Cherry Creek Basin Water Quality Monitoring Report Water Year 2018

SUBMITTED TO:

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APPENDIX C – USACE DATA - WY 2018

ACRONYMS/ABBREVIATIONS

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

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

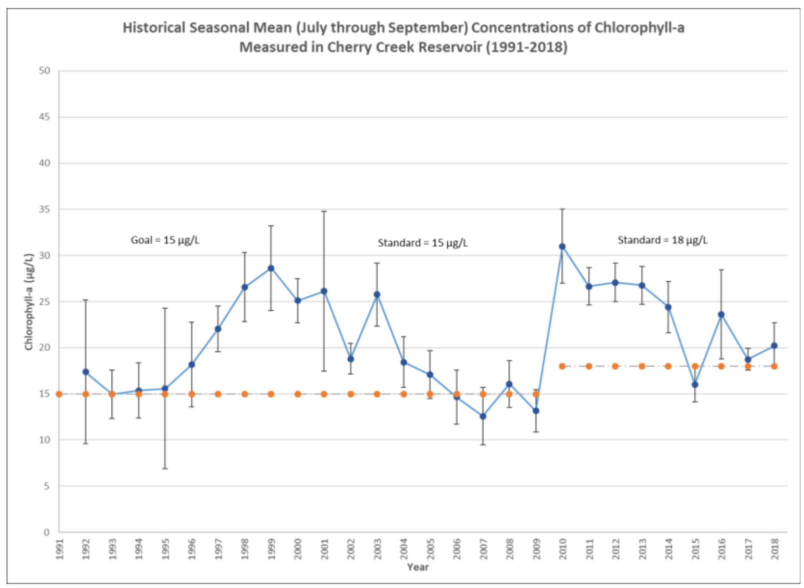
EXECUTIVE SUMMARY

The *Cherry Creek Basin Water Quality Monitoring Report – Water Year 2018* is a comprehensive outline of monitoring completed for the Cherry Creek Basin Water Quality Authority (CCBWQA or Authority) of Cherry Creek Reservoir (Reservoir) and watershed for the 2018 Water Year (WY 2018) between October 1, 2017 and September 30, 2018. The Reservoir and watershed monitoring programs are completed in accordance with the Cherry Creek Sampling and Analysis Plan (SAP), Quality Assurance Program Plan (QAPP), and regulatory requirements. The program includes regular monitoring of biological, physical, and chemical conditions of the reservoir, the streams and tributaries that feed the Reservoir, and precipitation and groundwater in the basin. Highlights of the findings from the monitoring completed during the 2018 Water Year are included in the Executive Summary below.

RESERVIOR HIGHLIGHTS

The highlights of the Reservoir monitoring in relation to Water Quality standards, results of Authority efforts, achieving beneficial uses and other notable details are outlined below.

Chlorophyll-a



During each sampling event of WY 2018, Chlorophyll-*a* (chl-*a)* levels were measured from composite samples collected from 0, 1, 2 and 3 m at all three monitoring sites in the reservoir. The chl-*a* measured concentrations ranged between 7.2mg/L and 33.0 mg/L, with an average value of 18.7 mg/L in WY 2018 (Figure A). The highest values were observed in February, March, April and May, and the lowest in November.

The seasonal (July through September) chl-*a* concentration through the WY 2018 growing season concentration was 20.2mg/L which is in exceedance of the 18 µg/L growing season average regulatory standard which allows one exceedance frequency of once in five years. Four of the last five (4/5) and eight of the last ten (8/10) years have exceeded this value.

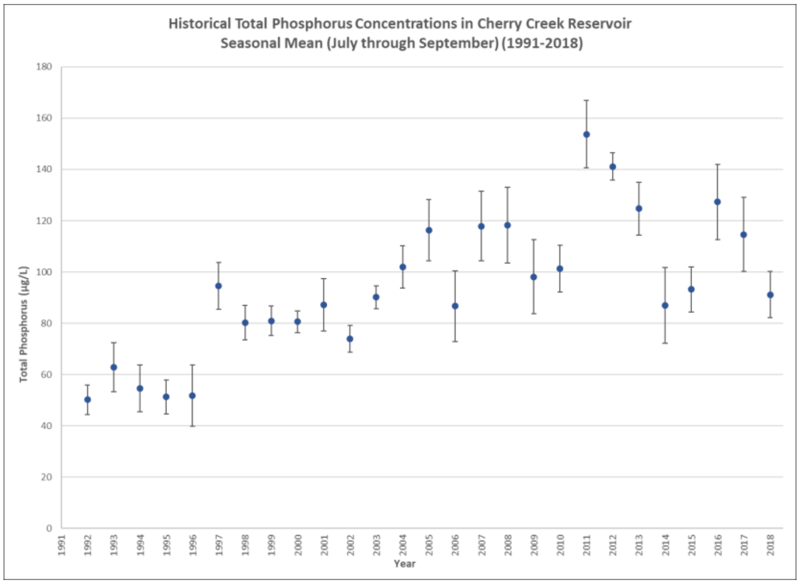
The WY 2018 seasonal mean was higher than the seasonal mean WY 2017 (18.7µg/L) but lower than the WY 2016 value (23.6 µg/L). Of the six (6) sampling events during the season (July 1-September 30), five of six (5/6) values had a mean value that exceeded the standard of 18 µg/L.

Transparency

The mean Secchi depth measurements of the three reservoir monitoring sites during WY 2018 ranged between 0.88 m and 1.83 m, with an average value of 1.06 m for the year. The seasonal mean was 1.05 m during the months of July to September. The Secchi depth measurements were similar for all three sites and followed the same trends when compared to the values collected during the same months in previous years.

The depth of 1% light transmittance into the water column had a strong correlation to the Secchi depth and ranged between 2.4 and 4.5 meters. The depth of 1% light transmittance ranged between 2.4 and 4.4 times the Secchi depth, but on average was approximately 3 times the Secchi depth.

Nutrients

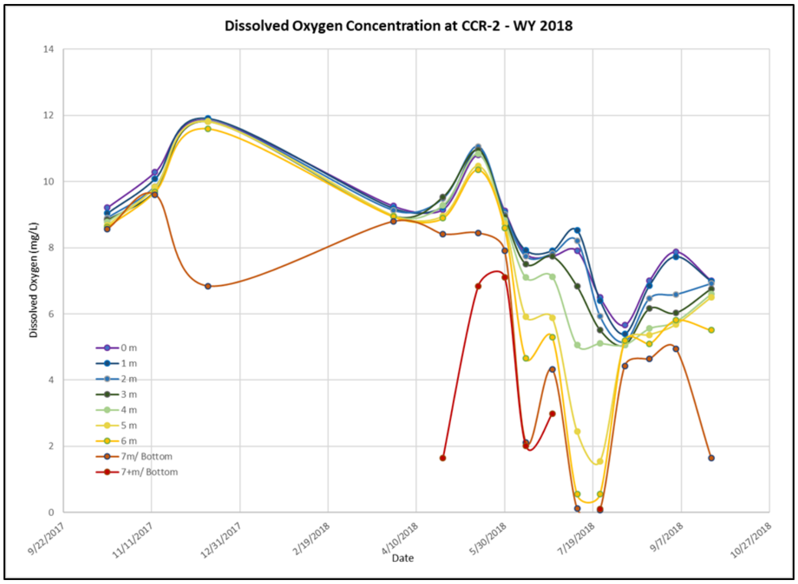


The WY 2018 seasonal mean (July-September) Total Phosphorus (TP) of 91.2 µg/L was lower than the WY 2017 (114.7 µg/L) and WY 2016 value (127.3 µg/L). The WY 2018 seasonal TP mean is also slightly lower than the long-term average of 93.8 µg/L measured from 1992- present. The seasonal mean values for TP appear to be increasing on a long-term scale although the last few years demonstrate a decreasing pattern.

During WY 2018, the monthly mean TP concentrations ranged between 67.1 µg/L and 105.2 µg/L with a mean value of 86.0 µg/L. The lowest values were present in May 2018 and the highest values in July 2018. The WY 2018 data suggests that there are high levels of TP in the Reservoir throughout the year contributing to eutrophic conditions.

Temperature and Dissolved Oxygen

Temperature and dissolved oxygen (DO) profiles were measured in Cherry Creek Reservoir during each sampling event. In addition, 15-minute temperature data was collected at CCR-2 at 1 m intervals from spring through fall 2018. Based on the data collected during WY 2018, the Reservoir met the temperature standards established for the Class I Warm Water Aquatic Life classification established by the Water Quality Control Commission (WQCC) in Regulation No. 38 (REG 38) of 29.2 ˚C Maximum Weekly Average Temperature (MWAT) and 32.5 ˚C Daily Maximum (DM). The maximum temperature measured in the surface profiles was 24.6 ˚C on July 10th 2018, and the highest temperature recorded by the continuous monitoring thermistors was 26.1 ˚C on July 19th 2018. On these same dates the total change in temperature was only approximately 4 degrees from top to bottom of the Reservoir. This data indicated that although there was some variability from the surface to the bottom in the warmer summer months, overall the Reservoir did not develop consistent thermal stratification.



During WY 2018, DO concentrations In Cherry Creek Reservoir also met the standards established for the Class I Warm Water Aquatic Life classification in WQCC Regulation No. 38, which requires that DO levels are 5.0 mg/L or above near the surface. The DO may be less than 5.0 mg/L near the bottom as long as there is a refuge with DO levels greater than 5.0 mg/L assessible for aquatic life. A few times levels from 5 m to the bottom were less than 5.0 mg/L during the monitoring events. However, during those times, the majority of the water column had DO levels that exceeded 5.0 mg/L providing adequate habitat (refuge) for aquatic life. Periods of low dissolved oxygen indicate high microbial activity or decomposition in the sediments which reduces DO concentrations.

pH, ORP and Conductivity

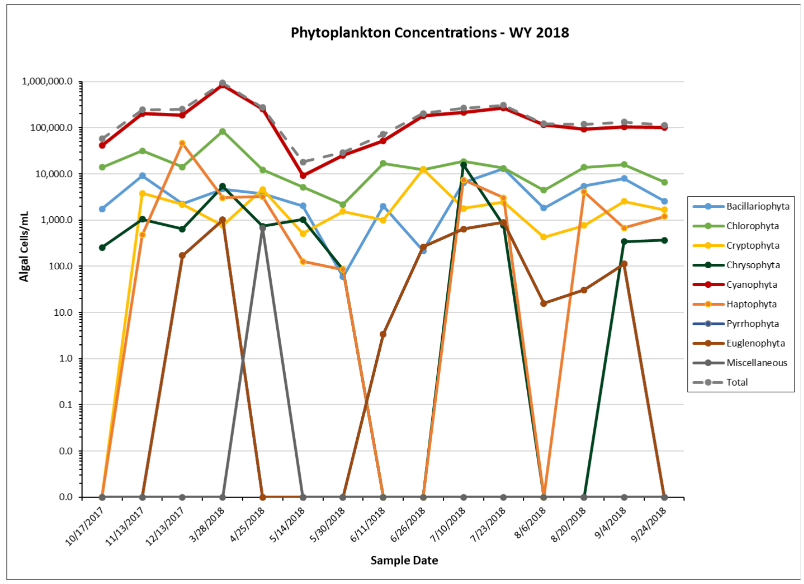
During WY 2018, the pH ranged between 7.7 and 8.6 which meets the instantaneous minimum and maximum standards of 6.5 and 9.0, respectively, set by REG 38. The higher pH values appeared to correlate with higher productivity and elevated chl-*a* in the Reservoir.

The Oxidation Reduction Potential (ORP) in Cherry Creek Reservoir in the photic zone ranged between from 73.5 mV and 47 miliVolts (mV). The ORP in the samples near or at the bottom of the reservoir ranged from -183 mV to 339 mV. The lower ORP values at the bottom of the Reservoir coincided with the lower DO measurements and the higher ORP values with higher DO levels and colder water temperatures.

The specific conductance (hereafter referred to as “conductivity” in this document) in Cherry Creek Reservoir in WY 2018 ranged from a minimum of 965 µS/cm to 1,198 µS/cm during WY 2018. There limited variability in conductivity from top to bottom of the Reservoir.

Phytoplankton

Phytoplankton samples from Cherry Creek Reservoir were collected and analyzed to identify and quantify the populations present. The results from WY 2018 indicate high productivity with diverse populations of 40 or more species present on most sampling dates. Cell counts were dominated by the Cyanophytes (cyanobacteria or blue-green algae) which were responsible for 75% or more of the total phytoplankton population throughout the year.



Some species of cyanobacteria are capable of producing toxins, but those species were not commonly observed during sampling in Cherry Creek Reservoir in WY 2018. *Chroococcaceae* spp. was the most common species of cyanobacteria, but it usually accounted for less than 10% of the total algal biovolume.

Bacillariophyta (diatoms) and Chlorophyta (green algae) were present in high numbers throughout the year and were responsible for more than 50% of the total algal biovolume on most sampling dates.

Along with the Cyanophytes, Bacillariophytes, and Chlorophytes, members of the Cryptophyte group (cryptomonads) were often present at levels of 1,000 or more cells/mL, which is a concentration associated with eutrophic conditions.

Phyrrophyta (dinoflagellates) bloomed in late fall 2017 and again in summer 2018 accounting for 28% of the total algal biomass in late June and 62% in mid-July.

Haptophytes (golden algae) are widely distributed in brackish or freshwater systems with higher salinities. They are of potential concern because they can produce toxins that are harmful to fish and other aquatic life. 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. Although concentrations of *Chrysochromulina parva* are usually relatively low, a peak was noted in December 2017, accounting for 18% of the total algal population and 48% of the algal biovolume.

Zooplankton

Zooplankton numbers and diversity from samples collected from Cherry Creek Reservoir during WY 2018 were both low compared to phytoplankton.

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

Copepods were typically the zooplankton present in the highest numbers accounting for over 50% of the total population throughout the summer months.

Cladocerans frequently comprised over half of the zooplankton biomass, although the species present in Cherry Creek Reservoir typically did not include large-bodied Daphnia that are an important source of fish food in many lakes. The lack of larger zooplankton may be related to the presence of high populations of gizzard shad (*Dorosoma cepedianum*). Gizzard shad are an important part of the food base for the Cherry Creek Reservoir walleye (*Sander vitreus*) fishery, but they are also effective filter feeders, especially at the larval stage (Johnson, 2014).

The most common cladocerans in Cherry Creek Reservior were *Daphnia ambigua*, *Bosmina longirostris*, and *Daphnia lumholtzi*. *Daphnia ambigua* is one of the smaller *Daphnia* and the bosminads, in general, are small cladocerans. *Daphnia lumholtzi* is an invasive species that can outcompete native species for food and is an undesirable food source for fish. No *Daphnia* were present in zooplankton samples collected on March 28th and August 20th 2018. The absence of *Daphnia* on two sampling dates and the general small size of the cladocerans present is likely due to predation by gizzard shad.

Trophic State Analysis

The Trophic State Index (TSI) of a lake is a relative expression of the biological productivity of a lake using total phosphorus, chl-*a* and transparency. Elevated values for the Trophic State Index are indicative of higher productivity. A TSI of less than 35 indicates oligotrophic conditions, a TSI between 35 and 50 indicates mesotrophic conditions, and a TSI greater than 50 indicates eutrophic conditions. Hypereutrophic, or excessively productive lakes, have TSI values greater than 70. Higher numbers are associated with increased probabilities of encountering nuisance conditions, such as excessive macrophyte growth and algal scums. Trophic state indices for Cherry Creek Reservoir for phosphorus, chl-*a* and transparency were all above 50, indicating that Cherry Creek Reservoir was eutrophic during WY 2018 (See Table 13, page 75).

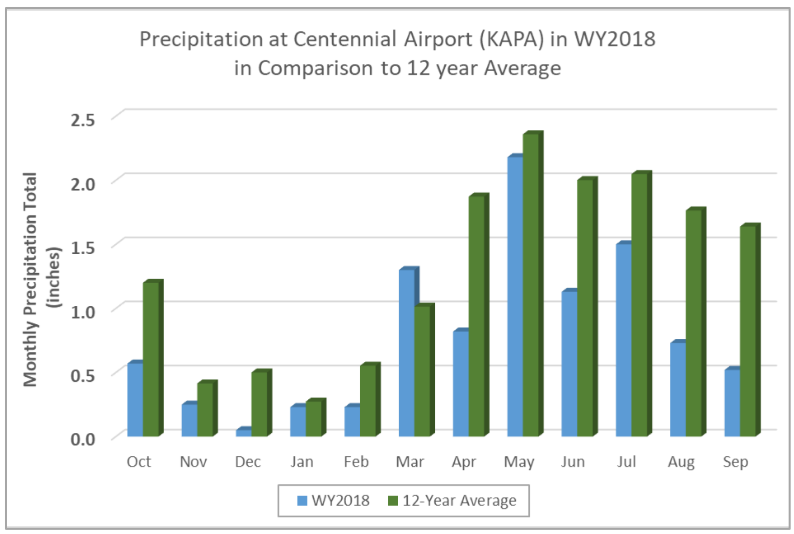
Table A. Trophic State Characteristics

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	**0.089**	**18.4**	**1.2**	**High**

Trophic state can also be assessed by comparing monitoring data to trophic state criteria, such as those developed by the U.S. EPA (1980). A comparison of Cherry Creek Reservoir monitoring data from WY 2018 to EPA trophic state criteria also indicates that Cherry Creek Reservoir was eutrophic in WY 2018. Although the Secchi depth indicated excessive productivity, this criterion does not take into account that suspended solids in the water may also affect transparency, such as is the case in Cherry Creek Reservoir.

WATERSHED HIGHLIGHTS

Precipitation



Precipitation in the watershed was much lower than average during the 2018 Water Year. The historical data from the National Ocean and Atmospheric Administration (NOAA) at the Centennial Airport Station (KAPA), indicated the area received 61% of the average precipitation based on the previous 12 years of data.

Although the watershed as a whole appears to have received less than average precipitation, total precipitation was slightly higher in areas towards the far southern and eastern areas of the basin where it was at or near average historical values.

Stream Flows

The yearly summary for the U.S. Geological Survey (USGS) gauge “Cherry Creek near Franktown, CO” in the southern area of the watershed listed a total annual flow of 1,570 Acre Feet (AF) with and an annual daily mean of 4.3 AF for WY 2018, which is approximately 47 percent of the annual mean discharge of 9.1 AF calculated from WY1940-WY 2018.

The yearly summary for the USGS gauge “Cherry Creek near Parker, CO” listed a total annual flow of 3,807 AF and an annual daily mean of 10.4 AF, which is approximately 92 percent of the annual mean discharge of 11.3 AF calculated from WY 1992 -WY 2018.

It is noteworthy that the headwater flows of Cherry Creek were 53% lower than average but flows were only 8% lower than average by the time the stream reached the USGS gauge "Cherry Creek near Parker, CO".

Cherry Creek

The WY 2018 data suggest some interesting trends and comparisons to Cottonwood Creek. Both upstream to downstream monitoring events indicate limited variability of pH. However, the data indicate that conductivity increases moving downstream, and appears to be increasing over time when compared to historical data.

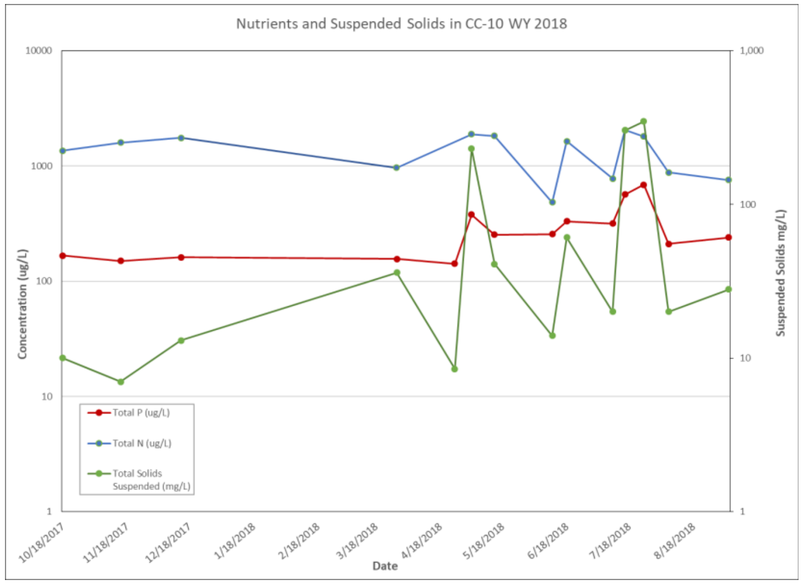
During both the November 2017 and May 2018 comprehensive upstream to downstream sampling, the level of TP remained relatively constant. However, total nitrogen (TN) increased from USGS gauge "Cherry Creek near Franktown, CO", downstream to the USGS gauge "Cherry Creek near Parker, CO", and then decreased all the way to the Reservoir and outflow, with the exception of elevated values at CC-5 and CC-8 respectively. During both events the TP levels from the outlet site (CC-O) were similar or less that those entering the Reservoir.

The biologically available forms of phosphorus and nitrogen (soluble reactive phosphorus (SRP), nitrate plus nitrate nitrogen (NO_3+NO_2-N), and ammonia nitrogen (NH_3-N) followed trends similar to the TP and TN concentrations from the upstream to downstream samples. During both bi-annual surface water sampling events, NH_3-N accounted for six percent (6%) or less of the TN present in Cherry Creek upstream of the Reservoir and twelve percent (12%) below the outlet. In contrast, NO_3+NO_2-N concentrations represented 25-75% of the TN upstream of the Reservoir and 1% below the outlet. The TP, SRP, TN and NO_3+NO_2-N levels during these sampling events indicate nutrient retention or utilization within the Reservoir before release from the outlet.

Conductivity and pH were monitored as surface water moves from the upper basin downstream to the Reservoir during both monitoring events. Conductivity increased 3.6-fold from upstream to downstream in November 2017 and 4.1-fold in May 2018 indicating increasing dissolved solids as the water moves downstream towards the Reservoir. The pH also increased downstream in the November 2017 samples but remained relatively consistent in May 2018, ranging from approximately 7.7 to 8.4 through the basin.

The pH values measured at CC-10 over time appear to have slightly decreased for a few years between 2009 and 2016 but increased again over the last 2 years. Conductivity values measured at CC-10 indicate an increasing trend over the last ten to twelve years, with most values double what they were a few years before.

The median TP concentrations were 150% higher in storm flows than base flow, and median TN concentrations were 91% higher in storm flows. The values of Total Suspended Solids (TSS) ranged between 7 and 347 mg/L and the median values were 1543% higher in storm than base flow conditions sampled.



The relationship between phosphorus and nitrogen and TSS concentrations is also reflected in the difference between the concentrations in samples collected at CC-10 during storm and base flow sampling events. Over time there is variability of both TN and TP during the base and storm flow monitoring. Typically storm flows increase the suspended sediments in the water, represented by higher values of TSS. During WY 2018, there was a distinct correlation of higher nutrient concentrations when the TSS levels were higher. These data suggest that storm events may contribute a larger percentage of the total nutrient loading to the Reservoir.

The WY 2018 flow-weighted phosphorus concentration was 236 µg/L, which was higher than WY 2017 but lower than WY 2016 and recent (2011 – 2015) flow-weighted total phosphorus concentrations. However, the WY 2018 flow-weighted average concentration for Cherry Creek station CC-10 remains much higher than the WY 2018 flow weighted total phosphorus concentration of 62.2 µg/L calculated for station CT-2 in lower Cottonwood Creek.

The WY 2018 flow-weighted nitrogen concentration was 1,883 µg/L, which was higher than WY 2017 (1260 µg/L), WY 2016 (1,012 µg/L), and the recent (2011 – 2015) flow-weighted total phosphorus concentration of 1,261 µg/L published in GEI (2016).

Similar to phosphorus, the WY 2018 flow-weighted nitrogen concentration for Cherry Creek station CC-10 remains much higher than the WY 2018 flow weighted total nitrogen concentration of 1,984 µg/L at site CT-2 just upstream of where Cottonwood Creek enters the Reservoir.

Cottonwood Creek

During WY 2018, the pH of water in Cottonwood Creek before it entered the Reservoir ranged from 7.9 to 8.2, with a median value of 8.15. The conductivity, or specific conductance, which represents dissolved solids in the water, at CT-2 ranged between 1,373 µS/cm and 1,648 µS/cm with a median value of 1,478 µS/ cm. This is higher than the median for Cherry Creek which was 1,098 µS/cm for WY 2018.

Summary statistics for total phosphorus, total nitrogen, and TSS concentrations at CT-2 during base and storm flows during WY 2018 are provided in Table 6. The TP concentrations ranged between 34 and 207 µg/L during the year. The median TP concentrations were 165% higher in storm flows than the base flow conditions. The TN concentrations ranged between 667 and 3790 µg/L during WY 2018. The median TN concentrations were 22% higher in storm flows. The values of TSS ranged between 4 and 56 mg/L and the median values were 1643% higher in storm flow conditions compared to base flows.

A similar relationship between nutrients and TSS is present at CT-2, although it was much less consistent than in Cherry Creek. In addition, the TP concentrations were much higher entering the Reservoir at CC-10 than at CT-2 during WY 2018.

POLLUTION REDUCTION FACILITIES (PRF) HIGHLIGHTS

Based upon the data collected in WY 2018, the Cottonwood PRF treatment train (Peoria Pond, stream reclamation completed on Cottonwood creek downstream and the Perimeter Pond) functioned by reducing TP concentrations by approximately 5 percent under base flow conditions and 65 percent during storm events. Sediment concentrations, measured as TSS, were reduced by approximately 15 percent under base flow conditions and 88 percent during storm flows. Based on the differences in reduction during high and low flow events, these PRFs functioned as designed to reduce phosphorus and sediment loading during WY 2018. (Table 7, page 40.)

However, when evaluating the two PRFs individually, it appears that the majority of the effectiveness of nutrient and sediment reduction can be attributed to the Perimeter Pond PRF. The TP concentrations from the CT-P1 above the Peoria Pond to CT-2 site below the Perimeter Pond were reduced by 5% under base flow conditions and 65% during storm events. CT-1 to CT-2 sampling during base flow conditions indicated a 40% reduction in TP, 19% reduction in TN and 51% reduction in TSS. When analyzing the Peoria Pond individually, the nutrient and suspended solids concentrations were slightly higher at CT-P2 than upstream at CT-P1. These values could be attributed to resuspension of sediments or breakdown of organic matter in the pond. In addition, the difference in sediment accumulation or time between dredging events could affect the results.

In WY 2018, TP, TDP, SRP and NO_3+NO_2-N were are all reduced from the upstream to downstream sites on McMurdo Gulch. In contrast, TN and NH_3-N slightly increased at the downstream site. During the sampling period, both TSS and VSS (Volatile Suspended Solids) values measured were higher downstream of the PRF but the difference was not very significant since the levels upstream were so low.

GROUNDWATER HIGHLIGHTS

Data from groundwater samples collected from the three monitoring wells upstream of the Reservoir as well as the one below suggests that the TP and SRP concentrations remained relatively consistent during both monitoring dates in WY 2018. In contrast, TN decreased as the wells get closer to the Reservoir, with a slight elevation at MW- Kennedy in November 2017, but the lowest values were measured below the outlet in May 2018.

The data from the comprehensive basin sampling of all Cherry Creek sites suggests little difference in TP concentrations between surface water and groundwater in November 2017 and May 2018. The mean concentrations of TP in the GW sites were 0.2 mg/ L in both November and May 2018. In contrast, the total nitrogen concentrations decreased toward the reservoir and below, with the exception of November 2017 which shows a slight increase in TN, NO_3+NO_2-N and NH_3-N, below the Reservoir at MW- Kennedy.

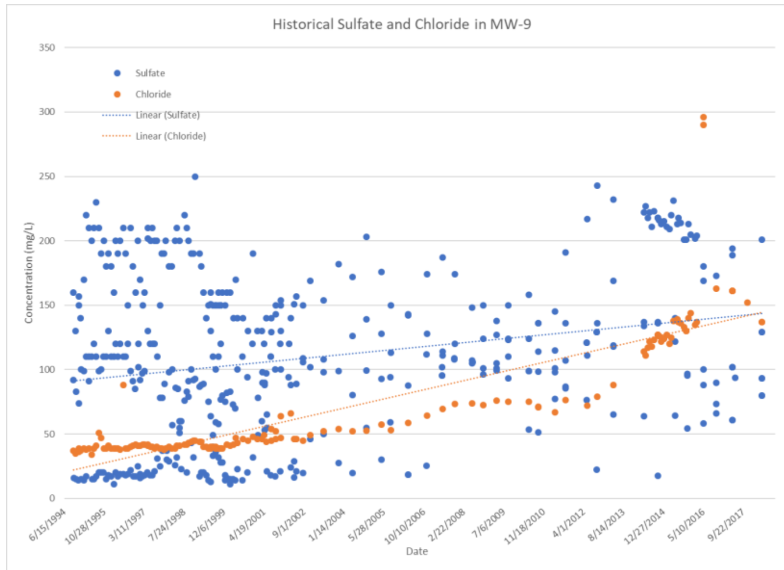
Both sampling events during WY 2018 indicated groundwater chloride concentrations averaged 140 mg/L and sulfate concentrations averaged 125 mg/L. The pH remained relatively constant and the conductivity seemed to follow the trend of the concentrations of chloride and sulfate in November 2017. However, during May 2018 sampling event, conductivity was more variable indicating additional dissolved solids were impacting the results.

