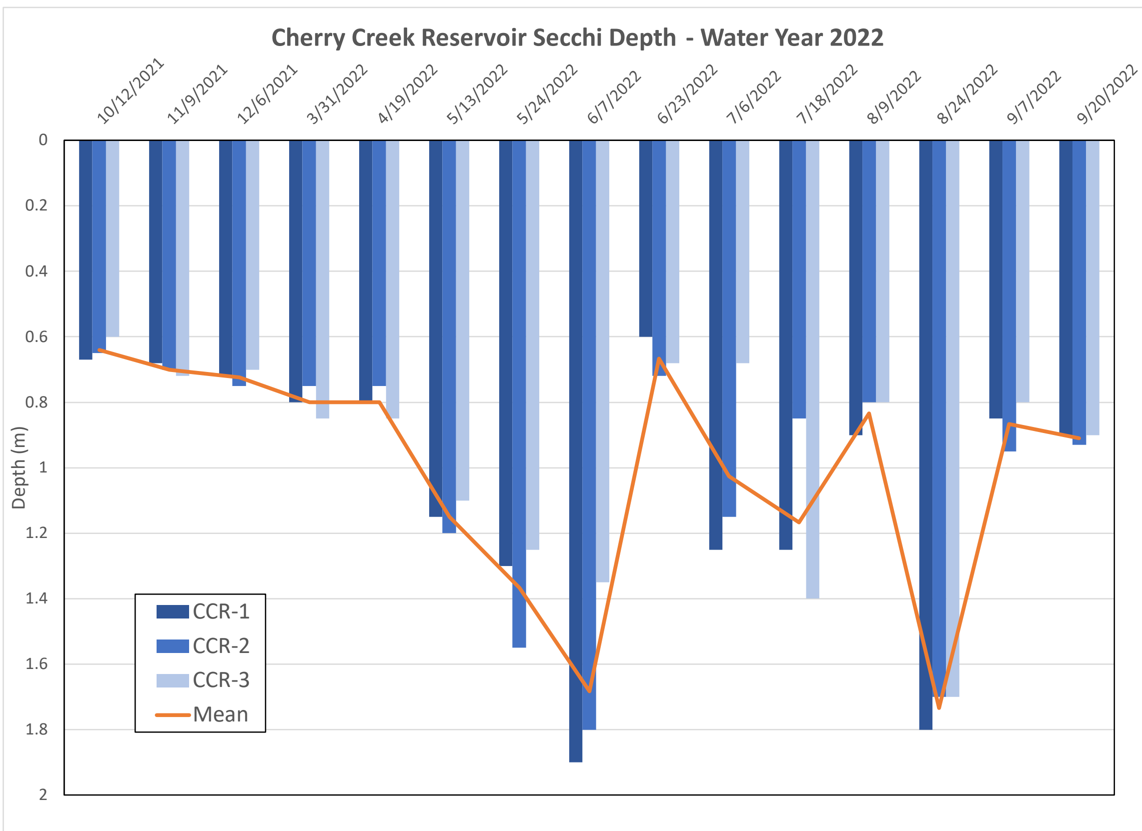


Figure 29. Secchi Depth in Cherry Creek Reservoir, Monitoring Sites CCR-1, CCR-2 and CCR-3, WY 2022.

Figure 30 shows the historical monthly mean Secchi depth and the WY 2022 monthly mean values with the standard deviations for both values. In WY 2022 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 May and August following storm events in both months. 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.

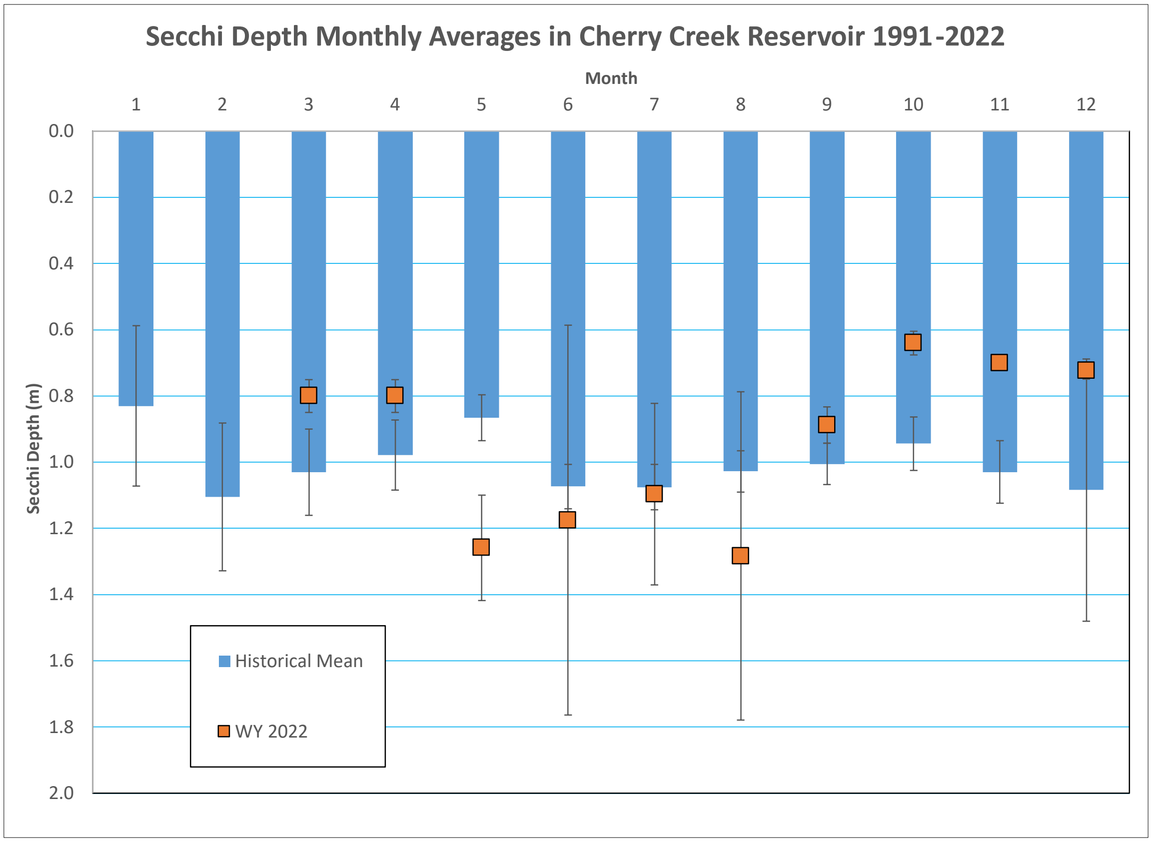


Figure 30. Historical and Monthly Mean Secchi Depth in Cherry Creek Reservoir from 1992-2022.

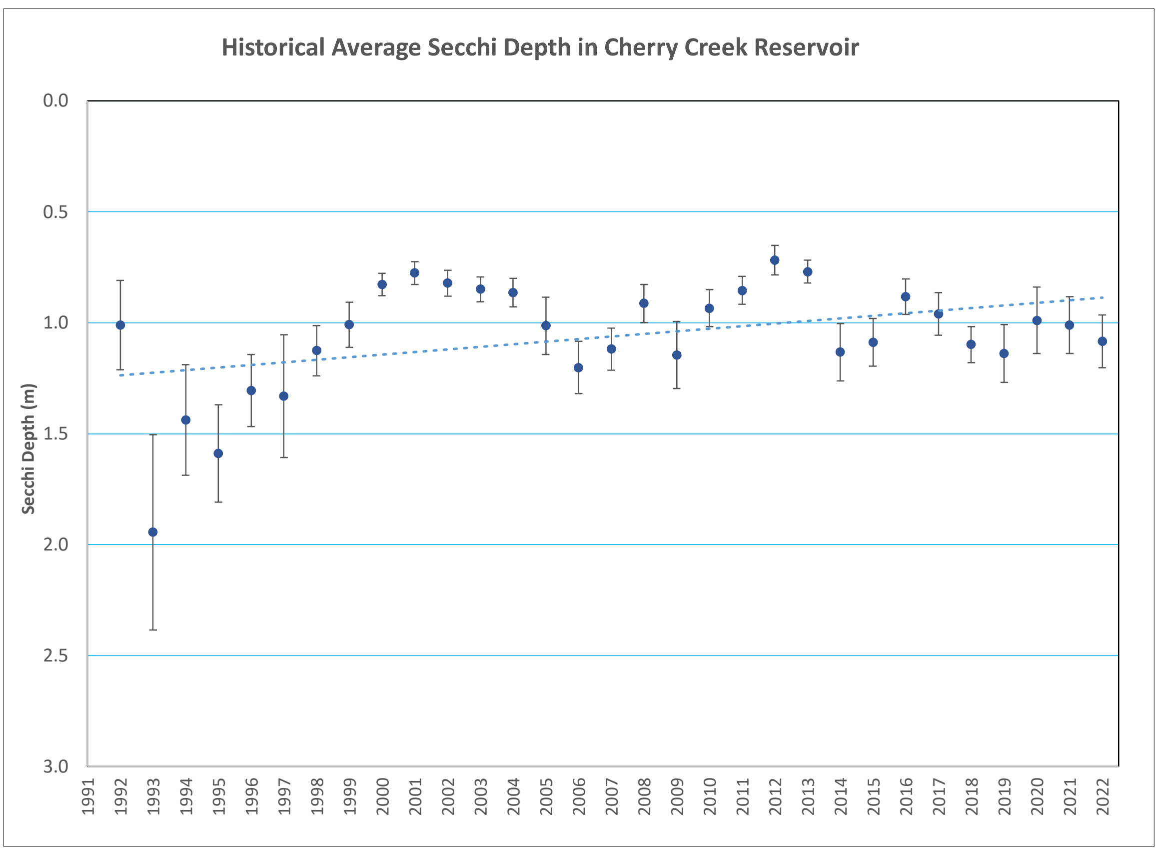


Figure 31. Annual Mean of Secchi Depth in Cherry Creek Reservoir from 1992-2022.

The historical annual mean Secchi depths for Cherry Creek Reservoir are pictured in Figure 31. 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 variability over time does demonstrate a trend of decreasing values, indicating a reduction in water transparency.

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 is considered the depth at which photosynthesis can occur; below that depth, primary productivity would be light limited. The depth of 99% light attenuation ranged from 1.9 to 4.6 m with an annual mean of 2.98 m during WY 2022. Similar to the Secchi depth measurements, the highest measurements were observed in early spring and late summer and the maximum depth was observed in late August following the notable storm event.

There is a clear relationship between Secchi depth and depth of 99% light attenuation (Figure 31). In WY 2022, the depth of 1% light transmittance ranged between 1.4 to 4.7 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 32 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.

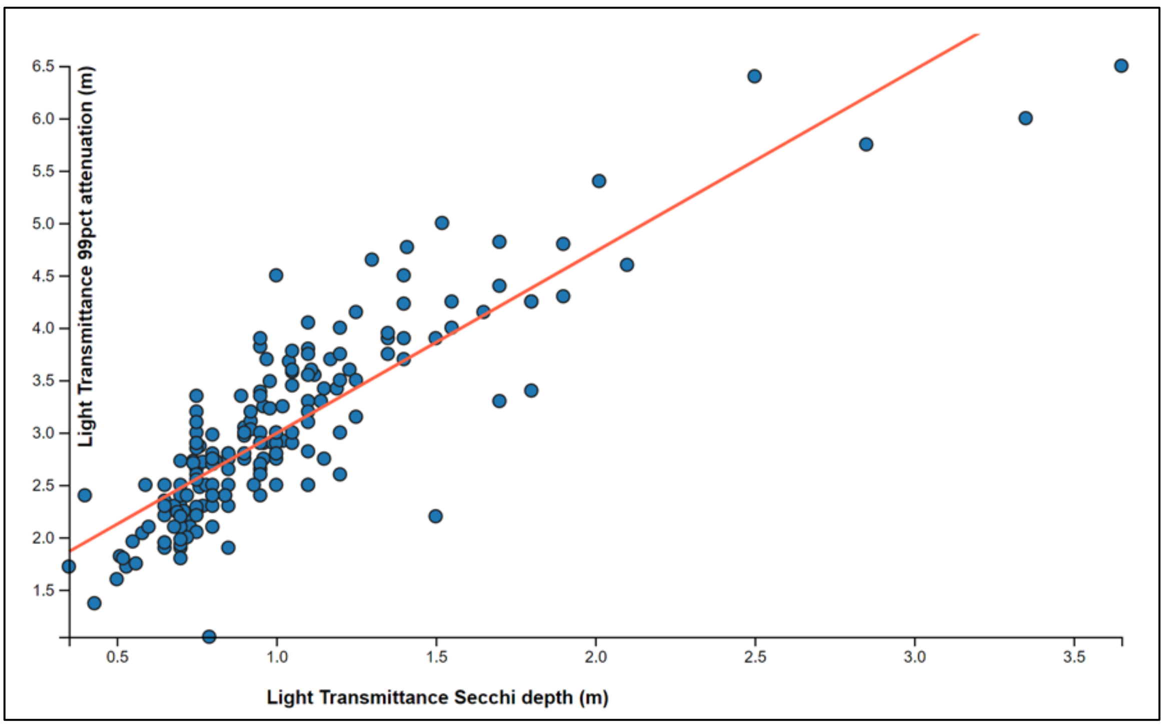


Figure 32. Relationship between Secchi Depth and Depth of 1% Light Transmittance at CCR-2. Cherry Creek Reservoir.

4.3 CHLOROPHYLL α

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 2022 chl α levels were measured from composite samples collected from 0, 1, 2, and 3 meters at all three monitoring sites in the Reservoir.

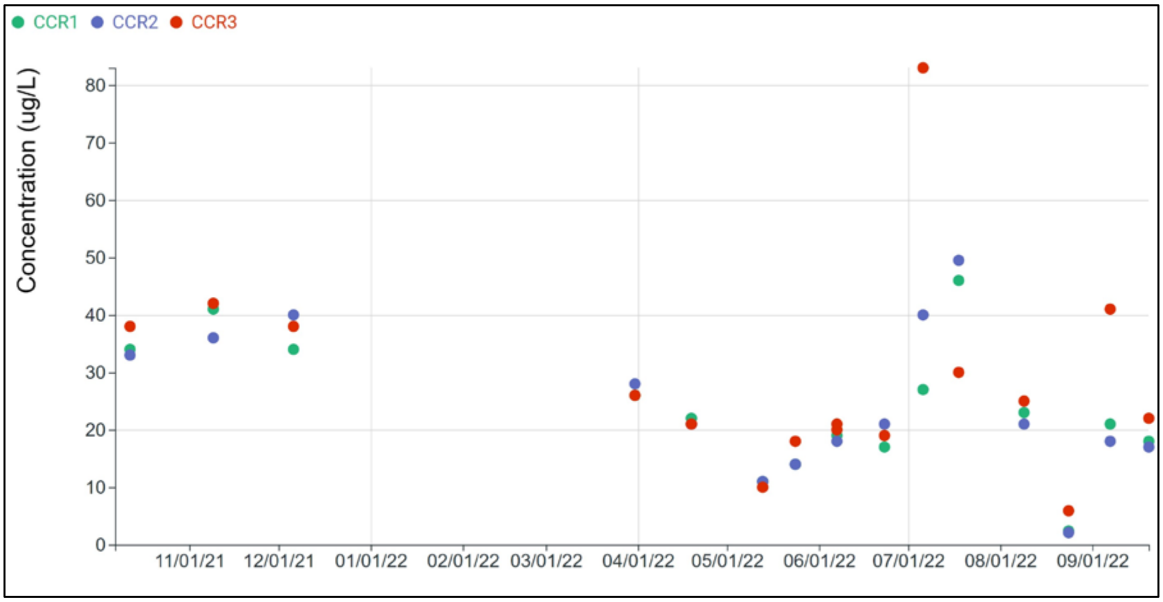


Figure 33. Monthly Chlorophyll *α* (µg/L) Concentrations in Cherry Creek Reservoir during WY 2022.

The chl α concentrations ranged between 2.1 µg/L and 83 µg/L, with an average annual value of 25.9 µg/L in WY 2022 (Figure 33). The highest mean concentrations were collected during the monitoring events in July, and the lowest during the second monitoring event in August. The monthly mean chl α concentrations in Cherry Creek Reservoir during October, November and December 2021 would all indicate severe nuisance conditions at 35, 39.7 and 37 µg/L respectively. However, these months are not normally periods of high recreational use when compared to the summer months.

The highest mean chl α concentrations were present during the two monitoring events in July. Concentrations were 50 µg/L on July 6th and 41.8 µg/L on July 18th when severe nuisance conditions with visible thick scums and accumulated cyanobacterial colonies present in all 3 reservoir monitoring locations.

The seasonal chl α concentration for WY 2022 through the growing season (July through September) concentration was 27.3 µg/L, which was higher than WY 2021 (22.2 µg/L) but lower than 2020 (28.4 µg/L) (Figure 34). Only one of the mean chl α concentrations during the six sampling events during the season (July-September), which was 3.5 µg/L in late August, was below the standard of 18 µg/L.

The seasonal mean chl α concentration for WY 2022 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.

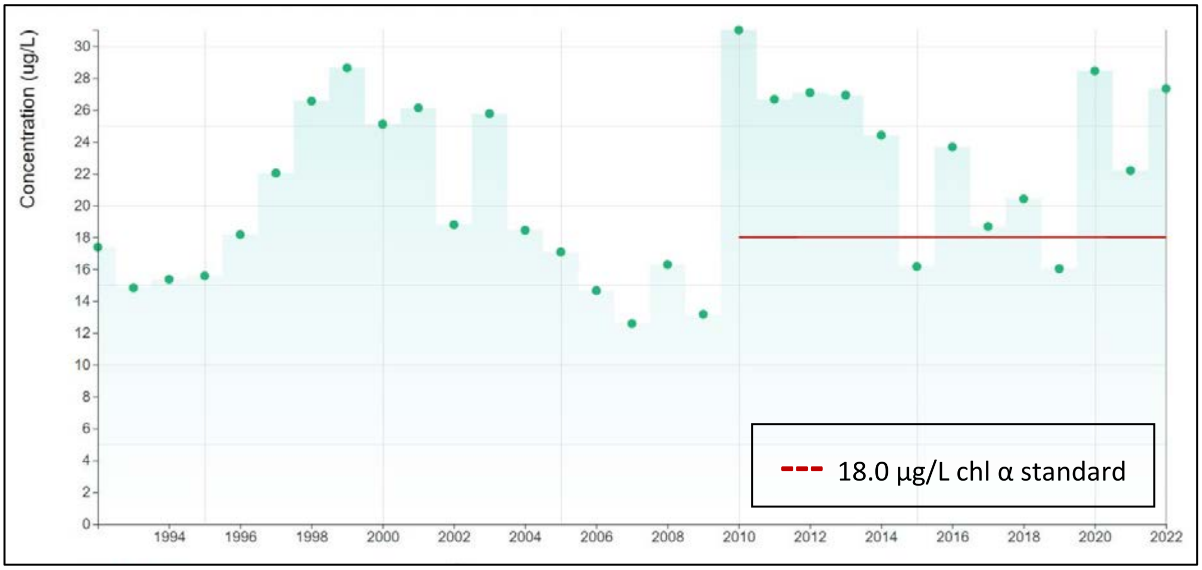


Figure 34. Seasonal Mean Chlorophyll *a* in Cherry Creek Reservoir WY 1991-2022.

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 chl α concentrations in Cherry Creek Reservoir indicate that some algal scums to severe nuisance conditions were present throughout the year, especially during the summer months.

When algal scums are evident, Colorado Parks and Wildlife monitors and tests for potential cyanobacteria toxins at multiple public areas. During the bloom observed from May 23rd through the 31st, samples tested did not detect toxin but “Caution” signage was placed around the Reservoir. During the next bloom, which was observed at multiple public areas from June 24th through 27th, CPW testing resulted in microcystin concentrations above the 10 µg/L recreational threshold so “Warning” signs were posted. Additional samples collected on June 27th were below the cyanotoxin threshold. Samples from the last bloom observed from July 6th through July 12th tested by CPW did not test positive for toxins.

4.4 TEMPERATURE

The Warm Water Aquatic Life classification for Cherry Creek Reservoir in Reg 38 has a standard of Maximum Weekly Average Temperature (MWAT) of 26.2˚C (79.2⁰F) and a Daily Maximum (DM) of 29.3˚C (84.6 ⁰F).

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 profiles from WY 2022 are plotted in Figure 35 and Figure 36, which illustrates the thermal stratification from April 14th through October 22nd, the period of time the thermistors were installed in 2022.

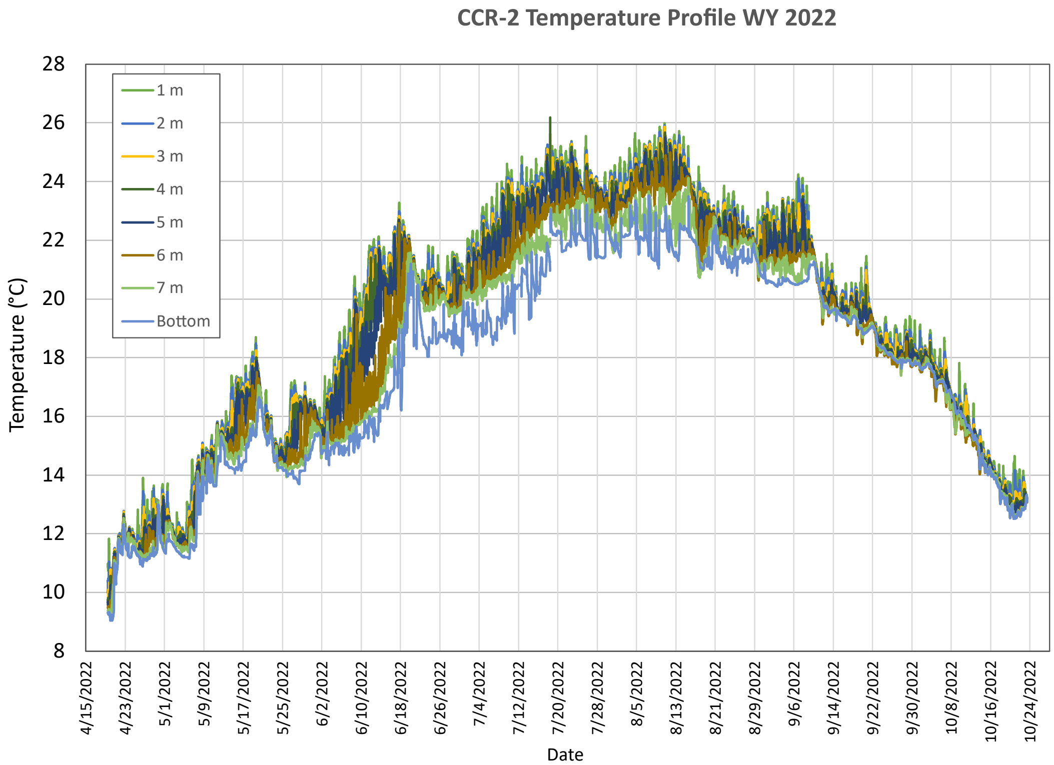


Figure 35. Temperature Depth Profile, Cherry Creek Reservoir, WY 2022.

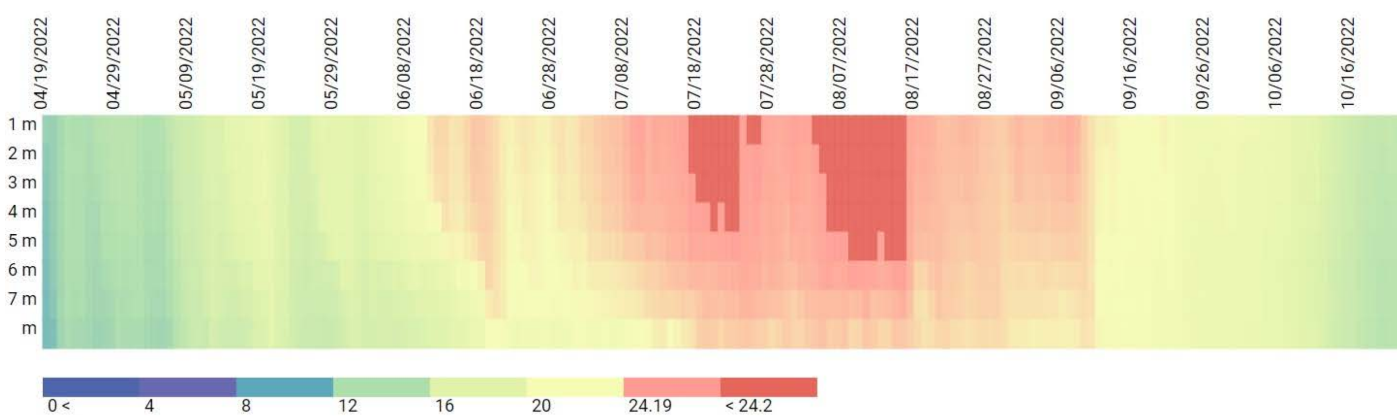


Figure 36. Continuous (15-min) Temperature Heat Profile, Cherry Creek Reservoir, WY 2022.

In addition to the continuous temperature loggers installed at CCR-2, temperature profiles were also collected during each monitoring event. Figure 37 illustrates the temperature profiles collected at Reservoir station CCR-2 during the routine monitoring events in WY 2022.

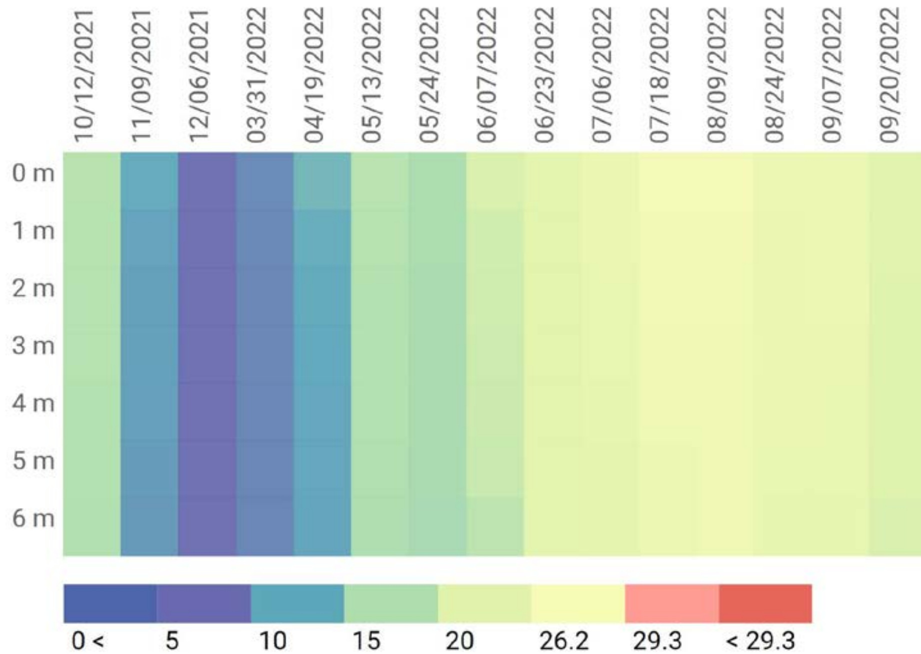


Figure 37. Temperature (˚C) Profile at CCR-2, Cherry Creek Reservoir, WY 2022.

The maximum temperature measured in the surface during the reservoir monitoring events was 25.7˚C (78.3ºF) at CCR-3 July 18, 2022 and on the continuous monitoring thermistors was 26˚C (78.8ºF) on August 10, 2022. Cherry Creek Reservoir did not exceed the MWAT or DM in WY 2022 and therefore attained the temperature standard.

The biggest temperature range measured in the vertical profiles during the monitoring events was 3.2˚C on June 7, 2022 from 19˚C (66.2ºF) to 15.8˚C (60.4ºF) (Figure 37). The largest temperature difference logged by the thermistors was approximately 6.7˚C on June 12, 2022 from top to bottom, but the mean difference for the season (July-Sept) was only 2 ˚C. However, as the season progressed and Reservoir water levels decreased, the thermistors at the bottom of the Reservoir (7 m and 7.5 m/bottom) lowered into the sediment and were not representative of actual water depth. On a few dates, temperatures seen at and near the bottom were affected by water level and were even slightly higher than the thermistor at 7 m.

Although Cherry Creek Reservoir has a destratification system, some of the characteristics of turnover events still occur. Spring turnover appeared to be in mid-May and Fall turnover was in early September. However, it is difficult to determine the main turnover events since the Reservoir appears to be polymictic, or able to mix multiple times a season. There was some variability in temperature from the surface to the bottom which was much more apparent during the warmer summer months of July and August, but during the rest of the year thermal stratification was limited in the Reservoir.

4.5 DISSOLVED OXYGEN

Reg 38 assigns a minimum chronic dissolved oxygen standard of 5.0 mg/L to the Reservoir. The standard requires dissolved oxygen to be at least 5.0 mg/L in the upper portion of a lake or reservoir and that if DO is below 5.0mg/L, adequate refuge for aquatic life (with DO above 5.0mg/L) needs to be available at other depths or locations in the Reservoir at the same time period. Dissolved oxygen concentrations are measured at 1 m depth intervals through the water column during each monitoring event at each site. Cherry Creek Reservoir did not meet the DO standard in WY 2022.

Figure 38 displays the average daily DO concentrations from the continuous loggers installed in CCR. The DO loggers recorded 4 events when the daily DO concentrations at the surface (0.5m) averaged below 5.0 mg/L. These four events were August 15th, August 23rd through 28th, September 10th and again on September 21st for a total of 8 days. The longest low-oxygen event occurred between August 23rd and 28th following the large August 15th storm event that added over 1,000 AF of inflow to the Reservoir. The significant increase in flow likely mixed low DO from the bottom of the Reservoir to the surface and decreased the DO concentrations. In addition, the severe cyanobacteria bloom that was present prior to the storm also died off following the storm. This cyanobacteria die-off could have added an additional dissolved oxygen demand from the decomposition of the dead algae cells.

DO concentrations below 5.0 mg/L at or near the bottom of the reservoir during the warm summer months, are likely due to by high microbial activity or decomposition in the hypolimnion and sediments, which reduces DO concentrations.

Figure 39 illustrates the DO concentrations from the surface (0 m) to the bottom (6 m average values) in the Reservoir at station CCR-2 during the monitoring events during WY 2022. The profiles from the other two sites (CCR-1 and CCR-3) are available on the data portal.

DO concentrations during the monitoring events at CCR-2 were below 5.0 mg/L DO standard at 6 m from June through September, at 5 m and below, and 4 m and below early Sept. During the month of August DO was below 5.0 mg/ L from 3 m and below and August 24th the DO was below 5.0 mg/L at all depths at all sites. The DO concentrations at CCR-1 demonstrated a similar trend to CCR-2 throughout the year, although slightly higher DO concentrations were measured at each depth. DO concentrations were below 5.0 mg/L at variable depths from 4 m to bottom in early August and on August 24th, 2022 DO concentrations were below 5 mg/L at all depths. At site CCR-3, the DO was at or below 5.0 mg/L at depths from 3 m to the bottom from August through September and again on August 24th the DO was below 5.0 mg/L at all depths.

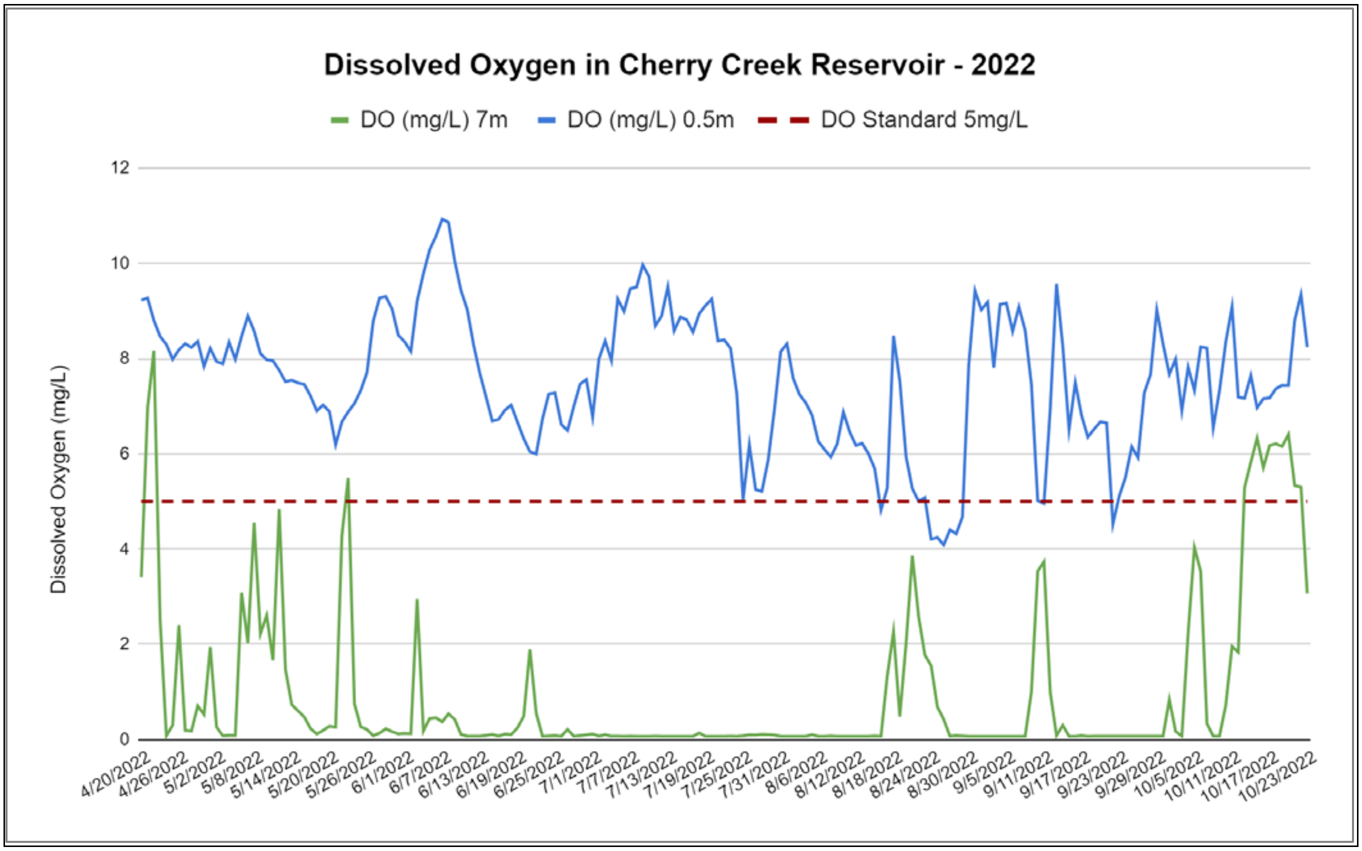


Figure 38. Dissolved Oxygen Daily Averages in Cherry Creek Reservoir, 2022

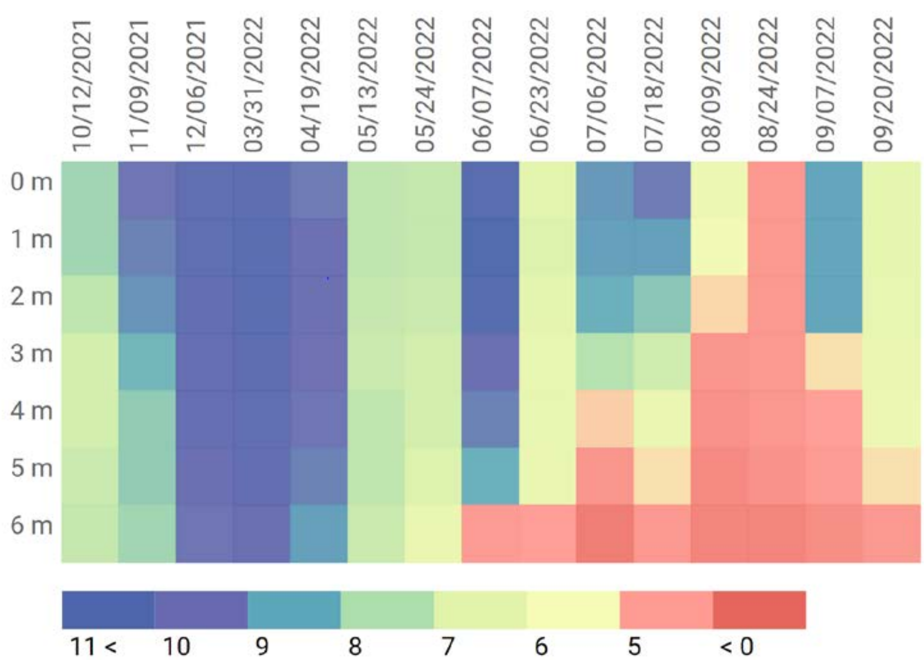


Figure 39. Dissolved Oxygen (mg/L) Profile at CCR-2. Cherry Creek Reservoir, WY 2022.

4.6 pH

Reg 38 assigns a pH standard for Cherry Creek Reservoir based on the acceptable H Range of 6.5 to 9.0 for protection of aquatic life. Assessment of pH data is based on comparison of the 15th percentile of the data to a lower pH limit of 6.5 and comparison of the 85th percentile of the data to an upper pH limit of 9.0. Cherry Creek Reservoir attained the pH standard in WY 2022.

The pH ranged from 7.5 to 8.5 at CCR-1, 7.6 to 8.9 at CCR-2 and 7.8 to 10.2 at CCR-3 with a mean value of 8.3 during WY 2022. On July 7th 2022, the pH at CCR-3 was 10.2 at the surface and 8.6 at the bottom (>4 m) and the mean value was 9.2. On that date the max pH was 8.5 at the surface at CCR-1 and 8.8 at CCR-2. There were no other dates where any values exceeded a pH of 9.0 at any site.

The lowest pH values (7.7-7.9) were recorded from the surface to 6 m on August 24th 2022. Low pH values were also present at the bottom (6 m) or near the bottom (4-5 m) of the Reservoir from July through early September.

Overall, the values from CCR-2 are representative of pH in the Reservoir although some values were slightly lower at CCR-1 on some dates and higher at CCR-3. 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.

Higher pH values are usually correlated with higher productivity and elevated chl α concentrations in the Reservoir. For example, the highest chl α concentration measured in WY 2022 was 83 µg/L on July 6th, which coincided with the pH of 10.2 on the same date. In contrast, the lowest chl α concentrations were seen on August 24th, which was when the lowest pH values were also recorded through the water column.