During WY 2018, the pH values from the monitoring wells ranged between 6.5 and 7.5, with an historical mean value of near neutral at 7.12. The historical pH values from Monitoring Well MW-9 suggest that the pH at site MW-9 may be slightly decreasing over time.

The conductivity values at MW-9 suggest a slightly increasing trend over time, with a mean value of 807 µS/cm between 1995 and 2005 and a mean of 1103 µS/cm from 2006 to 2018.

Analysis of the historical data for MW-9 from 1994-2018 appears to show that chloride and sulfate may be increasing over time, although chloride may be less variable and increasing slightly more significantly.

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



The long-term TOC (Total Organic Carbon) concentrations in the alluvial groundwater samples collected from well MW-9 range from 2.7 µg/L to 4.3 µg/L, averaging 3.4 µg/L. The TOC concentrations measured in Nov 2017 were 3.32 mg/L and in May were 3.06 mg/L which are both slightly lower than the long-term averages. Historically, the dissolved fraction of the TOC in well MW-9 ranged between 66 percent and 100 percent, with a long-term average of 92 percent. In WY 2018, the Dissolved Organic Carbon (DOC) fraction was higher than the long-term average at 96 percent of the total.

WATER BALANCE HIGHLIGHTS

The estimated volumes of surface flow entering the Reservoir from these two surface water sources in WY 2018 are:

- Cherry Creek: 16,407 AF
- Cottonwood Creek: 3,228 AF

The estimated evaporative losses from the reservoir were 3,042 ac-ft during WY 2018, or approximately 44.1 inches (3.67 feet) per acre at the median surface area of 828 acres.

The USGS measured outflows for WY 2018 at Station 06713000, Cherry Creek below Cherry Creek Lake, CO totaled 15,653 AF, which were used for nutrient balance calculations.

The Reservoir WY 2018 water balance is summarized in Table B. The net ungauged inflows(+)/outflows(-) was mathematically calculated to result in the Reservoir change in storage to equal the -552 AF reported by the U.S. Army Corps of Engineers (USACE) for WY 2018, which includes ungauged surface water inflows into the reservoir, groundwater seepage from the reservoir through the dam, and measurement uncertainties. Net ungauged outflows for WY 2018 were 4,358 AF which were apportioned between the Cherry Creek and Cottonwood Creek inflows to calculate nutrient loading. Cherry Creek contributed 83.6% of the combined inflow and Cottonwood Creek contributed 16.4%, resulting in reductions surface inflows of 3,642 AF for Cherry Creek and 717 AF for Cottonwood Creek.

Table B. WY 2018 Water Balance

Water Source	Water Volume (AF)
Inflows	
Cherry Creek (CC-10)	16,407
Cottonwood Creek (CT-2)	3,228
Precipitation	666
Alluvial groundwater	2,200
Total Inflows	**22,501**
Outflows	
Evaporation	-3,042
Reservoir releases	-15,653
Total Outflows	**-18,695**
Net Ungauged Inflows/Outflows	
Calculation	-4,358
WY 2018 Change in Storage	**-552**

NUTRIENT BALANCE HIGHLIGHTS

Flow-weighted nutrient concentrations for WY 2018 are summarized in Table C.

Table C. Flow weighted nutrient loads to Cherry Creek Reservoir WY 2018.

		Source				
	Analyte	**Cherry Creek**	**Cottonwood Creek**	**Alluvial Groundwater**	**Precipitation**	**Flow - Weighted Total**
Inflow Concentration (ug/L)	Total Phosphorus	236	79	190	155	
	Total Nitrogen	1,833	1,984	430	2,009	
% of Total Inflow		70.4%	13.8%	12.1%	3.7%	
Flow-Weighted Concentration (ug/L)	**Total Phosphorus**	**166**	**11**	**23**	**6**	**206**
	Total Nitrogen	**1,290**	**274**	**52**	**74**	**1,691***

The WY 2018 flow-weighted TP concentration of all inflows of 206 ug/L is higher than WY 2017 (197 µg/L) and the 2011-2015 median of 200 µg/L but lower than WY 2016 (213 µg/L). The Cherry Creek Reservoir Control Regulation 72 (CR-72) has a flow-weighed TP goal of 200 ug/l total which is just below the calculated value for WY 2018.

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

The Reservoir inflows (nutrient loads) considered in the WY 2018 nutrient balance are:

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

Nutrient balances for total phosphorous and total nitrogen for Cherry Creek Reservoir are calculated for WY 2018 based on the nutrient calculations for inflow and releases. The WY 2018 total phosphorus and nitrogen mass balances are summarized in Table D. The difference between the inflow and the outflow loads indicate that a net 5,523 pounds of phosphorus and 47,145 pounds of nitrogen were retained in the Reservoir in WY 2018.

Table D. Nutrient Mass Balance for WY 2018

	Total Phosphorus	Total Nitrogen
Source	**Mass (pounds)**	**Mass (pounds)**
Surface Water		
Cherry Creek (CC-10)	8,187	63,638
Cottonwood Creek (CT-2)	539	13,358
Reservoir Release (CC-Out)	-4,622	-35,373
Alluvial Groundwater		
Inflow	1,137	1,885
Atmospheric		
Precipitation	281	3,637
Evaporation	0	0
WY 2018 Change in Storage	**5,523**	**47,145**

The total phosphorus inflow load calculation for WY 2018 is lower than WY 2017, WY 2016, and WY 2015 but higher than the historical means from 2011-2015 and the long-term mean from 1995-2015. The lower outflows during WY 2018 may have contributed to the higher mass retention of total phosphorus. The total nitrogen loads from WY 2018 are higher than any values from previous years or long-term mean values. The lower inflows during WY 2018 also contributed to higher retention rates of nitrogen in the Reservoir which were calculated to be much higher than in previous years.

RECOMMENDATIONS AND CONCLUSIONS

Recommendations

During the 2018 monitoring and data analysis efforts, recommendations for improvement and enhancement of the sampling program and analysis were developed. The following recommendations could help facilitate examining long-term water quality trends and additional factors impacting water quality within the watershed and sub-basins of Cherry Creek.

- Install level monitoring and stormwater collection equipment at the Piney Creek Site.

- Continue monitoring nitrogen and phosphorus ratios to determine relationships between chl-*a* and phytoplankton populations and the limiting nutrient in Cherry Creek Reservoir.
- Compare data from USACE Tri-Lakes Monitoring Program.
- Work with Colorado Parks and Wildlife (CPW) and downstream water users to assess attainment of beneficial uses in more detail.
- Continue the split analysis between IEH and High Sierra Laboratory through 2019 to ensure that the current limits provide the highest quality and accurate information for determination of nutrient ratios in the Reservoir.
- Install a stable cross section at CC-10 monitoring site in order to help obtain more accurate flow measurements, assist in calibration of the watershed model, and reduce chances for storm sampling equipment failure. The damage to the stream banks up stream of the monitoring site has resulted changes to the dynamics in in this section of stream which may have impacts to the sensitivity of the model flows at that site. The bottom of the stream at the level gauge has shown fluctuation and the sampling equipment has been buried causing lost samples and maintenance requirements.
- Evaluate options for analyzing the PRF ponds using a mass balance approach similar to the Reservoir on a smaller scale.

Conclusions

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

The assessment of the destratification system and feasibility of increasing mixing rate could provide important information to determine potential impacts to water quality if results indicate changes to existing operations would be beneficial.

Storm events appear to play a large role in nutrient and sediment loading of the reservoir. The current wetland PRFs appear to reduce sediment and nutrient loads during intermittent high flows. Assessment of these PRFs to determine scale and frequency of maintenance of these wetlands necessary to maintain storage capacity and reduce organic accumulation is vital to maintaining long-term function.

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

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

1.0 INTRODUCTION

The Cherry Creek Basin Water Quality Authority's (CCBWQA, or Authority) mission is to "Protect beneficial uses by preserving, enhancing, and balancing the water quality in Cherry Creek Reservoir and Cherry Creek watershed". And the vision is "water quality in Cherry Creek Reservoir and Watershed that optimizes beneficial uses for the public. Beneficial uses include recreation, fisheries, water supply, and agricultural uses. The CCBWQA was formally created by statute in 1988 by the Colorado State Legislature. The Authority Board consists of representatives from two counties, eight cities, a representative from special districts that provide water and wastewater treatment in the basin, and seven public representatives appointed by the Governor.

Figure 1. Cherry Creek Basin

The Cherry Creek Basin watershed includes over 386 square miles and 600 miles of creeks and streams. Cherry Creek Reservoir (Reservoir) is 880 surface acres, and is located near the base of the watershed, south of I-225 and west of Parker Rd., in Cherry Creek State Park. Cherry Creek State Park is approximately 4,000 acres and one of the most productive fisheries and widely enjoyed recreational areas in Colorado. The park has miles of trails to view birds and wildlife with scenic views of the Rocky Mountains in the background.

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

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

2.0 MONITORING PROGRAM

The WQCC's Cherry Creek Reservoir Control Regulation No. 72 (5 CCR 1002-72), (CR72), requires that the Authority execute a water quality monitoring program of the Cherry Creek watershed and Reservoir for Reservoir 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 Pollution Reduction Facilities (PRFs) to determine inflow and outflow nutrient concentrations. The sample collection and analysis provide data required to evaluate the nutrient sources and transport, characterize the reductions in nutrient concentrations, and calculate and document compliance with water quality standards. In addition, this data will be used to update the Reservoir and Watershed models.

The *Cherry Creek Basin Water Quality Monitoring Report - Water Year 2018* outlines the Authority monitoring program, data collected during the 2018 water year, and an evaluation of the results.

The WY 2018 monitoring program review is comprised of an assessment of data and results from the Reservoir and watershed, including water quality and quantity of surface water, groundwater, stormwater, and the effectiveness of Pollutant Reduction Facilities (PRFs). The water quality data and results described herein are made available on the Authority's Data Portal, http://www.ccbwqportal.org.

2.1 SAMPLING PROGRAM OBJECTIVES

The 2018 Sampling and Analysis Plan/Quality Assurance Project Plan (SAP/QAPP) provides the foundation for the sampling and analysis program activities, including sampling methods, QA/QC (quality assurance/quality control) protocols, etc. All monitoring activities and analytical work are performed in accordance with this document.

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

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

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

- Flow-weighted total phosphorus (TP) and total nitrogen (TN) concentrations transported to Reservoir from Cherry Creek and Cottonwood Creek.
- Calculate base flow and storm flow concentrations for nitrogen and phosphorus in tributary inflows, as well as concentrations in the Reservoir and the outflow.
- Long-term water quality trends in the Cherry Creek Basin over time.

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

2.2 SAMPLING PROGRAM DESCRIPTION

The monitoring and sample collection for the 2018 Water Year (WY) was completed by Tetra Tech between October 1st and December 31st, 2017 and by Solitude Lake Management from March 29th, 2018 to September 30, 2018. The 2018 Monitoring Program was conducted in accordance with the 2018 Cherry Creek Basin Water Quality Authority Routine Sampling and Analysis Plan/Quality Assurance Project Plan (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 nineteen (19) stream sites on Cherry Creek, Cottonwood Creek, Piney Creek, and McMurdo Gulch and four (4) alluvial groundwater sites along the mainstem of Cherry Creek. All sites are displayed on Figure 2., Cherry Creek Basin Monitoring Site Locations.

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

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

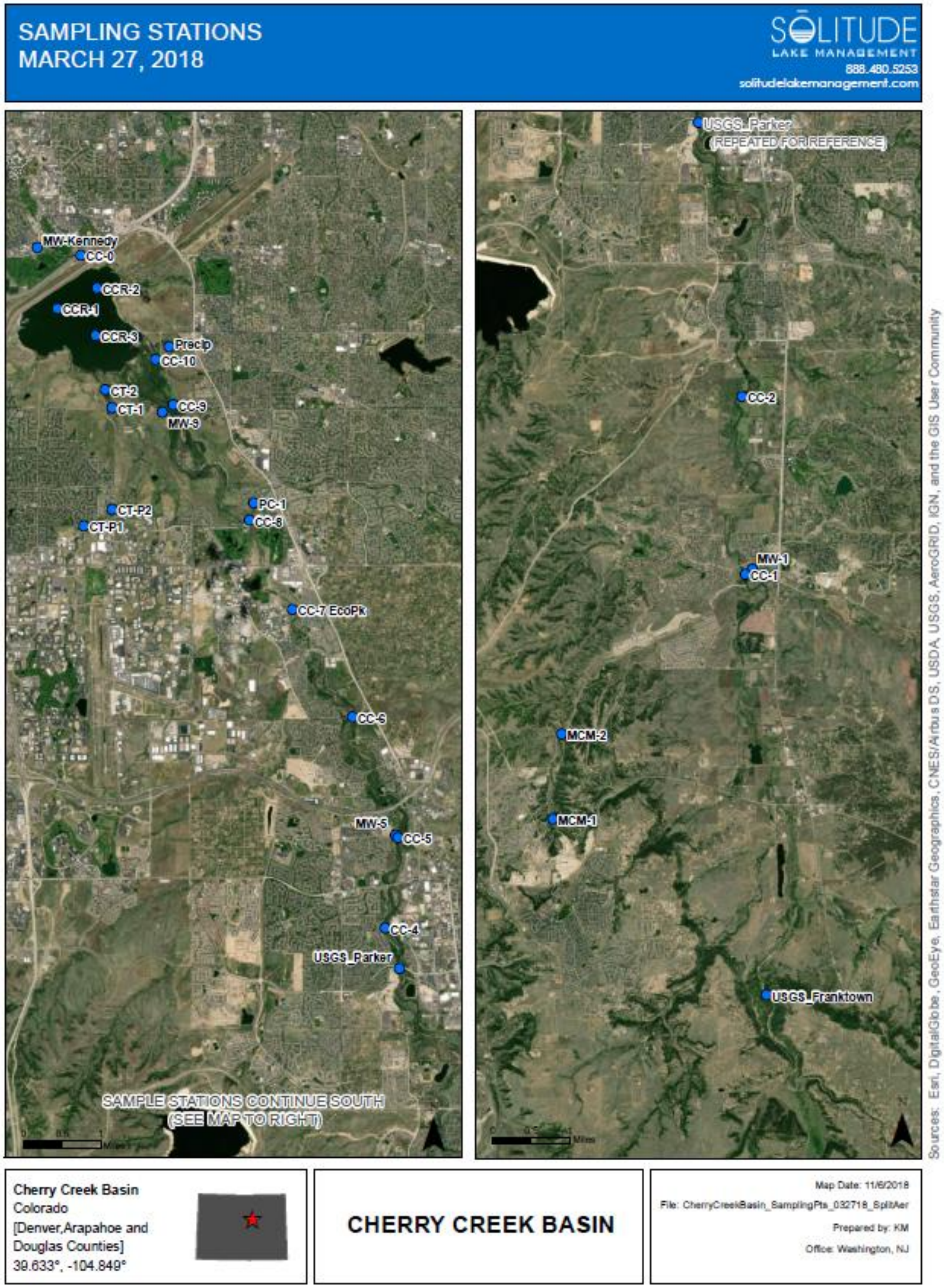


Figure 2. Cherry Creek Basin Monitoring Site Locations

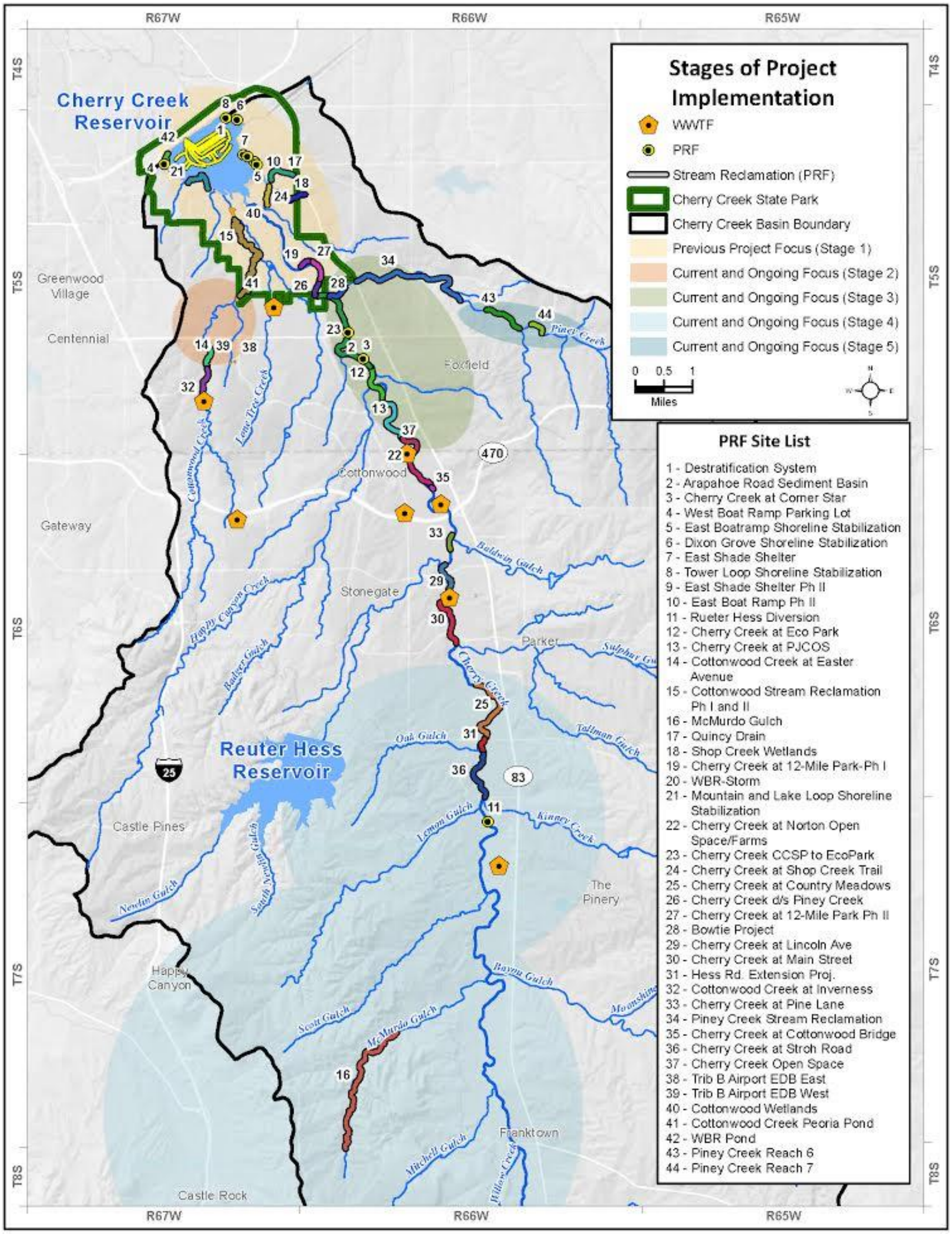


Figure 3. CCBWQA Water Quality Improvement Projects and Pollution Reduction Facilities

2.2.3 SAMPLING FREQUENCY

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

Table 1. Reservoir Sampling Sites, Parameters, and Frequency

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

Table 2. Precipitation Site Sampling Parameters

Analyte	Precipitation Site
Total Nitrogen	X
Total Phosphorus	X

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

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

2.2.4 LABORATORY ANALYSIS

Analytical services were provided by laboratories in accordance with laboratory QA/QC protocols outlined in the QAPP. One additional laboratory was added during WY 2018 in order to test capabilities and results of a lab that specializes in low-level nutrient water testing.

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 (40CFR 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).

High Sierra Water Laboratory

High Sierra Water Lab (HS) specializes in low-level nutrient water testing. They participate in the USGS Standard Reference Sample Program, which has the highest method accuracy. This lab was added during the 2018 season due to the differences in detection limits provided by IEH and previous laboratories.

In 2016, when Tetra Tech took over the monitoring project, the analysis was changed to IEH Analytical although split samples were run between GEI Consultants and IEH Analytical to compare and understand variability. Tetra Tech provided support for switching labs to IEH in Appendices C of the 2016 and 2017 Annual reports. Upon detailed analysis of the data, the reporting limits provided by IEH were higher than previously provided by GEI and as specified in the SAP/QAPP.

As part of the QA/QC protocol, nutrient samples were split between IEH Analytical and High Sierra Water Labortory to understand lab variability and differences in detection/reporting limits. Split analysis of Reservoir samples was completed monthly in August, September, and October 2018 between High Sierra and IEH. A preliminary analysis was completed to determine differences between the two labs and if the lower detection limits would affect the nutrient ratios. The difference in nutrient data provided by IEH and HS did not appear to affect the nutrient limitation calculations. The nitrogen to phosphorus (N:P) ratios were calculated substituting 0.001 mg/L (half of the HS detection limit of 0.002 mg/L for TP), 0.005 mg/L (half of the IEH reporting limit of 0.010 mg/L for NO_3+NO_2-N and NH_3-N), and 0.009 mg/L (the concentration just below the IEH reporting limit for NO_3+NO_2-N and NH_3-N) for non-detectable values of NO_3+NO_2-N and NH_3-N. Even in a theoretical scenario, when both NO_3+NO_2-N and NH_3-N were below the reporting limit, the N:P ratio did not show a change in the limiting nutrient until P was less than 0.002 mg/L. After the analysis, the difference in detection limits did not seem to affect the N:P ratios because all nutrient concentrations were so low. Table 4. summarizes the analytical laboratories and laboratory managers used during the 2018 program.

Table 4. Analytical Laboratories

Laboratory/Manager	Analytical Services
IEH Analytical, Inc., Damien Gadomski, Ph.D.	Nutrients, inorganics, organics, and chl-*a*.
PhycoTech, Inc., Ann St. Amand, Ph.D.	Phytoplankton and Zooplankton, identification, enumeration, concentration, biovolume and biomass.
High Sierra Water Laboratory Collin Strasenburgh	Low level nutrients, monthly splits (August, September, and October)

2.2.5 WATER QUALITY METHODS AND ANALYTE DESCRIPTION

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

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

pH

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

Oxidation Reduction Potential

Oxidation reduction potential measurements are used to quantify the exchange of electrons during redox[2] or oxidation-reduction reactions. Electrical activity is reported in millivolts (mV), which is very similar to a pH probe. At the water/sediment boundary layer, microbial organisms facilitate the chemical reactions but do not actually oxidize or reduce the compounds. Redox reactions provide energy for microbial cells to carry out their metabolic processes (Wetzel 2001). The combination of microbial organisms and redox reactions are responsible for the breakdown of organic matter and development of anoxic conditions near the sediment boundary in reservoirs during the summer. Higher ORP values indicate an oxidative environment and high potential to break down organic matter in the water. Low and negative values indicate a reducing environment and usually correlate to lower dissolved oxygen concentrations and higher microbial decomposition activity usually present at deeper sites and in the sediments of lakes.

Conductivity

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

Dissolved Oxygen

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

Temperature

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

[2]Redox is a chemical reaction in which the oxidation states of atoms are changed.

Secchi Depth

The Secchi depth of a waterbody is way to quantity turbidity or water clarity and is measured when an 8" black and white disk is no longer visible as it is lowered into the water column. The measurement is based on the amount of light scattered by particles in the water column. The Secchi depth is higher when there are less 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 percent 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 percent light transmission is accomplished by using an ambient and underwater quantum sensor attached to a data logger. The ambient quantum sensor remains on the surface, while the underwater sensor is lowered into the water on the sunny side of the boat. The underwater sensor is lowered until the value displayed on the data logger is 1 percent of the value of the ambient sensor, and the depth is recorded.

Chlorophyll-a

Chlorophyll is the green pigment that allows plants to photosynthesize. The measurement of chl-*a* 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-*a* is a measurement of the portion of the pigment that was still actively respiring and photosynthesizing at the time of sampling and does not include dead biomass. In surface water, lower chl-*a* 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 growth is soluble, inorganic orthophosphate or soluble reactive phosphorus. Organic phosphates quickly bind to soil particles and plant roots and consequently, much of the phosphorus in aquatic systems is bound and moves through the system as sediment particles. This organic form of phosphorus is considered to be biologically unavailable. However, under anoxic (low oxygen) conditions, bound phosphorus can be released from bottom sediments, and the concentration of biologically available orthophosphate can increase dramatically. The erosion of soil particles from steep slopes, disturbed ground, and streambeds is the primary source of phosphorus in aquatic systems. Surface runoff containing phosphorus from fertilizers, wastewater effluent and decaying organic matter will also contribute to biologically available phosphorus enrichment.

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

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

Nitrogen

Nitrogen has a complex cycle and can exist in organic and inorganic, particulate and soluble forms. The soluble, inorganic, oxidized forms are nitrate (NO_3^{-1}), and nitrite (NO_2^{-1}) which are normally found in surface water. The reduced 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, and various other reduced forms of nitrogen can be produced by decomposition processes. Particulate and dissolved organic forms of nitrogen are not immediately available to drive algal growth but can be converted to ammonia by bacteria and fungi, and can be oxidized to form nitrites and then nitrates. Surface runoff can contain inorganic nitrogen from fertilizers and organic nitrogen from animal waste, wastewater, etc.

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

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

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

Nitrogen/Phosphorus Levels and Ratios

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

Trophic State

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

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

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

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

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

Chloride and Sulfate

Chloride and sulfate are major ions that can be indicators of pollutants entering a watershed due to de-icing activities, treated wastewater discharge, stormwater runoff etc. Chloride and sulfate are two dissolved solids that impact conductivity.

Total Suspended Solids

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

Total 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.

2.2.6 CHL-A SAMPLING METHOD

Based on the chl-*a* analysis lab comparison completed between GEI and IEH in 2016 and 2017 it appears that additional variables may also play a role in laboratory results. In 2018, Solitude Lake Management field-filtered all chl-*a* samples instead of shipping samples for laboratory filtration as completed in 2016 and 2017. Some split samples of field-filtered and shipped samples for laboratory filtration were completed during WY 2018. Based on the preliminary analysis, all field-filtered samples had slightly higher chl-*a* than the samples that were shipped for laboratory filtration. It is also estimated that the determination that the GEI data were generally higher that IEH may also be due to quick sample processing in the local lab vs. filtration the following day after the samples are shipped overnight to the laboratory. GEI verified that, although they did not field filter the samples, they were all filtered on the same day they were collected prior to 2016. In addition, GEI was filtering all samples in the dark.

In 2018, eight samples were run as duplicate,s as either field-filtered, or laboratory-filtered to determine if one method consistently provided higher results. The laboratory-filtered samples were consistently a few micrograms or approximately 10-20% lower than the field-filtered samples. However, the same amount of variability was present between duplicates where both samples were field-filtered, although some results were higher and some lower.

Although all methods used are approved Standard Methods, additional analysis on field vs. laboratory filtration will be completed in 2019 to determine how much variability may be present in the slightly modified chl-*a* sampling methods and if it has a conclusive effect on results.

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 W 20Y18, nineteen (19) surface and groundwater sites were monitored on a monthly, every other month or bi-annual frequency.

Monthly Base Flow Sampling

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

Every Other Month Base Flow Sampling

When there is sufficient flow, one sample is collected every other month from the following sites CT-P1, CT-P2, MCM-1, MCM-2, and PC-1. Samples are collected midstream from mid-depth and kept cool until shipped to the laboratory for chemical analysis.

Bi-Annual Base Flow Sampling

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

Bi-Annual Groundwater Sampling

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

Storm Event Sampling

Samples from storm flow events are collected using ISCO automatic samplers, which are programmed to collect samples when the flow reaches a threshold level. The threshold level is determined by analyzing annual hydrographs from each stream and determining levels associated with storm events. When the threshold is reached, the ISCO collects a sample every 15 minutes for approximately 2.5 hours (i.e., a timed composite) or until the water recedes below the threshold level. This sampling procedure occurs at CT-P1, CT-2, CC-10, and CC-7 EcoPark. Following the storm event, water collected by the automatic samplers is combined and stored on ice until transferred to the laboratory for analysis. Up to seven storm samples are collected from each of the monitoring sites during the April to October storm season.

The watershed monitoring program evaluates surface water and groundwater:

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

3.1 PRECIPITATION

Historically, precipitation in the Cherry Creek watershed has been measured at NOAA's Centennial Airport weather station (KAPA) located at Lat 39.56°N Long 104.85°W and an elevation of 5,869 ft. This station measured a total of 9.5 inches of precipitation in WY 2018, approximately 61% percent of the 12-year average. March was the only month that received above average precipitation, as shown in Figure 4. When looking at the annual precipitation map, the watershed as a whole appears to have received less than average precipitation although the total precipitation was slightly higher towards the far southern and eastern areas of the basin where WY 2018 precipitation was near or equal to average. (Figure 5.)