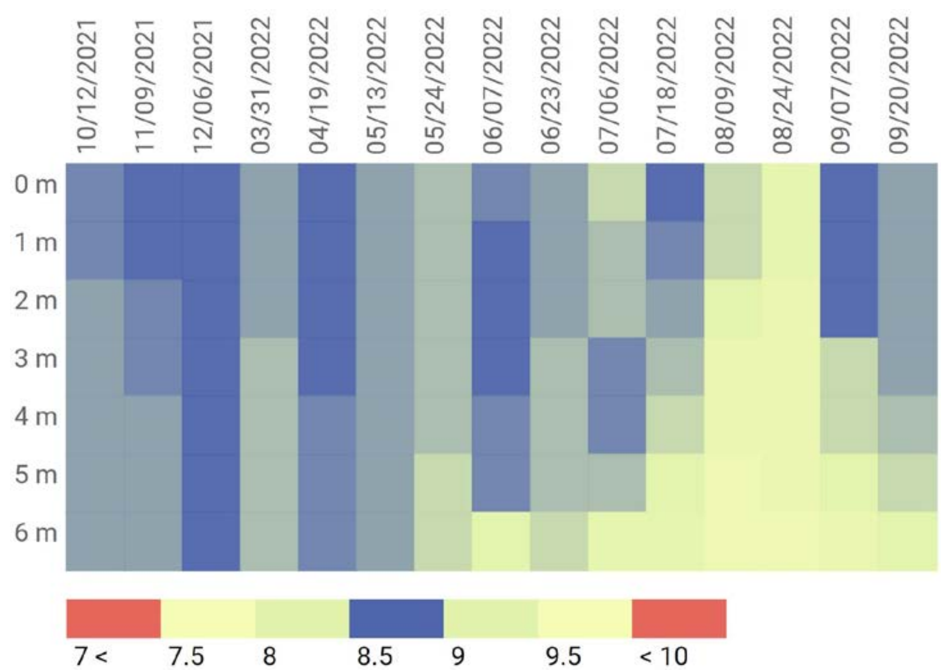


Figure 40. pH Depth Profile from CCR-2, Cherry Creek Reservoir, WY 2022.

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 CCR-2 are displayed in Figure 41. Higher ORP values indicate an oxidative state and increased potential to break down organic material, whereas low and negative values indicate a reducing environment.

During WY 2022, the ORP in the photic zone ranged from 92 mV in early August at CCR-2 to 288 mV in late May at CCR-3. The ORP in the samples near or at the bottom of the Reservoir ranged from -22 mV in the first monitoring event in August to 272 mV during the first monitoring event in June. On June 7th the ORP values increased approximately 11 mV with depth and were the highest values present of the entire year, averaging 251 mV between the 3 sites.

The lowest ORP values throughout the water column were present on August 9th and July 6th at CCR-2, when values ranged from 92-103 mV and 110-138 mV respectively.

Lower ORP values indicate a reducing environment at the bottom of the Reservoir, which usually coincided with lower DO and lower pH measurements. These lower values are an indication of decomposition processes in the sediments and the sediment-water interface, as well as seasonal trends normally seen in the Reservoir. Higher ORP values, indicating an oxidative environment, were present during periods with higher DO levels and colder water temperatures.

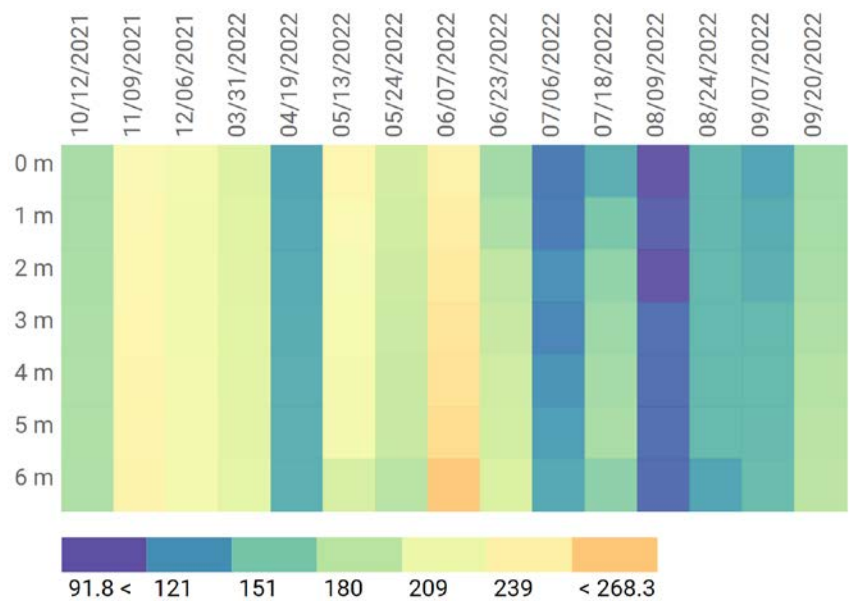


Figure 41. Oxidation Reduction Potential (mV) Depth Profile at CCR-2, Cherry Creek Reservoir, WY 2022.

4.8 CONDUCTIVITY

The specific conductance, or conductivity, is a representation of dissolved solids (e.g., salts, minerals) in Cherry Creek Reservoir. During WY 2022, the specific conductance, ranged from a minimum of 1,264 µS/cm to 1,372 µS/cm. Limited variability in conductivity was observed from the top to bottom of the Reservoir (<7 µS/cm) and between the three monitoring sites. CCR-2 corresponded to values observed throughout the Reservoir, with surface specific conductance concentrations ranging from 1,270 µS/cm on August 24th to 1,372 µS/cm on May 13th (Figure 42). The specific conductivity was the highest May, decreased slightly in early June, and remained between 1,335-1,362 µS/cm from June 23rd through August 9th. Historically, increasing trends in conductivity are observed over the summer months. Overall, the highest conductivity in the Reservoir was slightly lower than WY 2021 and WY 2020 but is higher than historical values since monitoring of this parameter started in 1999.

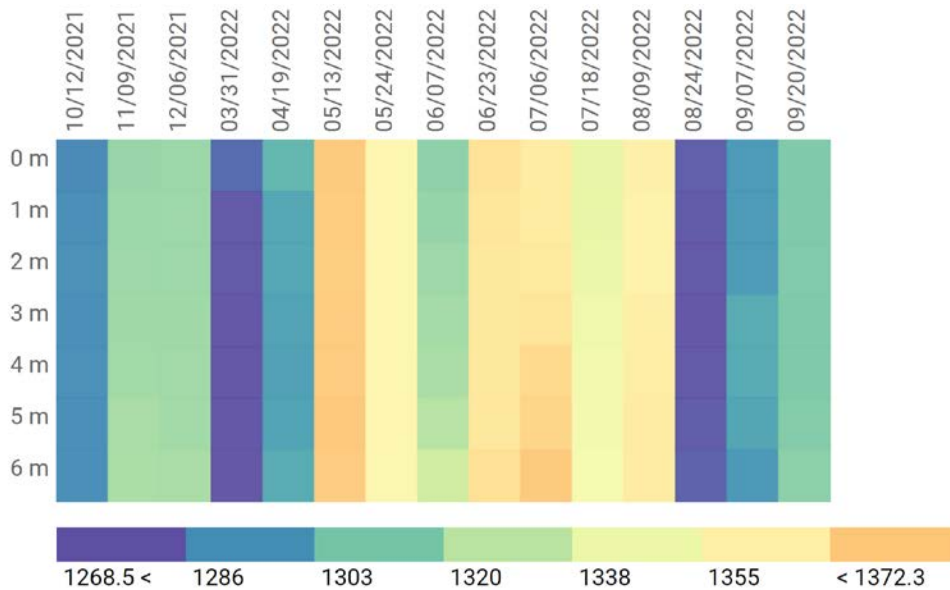


Figure 42. Conductivity (Specific Conductance µS/cm) Depth Profile at CCR-2, Cherry Creek Reservoir, WY 2022.

4.9 TOTAL PHOSPHORUS

Total phosphorus (TP) 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.

TP sampling is conducted 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 2022 seasonal mean of 66.2 µg/L is lower than the WY 2021 seasonal mean of 76.7 µg/L and was much lower than the previous few years, WY 2020 (128.2 µg/L), WY 2019 (107.2 µg/L), and WY 2018 (91.2 µg/L). The WY 2022 seasonal TP mean is also lower than the long-term average of 93.9 µg/L measured from 1992-present.

Although there are no currently applicable 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. The WQCD is proposing new nutrient criteria standards for high priority lakes in 2023 which will likely be more stringent that the interim criteria. Figure 43 displays the historical seasonal phosphorus concentrations in Cherry Creek Reservoir with the interim phosphorus criterion of 83 µg/L represented by the orange line. The historical analysis indicates that seasonal TP concentrations in Cherry Creek Reservoir were below 83 µg/L 10 of 11 years prior to 2002 but has exceeded 83 µg/L every year since 2003, with the exception of 2021 and 2022.

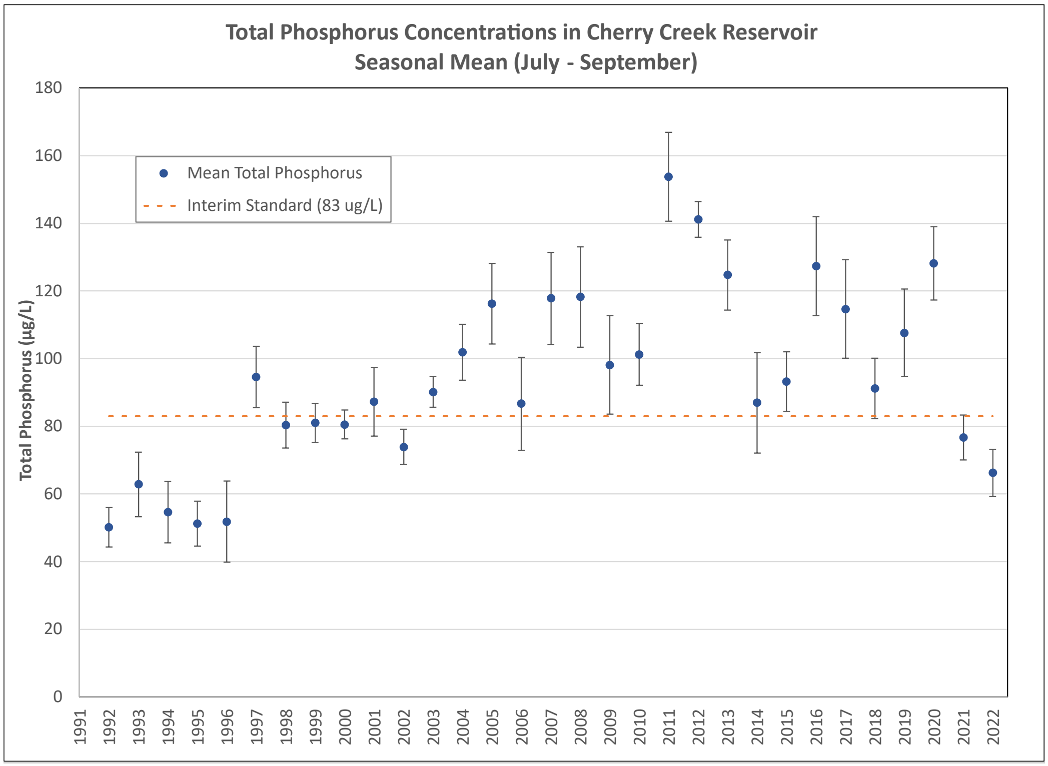


Figure 43. Seasonal Mean TP Concentrations in Photic Zone, Cherry Creek Reservoir, 1992-2022.

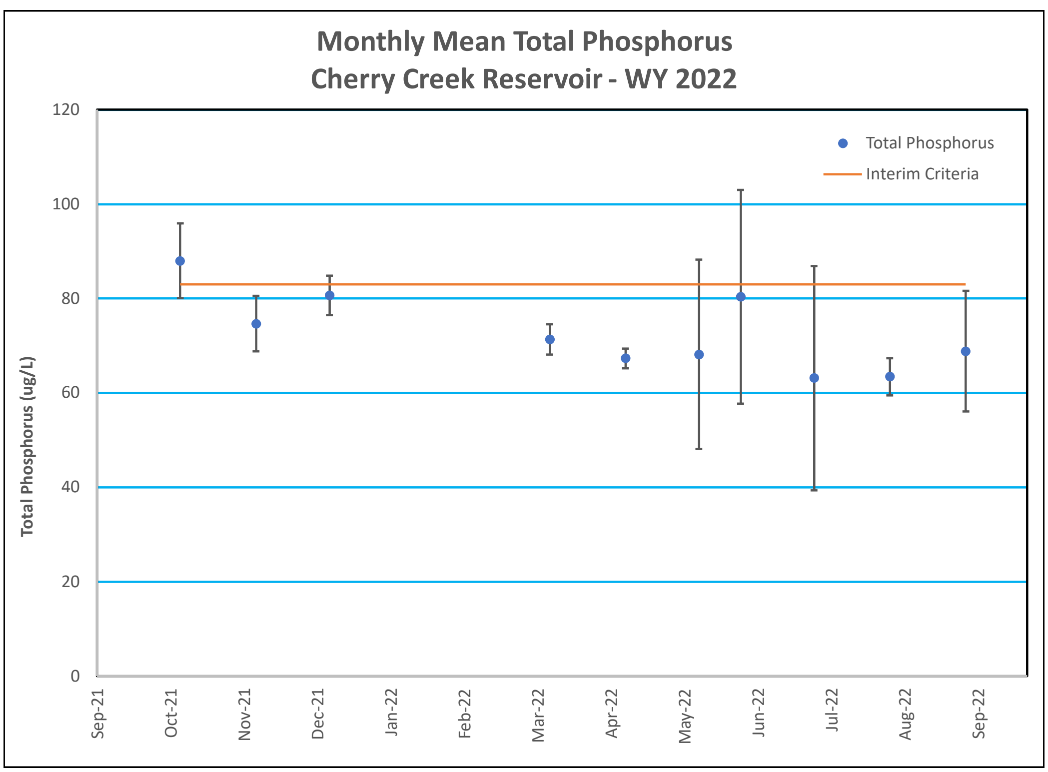


Figure 44. Monthly Total Phosphorus (Photic Zone), Cherry Creek Reservoir, WY 2022.

During WY 2022, the monthly mean TP concentrations ranged between 63 µg/L and 88 µg/L, with a mean value of 73 µg/L (Figure 44). The lowest monthly mean TP concentrations were observed in July and August and the highest in October 2021. With the exception of October, all monthly mean TP concentrations were below the interim criteria of 87 µg/L. The WY 2022 data suggests that the elevated TP concentrations in the Reservoir throughout the year are contributing to eutrophic conditions.

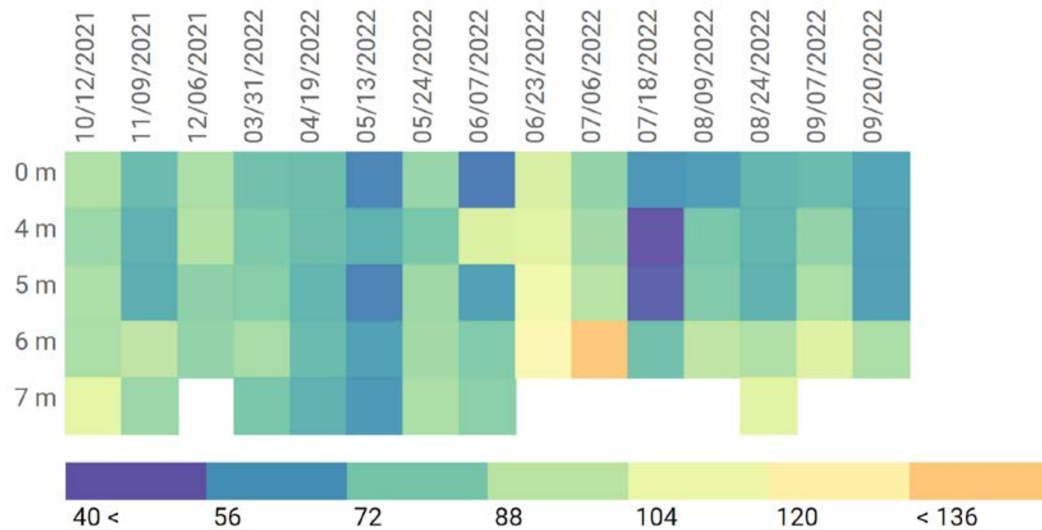


Figure 45. Total Phosphorus Profile at CCR-2, Cherry Creek Reservoir, WY 2022.

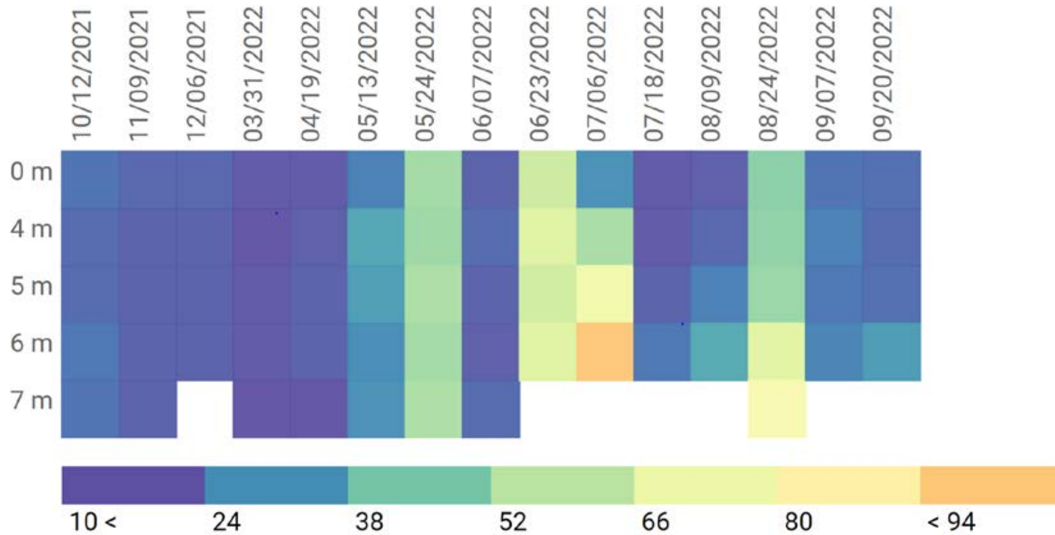
Figure 45 displays the TP concentrations depth variability through WY 2022 in Cherry Creek Reservoir. In addition to the photic zone (which is represented by a composite sample of 0, 1, 2, and 3 m depths), samples in 1 m increments from 4-7 m are collected at the CCR-2 monitoring site. The highest concentration in the photic zone (0-3 m) was 96 µg/L on June 23, 2022.

The samples from below the photic zone had TP concentrations that generally increased with depth and were highest in the samples representing the bottom, from late May through September. TP concentrations at station CCR-2 ranged from 50 µg/L to 96 µg/L in the photic zone, with the highest concentration of 136 µg/L observed at 6 m on June 23rd. The TP depth profiles at Reservoir monitoring station CCR-2, and the concentrations from the photic zone composite at CCR-1 and CCR-3, available on the data portal, show similar results.

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 have a higher density than warmer surface waters and sink 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 and decomposition or internal loading.

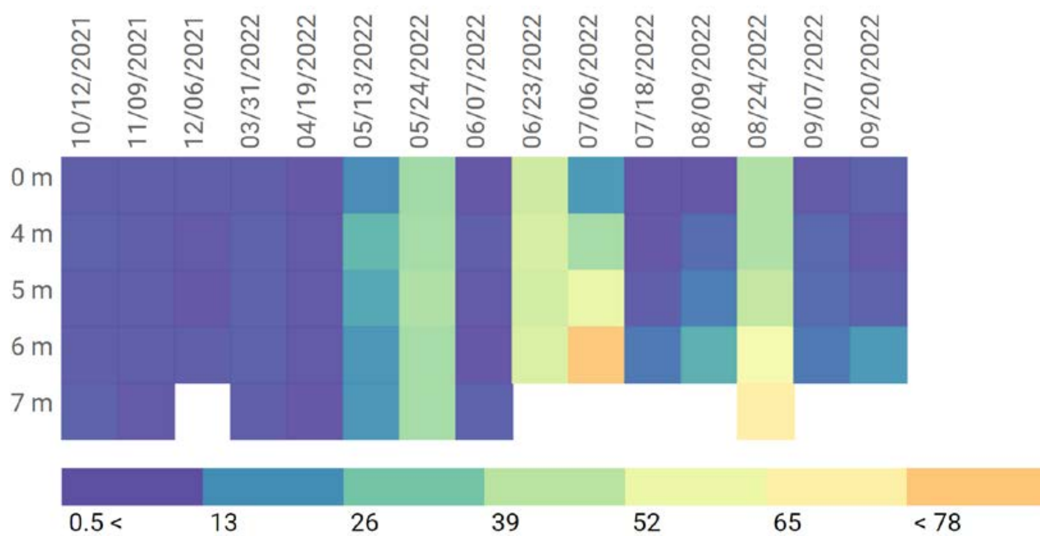
4.10 DISSOLVED AND SOLUBLE REACTIVE PHOSPHORUS

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 2022.



Total Dissolved Phosphorus (µg/L)

Figure 46. Total Dissolved Phosphorus Profile at CCR-2, Cherry Creek Reservoir, WY 2022.



Soluble Reactive Phosphorus (µg/L)

Figure 47. Soluble Reactive Phosphorus Profile at CCR-2, Cherry Creek Reservoir, WY 2022.

During WY 2022, both TDP and SRP remained relatively constant through late fall and winter 2021, but levels throughout the water column but show much more variability as the temperatures warm and the season progresses (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. TDP and SRP concentrations were highest in the photic zone on June 26th, 56 µg/L and 43 µg/L respectively, and highest at 6 m on July 6th, 94 µg/L and 78 µg/L respectively. There was an association of lower levels of TDP and SRP during events when DO levels were low and pH was elevated. The concentrations were more consistent at all depths in the water column through late June when concentrations started to increase with depth. As the season progressed, primary productivity in the photic zone was utilizing the available forms of phosphorus as they were released and mixed through the water column.

4.11 TOTAL NITROGEN

The seasonal mean (July thorough Sept) of Total Nitrogen (TN) in the Reservoir in WY 2022 of 984 µg/L is higher than WY 2021 (860 µg/L), WY 2019 (689 µg/L), and WY 2018 (848 µg/L) but lower than WY 2020 (990 µg/L). The WY 2022 seasonal mean is also higher than the long-term average of 896 µg/L calculated from 1992-present. As illustrated by Figure 48, the seasonal mean values for TN are variable but similar to the range of most historical values.

Although there is currently no 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 interim 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 current warm water total nitrogen criterion for large reservoirs is 910 µg/L TN as a summer (July 1-September 30) average in the mixed layer (median of multiple depths), with an allowable exceedance frequency of one-in-five years. The WQCD is proposing new nutrient criteria standards for high priority lakes in 2023 which will likely be more stringent that the interim criteria and will likely include nitrogen in addition to phosphorus. Figure 48 indicates that TN concentrations in Cherry Creek Reservoir have exceeded this concentration more than 50% of the time dating back to 1994 with the large reservoir nitrogen criterion of 910 µg/L represented by the orange line.

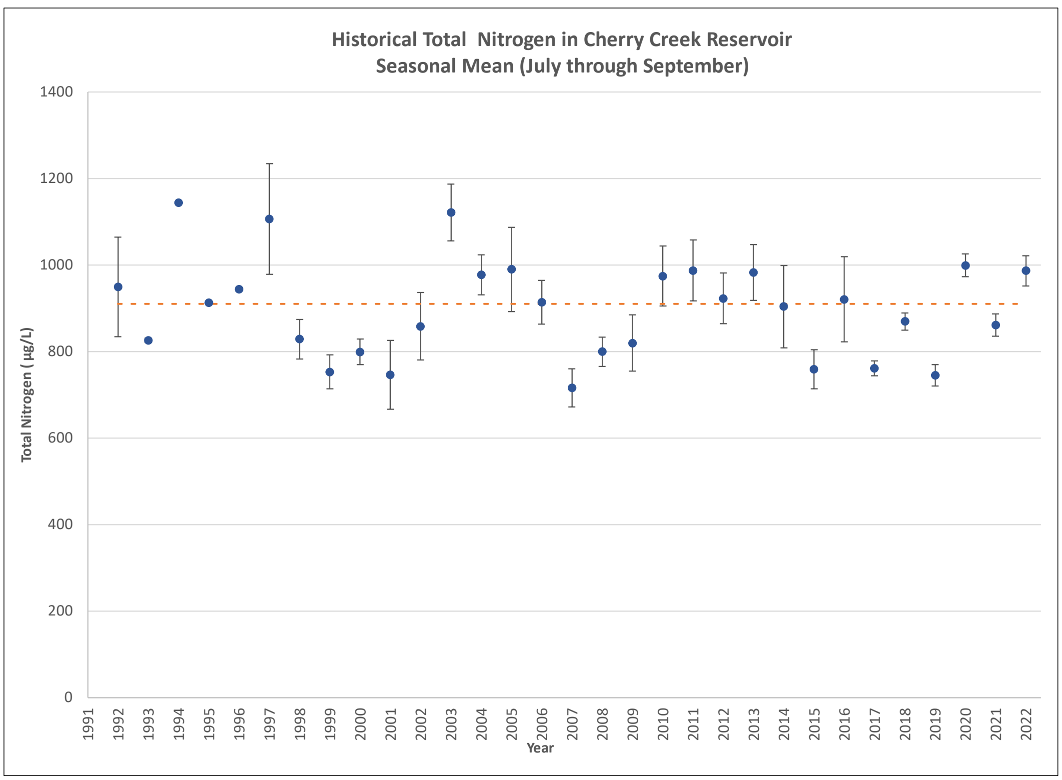


Figure 48. Seasonal Mean TN Concentrations in Photic Zone of Cherry Creek Reservoir 1992-2022.

During WY 2022, monthly TN concentrations from the photic zone in Cherry Creek Reservoir ranged between 589 µg/L and 1,204 µg/L with a mean value of 959 µg/L (Figure 49). The highest TN concentrations were present in July, slightly lower in November at 1,187 µg/L, followed by March and April which were 1,057 µg/L and 1,036 µg/L, respectively (Figure 50).

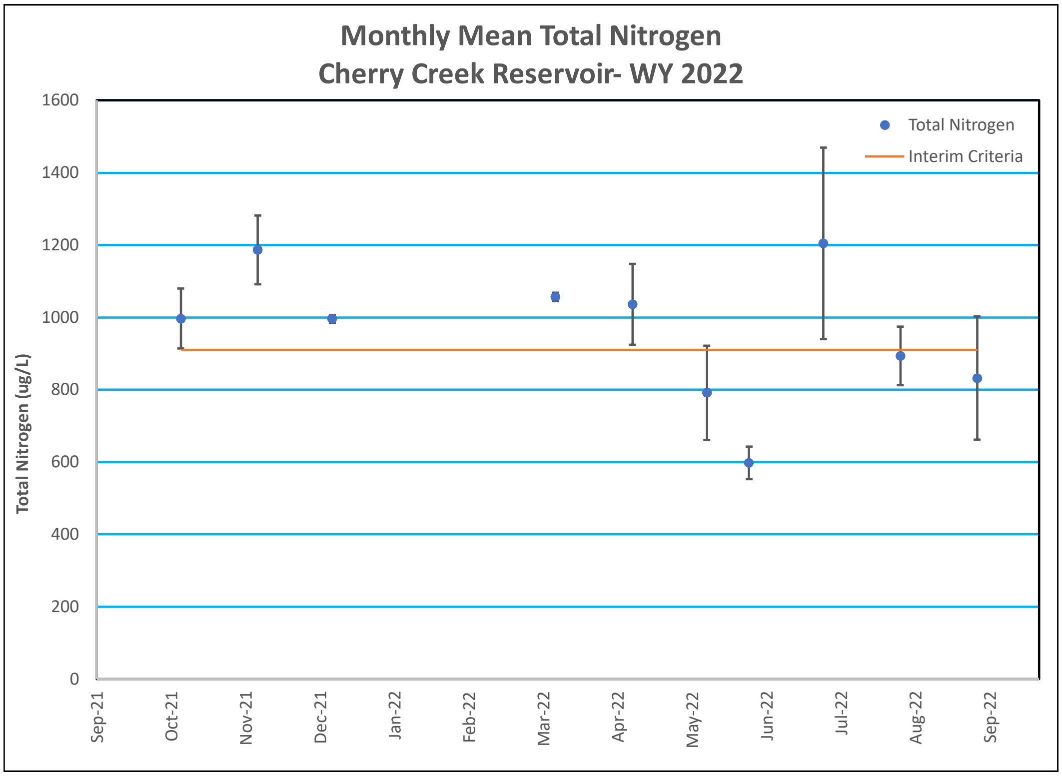


Figure 49. Monthly Total Nitrogen Concentrations in Photic Zone, Cherry Creek Reservoir, WY 2022.

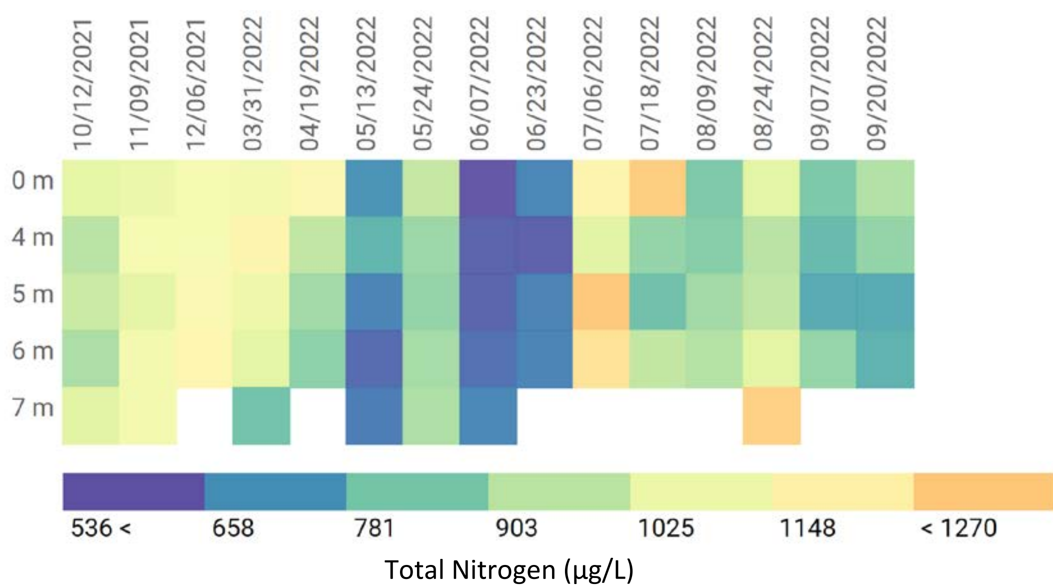


Figure 50. Total Nitrogen Depth Profile at CCR-2, Cherry Creek Reservoir, WY 2022.

When evaluating TN with depth from the samples collected at CCR-2 during WY 2022, the low concentrations observed on May 13th, June 7th and June 23rd were relatively consistent throughout the water column. In addition, both July monitoring events had the highest TN concentrations of the season at the surface on July 18th (1,260 µg) and at 5 m on July 6th (1,270 µg). The August 24th sample at 7 m was near the highest concentrations observed at 1,250 µg/L, which corresponded to the low chl α and could be the result algae dying off and settling to the bottom of the Reservoir. The data from the other 2 monitoring sites from the photic zone are available on the data portal.

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 but were very low and often below the detection limit during WY 2022. 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 2022. The highest concentrations among the 3 sites were seen on May 24th (35 µg/L in the Photic zone and 45 µg/L at 5 and 6 m), and June 23rd, 2022 (26 µg/L). All other mean concentrations were at or below 25 µg/L. On 8 of the 15 monitoring events in WY 2022, and 4 of the 6 during the July- Sept season, NO_3+NO_2-N concentrations were below the detection limit of 5 µg/L in the photic zone (0-3 m) at CCR-2. When NO_3+NO_2-N concentrations are low, it is one indicator that algal growth in the Reservoir is limited by nitrogen concentrations.

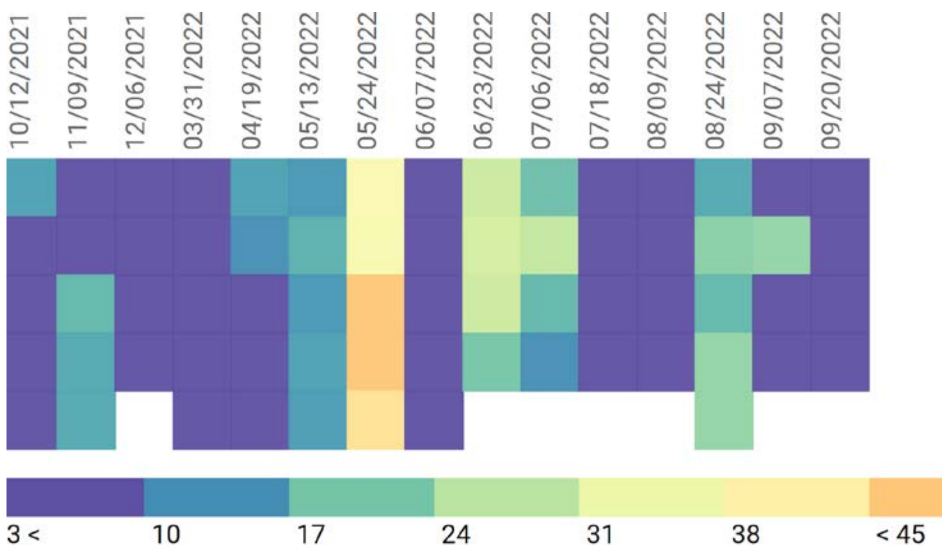


Figure 51. Nitrate/Nitrite Depth Profile at CCR-2, Cherry Creek Reservoir, WY 2022.

Ammonia concentrations (shown as NH_3-N in Figure 52) were elevated at depth from late June through August, but lower in surface water on most dates. This is an indication of a highly productive reservoir. Ammonia, like nitrate, is a readily available form of nitrogen for algal growth.

On 10 of the 15 monitoring events in WY 2022, and 5 of the 6 during the July- Sept season NH_3-N, concentrations were below the detection limit of 5 µg/L in the photic zone (0-3 m) at CCR-2. The increases in ammonia concentrations in the deeper layers also correlated to the periods of lower oxygen at the bottom of the Reservoir. NH_3-N was highest throughout the water column on August 24th, when concentrations were 148 µg/L in the photic zone and 219 µg/L at 7 m. These elevated ammonia values also corresponded to the date of the lowest chl α concentrations. These concentrations are likely due to the release of ammonia from phytoplankton as the bloom that was present and died off. Ammonia was also elevated in the photic zone in October 2021 at 144 µg/L.

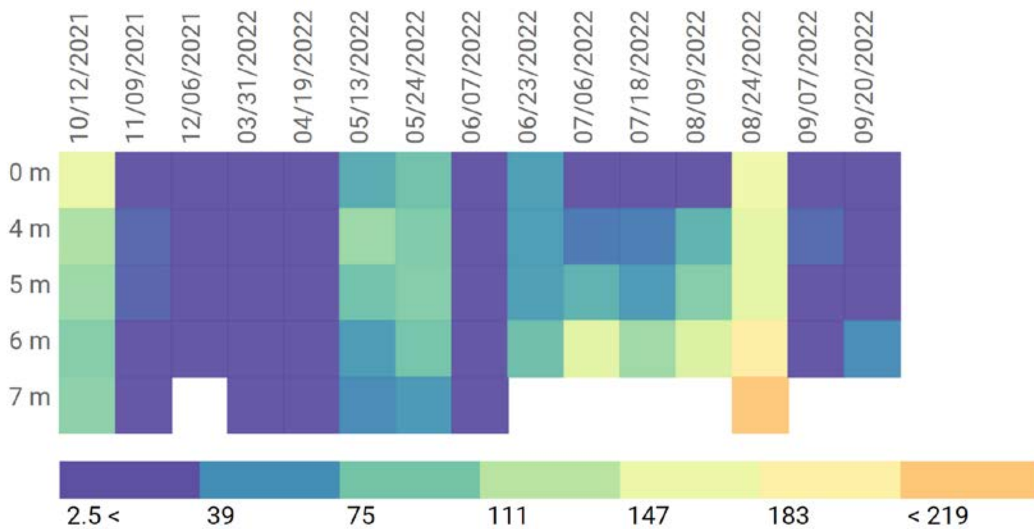


Figure 52. Ammonia Depth Profile at CCR-2, Cherry Creek Reservoir, WY 2022.

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 was not calculated until TDN was analyzed from late June through the rest of the year. TN was nearing limitation throughout most of WY 2022 with a mean value of 11.9 and a seasonal mean of 12.9.

Based on the nutrient ratios at site CCR-2 during WY 2022, it appears that the bioavailable forms of nitrogen (TIN) were limited with the exception of 4 dates from April through September and 2 dates during the dates the seasonal average is calculated (July through September). The mean TIN:SRP ratio was 9.4 for WY 2022 and had a seasonal mean of 8.2 from July through September. Although there was some variability, the concentrations of chl α had relatively higher values following limitation of one or more forms of nitrogen. (See Phytoplankton Section 4.15).

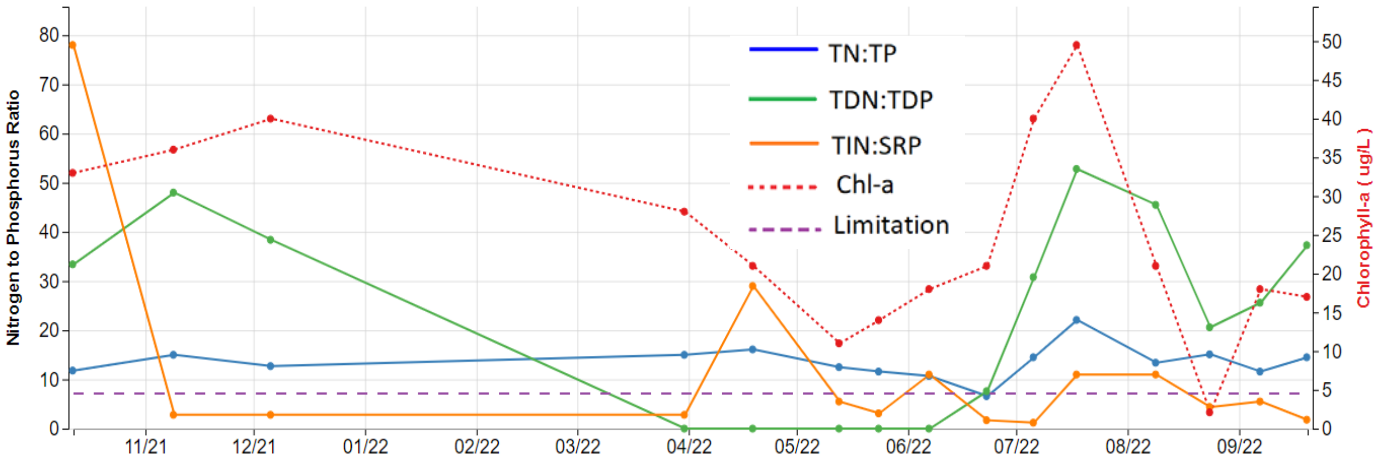


Figure 53. Nutrient Ratios for and Chlorophyll *a* in Cherry Creek Reservoir in WY 2022.