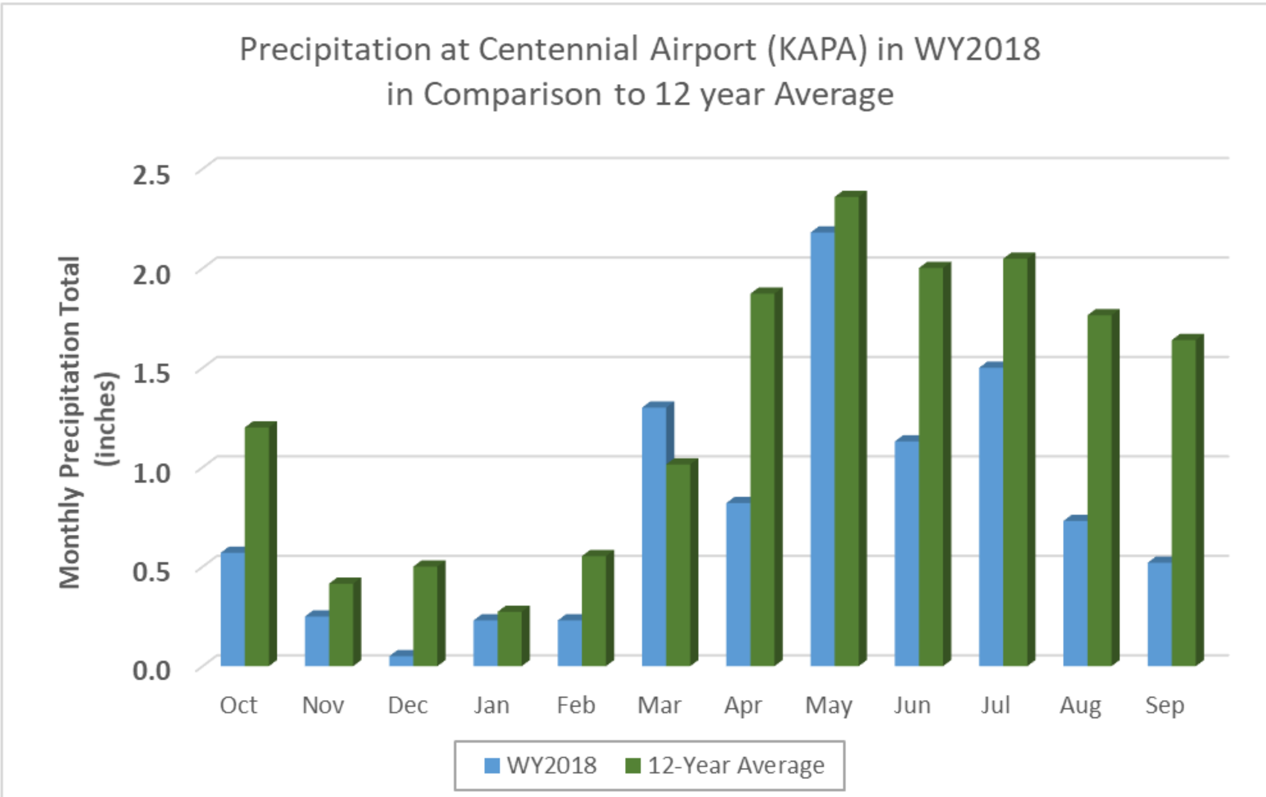


Figure 4. Monthly Precipitation in WY18 compared to 12-year average.

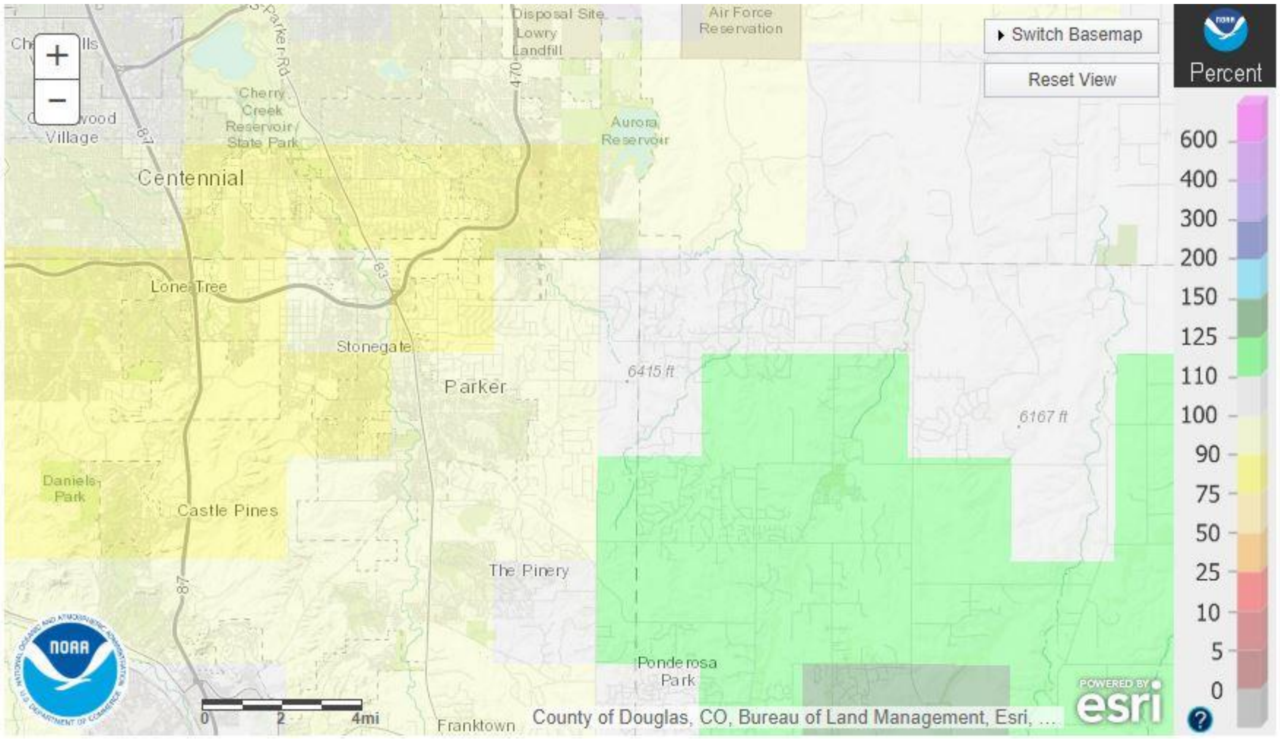


Figure 5. Percent of Normal Precipitation in the Cherry Creek Watershed. (https://water.weather.gov/precip/)

3.2 STREAM FLOWS

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

The USGS Cherry Creek near Franktown station is located in Castlewood Canyon State Park at Lat 39°21'21", Long 104°45'46" referenced to North American Datum of 1927, in NE 1/4 sec.15, T.8 S., R.66 W., Douglas County, CO, Hydrologic Unit 10190003, on right bank. The station is 1.3 mi downstream from Castlewood Dam site, 1.5 mi upstream from Russellville Gulch, and 2.5 mi south of Franktown. This station has a drainage area of 169 mi^2. The USGS WY 2018 summary statistics list a total annual flow of 1570 AF with an annual daily mean of 4.3 AF. This rate was approximately 47 percent of the annual mean discharge of 9.1 AF calculated from WY1940-WY 2018. Figure 6 shows the estimated daily discharge along with the median daily statistic from the last 78 years.

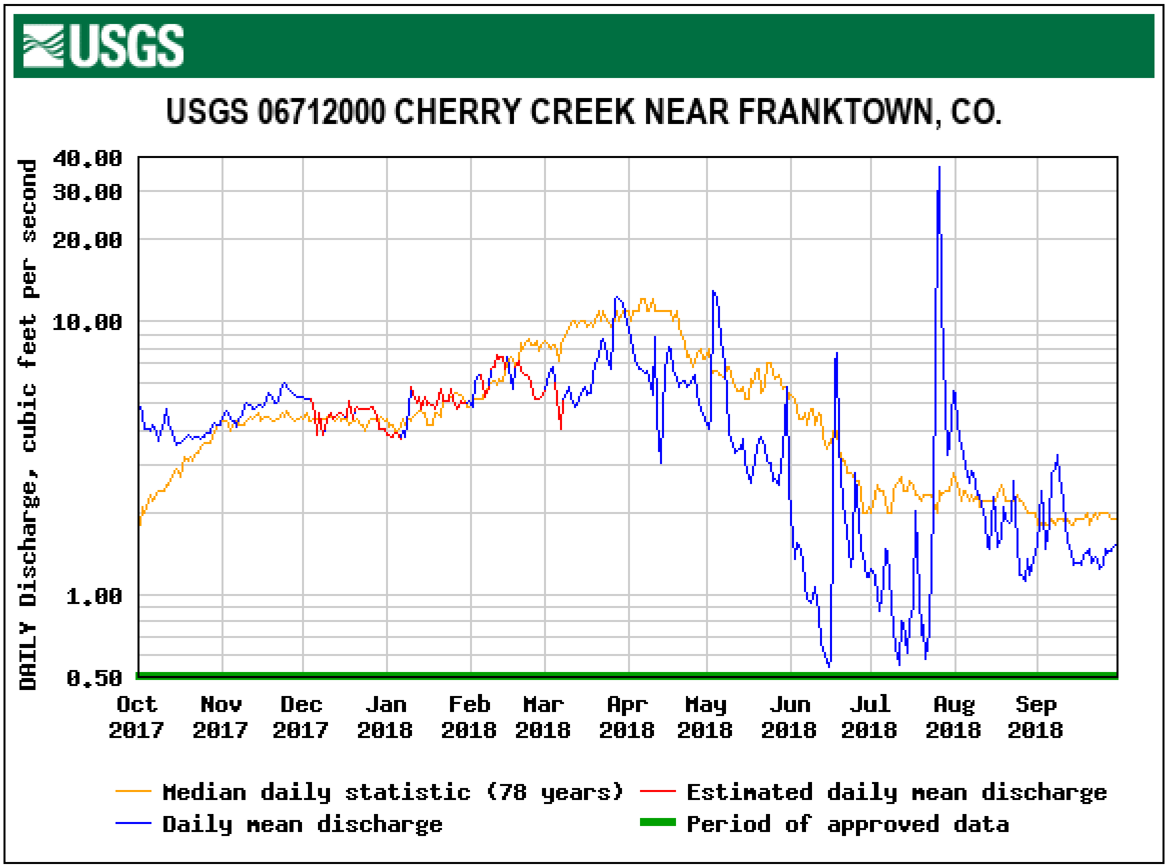


Figure 6. WY 2018 Daily Mean Discharge and Historical Median Flows for USGS Gauge near Franktown

The USGS Cherry Creek near Parker station is located Lat 39°31'09", Long 104°46'45" referenced to North American Datum of 1927, in SE 1/4 NW 1/4 NE 1/4 sec.21, T.6 S., R.67 W., Douglas County, CO, Hydrologic Unit 10190003, on right bank 200 ft upstream from Main Street, 1,100 ft downstream from mouth of Sulphur Gulch, and 0.8 mi west of City of Parker. The station has a drainage area of 287 mi².

The USGS WY 2018 summary statistics list a total annual flow of 3807 AF with an annual daily mean of 10.4 AF. This rate was approximately 92 percent of the annual mean discharge of 11.3 AF calculated from WY 1992 -WY 2018. Figure 7 shows the estimated daily discharge along with the median daily statistic from the last 27 years.

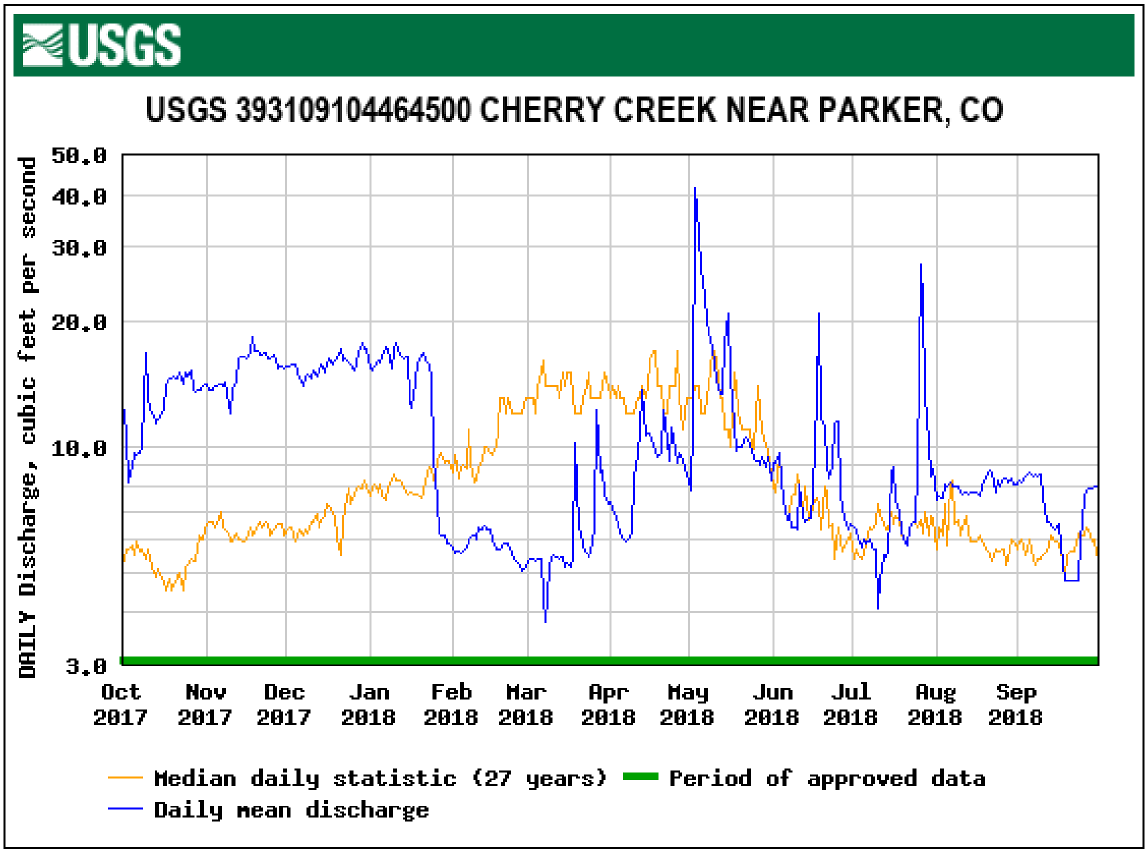


Figure 7. WY 2018 Daily Mean Discharge and Historical Median Flows for USGS Gage near Parker

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

The estimated WY 2018 flow at the CC-10 monitoring site totals 16,407 AF with an average daily discharge of 22.7 cfs. The estimated WY 2018 flow at the CT-2 monitoring site total 3,228 AF with an average daily discharge of 4.5 cfs.

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 2018 daily inflow estimates are included in Appendix C.

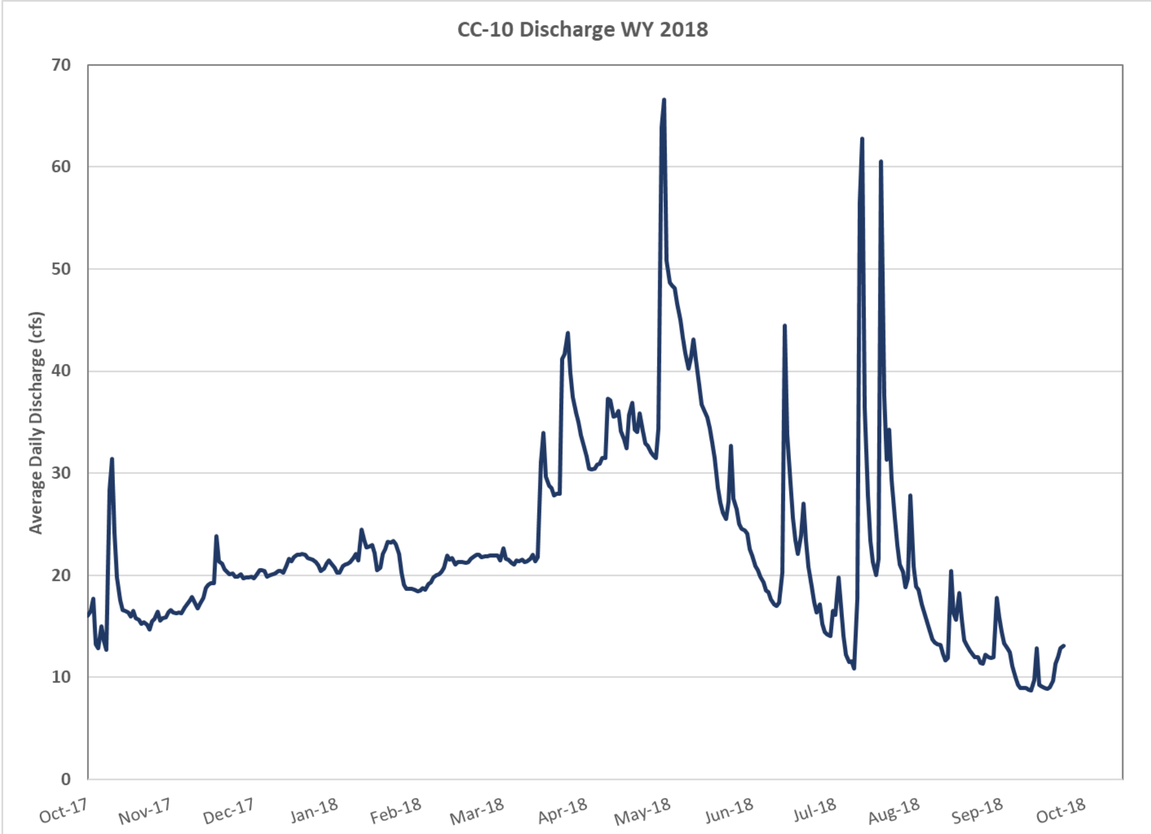


Figure 8. Daily Discharge Rates at CC-10 during WY 2018.

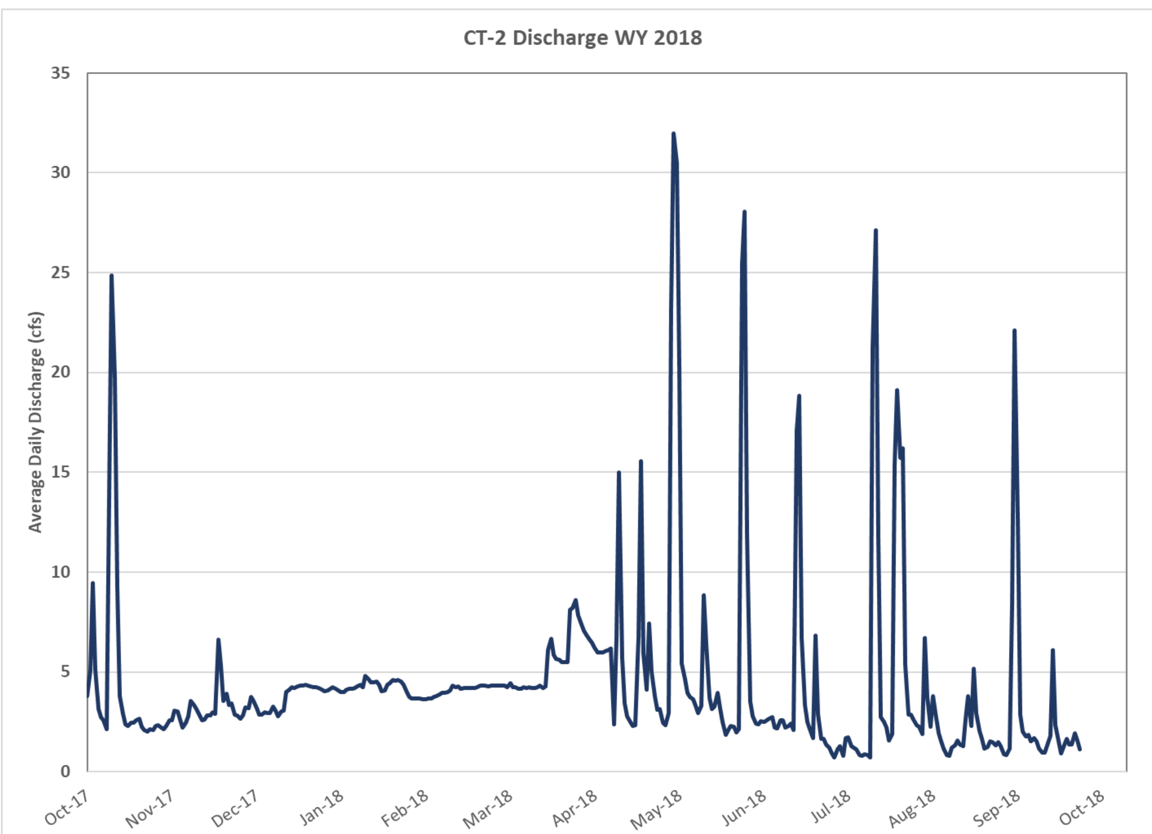


Figure 9. Average Daily Discharge at CT-2 during WY 2018.

3.3 CHERRY CREEK WATER QUALITY

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

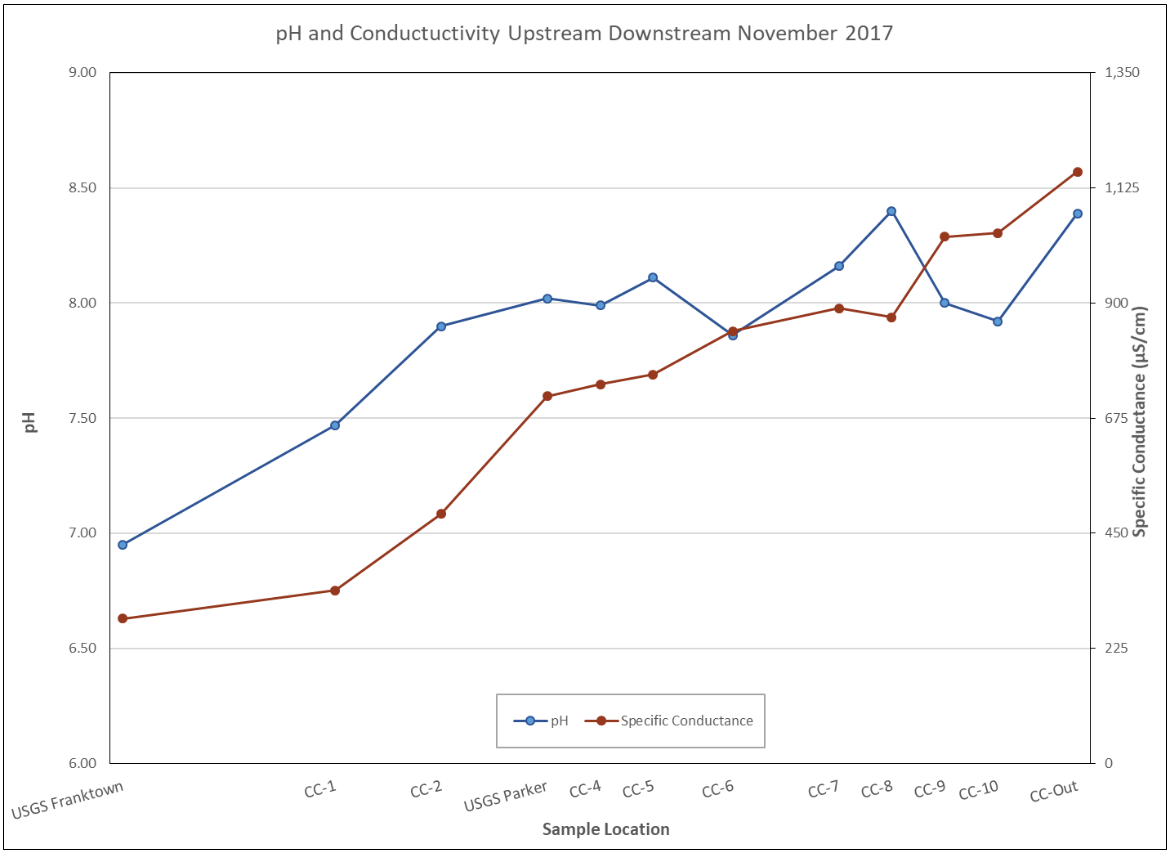


Figure 10. pH and Conductivity Upstream to Downstream on Cherry Creek, November 2017.

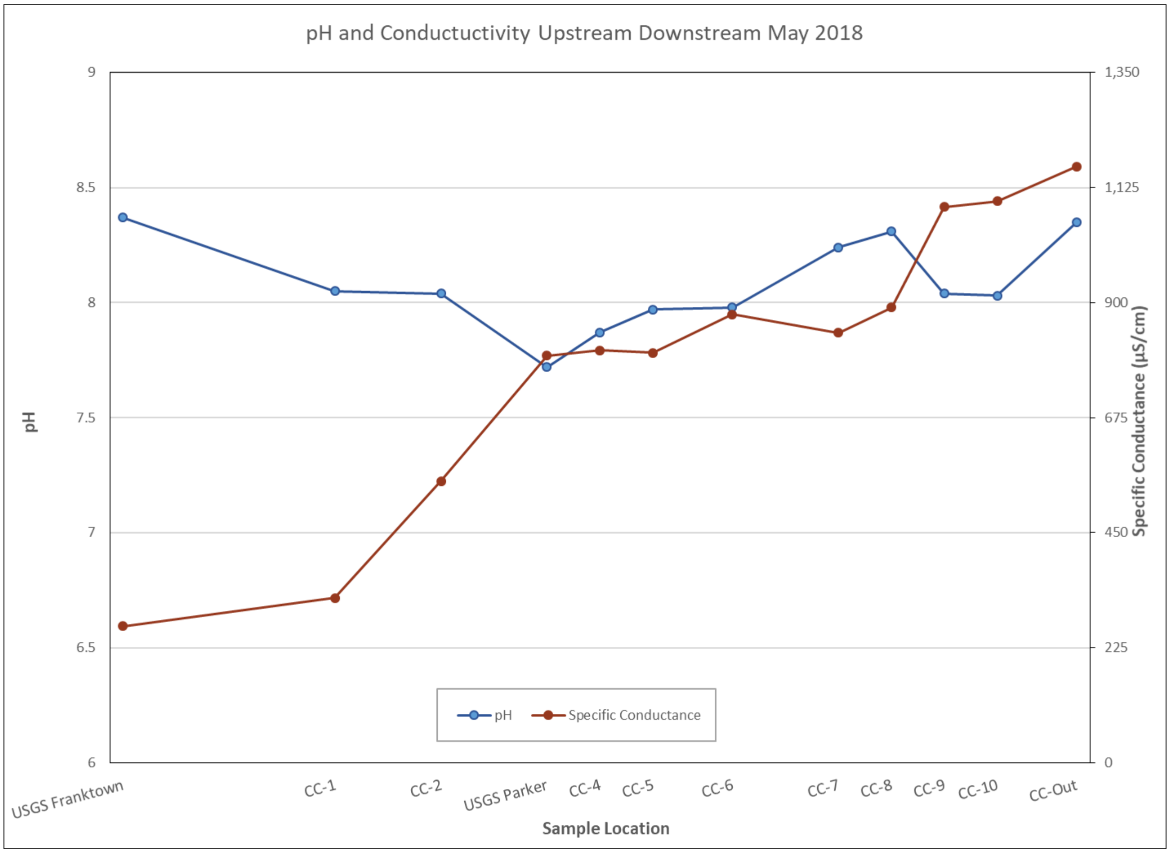


Figure 11. pH and Conductivity Upstream to Downstream on Cherry Creek, May 2018.

The specific conductance (conductivity) and pH were monitored as surface water moves from the upper basin downstream to the Reservoir in November 2017 and May 2018 (Figure 10 and Figure 11). Conductivity increased 3.6-fold from upstream to downstream in November 2017 and 4.1-fold in May 2018. The increasing conductivity in the upstream to downstream samples indicates increased dissolved solids, such as salts, in the water as it moves towards the Reservoir. The pH also increased downstream in the November 2017 sampling event but remained relatively consistent in May 2018, ranging from approximately 7.7 to 8.4 through the basin.

The historical pH values measured at CC-10 appear to have slightly decreased for a few years between 2009 and 2016 but have increased again over the last 2 years (Figure 12). The specific conductance values measured at CC-10 indicate an increasing trend over the last ten to twelve years, with most values double what they were a few years before (Figure 13).

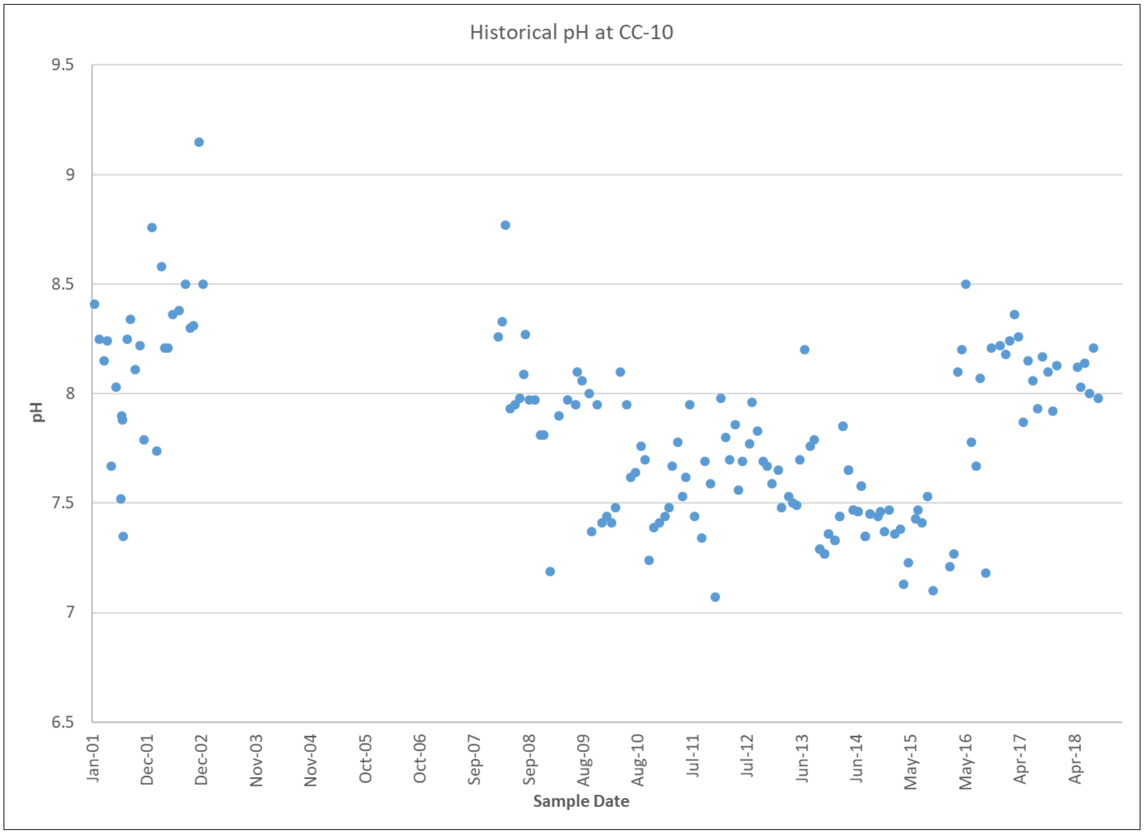


Figure 12. Historical pH Values at CC-10 through WY 2018

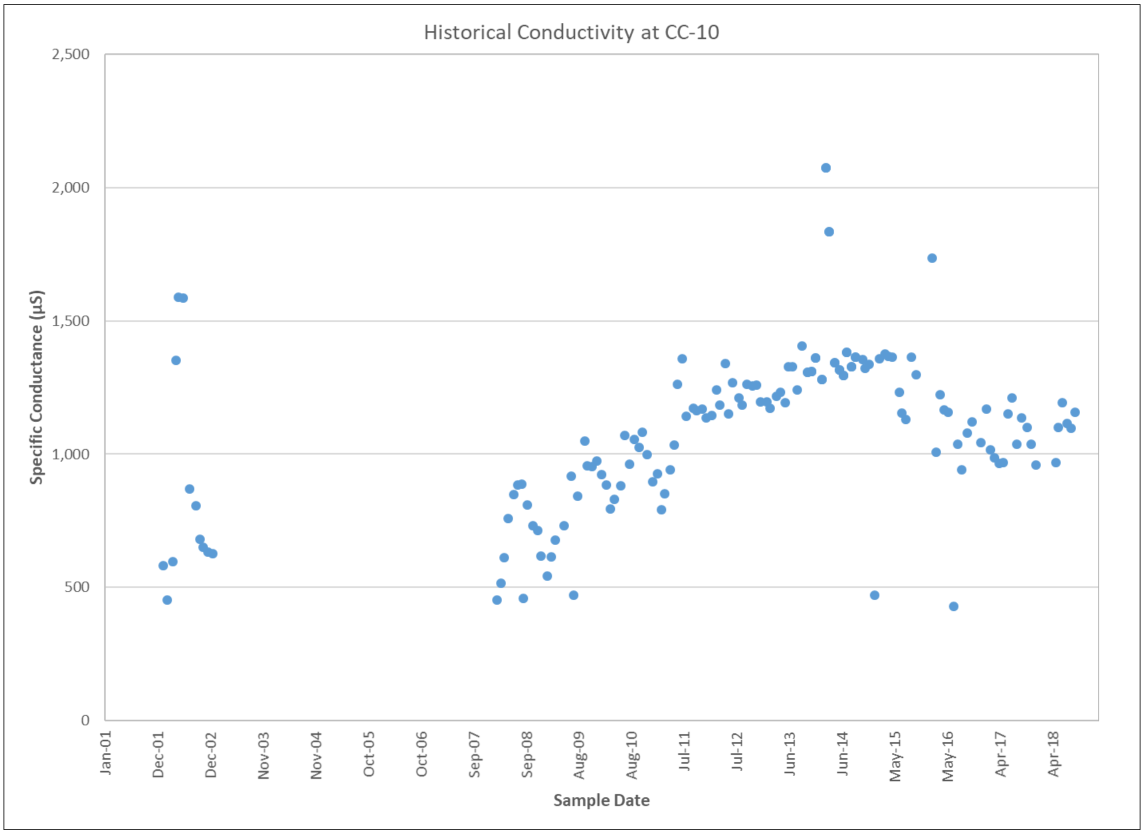


Figure 13. Historic Conductivity at CC-10 through WY 2018

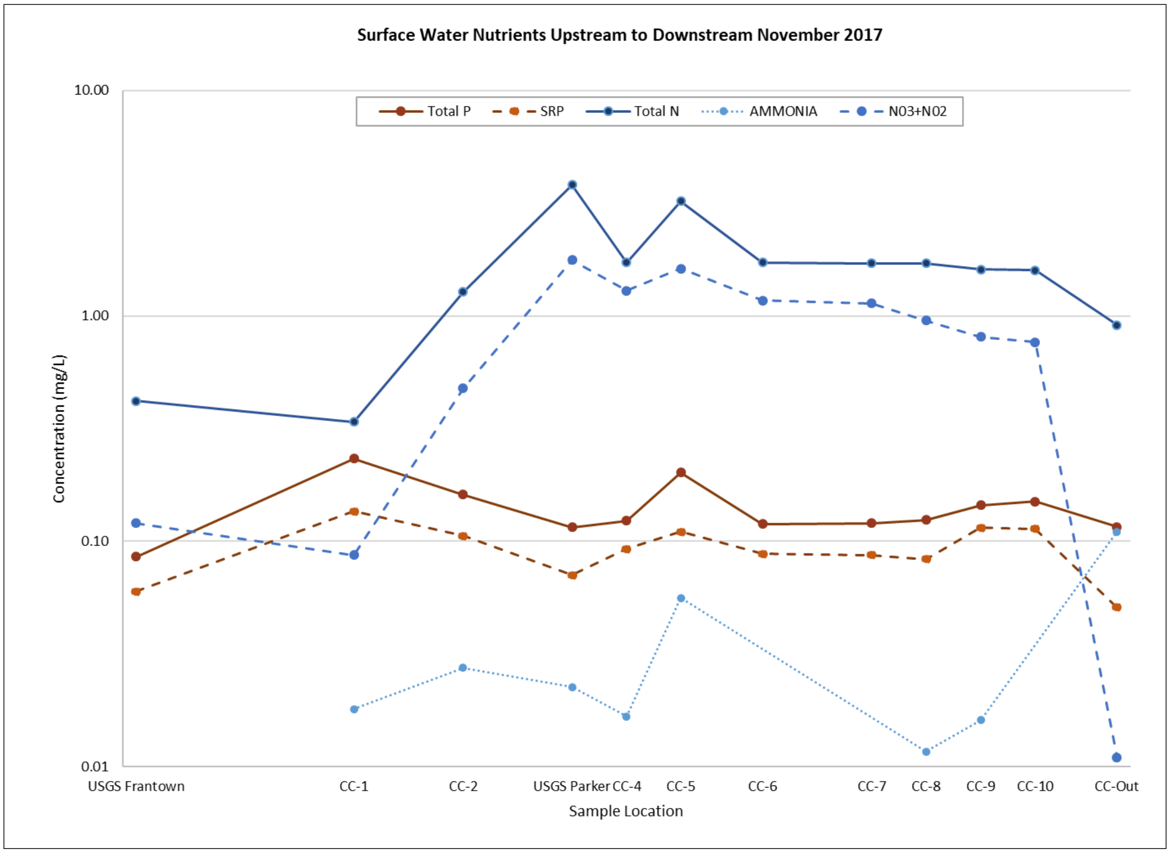


Figure 14. Surface Water Nutrient Sampling of Cherry Creek, November 2017 .

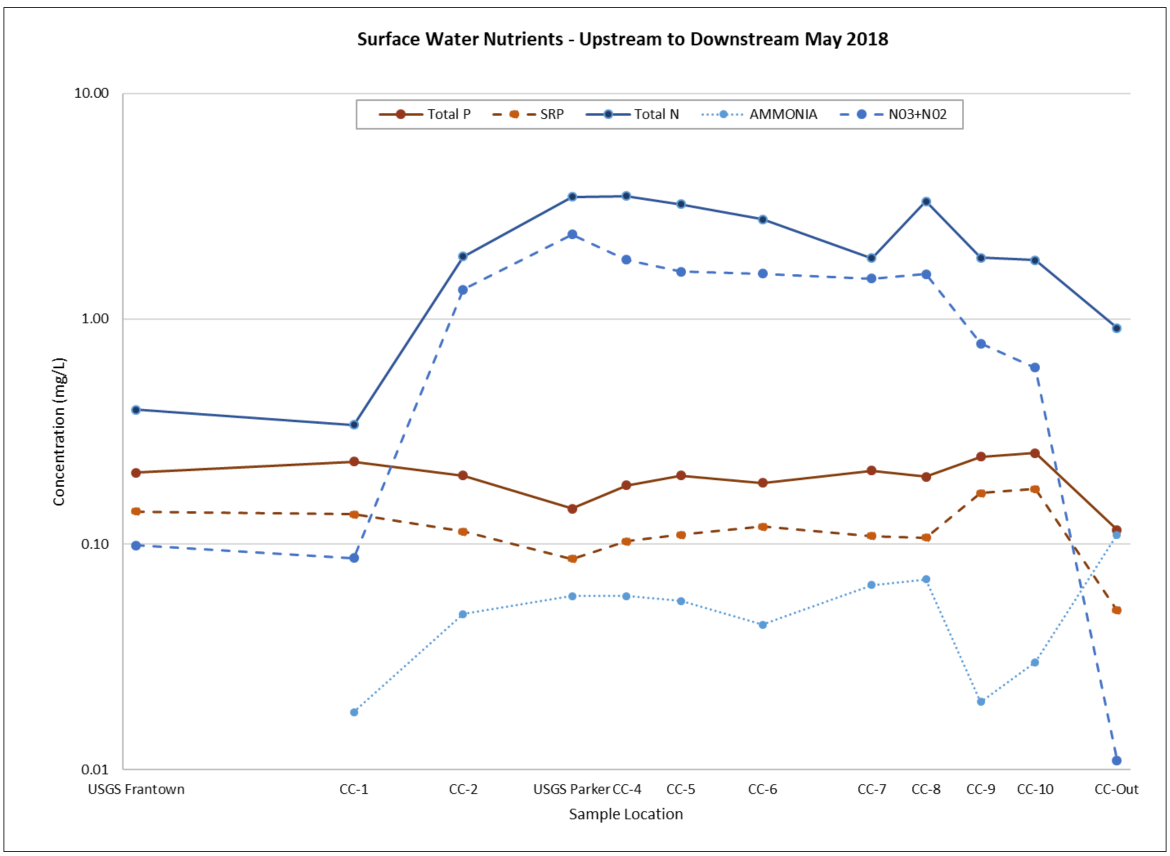


Figure 15. Surface Water Nutrient Sampling of Cherry Creek, May 2018.

During the November 2017 comprehensive upstream to downstream sampling, the level of TP remained relatively constant. However, the TN increased from the USGS near Franktown site downstream to USGS near Parker site, dipped slightly at CC-4, increased at CC-5 and then decreased all the way to the Reservoir and outflow (Figure 14).

During the May 2018 comprehensive upstream to downstream sampling (Figure 15), the of level TP again remained relatively constant. During this event the TN increased from the USGS near Franktown site downstream to USGS near Parker site, then showed a decreasing trend all the way to the Reservoir and outflow with the exception of a slight increase at CC-8 (Figure 15). During both events the TP levels from the outlet site (CC-O) were less than those entering the Reservoir.

In both the November 2017 and May 2018 surface water sampling events, NH_3-N accounted for six percent (6%) or less of the TN present in Cherry Creek upstream of the Reservoir and twelve percent (12%) below the outlet. In contrast, the NO_3+NO_2-N represented 25-75% of the TN upstream of the Reservoir and 1% below the outlet.

The TP, SRP, TN, and NO_3+NO_2-N levels at CC-0 during these sampling events indicate nutrient retention or utilization within the Reservoir before release from the outlet.

Table 5. Total Phosphorus and Total Nitrogen at CC-10 during Base Flow and Storm Events, WY 2018.

Statistic	Total Phosphorus (ug/L)			Total Nitrogen (ug/L)			Total Suspended Solids (mg/L)		
	Base Flow	Storm Sampling Events	Difference between base and storm flow	Base Flow	Storm Sampling Events	Difference between base and storm flow	Base Flow	Storm Sampling Events	Difference between base and storm flow
Count	10	4 **		9	4**		10	4**	
Minimum	142	332	134%	484	1,640	239%	7	61	771%
Maximum	316	687	117%	1820	2,050	13%	41	347	746%
Mean	205	491	140%	1155	1,845	60%	19	201	958%
Median	189	472	150%	964	1,845	91%	14	230	1,543%

* TN was not analyzed in 4/25/18 samples due to laboratory error

**Due to site conditions and related equipment failure, 5/3/18 only had two bottles full and the 6/18/18 sample was a grab sample.

Summary statistics for total phosphorus, total nitrogen, and TSS concentrations at CC-10 during base and storm flows during WY 2018 are provided in Table 5. The TP concentrations ranged between 142 and 678 µg/L during the year. The median TP concentrations were 150% higher in storm flow than base flow. The TN concentrations ranged between 484 and 2,050 µg/L during WY 2018. The median TN concentrations were 91% higher in storm flows. The values of TSS ranged between 7 and 347 mg/L and the median values were 1543% higher in storm flow than base flow conditions sampled.

The relationship between phosphorus and nitrogen and TSS concentrations is also reflected in the difference in concentrations from samples collected at CC-10 during storm and base flow sampling events. Figure 16 illustrates the relationship between TP and TN and both nutrients in relation to TSS in the water. Over time there is variability of both TN and TP during the base and storm flow monitoring. Typically storm flows increase the suspended sediments in the water, represented by higher values of TSS. During WY 2018, there was a distinct correlation of higher nutrient concentrations when the TSS levels were higher. This data suggests that storm events may contribute a larger percentage of the total nutrient and sediment loading to the Reservoir. Due to sedimentation and related equipment failure at CC-10 some storm event samples were not collected in WY 2018. However, this relationship will continue to be examined.

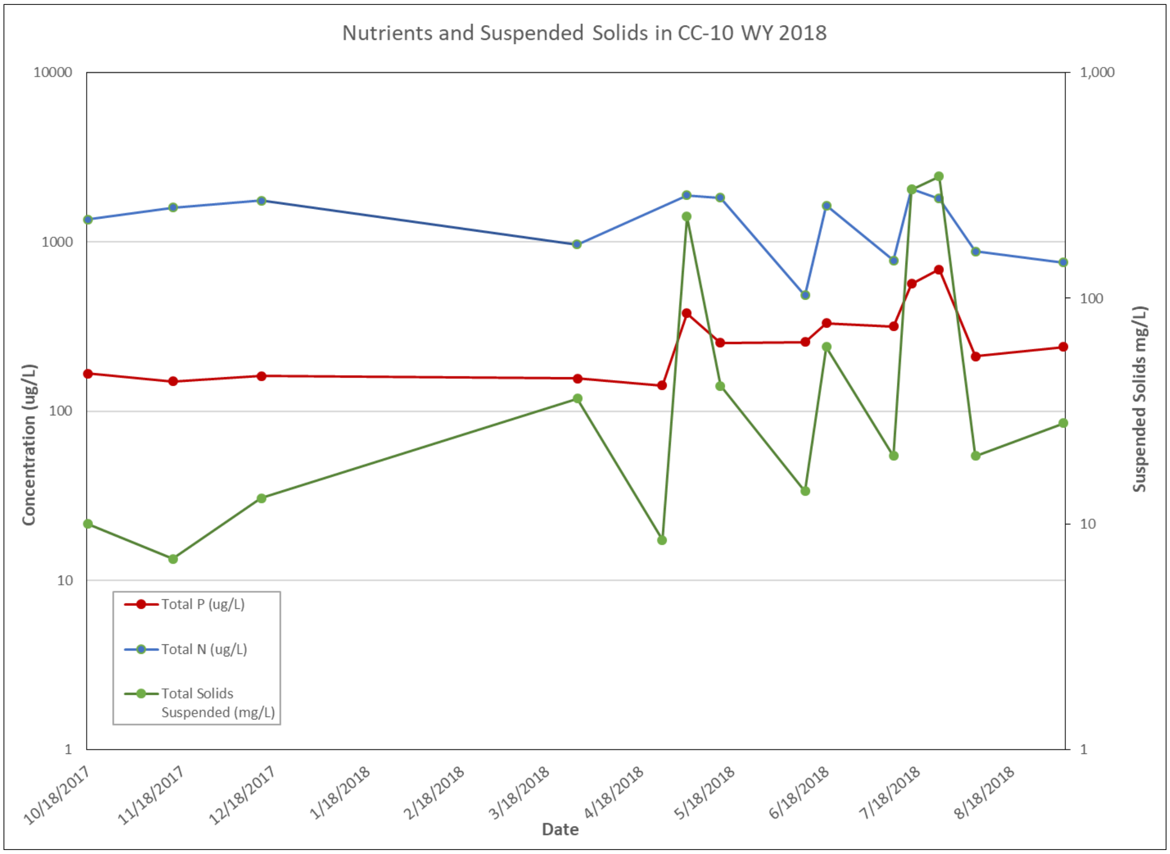


Figure 16. Comparison of Total Phosphorus and Nitrogen to Total Suspended Solids at CC-10, WY 2018.

3.3.1 PINEY CREEK

Piney Creek is one of the tributaries which feeds Cherry Creek. A sampling site was added on this creek in order to determine water quality from this sub-basin and potential influence on the water quality in Cherry Creek. This site was sampled every other month during 2018 but only 3 of the dates fell in WY 2018 (April, June and August). The mean values for each of the analytes from the 3 samples are listed in the table below. As a reference the mean values for the same parameters from Cherry Creek at CC-10 from the same dates are listed in the table for comparison.

Table 6. Water Quality in Piney Creek and Cherry Creek, April, June and September WY 2018.

	Mean Concentration	
	Site	
Analyte	**PC-1**	**CC-10**
TP, µg/L	0.07	0.20
SRP, µg/L	0.04	0.19
TDP, µg/L'	0.05	0.17
TN, µg/L*	0.75	0.68
NO_3+NO_2-N, µg/L	0.24	0.46
NH_3-N, µg/L	0.01	0.01
TSS, mg/L	5.2	10.6
TVSS, mg/L	1.9	3.0

With the exception of TN, all nutrient and suspended solids mean concentrations were lower in Piney Creek than just below the confluence with Cherry Creek during the same time period. In future years, additional sampling will be completed at this site as well as upstream and downstream of the confluence with Cherry Creek to evaluate the water quality in storm flows in addition to base flow conditions.

3.4 COTTONWOOD CREEK WATER QUALITY

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

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

During WY 2018, the pH of water in Cottonwood Creek before it entered the Reservoir ranged from 7.9 to 8.2, with a median value of 8.15. Conductivity at CT-2 ranged between 1,373 µS/cm and 1,648 µS/cm with a median value of 1,478 µS/ cm. This is higher than the median for Cherry Creek, which was 1,098 µS/cm for WY 2018.

Summary statistics for total phosphorus, total nitrogen, and TSS concentrations at CT-2 during base and storm flows during WY 2018 are provided in Table 6. The TP concentrations ranged between 34 and 207 µg/L during the year. The median TP concentrations were 165% higher in storm flows than the base flow conditions measured. The TN concentrations ranged between 667 and 3790 µg/L during WY 2018. The median TN concentrations were 22% higher in storm flows. The values of TSS ranged between 4 and 56 mg/L and the median values were 1643% higher in storm than base flow conditions sampled.

The concentrations of TP and TN measured at CT-2 in WY 2018 are shown in Figure 17 with the TSS values on the second axis as a comparison. As pictured, a similar relationship between nutrients and TSS is present at CR-2, although it is much less than Cherry Creek. In addition, the TP concentrations are much higher entering the Reservoir at CC-10 than at CT-2 during WY 2018.

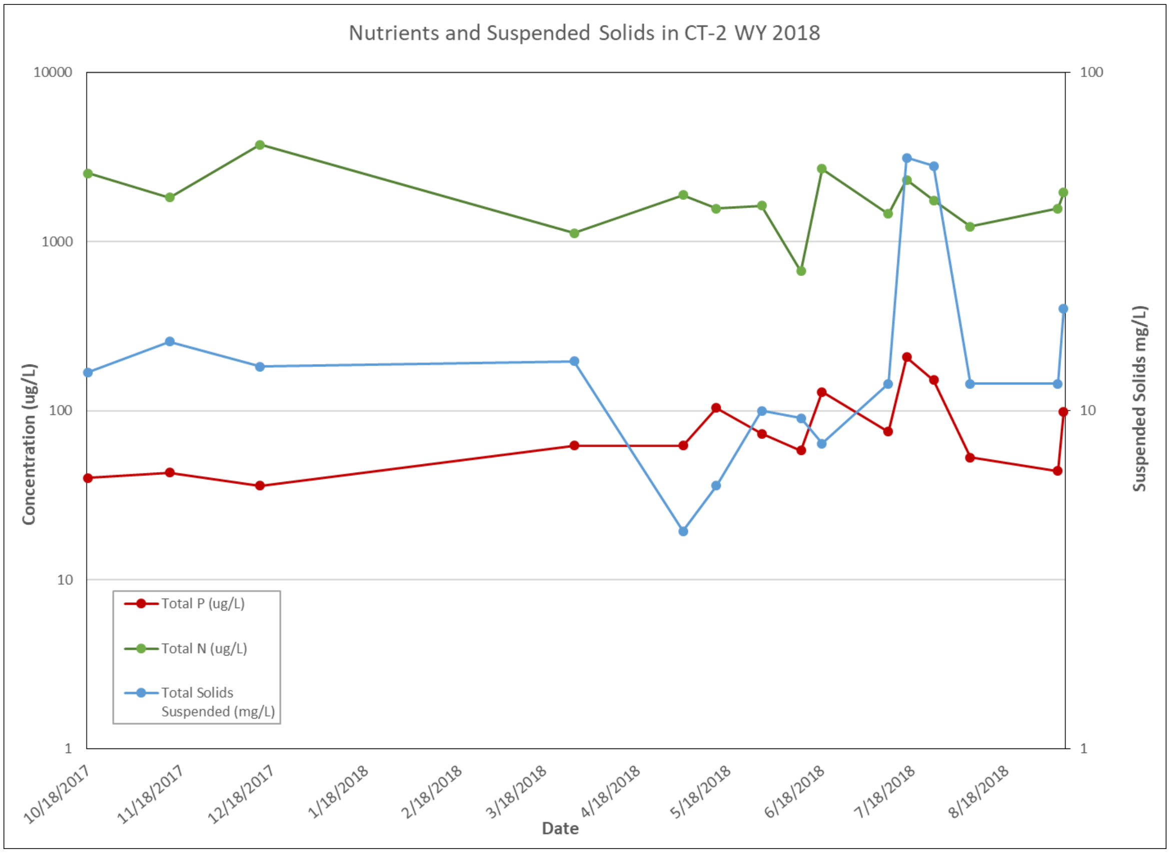


Figure 17. Comparison of Nutrients and Suspended Solids at CT-2 during WY 2018.

Table 7. TN and TP at CT-2 During Base Flow and Storm Events, WY 2018.

Statistic	Total Phosphorus (µg/L)			Total Nitrogen (µg/L)			Total Suspended Solids (mg/L)		
	Base Flow	Storm Sampling Events	Difference between base and storm flow	Base Flow	Storm Sampling Events	Difference between base and storm flow	Base Flow	Storm Sampling Events	Difference between base and storm flow
Count	10	6		9*	6		10	6	
Minimum	34	99	191%	667	1,630	144%	5	4	-20%
Maximum	58	207	257%	3,790	2,690	-29%	16	56	250%
Mean	45	120	167%	1,832	2,038	11%	11	25	134%
Median	43	114	165%	1,570	1,920	22%	12	15	25%

* TN was not analyzed in 4/25/18 samples due to laboratory error

Summary statistics for total phosphorus and total nitrogen concentrations at CT-2 in WY 2018 base flow and storm sampling events regimes are provided in Table 7.

3.5 POLLUTANT REDUCTION FACILITIES

The Cherry Creek Basin has multiple pollution reduction facilities (PRFs) in various locations through the watershed. The SAP includes assessment of the effectiveness of selected PRF projects in relation to changes in nutrients and sediment loading. The current monitoring program includes assessment of the PRFs on McMurdo Gulch and Cottonwood Creek.

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

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

During WY 2018, during base flow conditions, there was an increase in TDP, TN and NO_3+NO_2-N between CT-P1 and CT-2 although TP, SRP, NH_3-N decreased. During storm flow conditions, TP and TN decreased and SRP, TDP, NH_3-N increased. TSS and VSS concentrations decreased from upstream to downstream during both base flow and stormflow conditions (Table 8).

Based upon the data collected in WY 2018, the Cottonwood PRFs as a whole (between Peoria Pond and Perimeter Pond) functioned by reducing TP concentrations by approximately 5 percent under base flow conditions and 65 percent during storm events. Sediment concentrations, measured as TSS, were reduced by approximately 15 percent under base flow conditions and 88 percent during storm flows. Based on the differences in reduction during high and low flow events, the PRFs reduced phosphorus and sediment concentrations in downstream flows during WY 2018.

However, when evaluating the two sections individually, (Table 9 and Table 10) it appears that the majority of the effectiveness of nutrient and sediment reduction can be attributed to the Perimeter Pond PRF. The TP concentrations from site CT-P1 above the Peoria Pond to site CT-2 below the Perimeter Pond were reduced by 5% under base flow conditions and 65% during storm events. CT-1 to CT-2 sampling during base flow conditions indicated a 40% reduction in TP, 19% reduction in TN and 51% reduction in TSS. When analyzing the Peoria Pond individually, the nutrient and suspend solids concentrations were slightly higher at CT-P2. The increases could be due to resuspension of sediments or breakdown of organic matter in the pond. The difference could also indicate sediment removal may be needed to remove organic material and to restore capacity and function.

Table 8. Pollutant Reduction Analysis of the Cottonwood PRFs in WY 2018

Flow	Median Concentration Base Flow			Median Concentration Storm Flow		
Site	CT-P1	CT-2	Percent Change	CT-P1	CT-2	Percent Change
Events	5	10		6	6	
Analyte						
TP, µg/L	47	45	-5%	343	120	-65%
SRP, µg/L	11	7	-33%	24	31	33%
TDP, µg/L*	19	19	3%	19	47	154%
TN, µg/L*	1,025	1,649	61%	2,292	2,038	-11%
NO_3+NO_2-N, µg/L	562	1,072	91%	562	859	53%
NH_3-N, µg/L	70	64	-8%	113	126	12%
TSS, mg/L	13	11	-15%	209	25	-88%
TVSS, mg/L	3	3	-8%	28	7	-73%

*TN was not analyzed in 4/25/18 samples due to laboratory error

Table 9. Pollutant Reduction Analysis of the Cottonwood Creek "Perimeter Pond" Wetland PRF in WY 2018.

Median Concentration			Percent Change
Flow	Base		
Site	CT-1	CT-2	
Events	10	10	
Analyte			
TP, µg/L	91	55	-40%
SRP, µg/L	8	7	-17%
TDP, µg/L	18	18	-1%
TN, µg/L*	2,172	1,752	-19%
NO_3+NO_2-N, µg/L *	1,154	777	-33%
NH_3-N, µg/L	71	76	7%
TSS, mg/L	23	11	-51%
TVSS, mg/L	5	3	-25%

*TN was not analyzed in 4/25/18 samples due to laboratory error

Table 10. Pollutant Reduction Analysis of the Peoria St. Wetland PRF in WY 2018.

Median Concentration			Percent Change
Flow	Base		
Site	CT-P1	CT-P2	
Events	5	5	
Analyte			
TP, µg/L	47	59	24%
SRP, µg/L	11	13	24%
TDP, µg/L	16	18	7%
TN, µg/L*	1,025	1,473	44%
NO_3+NO_2-N, µg/L*	455	554	22%
NH_3-N, µg/L	70	73	5%
TSS, mg/L	13	16	26%
TVSS, mg/L	3	4	21%

*TN was not analyzed in 4/25/18 samples due to laboratory error

One of the upper tributaries of Cherry Creek is McMurdo Gulch, which had a stream reclamation completed to function as a PRF. Routine water quality samples only under base flow conditions were collected every other month from monitoring site MCM-1, upstream of the stream reclamation project area, and MCM-2, downstream.