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 expressed as three separate indices based on observations of TP concentrations, chl α concentrations, and Secchi depths from a variety of lakes. TP 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. The three are related in many lakes because transparency is often limited by algal growth and algal growth can be limited by phosphorus 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 TSI 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 2022 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 WY 2022, concentrations in Cherry Creek Reservoir averaged 68.2 µg/L for TP, 22.8 µg/L for chl α, and 1.12 m for the Secchi depth. Based on these values, calculated trophic state indices were 65 for TP, 61 for chl α, and 58 for Secchi depth. All three TSI indices signify that Cherry Creek Reservoir was eutrophic in WY 2022.

Table 22. Trophic State Indices for Cherry Creek Reservoir WY 2018-2022.

Year	Trophic State Index (TSI)		
	Total P	Secchi Depth	Chlorophyll *a*
2018	69	58	59
2019	71	57	57
2020	72	59	61
2021	67	56	60
2022	65	58	61
Trophic State	**Eutrophic**	**Eutrophic**	**Eutrophic**

Figure 54 displays the historical TSI for Cherry Creek Reservoir for each of the parameters for the May-September averages for total phosphorus, Secchi depth, and chl α from 2002 to 2022. Based on this index, Cherry Creek Reservoir is considered Eutrophic for Secchi depth and chl α, and ranges between Eutrophic and Hypereutrophic based on total phosphorus concentrations. Although the TSI has shown variability over time, the TSI for TP in WY 2022 was lower than the previous 4 years. The WY 2022 TSI for chl-α is the same as WY 2020 and slightly higher than WY 2018, 2019, and 2021.

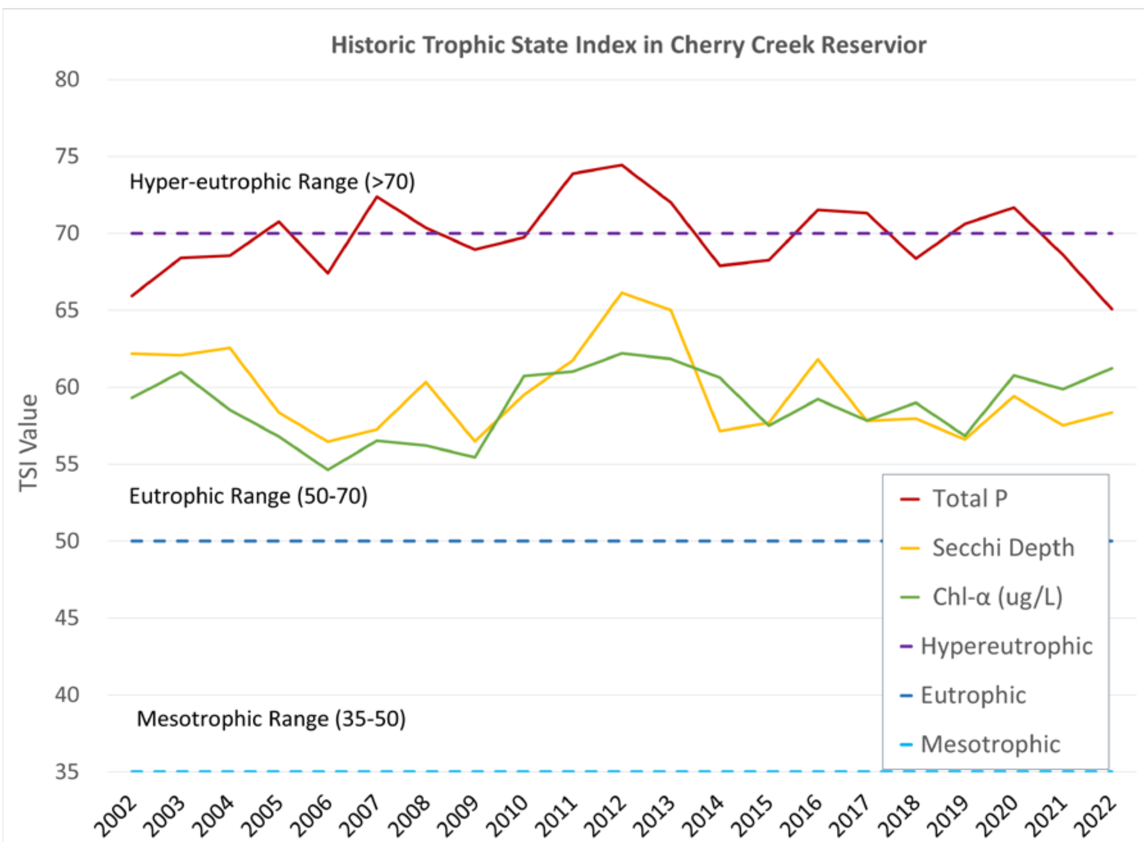


Figure 54. Trophic State Index for Cherry Creek Reservoir (2002-2022).

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 2022 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 2022.

Trophic State	Characteristic			
	Total P (mg/L)	Chlorophyll *a* (µg/L)	Secchi Depth (m)	Relative Productivity
Oligotrophic	< 0.005	< 2.0	> 8	Low
Mesotrophic	0.005 -0.030	2.0 - 6.0	4 – 8	Moderate
Eutrophic	**0.030 - 0.100**	**6.0 - 40.0**	2 – 4	High
Hypereutrophic	> 0.100	> 40.0	**< 2**	Excessive
Cherry Creek Reservoir	**0.068**	**22.8**	**1.12**	**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 value for Secchi depth is in the hypereutrophic range according to the EPA criteria during WY 2022. 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 a more important factor in determining water clarity for many reservoirs, where Secchi depth does not always provide a good indication of trophic state since these measurements cannot distinguish between algal productivity and inorganic suspended sediment. Inorganic turbidity plays a role in water transparency and associated Secchi depths in Cherry Creek Reservoir as well.

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 2022. 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 2022 indicate high productivity with diverse populations.

Phytoplankton populations in Cherry Creek Reservoir had an average of 33 species present on each sampling date, which is slightly less than the average of approximately 40 species on each date for each of the last three years. The minimum number of species present was 14 on July 6, 2022, and the maximum number was 53 on November 9, 2021. Both the minimum and maximum number of species present in WY 2022 were lower than corresponding values for water years 2019 through 2021. Higher numbers of species were present when water temperatures were lower in the spring and fall, while the number of species present decreased during the summer months when water temperatures were warmer.

Chlorophytes (green algae) had the highest number of different species on all sampling dates except for the two July sampling dates, peaking at 26 different species on November 9, 2021, and averaging approximately 15 species present for the entire year. Both chlorophytes and cyanophytes (blue-green algae) were represented by 5 species on July 6, when only 14 algal species were present, and cyanophytes had twice as many species (8) as chlorophytes (4) on July 18. Those were the two dates with the lowest number of species present during the year. Cyanophytes were the only other group to have at least 10 species present on a single sampling date and averaged 7.3 species per date. Bacillariophytes (diatoms), cryptophytes (cryptomonds), and chrysophytes (golden-brown algae) were the only other groups of algae that were present on each sampling date, with averages of 4.7, 2.3, and 1.5 species per sampling event, respectively.

Less common groups observed on at least half of the sampling dates included the pyrrhophytes (dinoflagellates), with 1-3 species present on 9 different dates and the haptophyte (golden alga), *Chrysochromulina parva*, the only golden algal species present in WY 2022, which was present on 8 different dates. The remaining groups, euglenophytes (6 dates, 1-2 species) and miscellaneous microflagellates (2 dates, unknown species) were much less common.

Cyanophytes are probably responsible for most 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 that can produce toxins have been observed in Cherry Creek Reservoir. Those observed during WY 2022 include *Aphanizomenon flos-aquae* (June and July 2022), *Dolichospermum* sp. (May through July 2022), *Microcystis aeruginosa* (June and July 2022), and *Pseudoanabaena limnetica* (October through December 2021, and April and September 2022). These potentially toxin-producing species were present at higher concentrations and biovolumes during WY 2022 than in previous years. The Reservoir was closed to contact by Colorado Parks and Wildlife (CPW) during the bloom in late June due to cyanotoxin detection above the recreational threshold. Although the bloom in July appeared to be more severed and resulted in higher chl α, toxins were not detected.

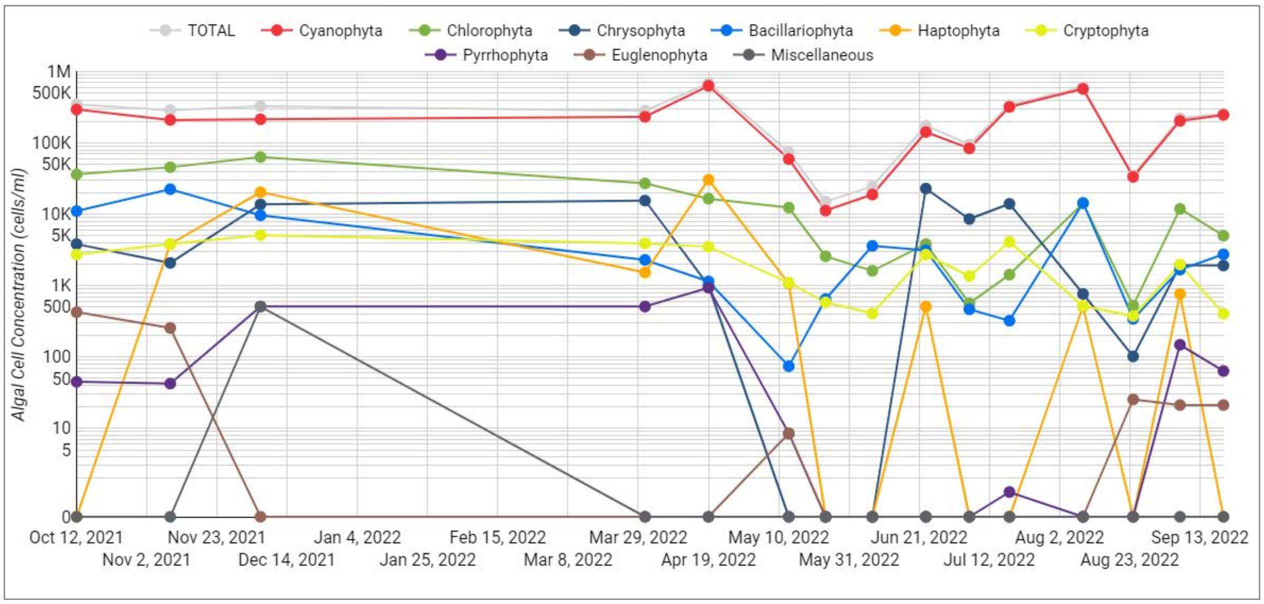


Figure 55. Phytoplankton Concentrations in Cherry Creek Reservoir, WY 2022.

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 218,530 cells/mL during WY 2022, with a minimum observed cyanophyte cell count of 11,274 cells/mL on May 24, 2022, and a maximum of 632,247 cells/mL on April 19, 2022. There were only three sampling dates during WY 2022 with cyanophyte concentrations less than 100,000 cells/mL. Relative cyanophyte cell counts ranged from 65-96% of the total phytoplankton population and averaged 87% of the total algal cell counts for all of WY 2022 (Figure 56 A), which was similar to the previous two years.

The most common cyanophytes were the small (<1 µm) species *Chroococcaceae* spp., present on all sampling dates, and *Synechococcus* sp. 1, present on all dates except May 24, 2022. *Chroococcaceae* spp. concentrations peaked at 362,287 cells/mL on August 9, 2022, and their concentrations averaged 106,786 cells/mL for all of WY 2022. *Synechococcus* sp. 1 peaked at 91, 847 cells/mL on April 19, 2022, and averaged 35,500 cells/mL for all of WY 2022. These two species combined for 64% of all cyanobacteria counts and over 55% of the total algal cell counts for WY 2022.

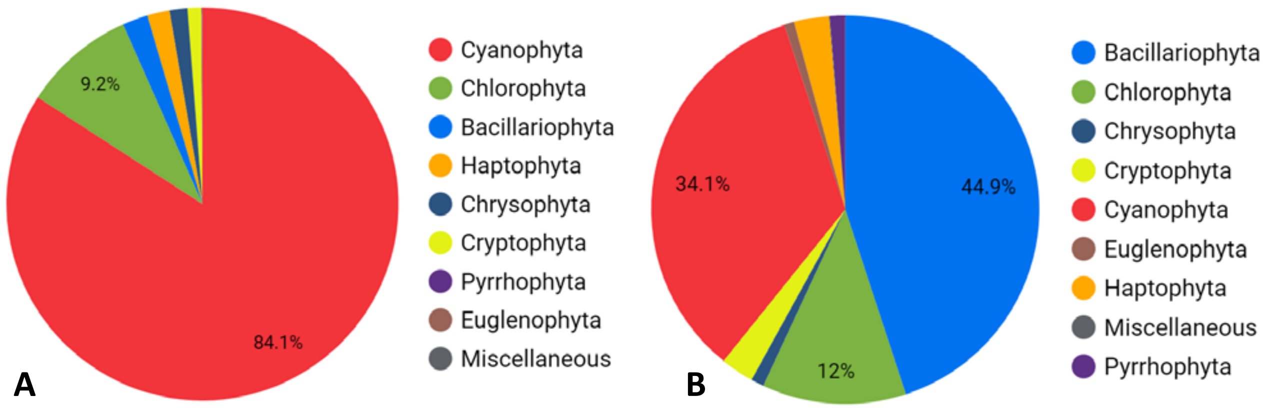


Figure 56. Relative Phytoplankton Concentration (A) and Biovolume (B), WY 2022.

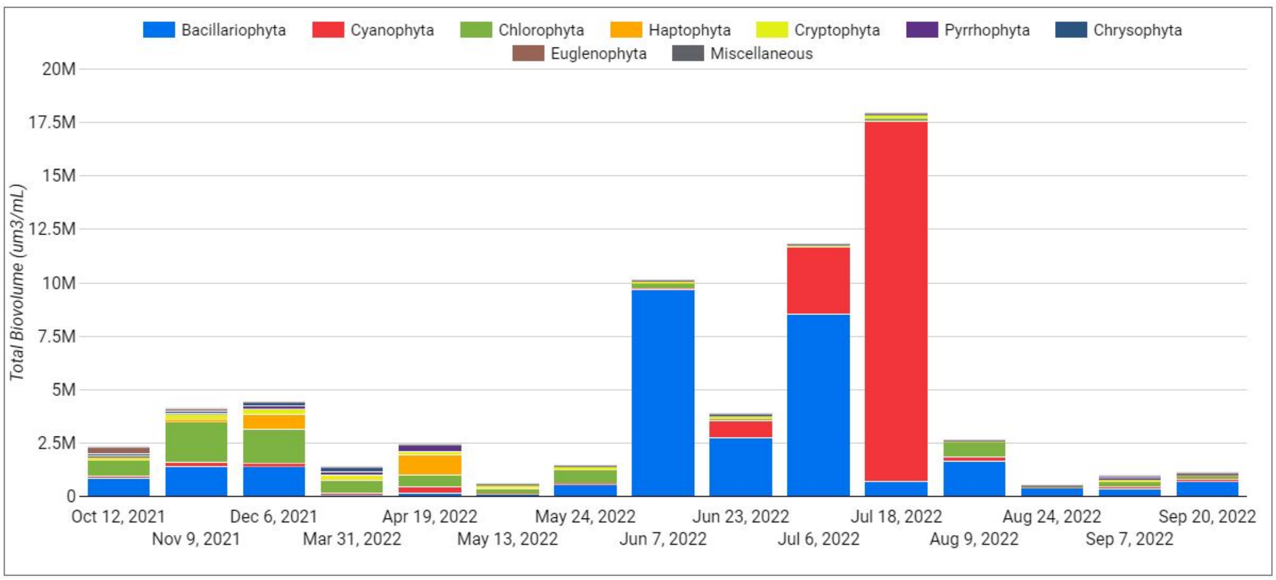


Figure 57. Phytoplankton Biovolumes in Cherry Creek Reservoir in WY 2022.

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 57).

The impact of *Chroococcaceae* spp. and *Synechococcus* sp. 1 was even less significant than other cyanophytes due to their small size. In contrast to their large contributions to total algal cell counts in WY 2022, these two species were responsible for only about 1% of the cyanophyte biovolume and less than 0.4% of the total algal biovolume for WY 2022. In contrast to their significant contributions to total cell counts, cyanophytes comprised 34% of the total algal biovolume in WY 2022. The total cyanophyte biovolume was heavily influenced by the presence of the very large species *Aphanizomenon flos-aquae* in late June and throughout July. This species is large enough to easily be seen by the naked eye and resembles grass clippings. On the three dates when it was observed, *Aphanizomenon flos-aquae* had a combined concentration of 274,600 cells/mL, but had a biovolume of 20,704,390 μm^3/mL. These figures represented 8% of the cyanophyte cell counts and 7% of the total algal cell counts for WY 2022. Due to their very large size, this species accounted for 93% of the cyanophyte biovolume, and 32% of the total algal biovolume for the entire year, in spite of being present on only three sampling dates.

This demonstrates how cyanobacteria with large cell size or smaller types that form multi-cellular colonies can easily be responsible for visible nuisance blooms.

Chlorophytes were present in high numbers throughout the year and were second only to the cyanophytes on 11 of the 15 sampling dates and for WY 2022 as a whole (Figure 55). Chlorophyte concentrations averaged 243,290 cells/mL for the 15 sampling dates and contributed 6% of the total cell counts in WY 2022. This is a lower percentage than observed over the last three years, largely due to the higher numbers of cyanophytes in WY 2022.

Chlamydomonas sp. and *Oocystis parva* were the two chlorophytes present on each sampling date, and both exceeded the 1,000 cells/mL threshold generally accepted as causing bloom conditions on six dates. *Monoraphidium capricornutum* and *Monoraphidium arcuatum* and unidentified algae in the order *Chlorococcales* were each present on 11 or more sampling dates. Those three species exceeded 1,000 cells/mL on a combined 11 occasions. Altogether, various chlorophytes exceeded counts of 1,000 cells/mL 28% of the time in WY 2022. *Monoraphidium arcuatum* was the individual chlorophyte species reaching the highest concentration during the year, with a count of 14,594 cells/mL on December 6, 2021. This concentration accounted for 4% of the total algal population on that date.

Many chlorophyte species are large, and most are larger than all but the largest cyanophytes. Green algae made up 12% of the total algal biovolume in WY 2022 (Figure 57B). This is lower than the previous three years, primarily due to the large biovolumes of *Aphanizomenon flos-aquae* in June and July, as mentioned above.

Chlamydomonas sp. had the highest biovolume of any chlorophyte in WY 2022, with a peak of 778,413 μm^3/mL on November 9, 2021. That was about 19% of the total algal biovolume on that date. *Chlamydomonas* sp. also had total biovolumes of over 100,000 μm^3/mL on 4 other dates. *Oocystis parva* had a peak biovolume of 356,208 μm^3/mL on December 6, 2021, and exceeded over 100,000 μm^3/mL on 3 other dates. There were 11 other large chlorophytes with total biovolumes of over 100,000 μm^3/mL on at least one date.

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 typically are most common during the spring or fall months when water temperatures are relatively low. Total diatom counts in Cherry Creek Reservoir in WY 2022 peaked at a concentration of 22,496 cells/mL on November 9, 2021, but this was only 8% of the total algal cell counts on that date due to high concentrations of cyanophytes and chlorophytes. The highest relative concentration of diatoms was 14.7% on June 7, 2022, but the overall diatom concentration was 3,610 cells/mL on that date and overall algal populations were low (Figure 55 and Figure 56).

Cyclotella sp. 1 was the most common diatom in WY 2022, when it was present on 11 sampling dates. *Aulacoseira granulata* and *Fragilaria crotonensis* were each present on 7 dates and no other diatom was present on more than 6 dates. The individual diatom species present at the highest concentration during WY 2022 was *Cyclotella atomus*, which reached a concentration of 19,645 cells/mL on November 9, 2021; this was over twice as high as the next highest diatom concentration. This species was present only from October through December 2021 but had 3 of the 5 highest diatom concentrations for WY 2022 and all were over 3,500 cells/mL. *Cyclotella* sp. 1 (4 dates) and 7 other species (1 or 2 dates each) were the only other diatoms present at over 1,000 cells/mL in WY 2022. Diatom cell counts averaged 2.0% of total phytoplankton cell counts in WY 2022, which was similar to the previous two years.

Because of their relatively large size, diatoms contributed 45.0% of the relative algal biovolume in WY 2022 (Figure 56 and Figure 57). That was a greater percentage than the previous three years. Diatoms made up 96% of the relative diatom biovolume on June 7, 2022. *Stephanodiscus niagarae* was the diatom with the highest biovolume on that date (7.70×10^6 μm^3/mL), which represented 79.4% of the diatom biovolume and 76% of the total algal biovolume for that date. This species also had the highest individual diatom biovolume for WY 2022, with 8.13×10^6 μm^3/mL on July 6, 2022. That biovolume represented 84% of the diatom biovolume and 81% of the total algal biovolume for that date.

Chrysophytes (golden-brown algae) were present in high numbers on several sampling dates in WY 2022, but usually in lower numbers than the green algae, diatoms, and cyanophytes (Figures 56). Chrysophytes accounted for 2% of the total algal cell counts in WY 2022 and individual species were present at concentrations of greater than 1,000 cells/mL about half of the time.

The highest chrysophyte cell count of 15,563 cells/mL was observed on March 31, 2022, when an unidentified chrysophyte was present at 13,777 cells/mL and *Malamonas* sp. was present at 1,786 cells/mL. That accounted for 5% of the total algal cell counts on that date. The highest relative chrysophyte cell count of 13% occurred on June 23, 2022, when an unidentified chrysophyte was the only chrysophyte species present and reached a concentration of 22,962 cells/mL. Unidentified chrysophytes were present on 12 sampling dates and *Polygoniochloris circularis* was present on 4 dates. No other chrysophyte was present on more than 2 dates.

Some chrysophytes are relatively large but chrysophytes made up only 1% of the total algal biovolume in WY 2022 (Figure 56Figure 57). An unidentified chrysophyte had the highest biovolume of 1.19×10^5 μm^3/mL on March 31, 2022, which was 8.84% of the total algal biovolume for that date. The highest relative chrysophyte biovolume also occurred on March 31, 2022, when an unidentified chrysophyte, with a biovolume of 1.19×10^5 μm^3/mL, and *Ochromonas* sp., with a biovolume of 96156 9.62×10^4 μm^3/mL, combined for 16% of the total algal biovolume.

Along with the cyanophytes, bacillariophytes, and chlorophytes, and chrysophytes, members of the cryptophtye group (cryptomonads) were present on all sampling dates in WY 2022 (Figure 55). Only three species of cryptomonads were identified in Cherry Creek Reservoir during WY 2022, with *Plagioselmis minuta* present on all sampling dates, *Cryptomonas erosa* present on 13 sampling dates and *Rhodomonas minuta* present on 6 dates. *Plagioselmis minuta* was usually the cyptomonad present in the highest numbers, peaking at 4,592 cells/mL on December 6, 2022, which was 1.4% of the total cell count on that date. As a whole, the cryptomonads contributed only 0.86% to the total cell count in WY 2022, which was nearly the same as in WY 2021.

The cryptomonads are typically relatively large algae and made up 3% of the total phytoplankton biovolume WY 2022 (Figure 57). Two large species, *Plagioselmis minuta*, on 5 dates, and *Cryptomonas erosa*, on 4 dates, were frequently present with biovolumes of over 100,000 μm^3/mL. *Plagioselmis minuta* peaked at a biovolume of 153,982 μm^3/mL on December 6, 2021, and *Cryptomonas erosa* peaked at a biovolume of 150,968 μm^3/mL on May 24, 2022. These figures represented 11% of the total algal biovolume for those two dates.

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 2022 and was less prevalent than in WY 2021, occurring on 8 sampling dates (Figure 55).

Chrysochromulina parva made up 1.57% of the total algal cell counts and 2.93% of the total algal biovolume in Cherry Creek Reservoir in WY 2022 (Figures 55, 56, 57A, and 58). These figures for the haptophytes are lower than the numbers for the three previous years. Concentrations of *Chrysochromulina parva* were variable throughout the year (Figure 55), reaching a peak concentration of 30,616 cells/mL and biovolume of 9.85×10^5 μm^3/mL, both on April 19, 2022. These numbers accounted for only 4.5% of the total algal population and, because of the large size of this species, 41.3% 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 2022. Phyrrhophytes (8 different species) were present on 9 sampling dates and euglenophytes (3 different species) were present on 6 dates. Phyrrhophytes and euglenophytes contributed less than or equal to 0.06% of total algal cell counts (Figure 56) and, because of their relatively large size, 1% of the total algal biovolume for WY 2022 (Figure 56 and Figure 57). Miscellaneous microflagellates were only present on December 6, 2021, where they made up 0.01% of total algal cell counts and 0.06% of total algal biovolume.

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. Monitoring populations is important because 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 and copepods are microscopic crustaceans that feed primarily on phytoplankton, while ostracods are omnivores and eat both small phytoplankton and other organic material. 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 2022 were 3-6 copepods, 1-4 cladocerans, and 0-7 rotifers present on each date. In addition, one protozoan and one ostracod were each present on a single date. An average of 10.1 zooplankton species were present on each sampling date, including immature forms. This is slightly lower than the average number of zooplankton species per sampling date in the three previous years.

Copepods were typically the zooplankton present in the highest numbers in Cherry Creek Reservoir during WY 2022 (Figure 61), averaging 52% of the total zooplankton population. This is similar to the averages for the previous three years. Relative copepod concentrations during WY 2022 ranged from 24% on July 18, 2022, to 95% on April 19, 2022. Unidentified, immature cyclopoid and/or calanoid copepods were the only zooplankton present on each sampling date. These two forms accounted for 46% of the total zooplankton population present during WY 2022**.**

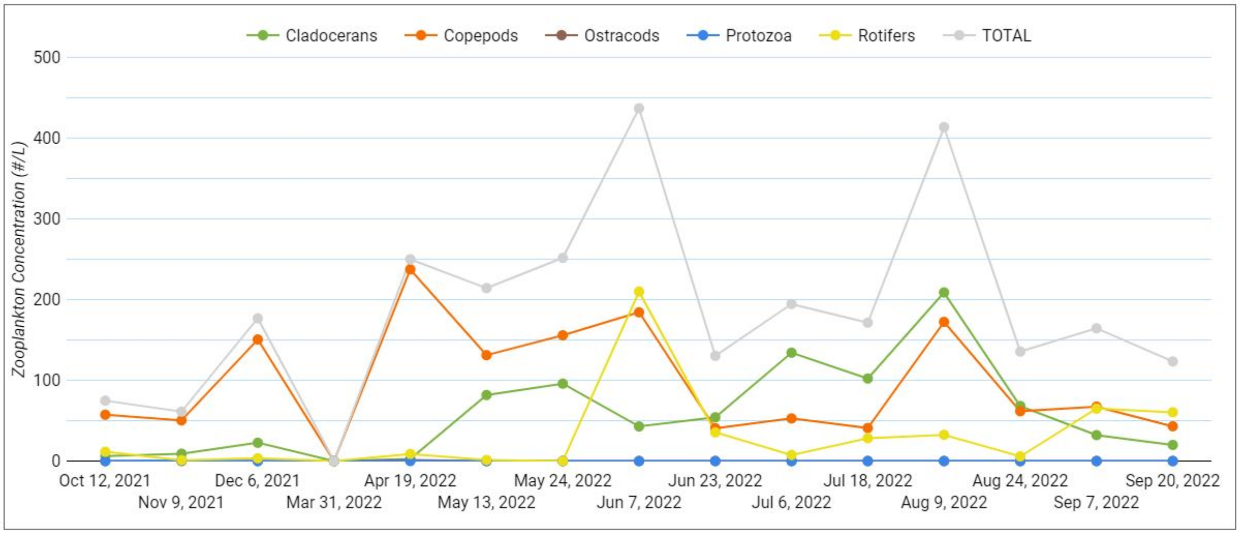


Figure 58. Total Zooplankton Concentrations – WY 2022.

Only four adult species of copepods were present in Cherry Creek Reservoir during WY 2022. *Diacyclops thomasi* and *Leptodiaptomus ashlandi* were each present on six dates, *Epischura nevadensis* was present on three dates, and *Acanthocyclops vernalis* was present on a single date. *Diacyclops thomasi* was the adult form reaching the highest concentration during the year, with 26.4 organisms/L present on April 19, 2022. That represented 10.6% of the total zooplankton population on that date.

Copepods made up a smaller fraction of the zooplankton biomass than copepod concentrations because they are generally smaller than the cladocerans (Figure 58 and Figure 59). Total copepod biomass during WY 2022 was 1,033 µg/L, which was only 10% of the total zooplankton biomass. Relative copepod biomass ranged from 2% of the total on August 24, 2022, to 93% on March 31, 2022 (Figure 60). March 31, 2022 was unusual because the total zooplankton biomass was only 0.012 µg/L on that date, with only *Bosmina longirostris*, a small cladoceran, and four small rotifer species being present along with low numbers of five copepod species on that date The relative total copepod biomass in WY 2022 was similar to the 12% of total zooplankton biomass observed in WY 2021. *Leptodiaptomus ashlandi* had the highest biomass of any copepod during the year, with a concentration of 102 µg/L on July 6, 2022. That value was 12% of total zooplankton biomass on that date.

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 2022. Cladoceran populations during WY 2022 averaged 31% of the total zooplankton population (Figure 59), which was higher than the relative populations of 20% of the total zooplankton population during WY 2021 but similar to WY 2019 and WY 2020. The highest relative cladoceran population was 69% of the total zooplankton population on July 6, 2022. An average of 2.7 cladoceran species were present on each sampling date, but only seven species of cladocerans were present during the year.

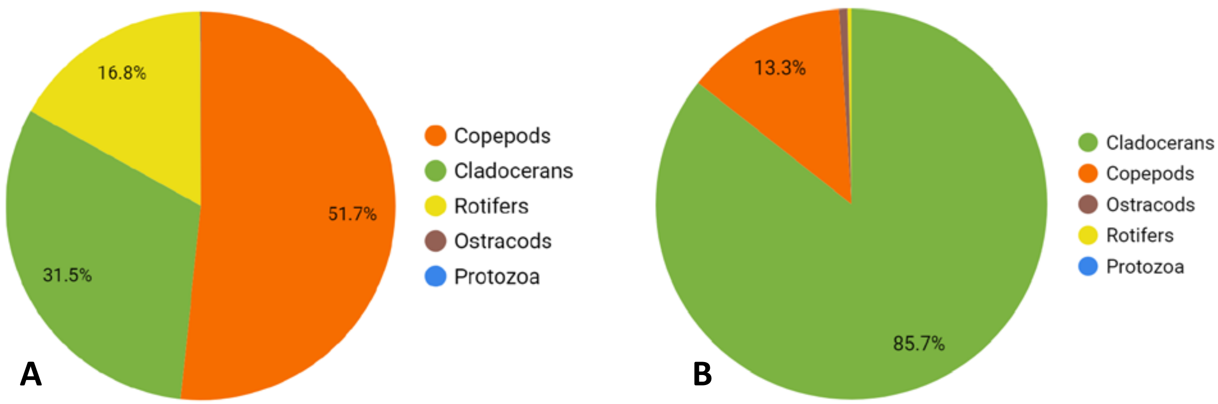


Figure 59. Relative Zooplankton Concentrations (A) and Biomass (B) in WY 2022.

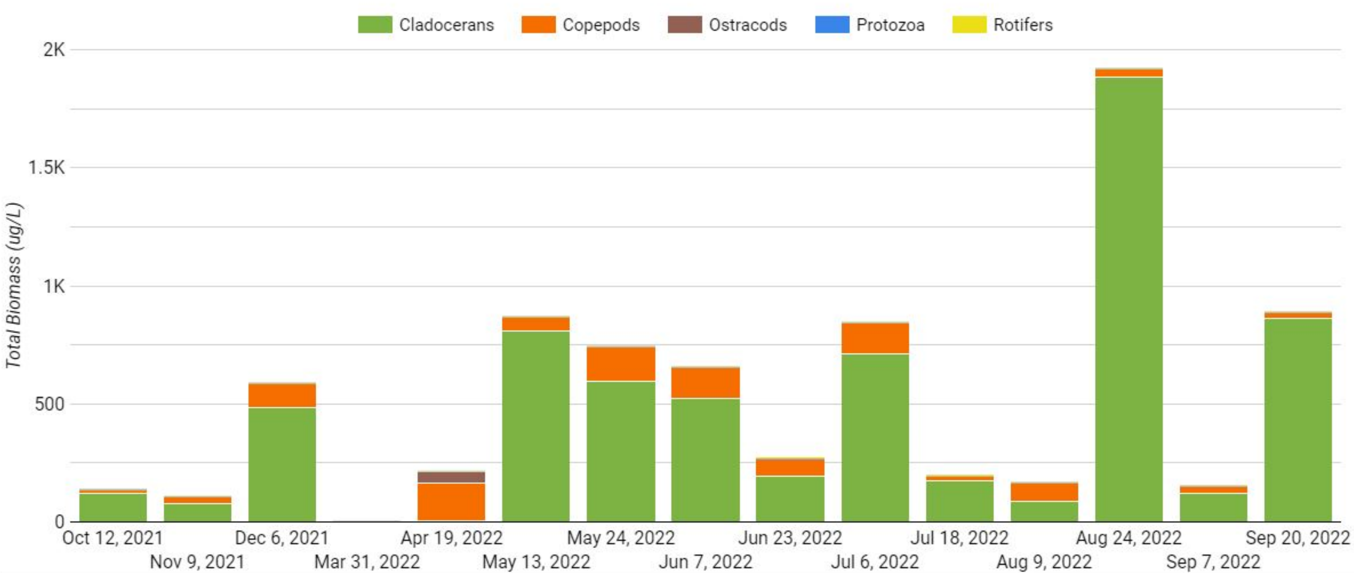


Figure 60. Total Zooplankton Biomass (µg/L) in WY 2022.

As in WY 2021, *Bosmina longirostris* was the most prevalent cladoceran in WY 2022, being present on 14 of the 15 sampling dates. No other cladoceran species was present on more than 6 dates. *Bosmina longirostris* also the cladoceran with the highest individual population in WY 2022, with 193 organisms/L present on August 9, 2022. That figure comprised 47% of the total zooplankton population on that date.

Cladocerans comprised over half of the total zooplankton biomass on all but two of the 15 sampling dates during WY 2022 (Figure 59 and Figure 60). Copepods contributed most of the biomass on March 31 and April 19, 2022, when zooplankton biomass was more than an order of magnitude lower than any other date (Figure 60). Cladoceran biomass averaged 86% of the zooplankton biomass for the entire year, with a range of 2% on April 9, 2022, to 98% on August 24, 2022. That was nearly the same as the average relative zooplankton biomass in WY 2021 (87%) and higher than WY 2020 (54%) and WY 2019 (65%).

Two large species, *Daphnia galeata*, present on 5 sampling dates, and *Daphnia lumholtzi*, present on six sampling dates, combined for 91% of the cladoceran biomass and 78% of total zooplankton biomass in WY 2022. The two species were never present on the same date, with *Daphnia galeata* present from May through July and *Daphnia lumholtzi* present from October through December 2021 and late August through September 2022. Both species had the highest biomass of any zooplankton species on the dates when they were present, with *Daphnia galeata* peaking at 756 µg/L on May 13, 2022, and *Daphnia lumholtzi* peaking at 1,864 µg/L on August 24, 2022. Those concentrations represented 87% and 97% of total zooplankton biomass, respectively, on those dates. For the year, *Daphnia galeata* made up 32% and *Daphnia lumholtzi* made up 44% of total zooplankton biomass.

Daphnia lumholtzi is an invasive species 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* has been frequently identified in Cherry Creek Reservoir every year since 2018 and is often a major contributor to zooplankton biomass.

Rotifers were the most diverse zooplankton in Cherry Creek Reservoir during WY 2022, with 12 different species present. Rotifers comprised a total of 16.8% of the total zooplankton population during WY 2022, which was similar to previous years. The maximum relative rotifer population was 49% of the total on September 20, 2022, but total zooplankton number were relatively low on that date. No rotifers were present on May 24, 2022. Rotifer populations reached a maximum concentration of 210 organisms/L on June 7, 2022, which was 48% of the total zooplankton concentration (Figure 58). *Keratella cochlearis* contributed 208 organisms/L to this total, which represented 99.0% of the rotifer population and 47.5% of the total zooplankton population on that date.

The most common rotifer in WY 2022, as in WY 2021, was *Keratella cochlearis*, which was present on 11 dates. Other common species were *Polyarthra dolichoptera*, present on 8 dates, and *Brachionus angularis* and *Keratella quadrata*, each present on 5 dates.

Due to their small size, rotifer biomass totaled only 26.1 µg/L during all of WY 2022 (Figure 62), which was 0.3% of the total zooplankton biomass for the year. The maximum rotifer biomass was 10.5 µg/L on June 23, 2022. This was mostly due to *Asplanchna priodonta*, which had a biomass of 10.3 µg/L. That comprised 98% of the rotifer biomass but only 4% of the total zooplankton biomass on that date.

Ostracods and protozoans made only minor contributions to the zooplankton community in Cherry Creek Reservoir during WY 2022, with each present only on a single date. An unidentified ostracod was present on April 19, 2022, with a concentration of 1.3 organisms/L and a biomass of 53 µg/L. This concentration represented 0.5% of the zooplankton concentration for the date and 0.04% of the total zooplankton population for the year. Due their relatively large size, the ostracod biomass represented 24.5% of the zooplankton biomass for the date and 0.68% of the total zooplankton biomass for the year. The protozoan, *Difflugia* sp., was present on November 9, 2021, with a concentration of 0.3 organisms/L and a biomass of 0.0001 µg/L and were insignificant, representing only 0.01% of the total zooplankton population and 1.3×10^{-6}% of the total zooplankton biomass for the year.

5.0 WATER BALANCE

The WY 2022 water balance for Cherry Creek Reservoir was calculated from the following equation:

$$\text{Ending Storage}_{9/30/2022} + \sum\text{Reservoir Inflows} - \sum\text{Reservoir Outflows} - \text{Starting Storage}_{10/1/2021} = \Delta\ \text{Storage}$$

Storage was based on daily surface elevations and area-capacity tables for Cherry Creek Reservoir provided by the USACE (Appendix A). The lake surface elevation and volume were 5548.7 ft and 11,497 AF on September 30, 2021, and 5547.1 ft and 10,267 AF on September 30, 2022. This results in a loss in storage of 1,230 AF (Δ Storage) during WY 2022.