Table 11. Pollutant Reduction Analysis of the McMurdo Gulch in WY 2018.

Median Concentration			Percent Change
Flow	Base		
Site	MCM-1	MCM-2	
Events	5	5	
Analyte			
TP, µg/L	357	278	-22%
SRP, µg/L	313	213	-32%
TDP, µg/L	337	228	-32%
TN, µg/L*	435	473	9%
NO_3+NO_2-N, µg/L *	185	70	-62%
NH_3-N, µg/L	14	16	13%
TSS, mg/L	2	14	544%
TVSS, mg/L	1	3	151%

*TN was not analyzed in 4/25/18 samples due to laboratory error

In WY 2018, TP, TDP, SRP, and NO_3+NO_2-N were all reduced upstream to downstream of the McMurdo project (Table 11). In contrast, TN and NH_3-N slightly increased at the downstream site. During the sampling period, both TSS and VSS values measured were higher downstream of the PRF. Although the percent increases were high, 544% and 151% respectively, the overall increase in TSS and VSS values were not that significant since the levels upstream were so low. The water level in McMurdo Gulch was also very low as the season progressed, which could have affected sampling results for these parameters.

3.6 GROUNDWATER

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

3.6.1 LEVEL AND TEMPERATURE

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

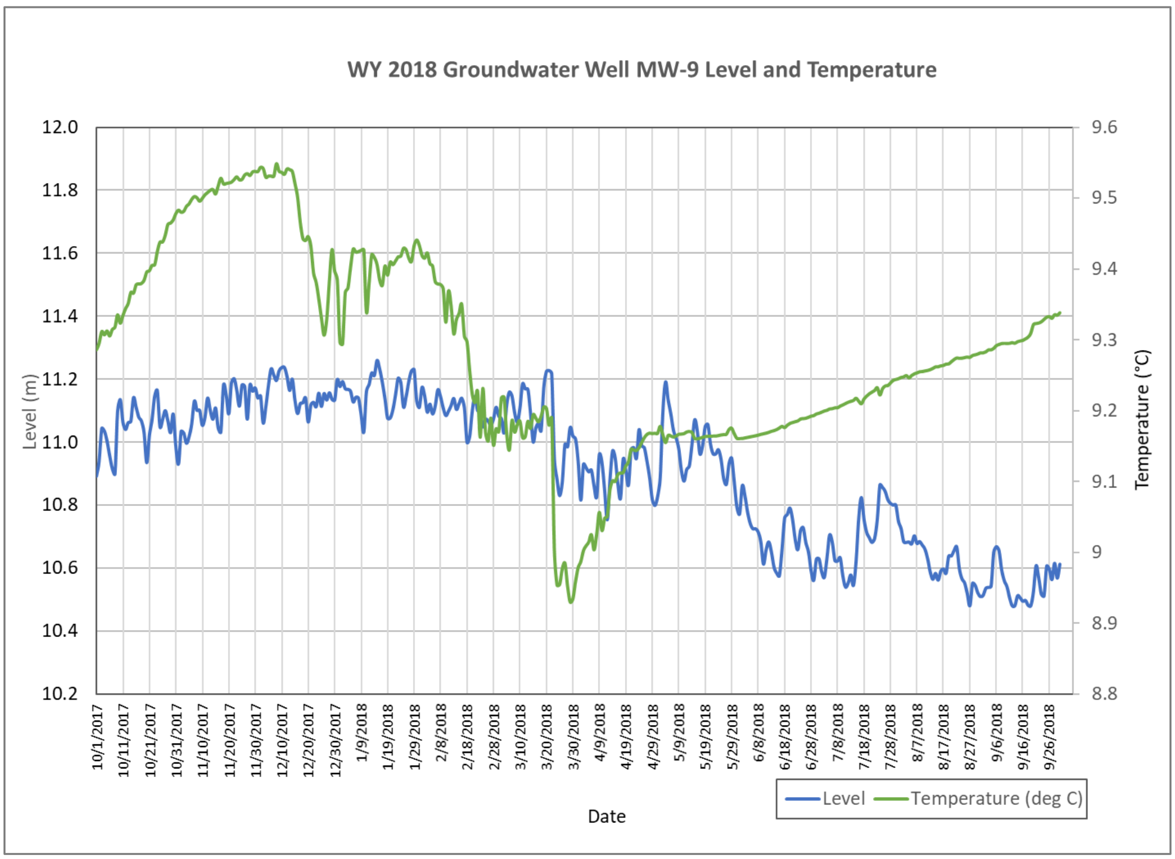


Figure 18. Daily Mean Level and Temperature in Groundwater Well MW-9.

The level and temperature in groundwater well MW-9 has some seasonal fluctuation. The highest temperatures were observed in late November through early December of 2017 and the lowest levels observed in March 2018. The water levels in MW-9 fluctuated daily but a decreasing trend was observed as the year progressed, with the lowest values observed in September 2018.

3.6.2 GROUNDWATER WATER QUALITY

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

Well MW-5 has been sampled since 1994 and is located immediately downgradient of the confluence with Newlin Gulch. This site is located where Pine Lane crosses Cherry Creek, approximately 0.65 km west of Parker Road.

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

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

The data suggest that the TP and SRP concentrations remain relatively consistent between the wells in November 2017 and May 2018. In contrast, TN decreases as the wells get closer to the Reservoir, with a slight elevation at MW-Kennedy in November 2017. TP and SRP concentrations were at the lowest levels below the outlet.

The data from the comprehensive basin sampling of all Cherry Creek sites suggests little difference in total phosphorus concentrations between surface water and groundwater in November 2017 and May 2018. The mean concentrations of TP in the GW sites were 0.2 mg/ L on both dates. In contrast, the TN concentrations decrease toward the Reservoir and below with the exception of November 2017, which shows a slight increase in TN, NO_3+NO_2-N, and NH_3-N below the Reservoir at MW-Kennedy. The combined values of nitrate+nitrite did not exceed the state drinking water standard for nitrate of 10 mg/L (5 CCR 1002-41.8)

As shown in Figure 21 and Figure 22, data from both sampling events during WY 2018 indicated groundwater concentrations of chloride averaged 140 mg/L and sulfate averaged 125 mg/L. Although these are not drinking water wells, these values did not exceed the state drinking water standard for sulfate of 250 µg/L (5 CCR 1002-41.8). The pH remains relatively constant and the conductivity seems to follow the trend of the concentrations of chloride and sulfate in November 2017. However, in May 2018, the conductivity was more variable indicating additional dissolved solids may be impacting the results.

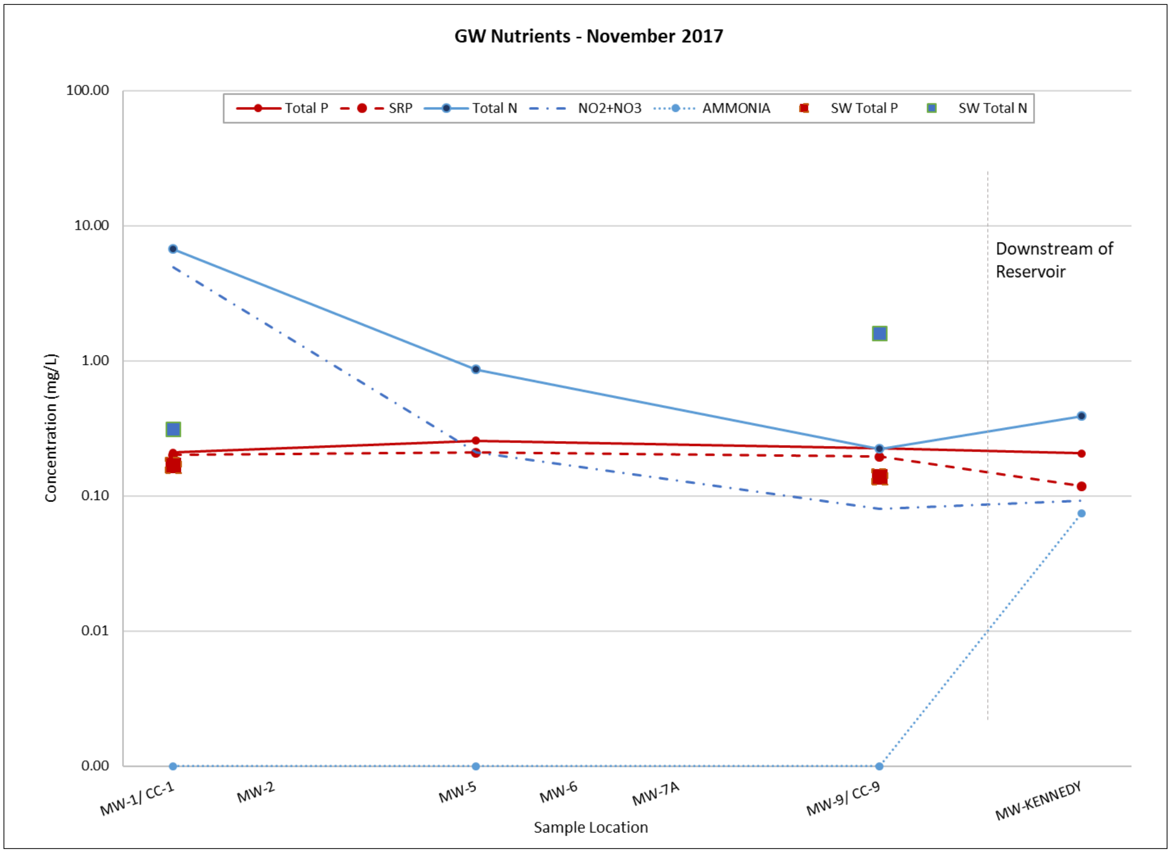


Figure 19. Groundwater Water Quality of Monitoring Wells in November 2017.

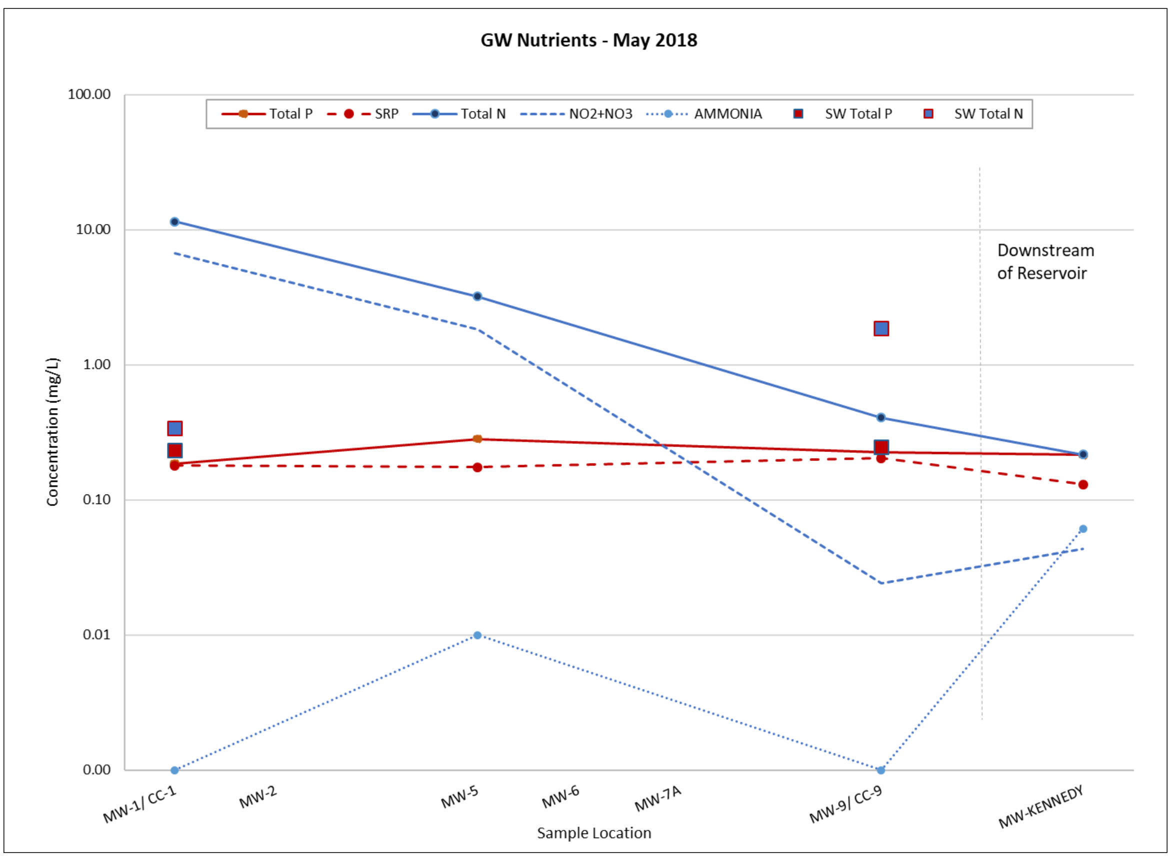


Figure 20. Groundwater nutrients from monitoring wells in May 2018.

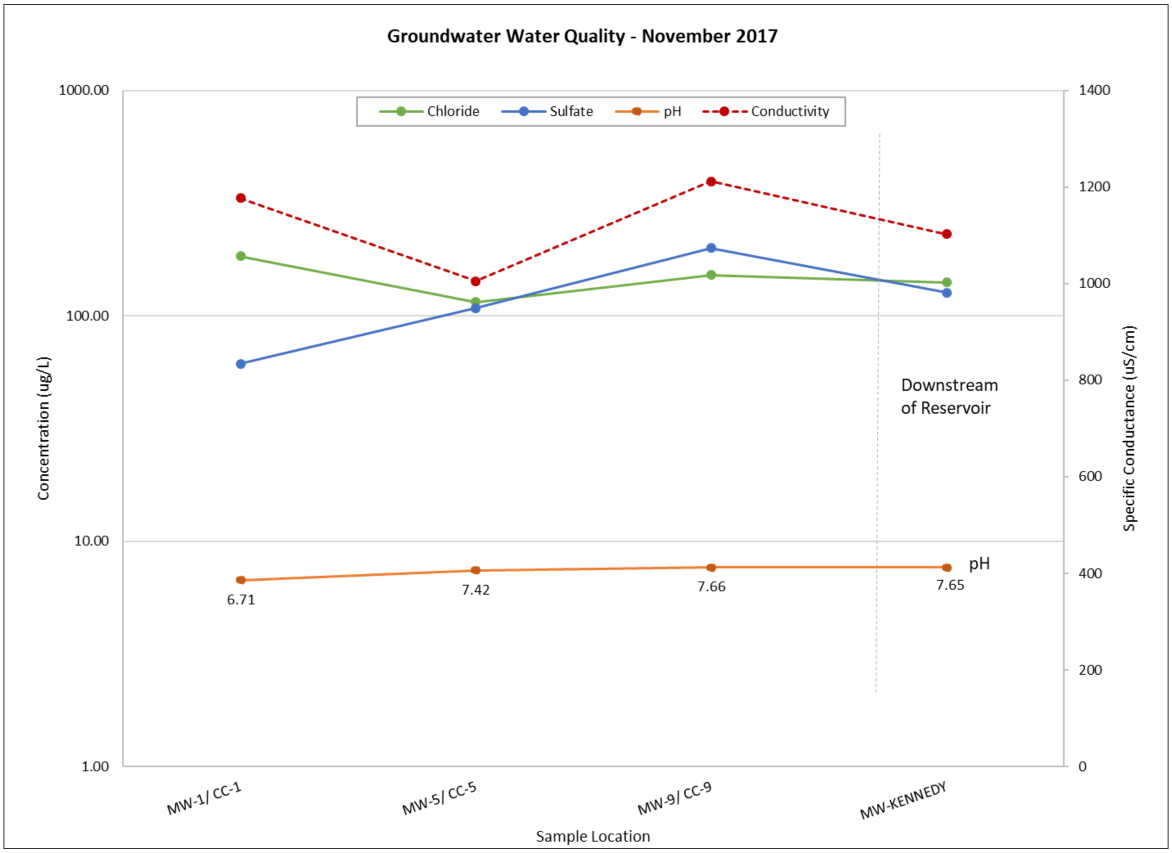


Figure 21. Groundwater Levels of Sulfate, Chloride, Specific Conductance, and pH, November 2017.

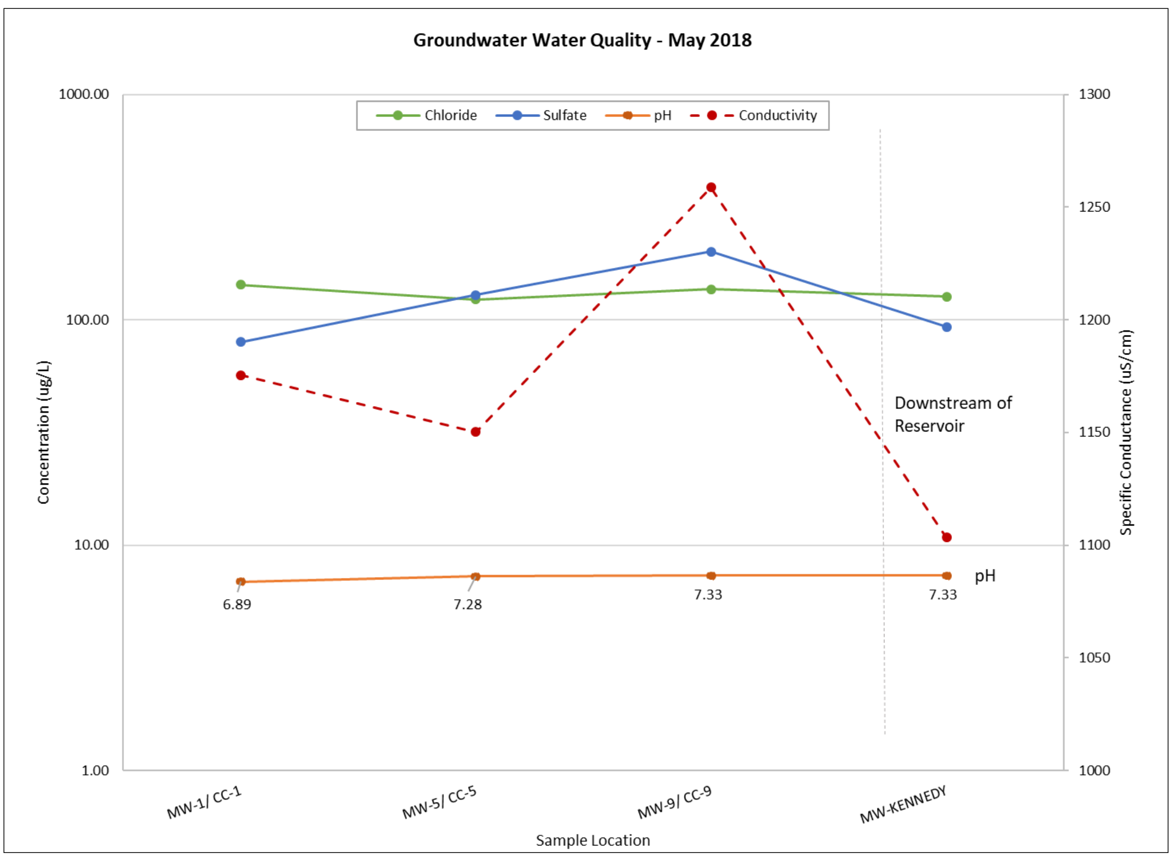


Figure 22. Groundwater Levels of Sulfate, Chloride, Specific Conductance, and pH, May 2017.

3.6.3 GROUNDWATER UPSTREAM OF RESERVOIR AT MONITORING WELL MW-9

The pH and specific conductance (conductivity) were monitored at all wells included in the SAP during both monitoring events. With the exception of a few outliers, pH values have ranged between 6.5 and 7.5 with an historical mean value of near neutral at 7.12. The historical pH values from Monitoring Well MW-9 1994-2018 are plotted in Figure 23. The data suggest that the pH at site MW-9 may be slightly decreasing over time.

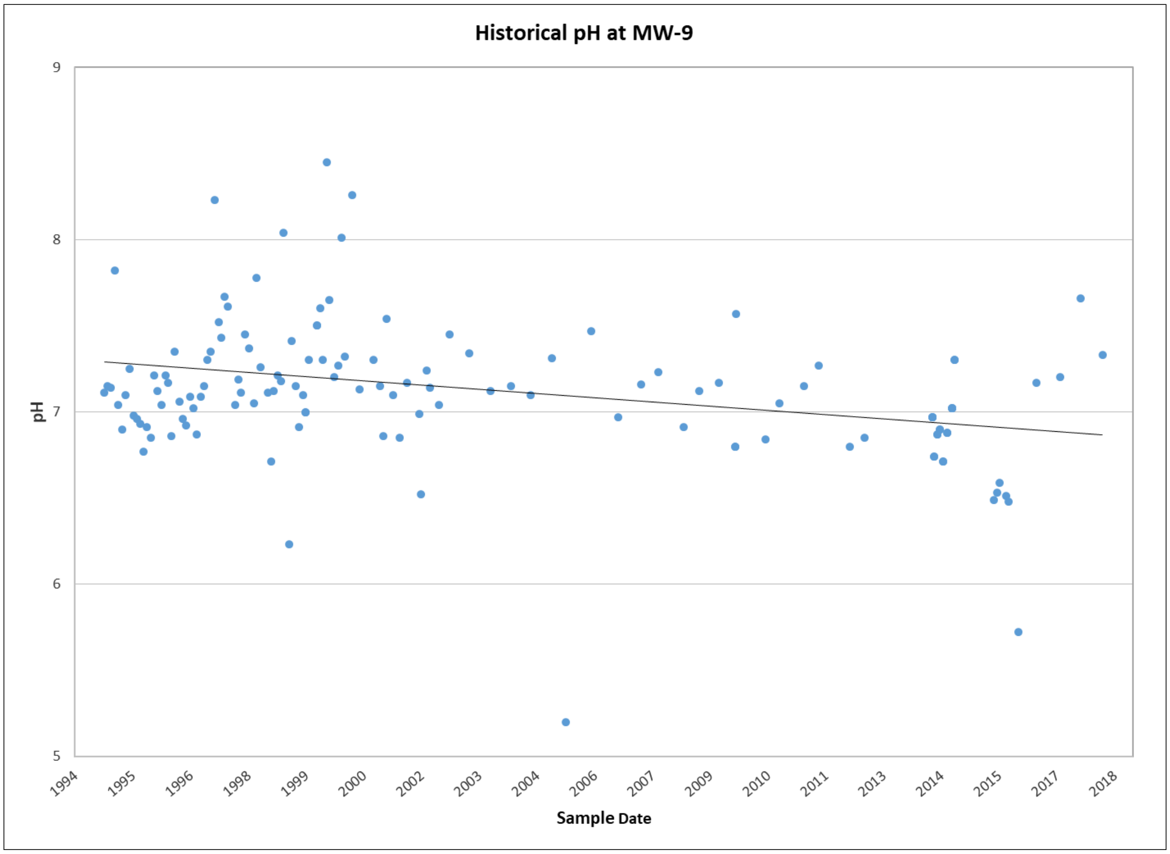


Figure 23. Historic pH Values in Well MW-9, 1994-2018.

The specific conductance values at MW-9 suggest a slightly increasing trend over time with a mean value of 807 µS/cm between 1995 and 2005 and a mean of 1103 µS/cm from 2006 to 2018. (Figure 24.)

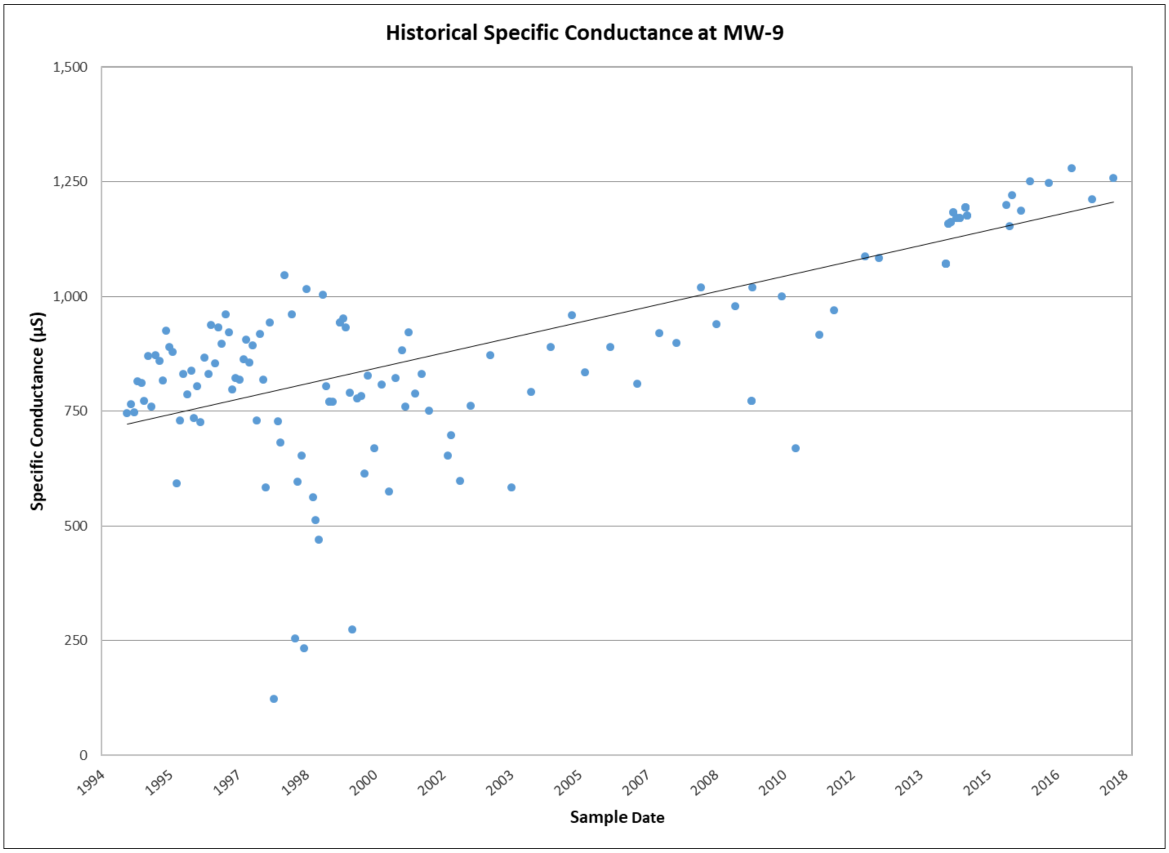


Figure 23. Historic Specific Conductance Values in Well MW-9, 1994-2018.

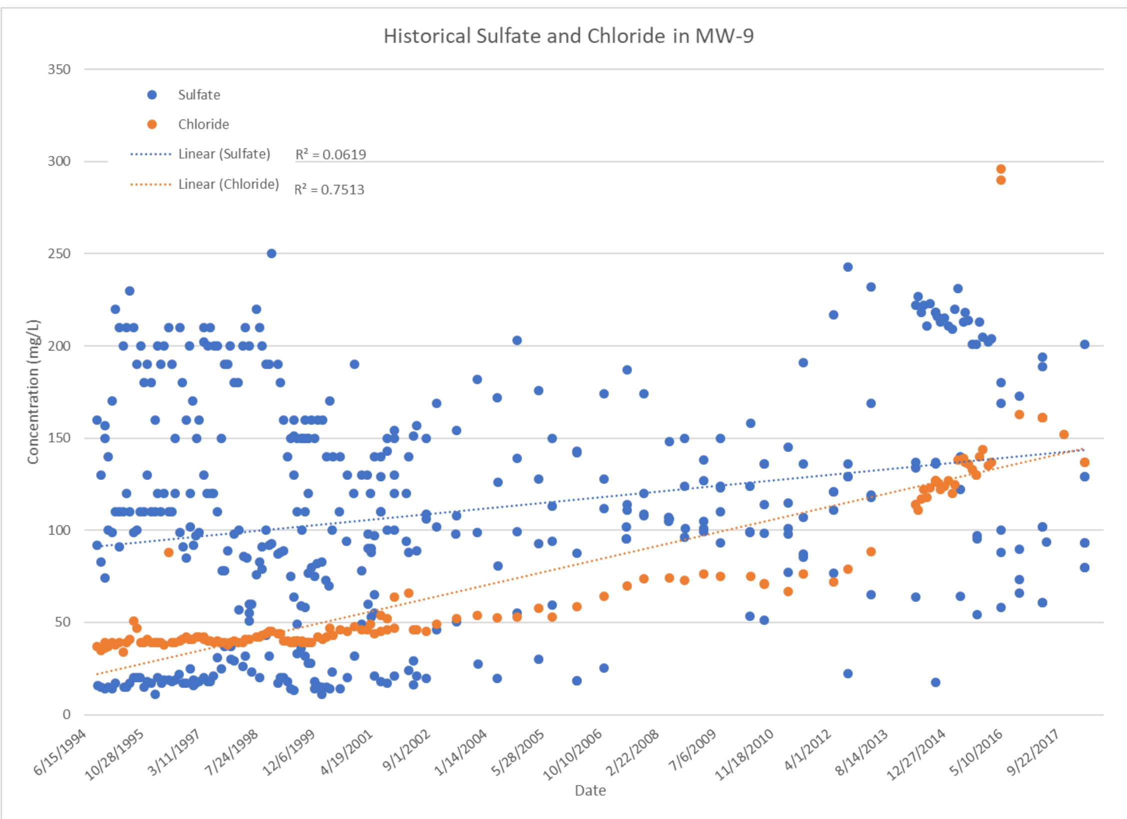


Figure 24. Historical Sulfate and Chloride at MW-9, 1994-2018.