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 new precipitation gauge at Cherry Creek State Park (CCSP, Section 3.1) by the corresponding lake surface areas, as provided by the USACE, on the dates with measurable precipitation. A total of 12.76 inches (1.06 feet) of precipitation was recorded at the CCSP weather station during WY 2022. The surface area of Cherry Creek Reservoir during WY 2022 varied between 774.8 acres on September 29, 2022, and 975.4 acres on August 6, 2022, with a median value of 801.3 acres. Surface areas were based on elevations and area-capacity tables for Cherry Creek Reservoir provided by the USACE. Based on these calculations, precipitation contributed an estimated 890 AF of water to the Reservoir during WY 2022.

Although there is no historical data from the CCSP station, precipitation at the Centennial Airport (KAPA) precipitation gauge, which had been used for previous reports, was used for historical reference. Only 11 inches of precipitation was recorded at the KAPA gauge during WY 2022, which was only 78% of the long-term average for that station (Figure 4).

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. Recent surveys and modeling conducted by RESPEC (2021) were used to estimate storm flows that overtopped Lakeview Drive. Those flows were not captured by the CC-10 staff gauge and were added to the CC-10 calculated flows to provide estimates of total Cherry Creek inflows to the reservoir (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 in conjunction with the Lakeview Drive overflows to provide a daily time step for Cherry Creek modeling efforts.

The DWR also collects daily storage data for Cherry Creek Reservoir. While there are slight differences between the daily storage volumes recorded, these differences could be explained by daily changes in volume and measurements collected at different times of day. The average difference in the daily storage between the USACE and Colorado Division of Water Resources for WY 2022 was only -2.1 AF, but the maximum difference was -377.6 AF on 8/16/22 which was the date with maximum precipitation for the year. The DWR elevation for that date was 5548.3 ft and the USACE elevation was 5548.7 ft (0.9 ft higher than the USACE elevation on 8/15/22 and less than the difference between DWR and USACE data on 8/16/22.

The estimated volumes of surface flow entering the Reservoir from surface water sources in WY 2022 are:

- Cherry Creek: 7,199 AF
    - *4,892 AF at CC-10 and 2,307 AF from Lakeview Drive that bypassed the monitoring station*
- Cottonwood Creek: 3,757 AF

Flow data from the Authority's gauging stations are available 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 3,197 AF during WY 2022, or approximately 3.9 feet (47.9 inches) per acre at the median surface area of 801.3 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 61). 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 2022 flows at the USGS gauge below the Reservoir averaged 18.7 cfs (37.1 AF/day) for an annual total of 13,536 AF. The 2022 outflow is 142% of the long-term average from 1951-2022 (13.2 cfs), but only 73% of the average for the previous 5 years of 25.9 cfs from 2017-2021.

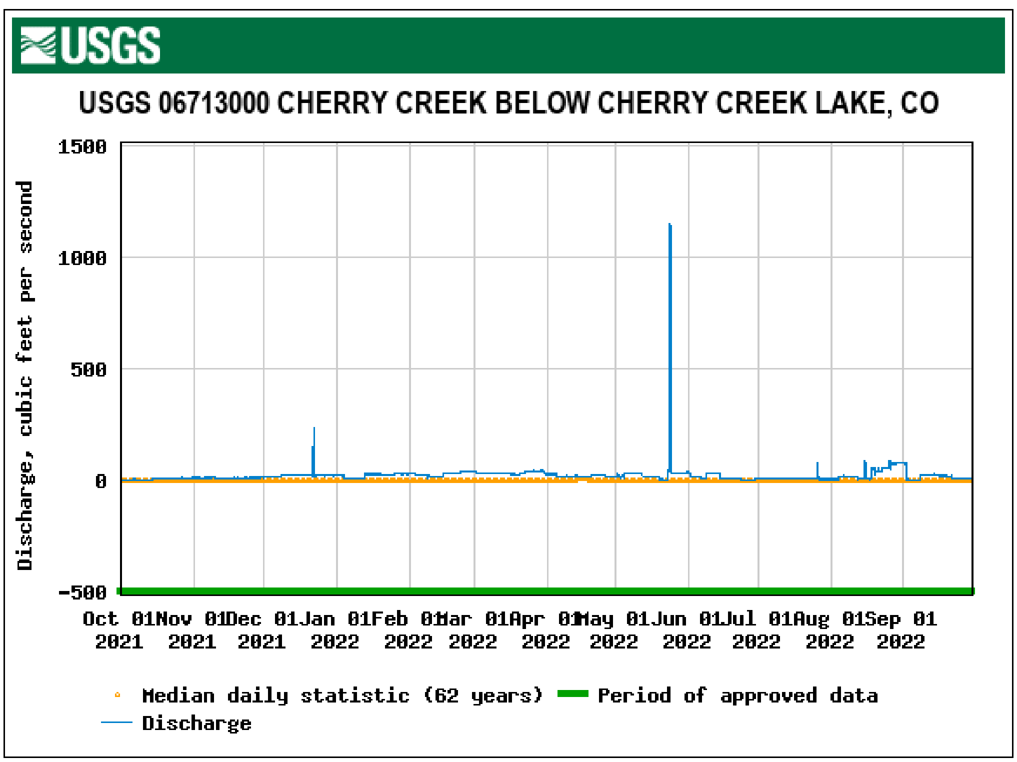


Figure 61. WY 2022 Hydrograph and Historical Median Flows for USGS Cherry Creek below Cherry Creek Lake.

The Reservoir WY 2022 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 loss in storage of 1,230 ac-ft reported by the USACE for WY 2022 (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 2022 were 1,457 AF.

Based on previous practice, the ungauged inflows for WY2022 were apportioned between Cherry Creek (including CC-10 inflows and Lakeview Drive overflows) and Cottonwood Creek to calculate nutrient loading (Section 6). Based on the uncorrected inflows For WY 2022, Cherry Creek contributed 66% of the combined inflow and Cottonwood Creek contributed 34% of the average daily surface stream inflows to Cherry Creek Reservoir. The ungauged inflows were calculated and allocated based on the daily values for all inflows and outflows used in the allocation equations, resulting in increases in surface inflows of 659 AF for Cherry Creek and 894 AF for Cottonwood Creek. The adjusted inflows were 7,858 AF for Cherry Creek and 4,651 AF for Cottonwood Creek.

The total inflow from Cherry Creek was much lower than previous years totaling only 45% of the average of the last 5 years. However, although the total flow in Cottonwood Creek was less than WY 2021, the flow in WY 2022 was 4% higher than the 5-year average.

The adjusted relative inflows to the Reservoir from Cherry Creek, Cottonwood Creek, groundwater, and precipitation for WY 2022 are pictured in Figure 62.

Table 24. Cherry Creek Reservoir WY 2022 Water Balance.

Water Source	Water Volume (AF)
Inflows	
Cherry Creek (CC-10)	4,892
Cherry Creek (Lakeview Dr)	2,307
Cottonwood Creek (CT-2)	3,757
Precipitation	890
Alluvial groundwater	2,200
Total Inflows	**14,046**
Outflows	
Evaporation	-3,197
Reservoir releases	-13,536
Total Outflows	**-16,733**
Net Ungauged Flows	
Calculation	**1,457**
WY 2022 Change in Storage	-1,230*

*Note: Values are rounded to the nearest AF.

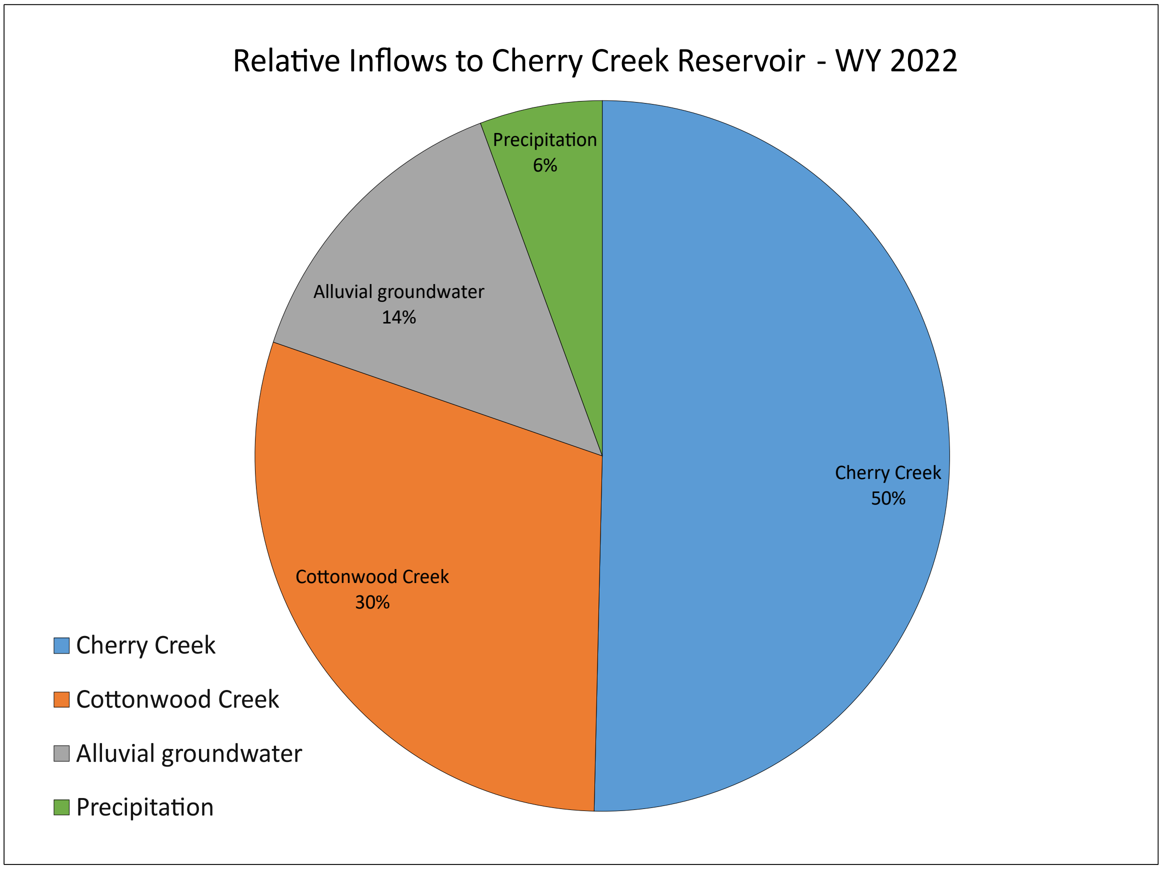


Figure 62. Relative Inflows to Reservoir Water Balance in WY 2022.

6.0 FLOW WEIGHTED NUTRIENT CONCENTRATIONS

Surface water 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, for the Cherry Creek and Cottonwood Creek inflows 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 2022, and concentrations from previous years, are outlined in Table 25.

The WY 2022 flow-weighted TP concentration for Cherry Creek was 217 µg/L, which is higher than flow-weighted TP concentrations for WY 2021 (203 µg/L), WY 2020 (188 µg/L), and the 5-year median from 2017-2021 (203 µg/L), but lower than WY 2019 (222 µg/L) and the long-term median from 2000-2016 (247 µg/L) (Table 25). The WY 2022 Cherry Creek flow-weighted TN concentration of 1,680 µg/L is higher than WY 2021 (1,396 µg/L), WY 2020 (1,501 µg/L), and WY 2019 (1,565 µg/L), as well as the 5-year median (2017-2021) flow-weighted TN concentration of 1,501 µg/L and long-term median from 2000-2016 (1,261 µg/L).

The WY 2022 flow-weighted TP concentration for Cottonwood Creek Station of 66 µg/L is similar to WY 2021 (65 µg/L) and the 5-year median from 2017-2021 (62 µg/L), but lower than WY 2019 (49 µg/L) and much lower than the long-term median from 200-2016 (91 µg/L). The WY 2022 Cottonwood Creek flow-weighted TN concentration of 2,245 µg/L is higher than WY 2021 (1,856 µg/L), the 5-year median from 2017-2021 (1,984 µg/L), and the long-term median from 2000-2016 (1,817 µg/L), but lower than WY 2020 (2,479 µg/L) and WY 2019 (2,427 µg/L).

Similar to the averages for the past 10 years, the surface water flow-weighted total phosphorus concentrations for WY 2022 were much higher for Cherry Creek at CC-10 than on Cottonwood Creek at CT-2 (Table 25). In contrast, the WY 2022, WY 2021 and the 5-year average flow-weighted total nitrogen concentrations were all higher at CT-2 than CC-10.

Table 25. Surface Water Flow-Weighted Nutrient Concentrations at CC-10 and CT-2.

Location	**Cherry Creek**		**Cottonwood Creek**	
Median	Total Phosphorus	Total Nitrogen	Total Phosphorus	Total Nitrogen
Water Year	Concentration (µg/L)			
WY 2000-2016	247	1,261	91	1,817
WY 2017-2021	203	1,501	62	1,984
WY 2019	222	1,565	49	2,427
WY 2020	188	1,501	53	2,479
WY 2021	203	1,396	65	1,856
WY 2022	**217**	**1,680**	**66**	**2,245**

The median groundwater concentrations of 254 µg/L of total phosphorus and 909 µg/L of total nitrogen for the period 2016-2022 were used in the calculation of flow-weighted nutrient concentrations in groundwater for WY 2022. A longer period of record was not used because TP and TN were not analyzed in groundwater prior to WY 2016. On earlier dates, total dissolved phosphorus (TDP) and total inorganic nitrogen (equal to the sum of NO_3+NO_2-N and NH_3-N) were analyzed. From 2016-2022 when both parameters were analyzed TDP averaged 91% of TP so it could be compared but TIN averaged only 57% of TN so would not be a good comparison.

The median nutrient concentrations in precipitation samples for the period of 2001-2022 of 100 µg/L for total phosphorus and 1,978 µg/L for 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 2022 are summarized in Table 26.

Table 26. Total Flow-Weighted Inflow Concentrations of TN and TP, WY 2022.

		Source				
	Nutrient	**Cherry Creek**	**Cottonwood Creek**	**Alluvial Groundwater**	**Precipitation**	**Weighted Total**
Inflow Concentration (µg/L)	Total Phosphorus	109	20	36	6	170
	Total Nitrogen	846	669	128	113	1,756
% of Total Inflow		50.4%	29.8%	14.1%	5.7%	100%

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 2022 flow-weighted TP concentration for all inflows of 170 µg/L is similar to the flow-weighted TP concentration for WY 2021 (176 µg/L) and WY 2020 (173 µg/L), but lower WY 2019 (188 µg/L), the previous 5-year median from 2017-2021 (188 µg/L), and the long-term historical median from 2000-2016 (201 µg/L) (Table 27). In contrast, the WY 2022 flow-weighted TN inflow concentration of 1,756 µg/L is higher than WY 2021 (1,420 µg/L), WY 2020 (1,491 µg/L), WY 2019 (1,609 µg/L), and the previous 5-year (1,491 µg/L) and long-term medians from 2000-2016 (1,401 µg/L).

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 2000-2016	201	1,401
WY 2017-2021	188	1,491
WY 2019	188	1,609
WY 2020	173	1,491
WY 2021	176	1,420
WY 2022	**170**	**1,756**

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 or dry deposition from the atmosphere. No current estimates for dry deposition or internal nitrogen loading are available, but those amounts are expected to be small relative to other nutrient sources. 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.

There is no way to track the internal cycling of nutrient release and biological uptake in the Reservoir. Internal loading is not constant and will vary depending on annual water and air temperatures, which affect stratification, biological productivity, inflows, and other factors affecting lake mixing. As noted above, the Nurnberg and LaZerte estimates allow us to estimate a potential range for magnitude of internal loading, but it cannot be used as a constant load. The CCBWQA SAP measurements include inflow concentrations, Reservoir water column concentrations, and outflow concentrations on an annual basis. Adding an estimated value for internal loading as an inflow would be misrepresentative.

Nitrogen can also 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 expected to be relatively small based on the magnitude of the other N sources listed and, therefore, can be excluded from mass balance and flow weighted calculations.

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, and it would be very difficult to try to accurately quantify these losses, they were not accounted for in the nutrient balance.

The flow-weighted nutrient concentrations for Reservoir outflows (losses) during WY 2022 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 Nutrient Concentrations at CC-0 and Evaporation, WY 2022.

Nutrient	Concentration (µg/L)	
	Cherry Creek Outflow	Evaporation
Total Phosphorus	111	0
Total Nitrogen	1,174	0

7.0 NUTRIENT BALANCE

The calculated WY 2022 phosphorus and nitrogen balances in 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 Storage$_{\text{Nutrients}}$) indicates that inflows exceed releases and that nutrients are being retained (stored) within the Reservoir. A negative change in storage (-Δ 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 2022 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 2022 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, and include TP and TN.

The nutrient concentrations in samples collected at CC-10, CT-2 and CC-Out in WY 2022 are summarized in Table 25 and Table 26. Nutrient concentrations in were combined with the WY 2022 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 2022.

Site	WY 2022 Nutrient Loading	
	Total Phosphorus (Pounds)	Total Nitrogen (Pounds)
Inflows		
Cherry Creek	4,673	36,138
Cottonwood Creek	844	28,865
Releases		
USGS Gage & CC-Out	-4,101	-43,224

7.2 PRECIPITATION LOADS

In WY 2022, 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 2022 and 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 2022 and the updated historical mean values which were used to calculate the total loading from precipitation during WY 2022.

- The median total phosphorus concentration from precipitation in WY2022 was greater than WY 2021 (40 µg/L) and the historical median of 100 µg/L (1991-2022).
- The median total nitrogen concentration from precipitation for WY 2022 was greater than the historical median value of 1,978 µg/L (1991-2022).

Table 30. Cherry Creek Reservoir WY 2022 Precipitation Nutrient Concentrations and Loads.

	WY 2022	
PRECIP	**Total Phosphorus**	**Total Nitrogen**
Maximum (µg/L)	386	3,080
Minimum (µg/L)	39	1,360
Median Concentration (µg/L)	185	2,255
Updated Historical Median (µg/L)	100	1,978
Inflow WY 2022 (AF)	890	
Total Loading (lbs)	**242**	**4,786**

Nutrient loads from precipitation were calculated by multiplying the historical median concentrations to account for the 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 2022 was 890 AF. The calculated precipitation loads for WY 2021 were:

- Total Phosphorus: 242 pounds
- Total Nitrogen: 4,786 pounds

The nutrient loads from precipitation during WY 2022 were lower than WY 2021 but were similar to the 5-year mean loading of 238 lbs of phosphorus and 4,284 lbs of nitrogen calculated from 2017-2021.

7.3 ALLUVIAL GROUNDWATER LOADS

Water samples from monitoring well MW-9 just upstream of Cherry Creek Reservoir are collected twice a year and are analyzed for total phosphorus and total nitrogen to account for nutrient loading from groundwater sources. The results are summarized in Table 31.

Table 31. Cherry Creek Reservoir WY 2022 Groundwater Concentrations and Loading.

	WY 2022	
MW-9	**Total Phosphorus**	**Total Nitrogen**
Maximum (µg/L)	283	2,800
Minimum (µg/L)	254	1,580
Median (µg/L)	269	2,190
Updated Historical Median (µg/L)	254	909
Inflow (AF)	2,200	
Total Loading (lbs)	**1,520**	**5,438**

The median TP concentration from MW-9 for WY 2022 was 269 µg/L which is lower than WY 2021 (306 µg/L) and WY 2020 (312 µg/L), but higher than the historical median from 2016- 2022 (254 µg/L).

The median TN from MW-9 for WY 2022 was 2,190 µg/L which is higher than WY 2021 (1,510 µg/L), WY 2020 (1,155 µg/L) and much higher than the median for WY 2019 (741 µg/L). The median values from 2016 to 2022 were used to calculate an updated historical median concentration for TN of 909 µg/L. Nutrient loads from groundwater were calculated using the historical median values due to variability in concentrations and limited measurements collected annually.