Figure 25 illustrates the historical chloride and sulfate concentrations from 1994-2018. It appears that both may be increasing over time although chloride may be less variable and increasing slightly more significantly.

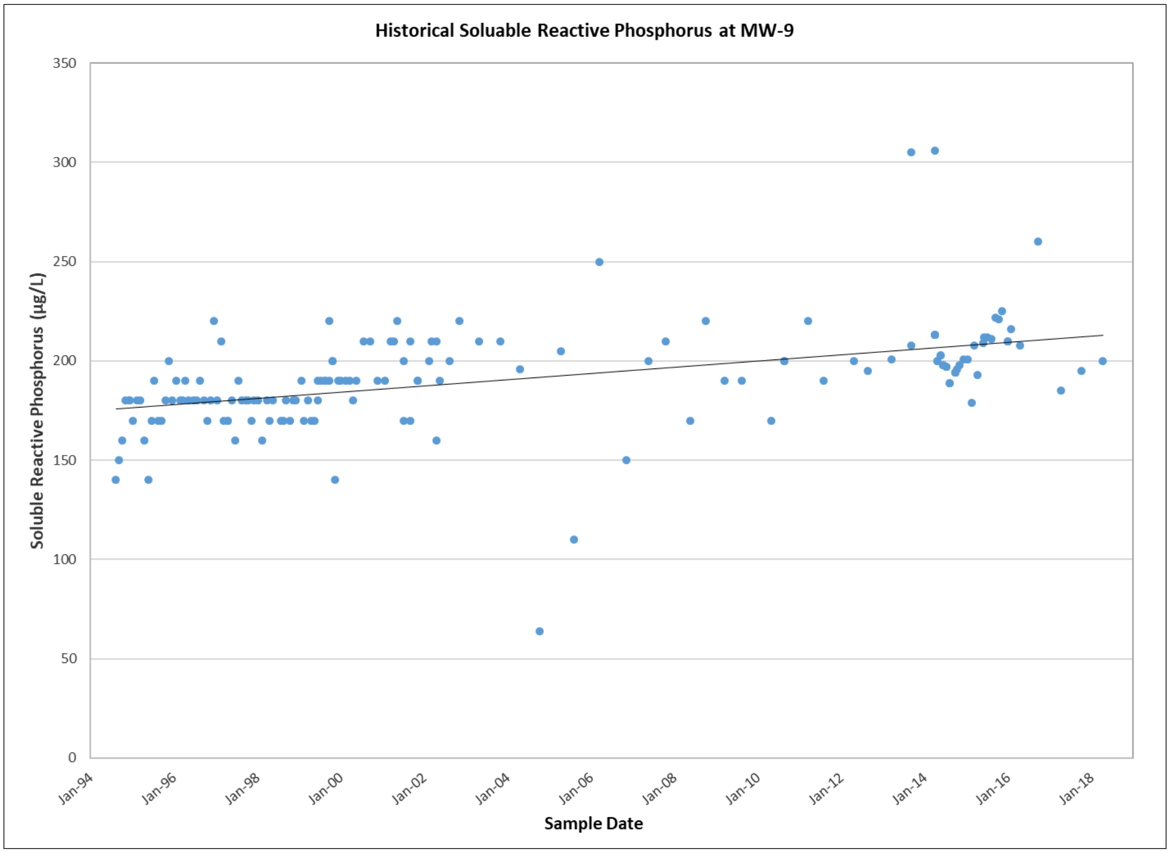


Figure 25. Historic SRP Concentrations in Groundwater Monitoring Well MW-9 (1994–2018)

Historically, the concentration of SRP in the groundwater upstream of the Reservoir at MW-9 also appears to be slightly increasing (Figure 25).

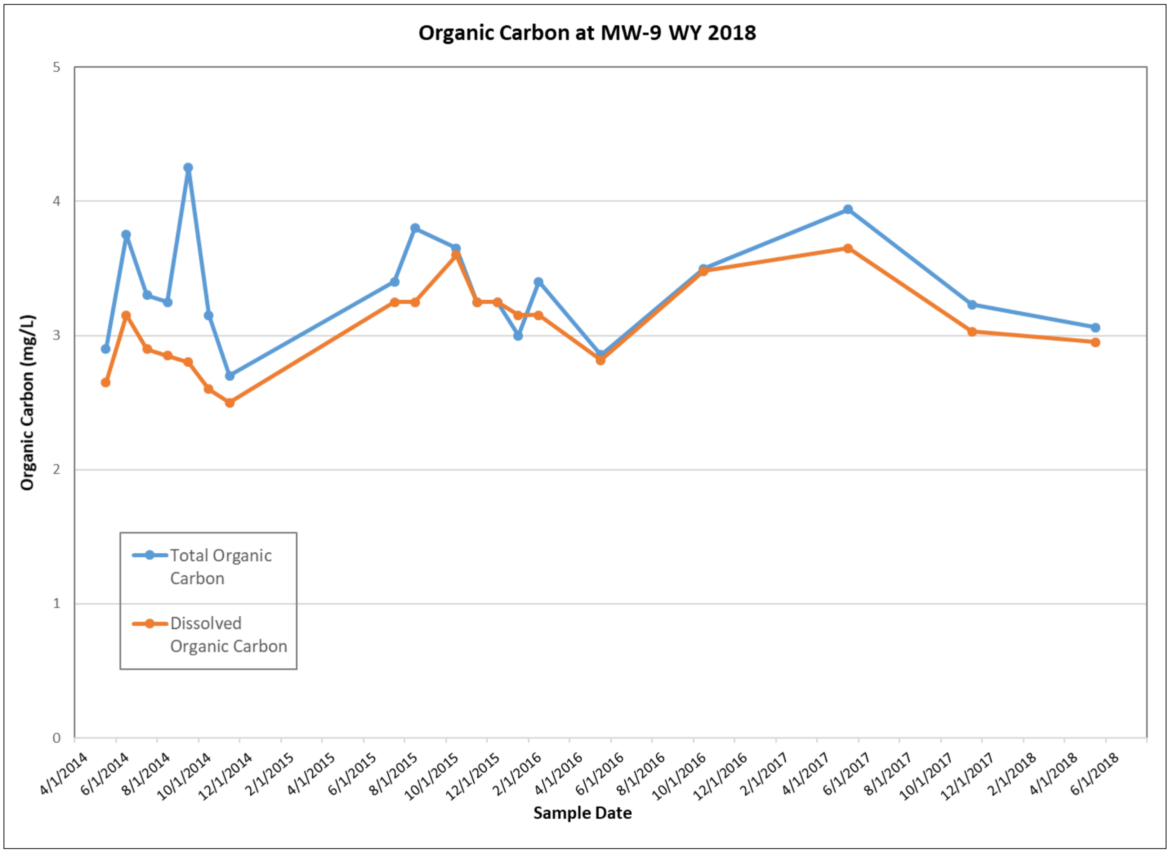


Figure 26. Total and Dissolved Organic Carbon Data from MW-9, 2014-2018.

The long-term TOC concentrations in the alluvial groundwater samples collected from well MW-9 range from 2.7 µg/L to 4.3 µg/L, averaging 3.4 µg/L (Figure 26). The TOC concentrations measured in November 2017 were 3.32 mg/L and in May 2018 were 3.06 mg/L, which are both slightly lower than the long-term average. Historically, the dissolved fraction of the TOC in well MW-9 ranged between 66 percent and 100 percent, with a long-term average of 92 percent. In WY 2018, the DOC fraction of TOC was higher than the long-term average at 96 percent of the total.

4.0 RESERVOIR MONITORING RESULTS

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

Three sites in the Reservoir are included in the monitoring program: CCR-1, CCR-2 and CCR-3. CCR-1 is also called the Dam site located in the northwest area within the Reservoir. The site was established in 1987 and sampling was discontinued in in 1996 and 1997 following determination that this site exhibited similar characteristics to the other two sites. Sampling recommenced in July 1998 at the request of consultants for Greenwood Village. CCR-2, called the Swim Beach site, is located in the northeast area within the Reservoir nearest the swim beach. CCR-3 is referred to as the Inlet site and corresponds to the south area within the reservoir closer to the inlets.

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

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

4.1 USACE RESERVOIR FLUSHING EXERCISE

On May 23rd, 2018 from 8:55 am to 5:45 pm the USACE performed the annual flushing exercise to verify the operation of the outlet gates. The USACE individually operated gates 1-5 with various flows ranging from 50 cfs to 1,300 cfs for durations of 10-45 minutes each. During this event approximately 79,218,000 gallons of water (243 AF) were released from the reservoir. Based on the data provided by USACE, the reservoir level decreased from 5550.6 to 5550.2 ft from May 22nd to May 23rd. Assuming the measurements were completed after the discharge, the reservoir was lowered by 0.4 ft during the flushing exercise.

4.2 TRANSPARENCY

Transparency is used an indicator for primary productivity and turbidity of the water column and can be a good reference point of the overall health of an aquatic ecosystem. In order to determine transparency, Secchi depths and the depth of 99% light attenuation were measured with a Secchi disk and a LI-COR quantum sensor at all three sites in the Reservoir (CCR-1, CCR-2 and CCR-3).

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

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

The Secchi depth measurements represent reduced clarity and eutrophic conditions through most of the year, with the exception of a few dates. The Secchi depths were very similar between CCR-1, 2, and 3, with the highest variance of 23% but an average of only 12% variance between the sites. Figure 27 depicts the Secchi depth measurements from the three sites during each sampling event in WY 2018 and indicates when the Cyanobacteria bloom was detected in the marina.

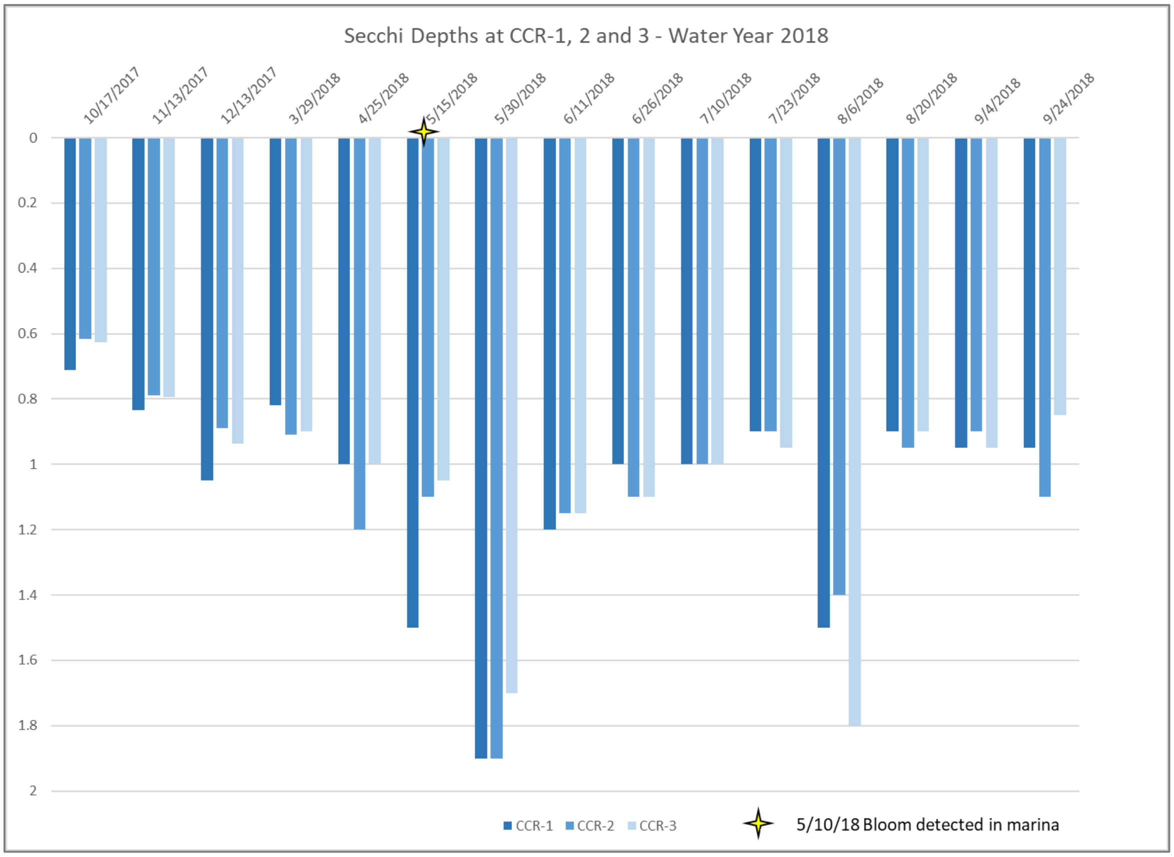


Figure 27. Secchi Depths in Cherry Creek Reservoir, Stations CCR-1, CCR-2 and CCR-3 during WY 2018.

Due to the similarity of the values between the three reservoir sites, the data and values from CCR-2 are below to illustrate the Secchi depths during each monitoring event.

Figure 28 shows the historical monthly mean Secchi depth as well as the values from WY 2018. The average Secchi depths are very similar to the previous year measurements at similar dates. The long-term monthly means seems to show less of a seasonal trend but increased variability during the colder months of January-March and December. The historical data shows the least variability and lower values in May which over the last 3 years have been average or above average values.

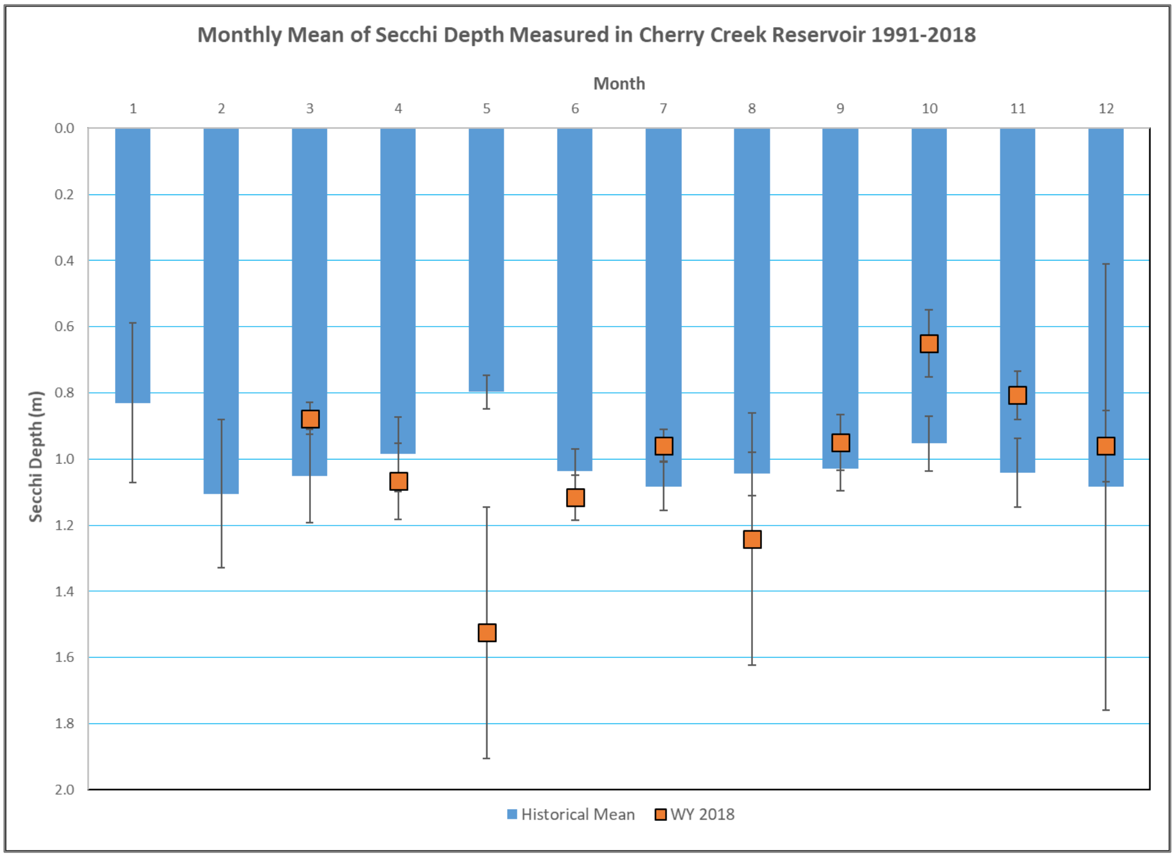


Figure 28. Monthly Mean of Secchi Depth at CCR-2 from 1992- 2018.

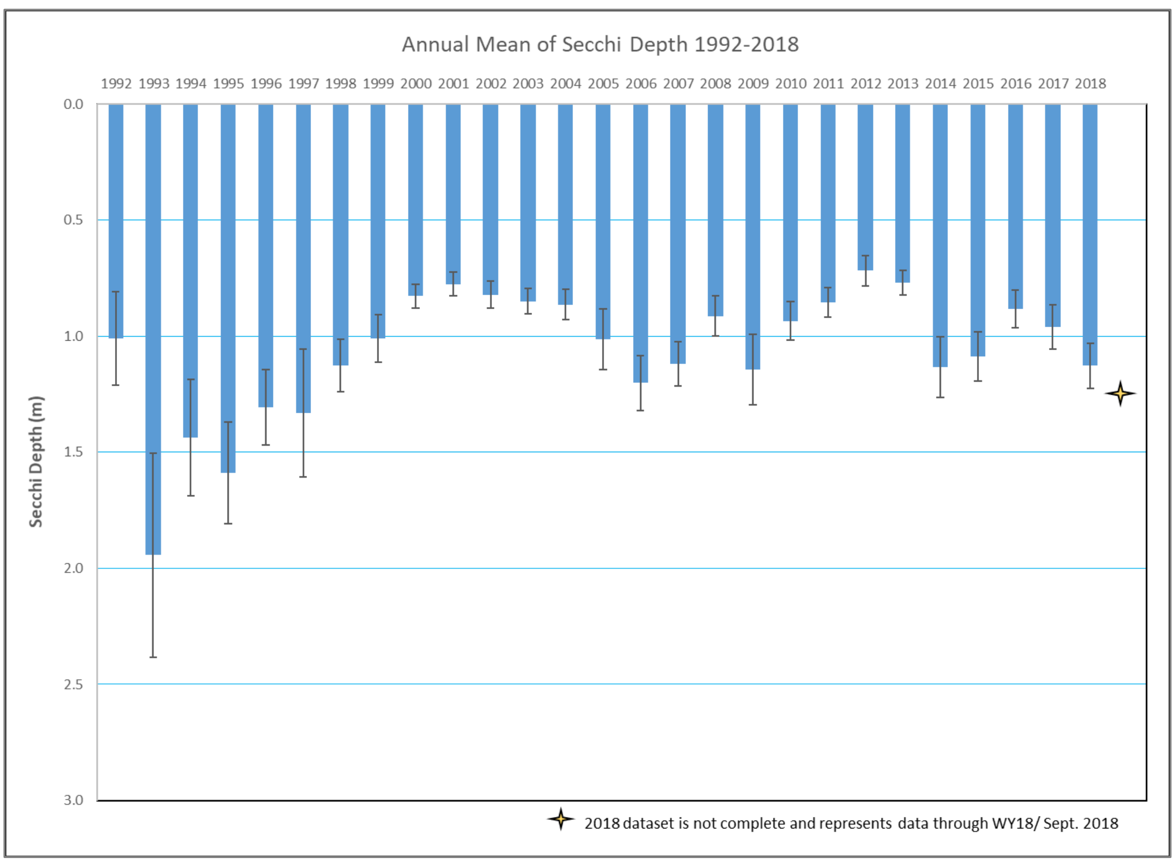


Figure 29. Annual Mean of Secchi Depth at CCR-2 from 1992- 2018.

The historical mean Secchi depth values at CCR-2 are pictured in Figure 29. From approximately 1998 to present, the annual mean Secchi depth has been in the eutrophic range, varying between approximately 0.75 m to 1.25 m. The lowest values were observed in 2000-2004 and again in 2011-2013.

The depth of 99% light attenuation or 1% light transmittance at site CCR-2 ranged from 2.1 m to 4.8 m during WY 2018. The lowest values were observed in the late summer and the maximum depths of 4.8 m. There is a clear relationship between Secchi depth and depth of 99% light attenuation (Figure 30).

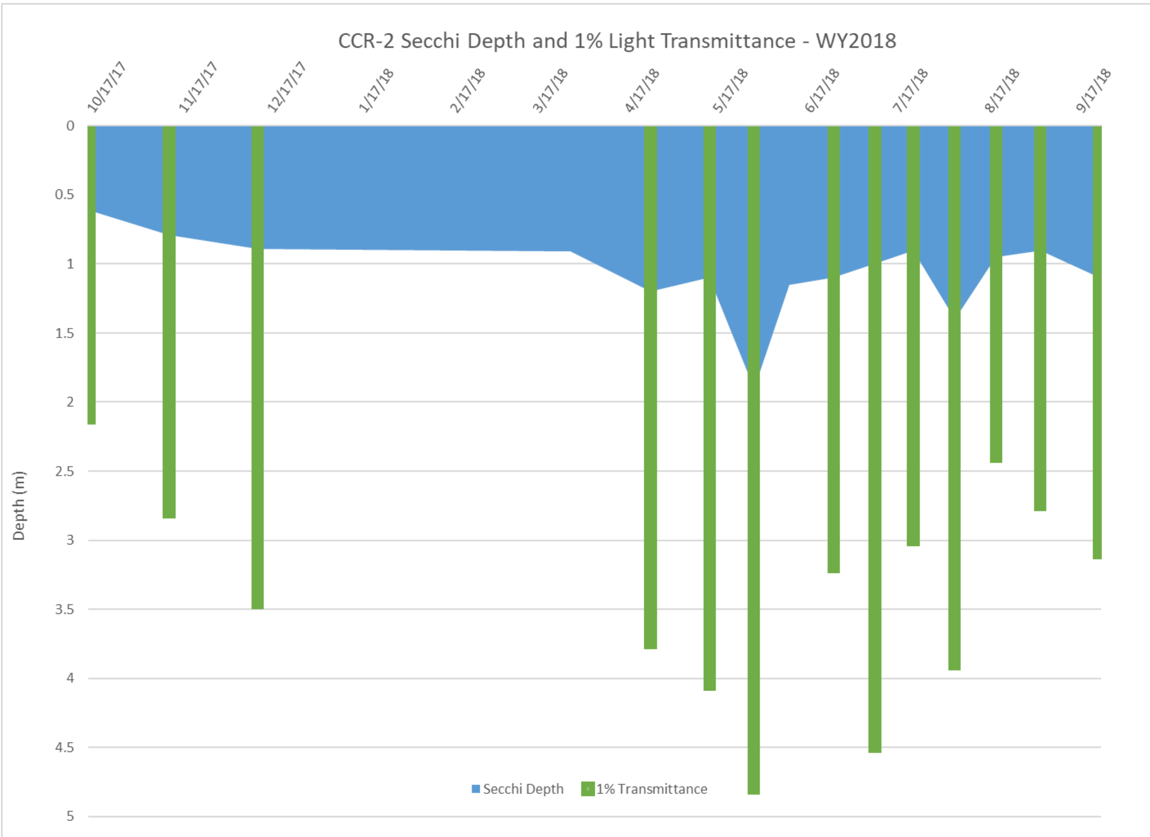


Figure 30. Secchi Depth and Depth of 1% Light Transmittance at CCR-2 during WY 2018.

The historical data from all three sites was then analyzed to determine the mathematic correlation between three (3) times the Secchi depth and depth of 99% light attenuation up to 6.5 m. Figure 31 illustrates the statistically significant relationship.

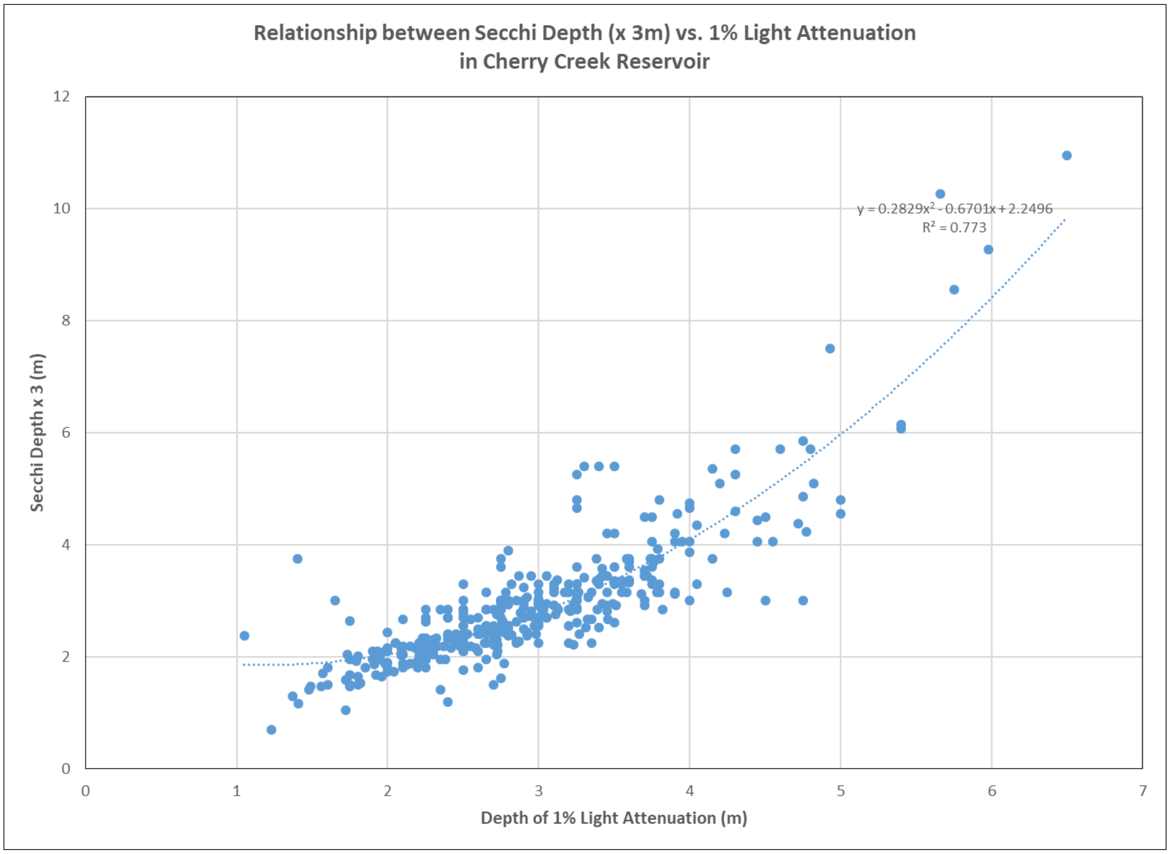


Figure 31. Relationship between 3x Secchi Depth and Depth of 1% Light Transmittance

4.3 CHLOROPHYLL-A

During each sampling event of WY 2018, chl-*a* levels were measured from composite samples collected from 0, 1, 2, and 3 m at all three monitoring sites in the reservoir. The chl-α concentrations ranged between 7.2 µg/L to 33.0 µg/L with an average value of 18.7 µg/L in WY 2018 (Figure 32). The highest values were observed in November 2017, July 2018, and August 2018 and the lowest in April, May and June.

The seasonal chl- α concentration for WY18 through the growing season (July through September) concentration was 20.2 µg/L, which was higher than WY 2017 (18.7 µg/L) but lower than the WY 2016 value (23.6 µg/L) (Figure 33). Of the six sampling events during the season (July 1-September 30), five had a mean value that exceeded the standard of 18 µg/L.

The seasonal mean for WY 2018 is in exceedance of the 18 µg/L growing season average regulatory standard which allows one exceedance frequency of once in five years. Four of the last five (4/5) and eight of the last ten (8/10) years have exceeded this value.