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 2022.

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 2022.

- Total Phosphorus: 1,520 pounds
- Total Nitrogen: 5,438 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 Tables 29 through Table 31.

Table 32. Total Phosphorus and Nitrogen Mass Balance in Cherry Creek Reservoir WY 2022.

Water Source	Total Phosphorus Mass (pounds)	Total Nitrogen Mass (pounds)
Inflows		
Cherry Creek (CC-10)	4,673	36,138
Cottonwood Creek (CT-2)	844	28,865
Precipitation	242	4,786
Alluvial groundwater	1,520	5,438
Total Inflows	**7,280**	**75,226**
Outflows		
Evaporation	0	0
Reservoir releases	-4,101	-43,224
Total Outflows	**-4,101**	**-43,224**
WY 2022 Change in Storage	**3,177**	**32,002**

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 ($\Delta\ Storage_{Nutrients}$) indicate that a net 3,177 pounds of phosphorus and 32,002 pounds of nitrogen were retained in the Reservoir in WY 2022.

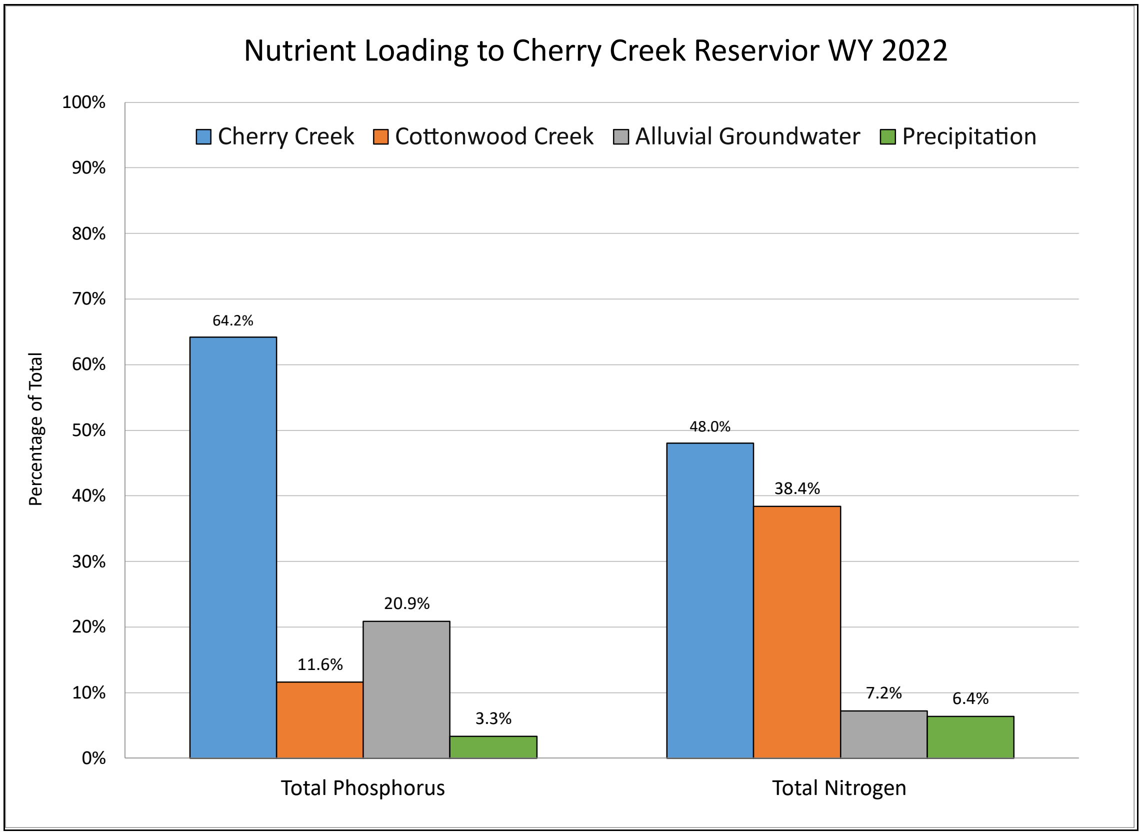


Figure 63. Nutrient Loading Percentages by Source to Cherry Creek Reservoir, WY 2022.

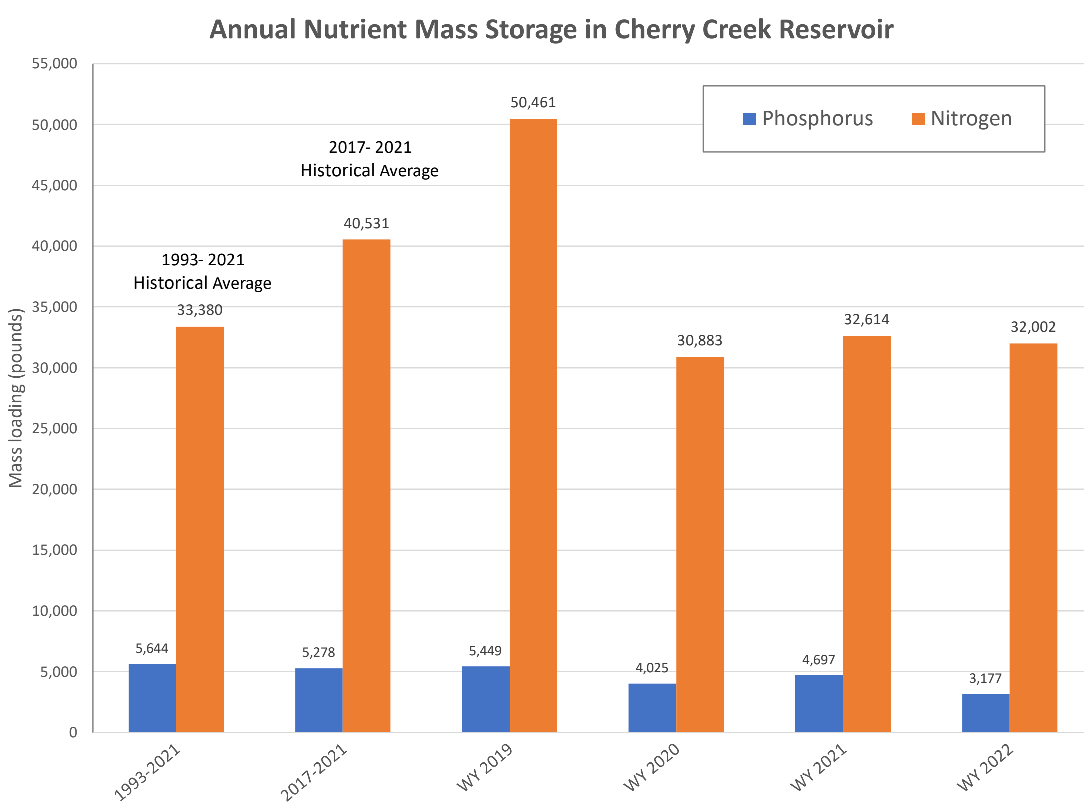


Figure 64. Current and Historical Phosphorus and Nitrogen Loading to Cherry Creek Reservoir.

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 2022 may been high in WY 2022 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.

The relative contributions of the inflow sources of phosphorus and nitrogen loading to the Reservoir in WY 2022 are represented in Figure 63.

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 64 shows a graphical representation. The calculated total phosphorus loads were higher than WY 2020 but lower than WY 2021, WY 2019, WY 2018, and the historical means from WY 2017-2021 and WY 1993-2021. The total nitrogen loads were slightly higher than WY 2020 but lower than WY 2021, WY 2019, WY 2018, and the historical means from WY 2017-2021 and WY 1993-2021.

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 Inflows		
Phosphorus	1993-2021	8,422	1,081	362	9,881	-4,548	5,644
Nitrogen		62,613	2,411	6,227	71,307	-37,951	33,380
Phosphorus	2017-2021	8,559	1,289	238	10,086	-4,808	5,278
Nitrogen		8,559	1,289	238	10,086	-4,808	5,278
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	362,672	-5,210	4,697
Nitrogen		71,251	3,428	5,888	80,567	-47,953	32,614
Phosphorus	**WY 2022**	**5,518**	**1,520**	**242**	**7,280**	**-4,133**	**3,177**
Nitrogen		**64,991**	**5,438**	**4,786**	**75,215**	**-43,526**	**32,002**

9.0 2022 CONCLUSIONS AND RECOMMENDATIONS

The water quality in Cherry Creek Reservoir and its tributaries is important to recreational boaters and watercraft users, fishermen, hikers, bikers, wildlife enthusiasts, and others that 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 CCBWQA's efforts to monitor and maintain watershed improvements to protect all beneficial uses. Although there is seasonal variability in relation to wind, temperature, and precipitation that can have negative impacts, for the most part the actions and projects of the CCBWQA and partners are working to maintain the water quality in the Reservoir despite the development in the watershed.

Conclusions

CCBWQA maintains an extensive and comprehensive water quality monitoring program that can be used to track changes over time in the Reservoir, effectiveness of control measures (e.g., BMPs, PRFs), support reservoir and watershed modeling, and support standards assessment. Key findings from monitoring conducted during 2022 include:

- Cherry Creek Reservoir did not meet the chl α seasonal standard for WY 2022 and also experienced dissolved oxygen concentrations lower than the Reg 38 standard for warm water aquatic life.
- Cherry Creek Reservoir continues to remain eutrophic to hypereutrophic in regard to total phosphorus, chl α, and transparency of the water. There were multiple severe cyanobacteria blooms in 2022 causing caution or closure to recreational users of the Reservoir. Again, during WY 20220, cyanobacteria were present at higher density or increased biovolume following or during periods of nitrogen limitation.
- 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. The WY 2022 inflows from Cherry Creek totaled about 45% of the 5-year average compared to previous years. Cottonwood Creek was within 4% of the 5-year inflow to the Reservoir.
- The WY 2022 conditions of low inflows to the Reservoir from below average Cherry Creek flows and precipitation resulted in low water level, elevated water temperatures, and longer residence time, which increased the potential for algae growth, cyanobacteria blooms, and high chl α concentrations.
- There continues to be notable differences in water quality between Cherry Creek, Cottonwood Creek and Piney Creek. Cherry Creek has much higher concentrations of phosphorus, but Cottonwood Creek has higher concentrations of nitrogen. Piney Creek continues to demonstrate lower concentrations of nutrients and suspended solids when compared to Cherry Creek during baseflow conditions. Stream characteristics vary in terms of stream channel morphology, flow patterns, wetlands, vegetation growth patterns, effects of storm events, watershed development, number of permitted WWTP discharge outfalls, and differences in runoff from the watersheds all play a role in water quality.
- The Cherry Creek watershed has seen drastic increases in population and both residential and commercial construction over time. Up-basin MS4 permittees are required to implement construction-phase and post-construction stormwater control measures (also known as BMPs) to treat regulated stormwater in urban areas, including at development thresholds much lower than other Colorado MS4s. Authority-implemented PRF projects have also been completed in order to reduce the water quality impacts of development in the Cherry Creek Basin. In WY 2022, the constructed wetland PRF ponds on

Cottonwood Creek functioned effectively to remove phosphorus and suspended solids during storm flow conditions. In addition, the PRF Ponds Cottonwood Creek have been functioning effectively when evaluating upstream to downstream concentrations on a long-term basis.

- Based on calculations, 3,177 lbs of phosphorus and 32,002 lbs of nitrogen were added to the stored nutrient mass in the Reservoir in WY 2022. The total nutrient mass storage in Cherry Creek Reservoir in WY 2022 was less than both WY 2021 and WY 2020, as well as less than this historical mean of 5,644 lbs of phosphorus and 33,380 lbs of nitrogen.

In summary, the data analysis shows that continued management of the watershed is vital to maintaining and improving the water quality in Cherry Creek Reservoir in order to preserve its 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 elevated chl α concentrations.

Recommendations for Future Monitoring

1. Continue monitoring of individual TDS components. The increases in conductivity seen over time may be due primarily due to increasing chloride concentrations in the watershed. 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 some analyses of these components were completed over the last 2 years, individual analyses for chloride, sulfate, magnesium, sodium, potassium, calcium, and alkalinity will continue to help determine what constituents may have the largest impacts.

2. Continue use of Lakeview Drive gauging station. The recent efforts to provide gauging on Cherry Creek upstream of the Reservoir to capture information from flows during large storm events that may bypass the current gaging station at CC-10 have been beneficial to water balance calculations. In WY 2022, the Lakeview Drive gauging station recorded multiple large storm events that resulted in flows that bypassed the monitoring station at CC-10.

3. Continue assessment of the differences in water quality and use of data analysis tools to find 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.

4. Use monitoring program data to evaluate effectiveness of the pilot wetland harvesting program. The pilot wetland harvesting project along the Cottonwood Creek stream corridor and the shoreline of the Perimeter wetland pond PRF has been completed for 2 years. The wetland plants in the project areas were collected to determine density and the plant material was analyzed for nutrient content which 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. In addition, after multiple years of data is collected, calculations may determine if the removal efforts have a statistically significant effect on water quality upstream to downstream of treated areas.

5. Continue analysis of nitrogen and phosphorus ratios, limiting nutrient trends, and relationships between chl α and phytoplankton populations to help evaluate the potential for cyanobacteria blooms and management in Cherry Creek Reservoir throughout the growing season.

6. Continue evaluation of water quality data to assess effectiveness of the reservoir destratification system. The current destratification system is not effective at reducing stratification during the season

and low DO concentrations at the bottom of the Reservoir likely lead to internal nutrient loading, which increases productivity. 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.

7. Continue biological monitoring program in the Reservoir and share information with CPW. 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. CPW does not currently have intensive monitoring programs for these species but sharing information from this monitoring program could be helpful.

8. Continue to evaluate whether additional monitoring locations are needed. 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.

8.0 REFERENCES

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

Carlson, R.E. 1977. A trophic state index for lakes. Limnol. Oceanogr. 22:361-369.

Cherry Creek Basin Water Quality Data Portal. LRE Water. https://www.ccbwqportal.org/

GEI Consultants, Inc. February 2016. *Cherry Creek Reservoir 2015 Water Year Aquatic Biological Nutrient Monitoring Study and Cottonwood Creek Pollutant Reduction Facilities Monitoring.* Prepared for the Cherry Creek Basin Water Quality Authority.

Goldman, C. R., and A. J. Horne. 1983. Limnology. McGraw-Hill Book Co., New York. 464p.

Halepaska and Associates, Inc. 1998 -2006. *Annual Reports, Baseline Water Quality Data Collection Study for the Upper Cherry Creek Basin*. Prepared for the Cherry Creek Basin Water Quality Authority.

Hutchinson, G. E. 1967. *A Treatise on Limnology, Volume 2, Introduction to Lake Biology and the Limnoplankton*. John Wiley and Sons, Inc., New York.

Hydros Consulting Inc. July 31, 2015. *Technical Memorandum, Key Findings to Tasks 3 and 3a, Cherry Creek Reservoir Water Quality Modeling Project: Model Calibration and Sensitivity Analyses.*

Johnson, B. 2014. Environmental Conditions for Walleye in Cherry Creek Reservoir. Prepared for the Cherry Creek Basin Water Quality Authority. (Attachment A in Cherry Creek Reservoir Model Documentation April 5, 2017. Prepared for The Cherry Creek Basin Water Quality Authority by C. Hawley and J.M. Boyer, Hydros Consulting, Inc, Boulder, CO.

Cherry Creek Reservoir Destratification Facilities Operation and Maintenance Annual Report, 2022.

Lewis, W. M. Jr. 1983. *A Revised Classification of Lakes Based on Mixing*. Can. J Fish. Aquat. Sci. 40:1779-1787.

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

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

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

Marzolf, G. R. 1990. Reservoirs as environments for zooplankton. pp. 195-208, In K. W. Thornton, B. L. Kimmel, and F. E. Payne (eds.), Reservoir Limnology. John Wiley and Sons, Inc., New York.

NOAA. National Weather Service. Advanced Hydrologic Prediction Service. https://water.weather.gov/precip/

Nürnberg, G., and LaZerte, B. 2008. *Cherry Creek Reservoir Model and Proposed Chlorophyll Standard*. Prepared for the Cherry Creek Basin Water Quality Authority.

Pennak, R.W. 1957. Species composition of limnetic zooplankton communities. Limnol. Oceanogr. 2:222-232.

Preisendorfer, R.W. 1986. Eyeball optic of natural waters: Secchi disk science. NOAA Tech. Memo. ERL PMEL 67. 90 p. NTIS PB86 224060/AS.

RESPEC. 2021. Monitoring Station CC-10 and Lakeview Drive Flow Ratings. External Memorandum prepared for the Cherry Creek Basin Water Quality Authority.

Reynolds, C.S. 1986. The Ecology of Freshwater Phytoplankton. Cambridge University Press, New York.

Schindler, D.W. 1977. Evolution of Phosphorus Limitation in Lakes. Science 195:260-262.

Solitude Lake Management. CCBWQA Annual Monitoring Report, WY 2018.

Solitude Lake Management. CCBWQA Annual Monitoring Report, WY 2019.

Solitude Lake Management. CCBWQA Annual Monitoring Report, WY 2020.

Solitude Lake Management. CCBWQA Annual Monitoring Report, WY 2021.

Standard methods for the analysis of water and wastewater, 20th Edition. 1998. APHA, AWWA, WEF. Washington, D.C.

Tetra Tech. February 2018. Water Year 2017 Cherry Creek Monitoring Report.

Tetra Tech. January 2017. 2016 Cherry Creek Monitoring Report.

TSTool. 2022. Colorado's Decision Support Systems. https://cdss.colorado.gov/software/tstool

U.S. EPA. 1980. Clean lakes program guidance manual. Report No. EPA-440/5-81-003. U.S. EPA, Washington, D.C.

US EPA. 2016. Policies and Guidelines. Available online: https://www.epa.gov/nutrient-policy-data/guidelines-and-recommendations (accessed on 15 December 2016).

US Geological Survey, Flows for *USGS Gage Cherry Creek below Cherry Creek Lake*. *https://waterdata.usgs.gov/nwis*

US Geological Survey. *Streamflow for USGS Gage Cherry Creek Near Franktown, CO.*

US Geological Survey. *Streamflow for USGS Gage Cherry Creek Near Parker, CO.* https://waterdata.usgs.gov/nwis

Vollenweider, R.A. 1968. The scientific basis of lake and stream eutrophication, with particular reference to phosphorus and nitrogen as eutrophication factors. Technical Report OAS/DSI/68.27. Organization for Economic Cooperation and Development. Paris.

Walmsley, R.D. and M. Butty. 1979. Eutrophication of rivers and dams. VI. An investigation of chlorophyll-nutrient relationships for 21 South African Impoundments. Contributed Report, Water Res. Comm., Pretoria, South Africa.

Water Quality Control Commission, 2015. Cherry Creek Control Regulation No. 72, 5-CCR-1002-72.

Water Quality Control Commission, 2022. South Platte Standards and Use Classifications, Regulation No. 38, 5-CCR-1002-38.

Water Quality Control Commission, 2017. Nutrient Control Regulation No. 85, 5-CCR-1002-85.

Water Quality Control Commission, 2021. The Basic Standards and Methodologies for Surface Water. Regulation No. 31, 5-CCR-1002-31.

Water Quality Control Commission, 2020. The Basic Standards for Ground Water. Regulation No. 41, 5-CCR-1002-41.

Welch, E. B., J. M Jacoby. 2004. *Pollutant Effects in Freshwater, Applied Limnology*. 3rd ed. Spoon Press.

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

APPENDICES

APPENDIX A – WY 2022 Cherry Creek Reservoir Daily Inflow and Outflow Data and Monthly Summary Information