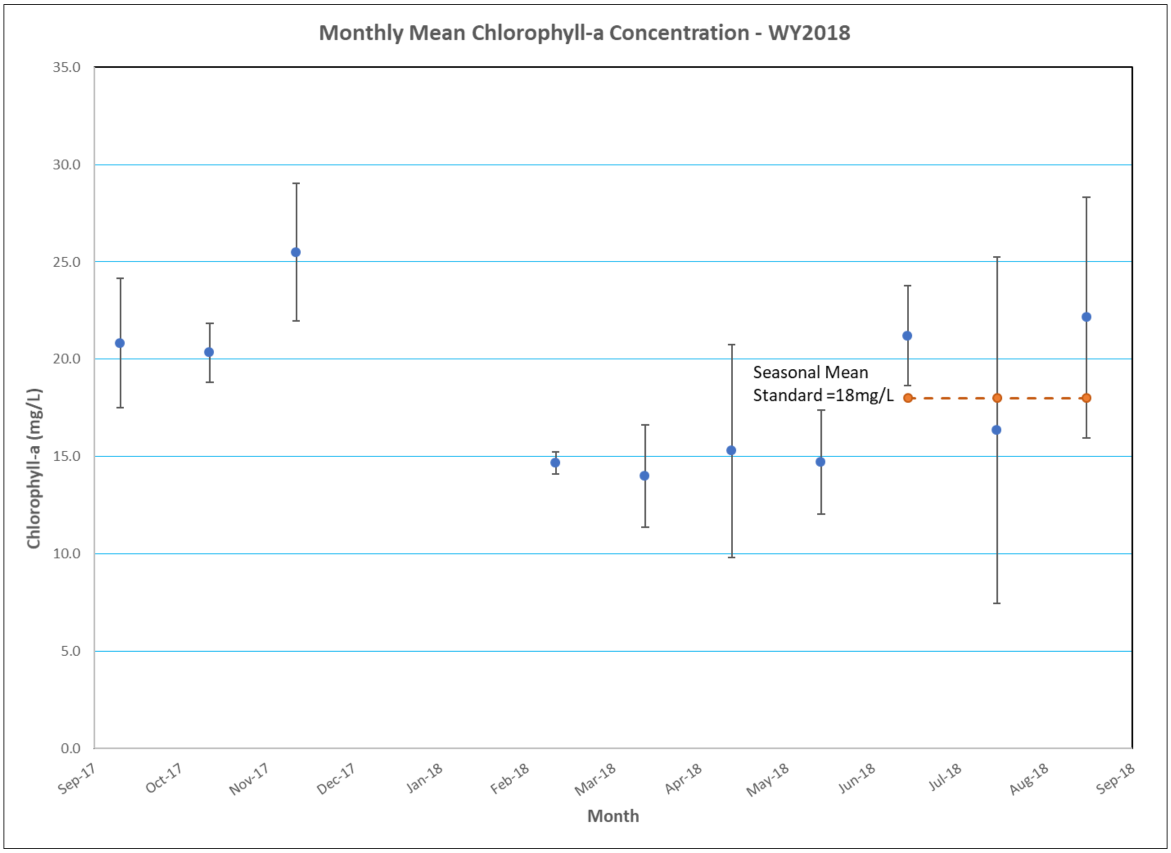


Figure 32. Monthly Mean of Chlorophyll-*a* Concentration in Cherry Creek Reservoir During WY 2018.

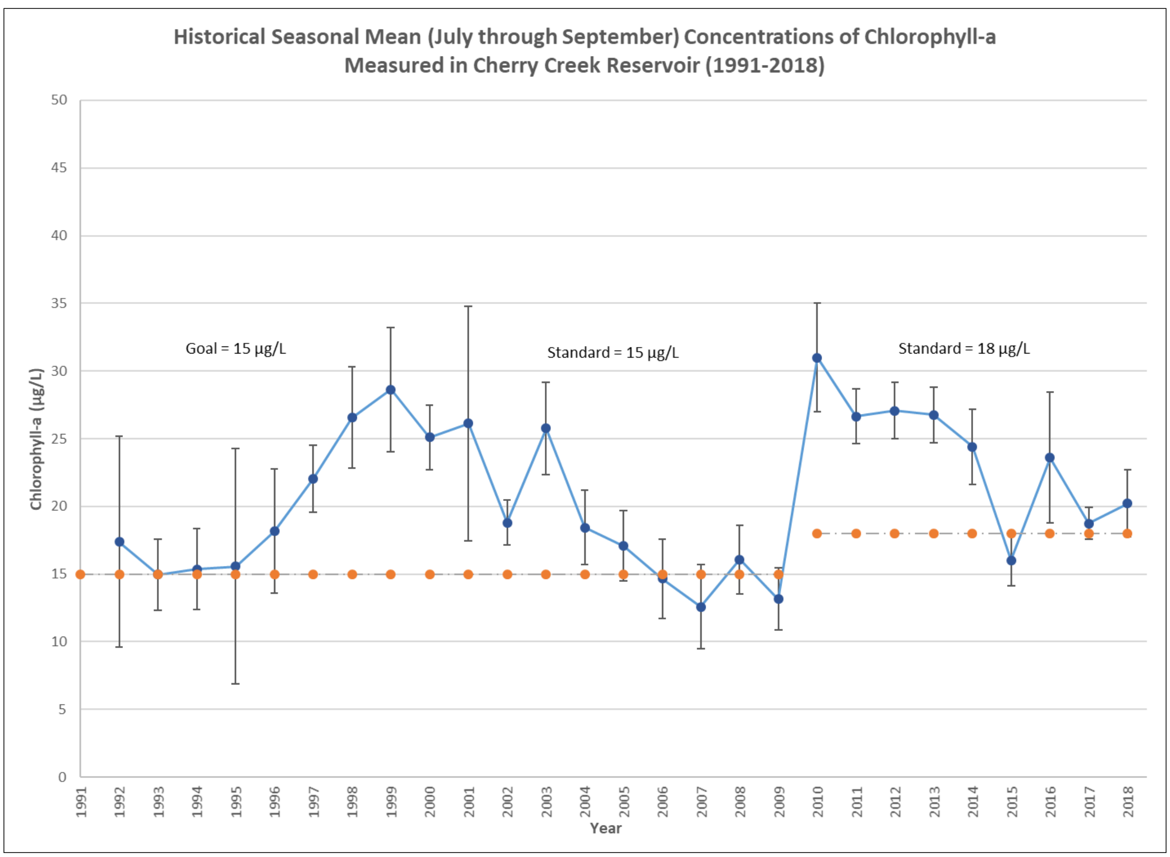


Figure 33. Historical Seasonal Mean of Chlorophyll-*a* in Cherry Creek Reservoir 1991-2018

Translating the impacts of chl-*a* 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-*a* concentrations and observed impacts (Table 12.) to describe perceptions of water quality by typical lake users. The maximum chl-*a* concentration in Cherry Creek Reservoir in WY 2018 was 33 µg/L, and the average of all readings during the summer months was 18.4 µg/L. This would indicate that lake users could notice some algal scums but would not perceive nuisance conditions on most days.

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

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

4.4 TEMPERATURE

Continuous temperature monitoring is completed at site CCR-2 in Cherry Creek Reservoir during the late spring, summer and early fall. The loggers are placed in even increments from one (1) meter of depth to the bottom of the Reservoir and are mounted on a State Parks buoy. The continuous temperature data from 2018 is plotted in Figure 34 which shows a clear picture of the stratification throughout the whole year where the mixing events are evident when there is little to no difference in temperature from the top to the bottom of the Reservoir.

Figure 35 shows the early spring temperature profile where it appears that three distinct destratification events occurred. The first occurred on April 29th where all loggers registered temperature of 12.9 degrees Celsius (^{o}C). The second on May 4th at 12.1 degrees C which was approximately 3 days since the destratification system was turned on (JRS Engineering, 2018). The system then operated intermittently from May 4th to 17th with eight high temperature shutdowns which required the system to be re-started. The third notable destratification was logged on May 21st where there was only a decrease from 15.5 ^{o}C at one (1) meter to 15.3^{o}C at the bottom of the Reservoir. During this period of time, the destratification system operated from May 17th and did not experience a shutdown again until May 23rd.

Figure 36 shows an enhanced view of the fall before the thermistors were removed from the Reservoir. During this period, it appears that on Sept 22nd the Reservoir de-stratified again and the temperatures at one (1) meter and the bottom were both 19.5 ^{o}C. Some temperature variability with depth occurred again until October 7th when the entire water column was at 14.7 ^{o}C.

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 WY 2018. The Reservoir met the temperature standards established for the Class I Warm Water Aquatic Life classification (WQCC Regulation No. 31) of 29.2 ˚C Maximum Weekly Average Temperature (MWAT) and 32.5 ˚C Daily Maximum (DM). The maximum temperature measured in the surface during the reservoir monitoring events was 24.6 ˚C on July 10th 2018, and the highest temperature recorded by the continuous monitoring thermistors was 26.1 ˚C on July 19th 2018. Although there was some variability from the surface to the bottom in the warmer summer months, overall the Reservoir did not develop consistent thermal stratification.

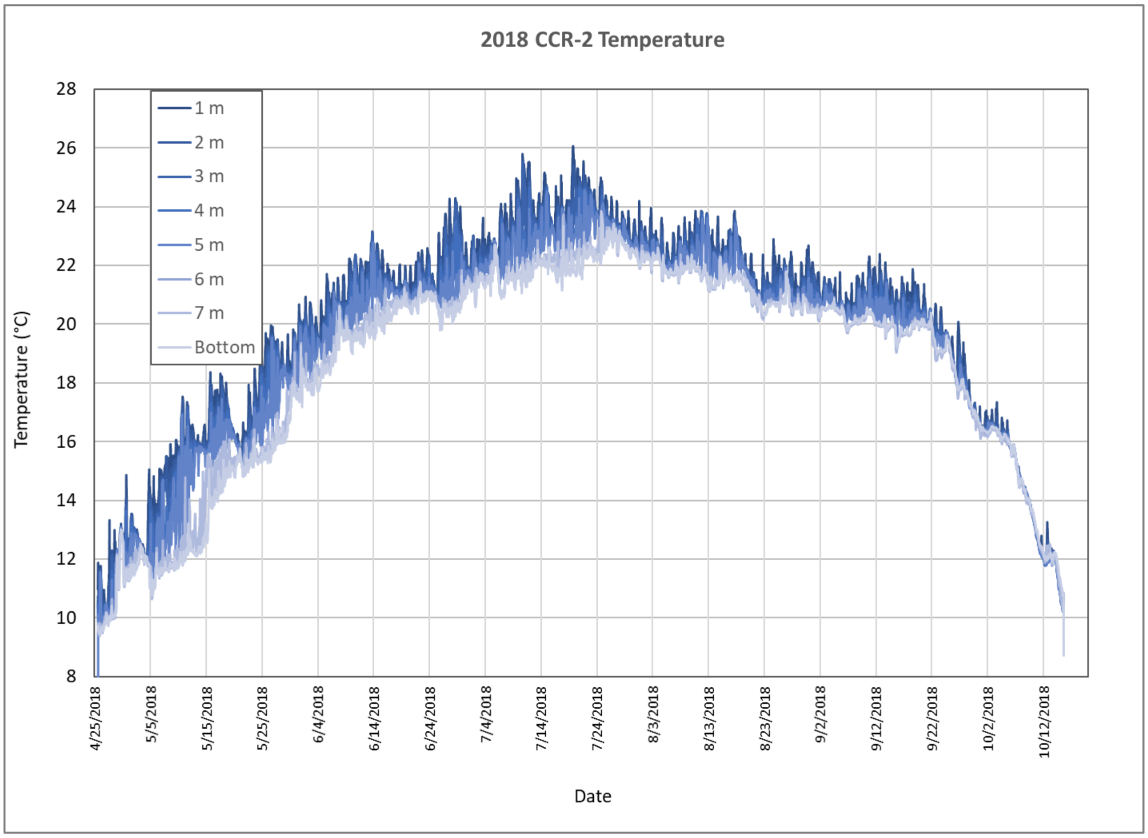


Figure 34. 2018 Temperature Profile of CCR-2 in Cherry Creek Reservoir

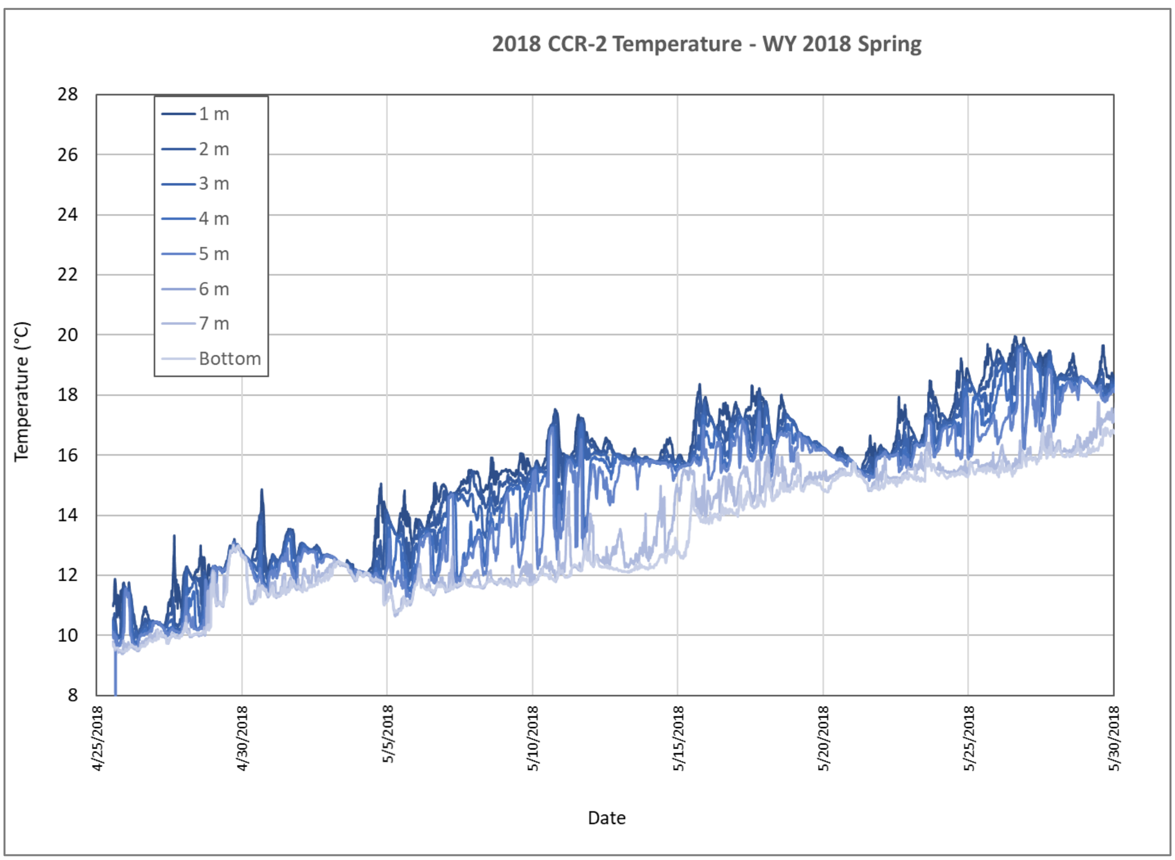


Figure 35. 2018 Temperature Profile of CCR-2 in Cherry Creek Reservoir, Spring Destratification.

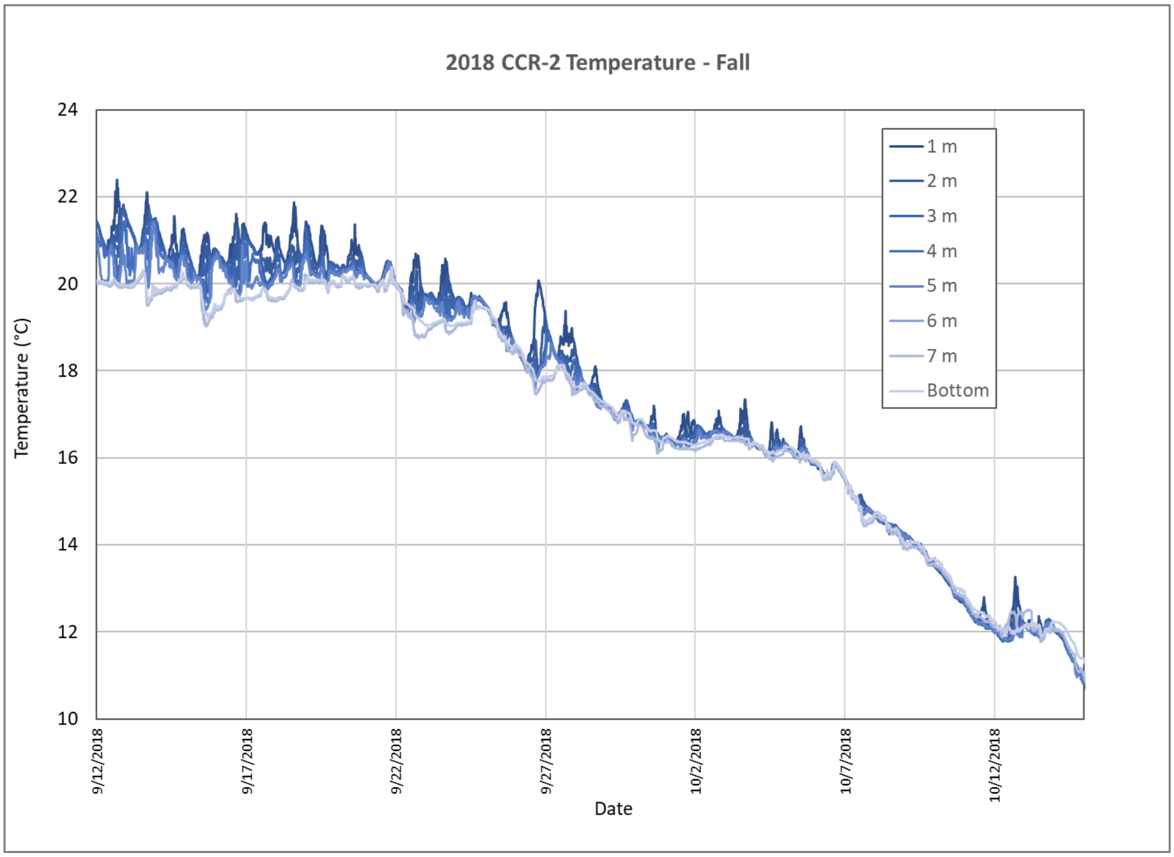


Figure 36. 2018 Temperature Profile of CCR-2 in Cherry Creek Reservoir, Fall De-stratification.

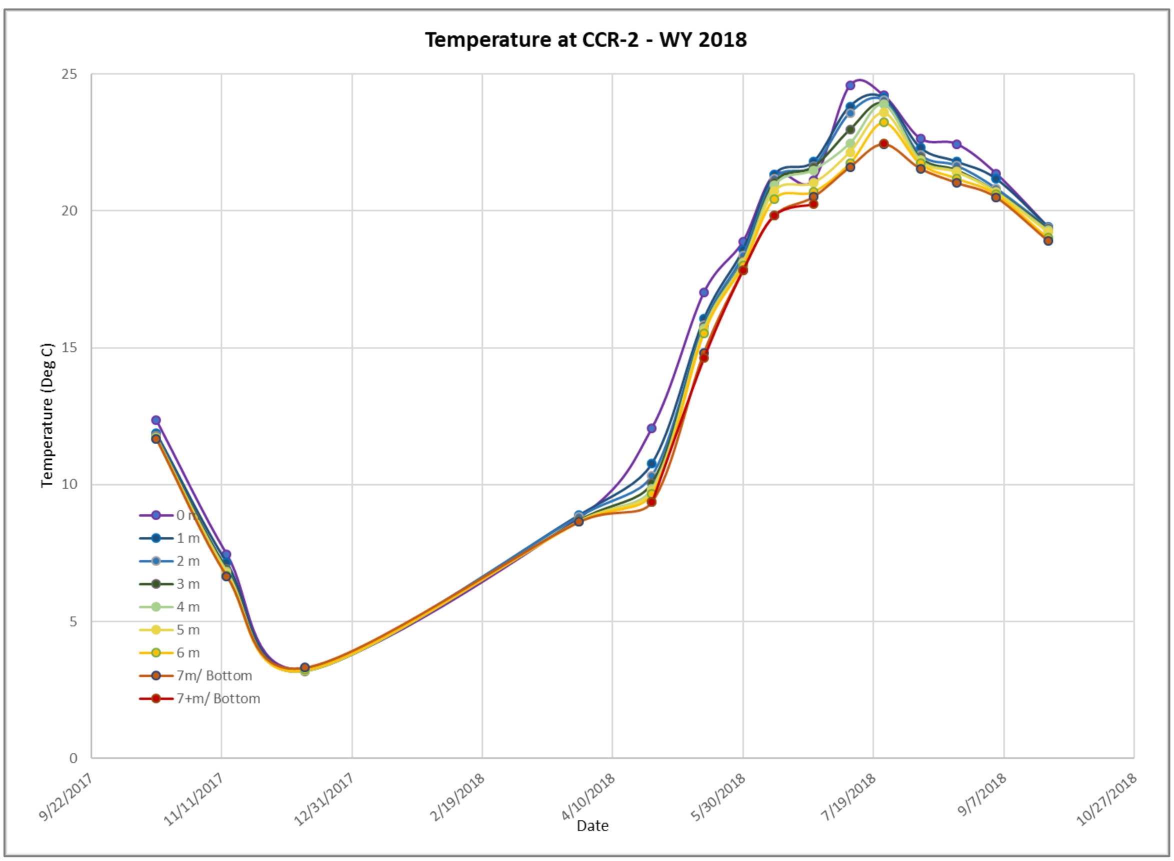


Figure 37. WY 2018 Temperature Profile in Cherry Creek Reservoir, Site CCR-2.

4.5 DISSOLVED OXYGEN

During WY 2018, Cherry Creek Reservoir had DO concentrations that met REG 38 requirements that requires levels of 5.0 mg/L or above near the surface. The DO may be less than 5.0 mg/L near the bottom as long as there is adequate refuge with DO levels greater than 5.0mg/L available for aquatic life.

Figure 38 illustrates the DO levels in the Reservoir at Station CCR-2 over time from the surface to the bottom. During the July 10th and July 20th 2018 sampling events, DO levels from 5 meters to the bottom were less than 5.0mg/L. However, during those times, the majority of the Reservoir had DO levels that exceeded 5.0mg/L to provide adequate habitat (refuge) for aquatic life. Periods of low dissolved oxygen indicate high microbial activity or decomposition in the hypolimnion and sediments which reduces DO concentrations.

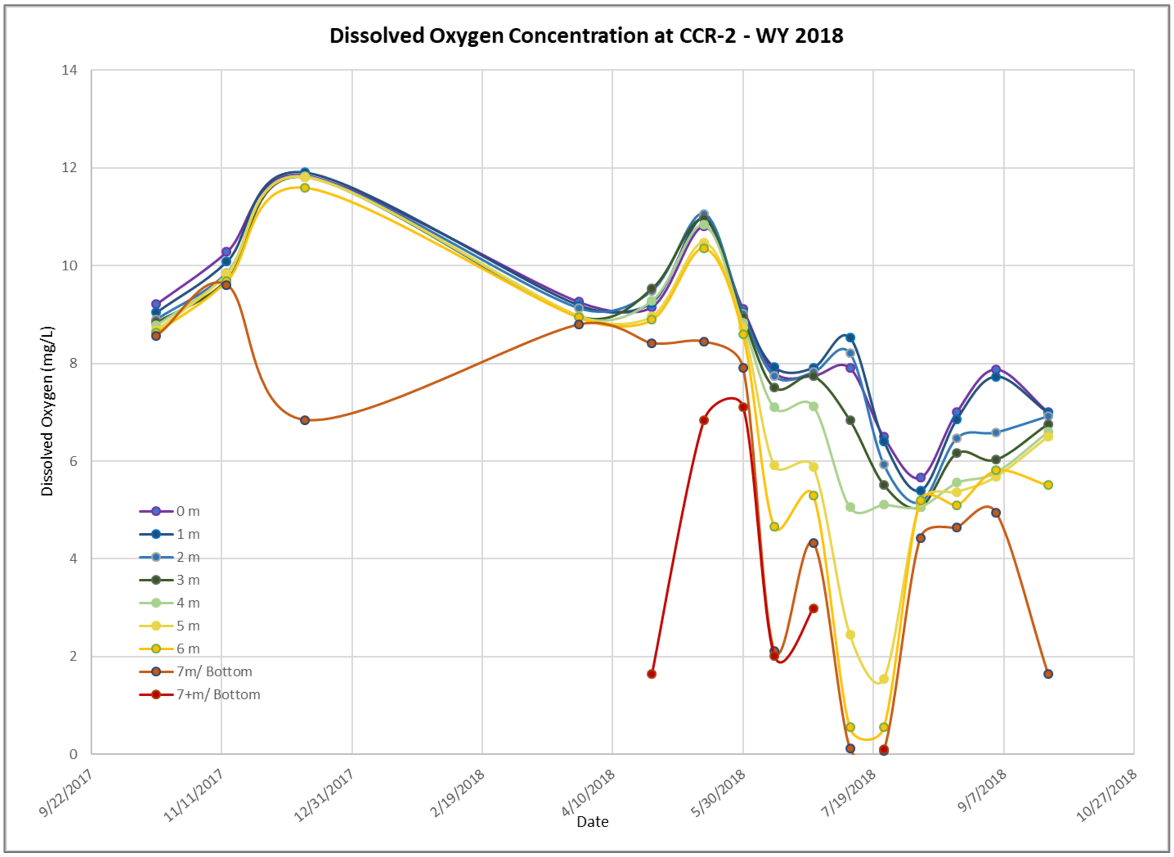


Figure 38. WY 2016 and WY 2017 DO Profile at Cherry Creek Reservoir Monitoring Station CCR-2.

4.6 PH

The pH in Cherry Creek Reservoir during WY 2018 ranged from 7.7 at the bottom of the Reservoir on July 10th to and 8.6 at the Reservoir surface on May 15th (Figure 39). The pH levels in the Reservoir met the instantaneous minimum and maximum standards of 6.5 and 9.0, respectively, during each of the monitoring events during WY 2018. Higher pH values correlate with higher productivity and elevated chl-*a* concentrations in the Reservoir.

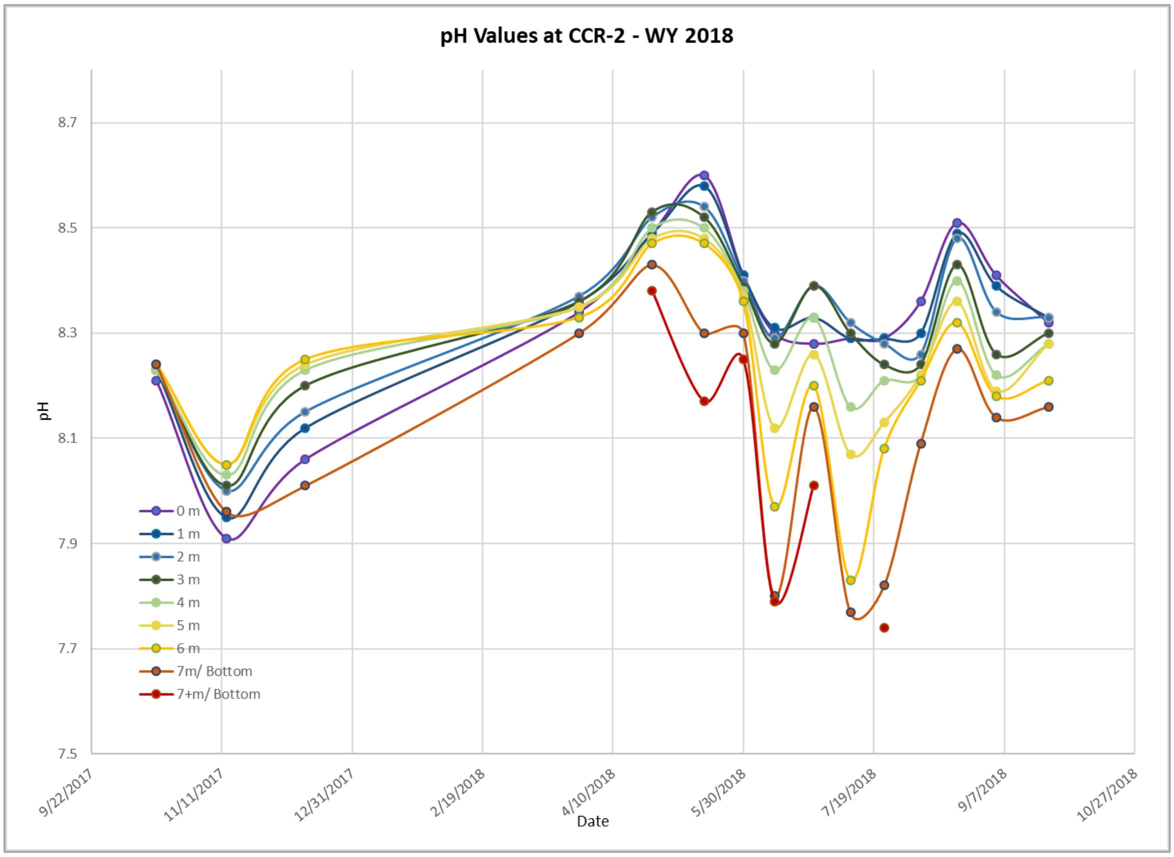


Figure 39. WY 2018 pH Profile in Cherry Creek Reservoir, Site CCR-2.

4.7 OXIDATION REDUCTION POTENTIAL

The Oxidation Reduction Potential (ORP) in Cherry Creek Reservoir in the photic zone ranged from 73.5mV in July 2018 to 247mV in October of 2017 (Figure 40). The ORP in the samples near or at the bottom of the reservoir ranged from -183mV in July 2018 and 339mV in October 2017. The lower ORP values measured in July coincided with the lower DO measurements in the Reservoir and the higher values in October were associated with higher DO values. In addition, the pH values during the low ORP values were also lower in the deeper samples. Low pH values are also an indication of decomposition processes.

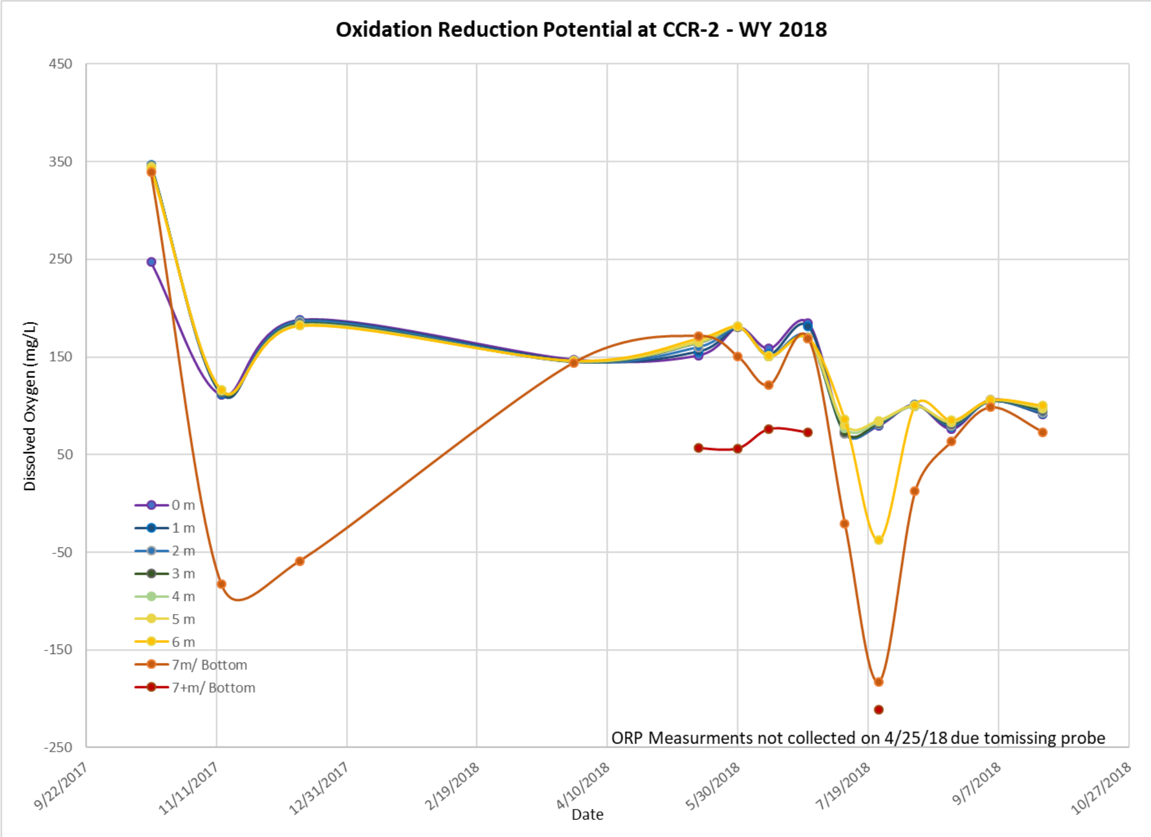


Figure 40. WY 2018 ORP Profile in Cherry Creek Reservoir, Site CCR-2.

4.8 CONDUCTIVITY

The conductivity in Cherry Creek Reservoir in WY 2018 ranged from a minimum of 965 µS/cm during the August 20th monitoring event and maximum of approximately 1,198 µS/cm during the March 28th and April 25th monitoring events (Figure 41). With the exception of one outlier in December 2017 at or near the bottom of the Reservoir, there was not much variability in specific conductance from top to bottom of the Reservoir.

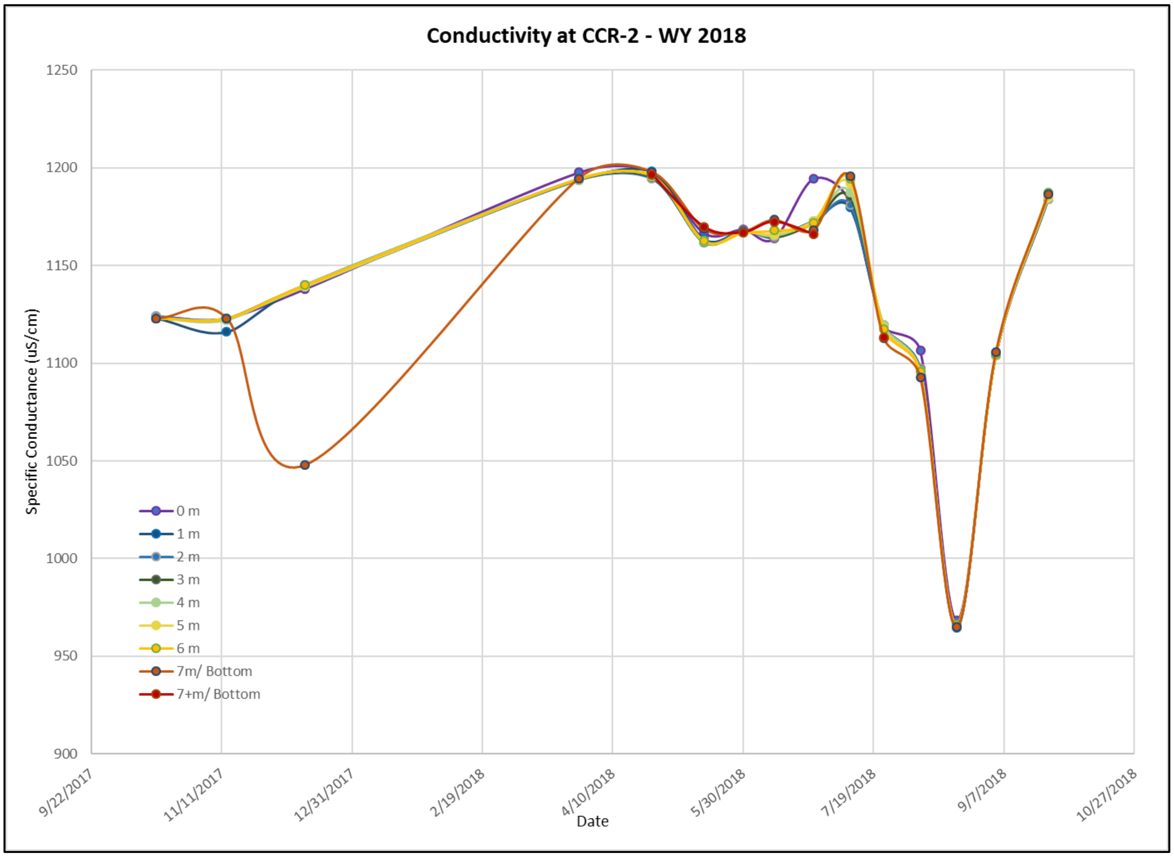


Figure 41. WY 2018 Conductivity Profile in Cherry Creek Reservoir, Site CCR-2.

4.9 TOTAL PHOSPHORUS

The SAP includes TP sampling at all three sites in the Reservoir (CCR-1, CCR-2, and CCR-3). Figure 42 shows the historical seasonal mean (July to September) TP concentration from the three (3) sites in the photic zone. The 2018 seasonal mean of 91.2 µg/L was lower than the WY 2017 (114.7 µg/L) and WY 2016 value (127.3 µg/L). The WY 2018 seasonal TP mean is also slightly lower than the long-term average of 93.8 µg/L measured from 1992-present. The seasonal mean values for TP appear to be increasing on a long-term scale although the last few years demonstrate a decreasing pattern.

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

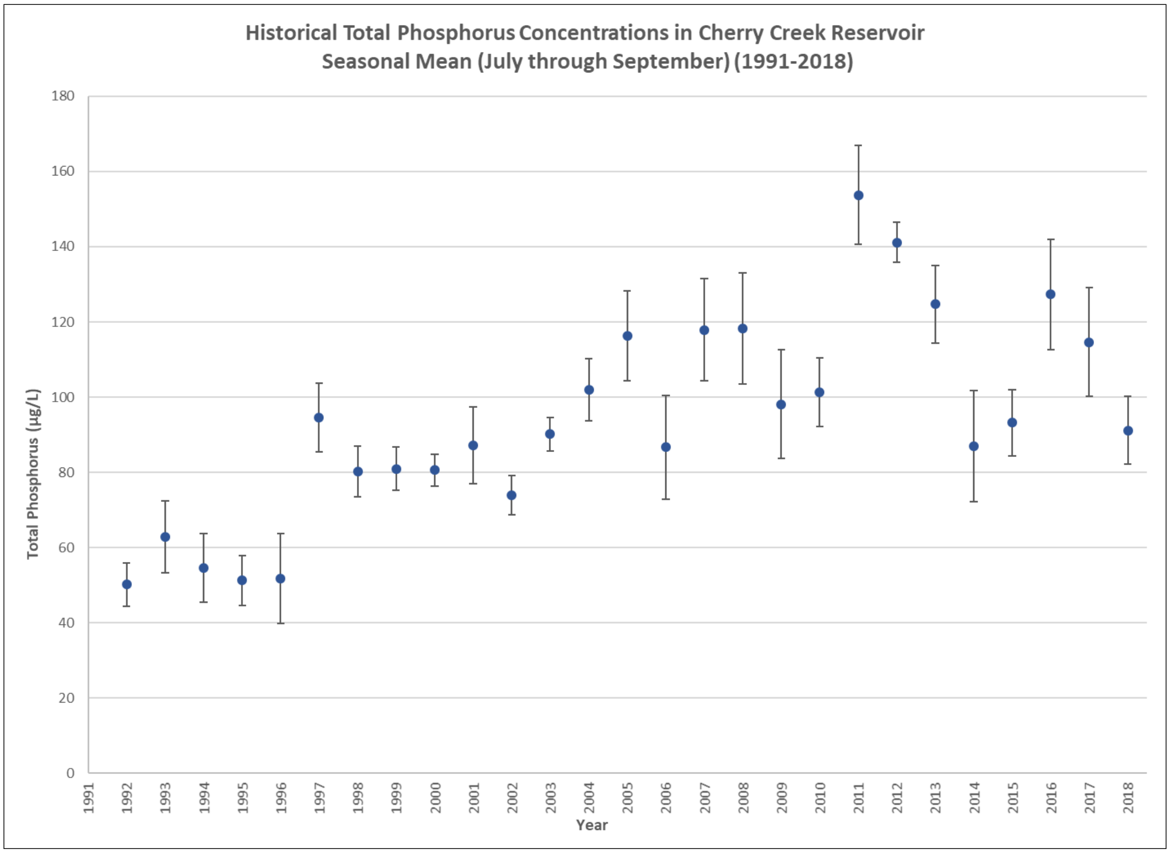


Figure 42. Historical Seasonal Mean TP Concentrations in Photic Zone of Cherry Creek Reservoir 1992-2018.

During WY 2018 as a whole, the monthly mean TP concentrations ranged between 67.1 µg/L and 105.2 µg/L with a mean value of 86.0 µg/L (Figure 43). The lowest values were present in May 2018 and the highest values in July 2018. The WY 2018 data suggests that there are high levels of TP in the Reservoir throughout the year contributing to eutrophic conditions.

The data illustrated in Figure 43 indicates that overall levels of TP in the Reservoir were above 60 µg/L during all of WY 2018, with most levels at or above 80 µg/L but only 6 of the 26 samples had TP levels above 100 µg/L.

During WY 2018, individual samples were also collected through the water column at CCR-2. Five samples were collected from the photic zone, which is a composite of 0, 1, 2, and 3 meters, and individual samples at depths of TP concentrations generally increased with depth. Average WY 2018 TP concentrations at station CCR-2 ranged from 83 µg/L in the 0-3 m composite samples to 137 µg/L in samples collected at the bottom of the water column at 4 m, 5 m, 6 m, and 7 m. Figure 44 illustrates the TP profiles with depth at Reservoir monitoring station CCR-2.

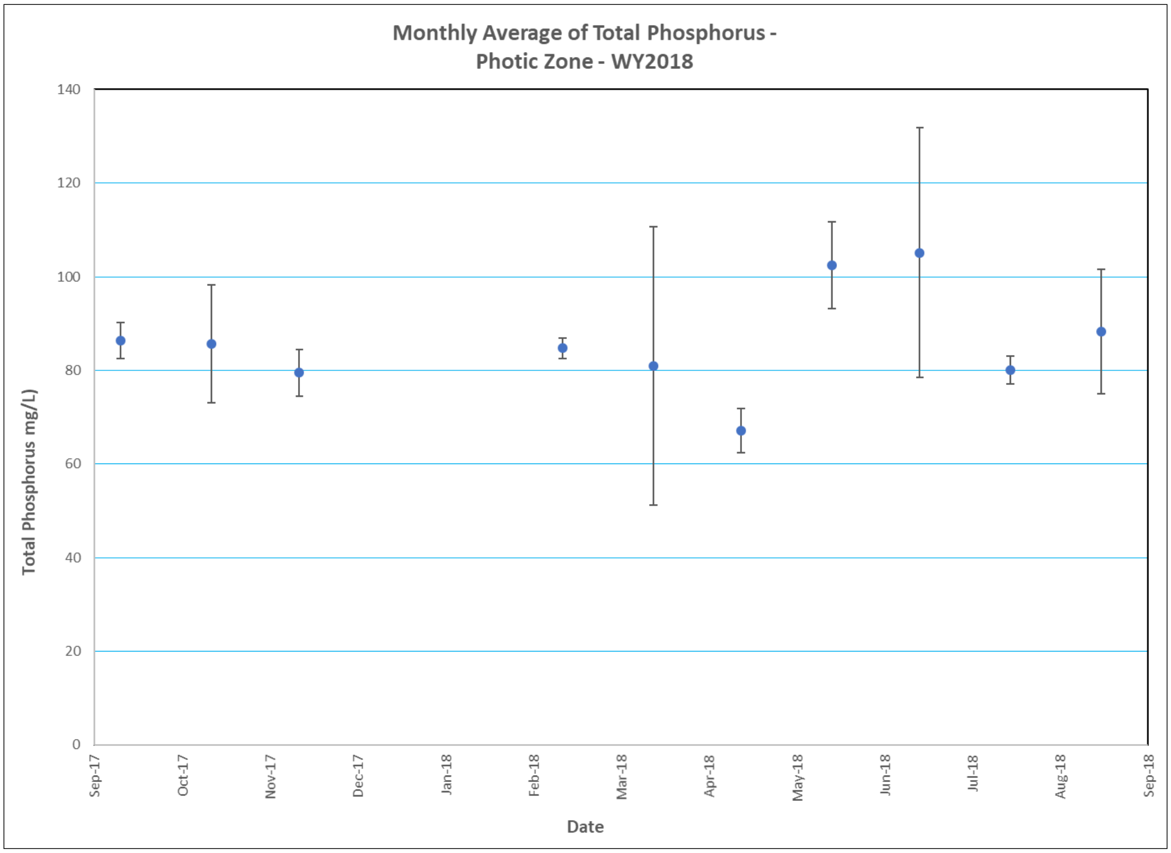


Figure 43. Monthly Average of Total Phosphorus in the Photic Zone, Cherry Creek Reservoir, WY 2018.

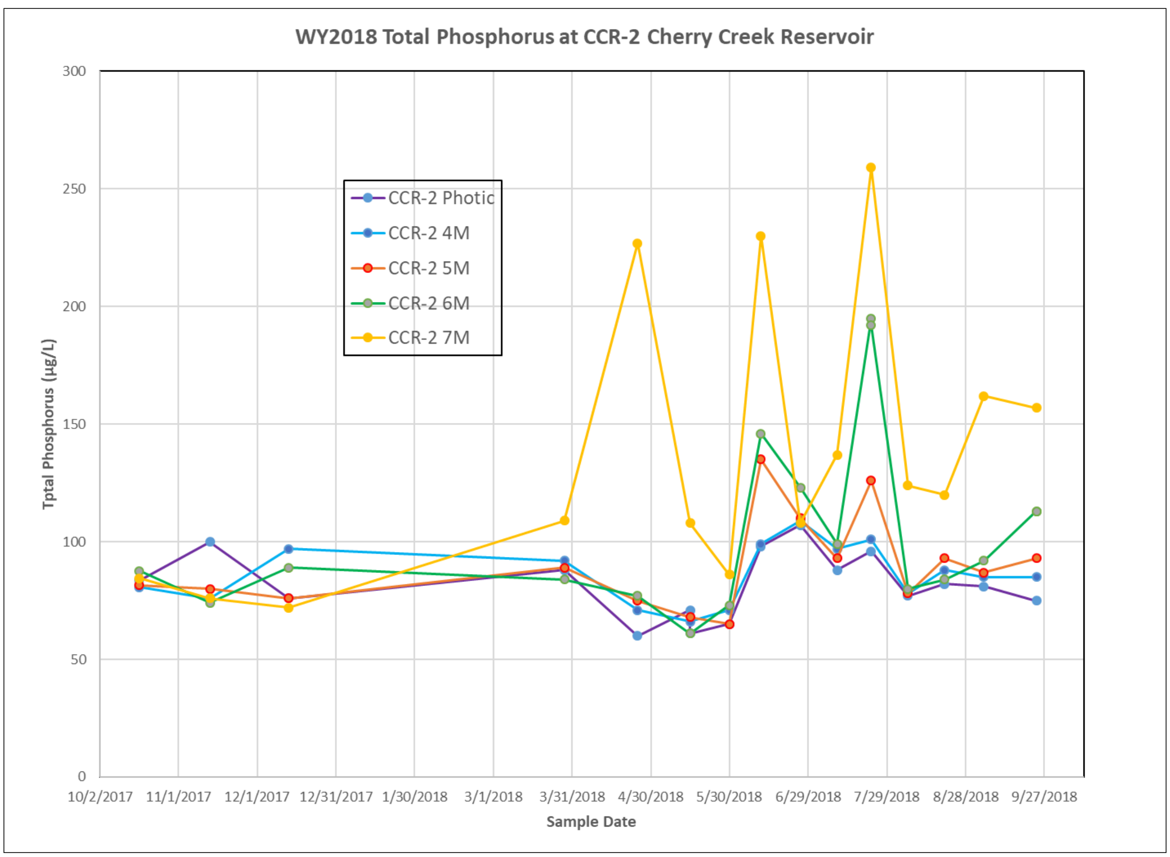


Figure 44. Total Phosphorus Profile at CCR-2 in Cherry Creek Reservoir, WY 2018.

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

A small increase in hypolimnetic TP concentrations was noted on April 25th, which was just 4 days before the first temperature destratification was noted on April 29th (Figure 35). At this time, there was also significant dissolved oxygen depletion in the hypolimnion, with DO concentrations below 2 mg/L at the bottom of the Reservoir (see Section 4.5).

Two additional events on June 26th and July 23rd, 2018 demonstrated significantly elevated TP above 200 µg/L at the 7 m depth, although the TP levels were also higher at all depths below the surface composite. The sample in late July was collected after the de-stratification system had been shut down for the season on July 4th. There was a temperature difference of only 1 ^{o}C between the 1 m depth and the bottom of the Reservoir. Mixing throughout the water column was also noted at the end of May and again in August.

4.10 DISSOLVED AND SOLUBLE REACTIVE PHOSPHORUS

Total Phosphorus is made up of both particulate and dissolved phosphorus. Particulate phosphorus is what remains after particulate phosphorus is filtered and remains suspended in the water column instead of settling to the bottom of a lake or reservoir. It includes both inorganic material, such as soil particles and clay minerals, and organic phosphorus, which includes particulate forms such as algal cells and plant fragments. Total dissolved phosphorus (TDP) includes dissolved organic and inorganic material. Dissolved inorganic phosphorus is usually reported as soluble reactive phosphorus (SRP), which represents the bioavailable form of phosphorus. Figures 45 and 46 depict the profiles of TDP and SRP from site CCR-2 during WY 2018.

During WY 2018 it appeared that both TDP and SRP remained relatively constant through late fall and winter 2017, but levels in the photic zone began to increase in late March 2018 (Figure 45 and 46). TDP levels in the photic zone decreased through the summer while the TDP levels at depths of 6 and 7 m increased from May through early August. Trends in SRP concentrations were similar to those for TDP. Since SRP is the bio-available form of phosphorus, it is typical to see decreases in SRP concentrations in the photic zone through the summer months as productivity increases. The trends of increased TDP and SRP were similar to those of TP although there was a strong correlation of lower levels of TDP and SRP in the photic zone during the events when levels were elevated at depth. On June 26th and July 20th, concentrations of TDP and SRP from the samples collected at 7 m were above 150 µg/L and 140 µg/L respectively. However, the photic zone levels were the lowest in the water column; TDP was less than 50 µg/L and SRP was less than 25 µg/L. The higher concentrations of TDP and SRP from samples collected at depths of 6 m and 7 m on July 23rd coincided with the lowest SRP concentrations observed during the growing season. This trend indicates that the primary productivity in the photic zone was utilizing the available forms of phosphorus as they were released and mixed through the water column.

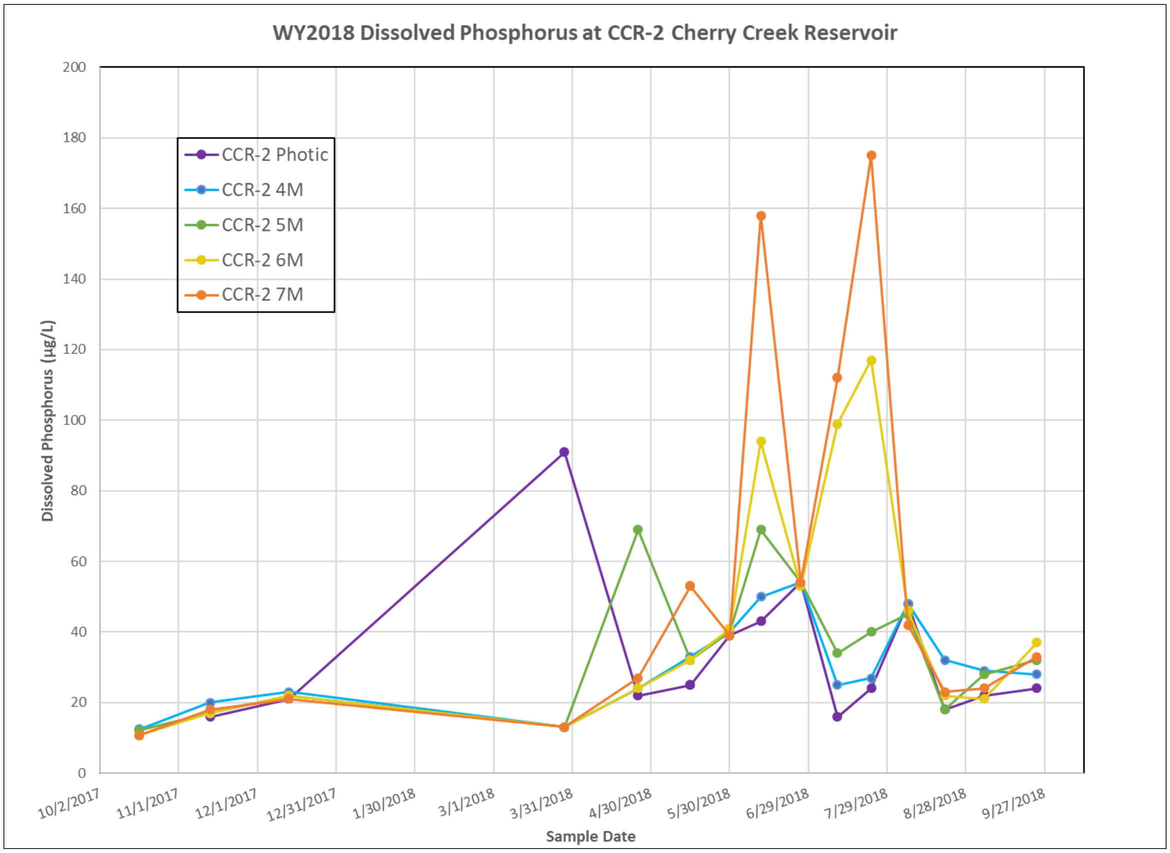


Figure 45. Total Dissolved Phosphorus Profile at CCR-2 in Cherry Creek Reservoir, WY 2018

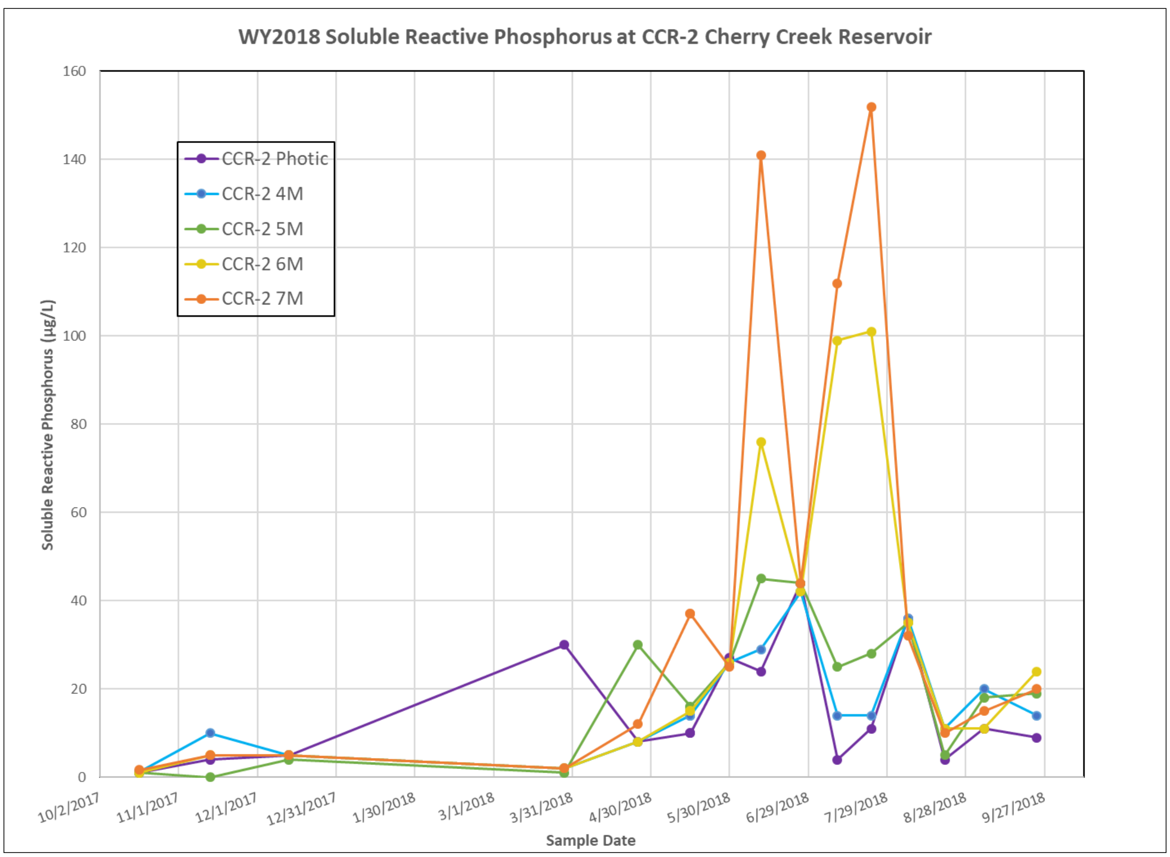


Figure 46. Soluble Reactive Phosphorus Profile at CCR-2 in Cherry Creek Reservoir, WY 2018

4.11 TOTAL NITROGEN

The seasonal mean (July thorough Sept) of Total Nitrogen (TN) in the Reservoir in WY 2018 was 848.1 µg/L which is higher than WY 2017 (761.2 µg/L) but lower than WY 2016 value (920.9 µg/L). As illustrated by Figure 47, the seasonal mean values for TN appear to be variable within the same range although a slight decreasing pattern may be present from 2010 to present. The WY 2018 seasonal mean is also slightly lower than the long-term average of 898.8 µg/L measured from 1992- present.

Although there is no site-specific standard for TN in Cherry Creek Reservoir, CDPHE Regulation 31 includes interim nutrient values for warm water reservoirs greater than twenty-five (>25) acres. These are criteria only, and do not become standards unless they are adopted as waterbody-specific standards during a basin-specific water quality standards rulemaking hearing. The warm water total nitrogen criterion for large reservoirs is 910µg/L TN as a summer (July 1-September 30) average in the mixed layer (median of multiple depths). The seasonal mean for Cherry Creek in the photic zone was less than the interim values for WY 2018.

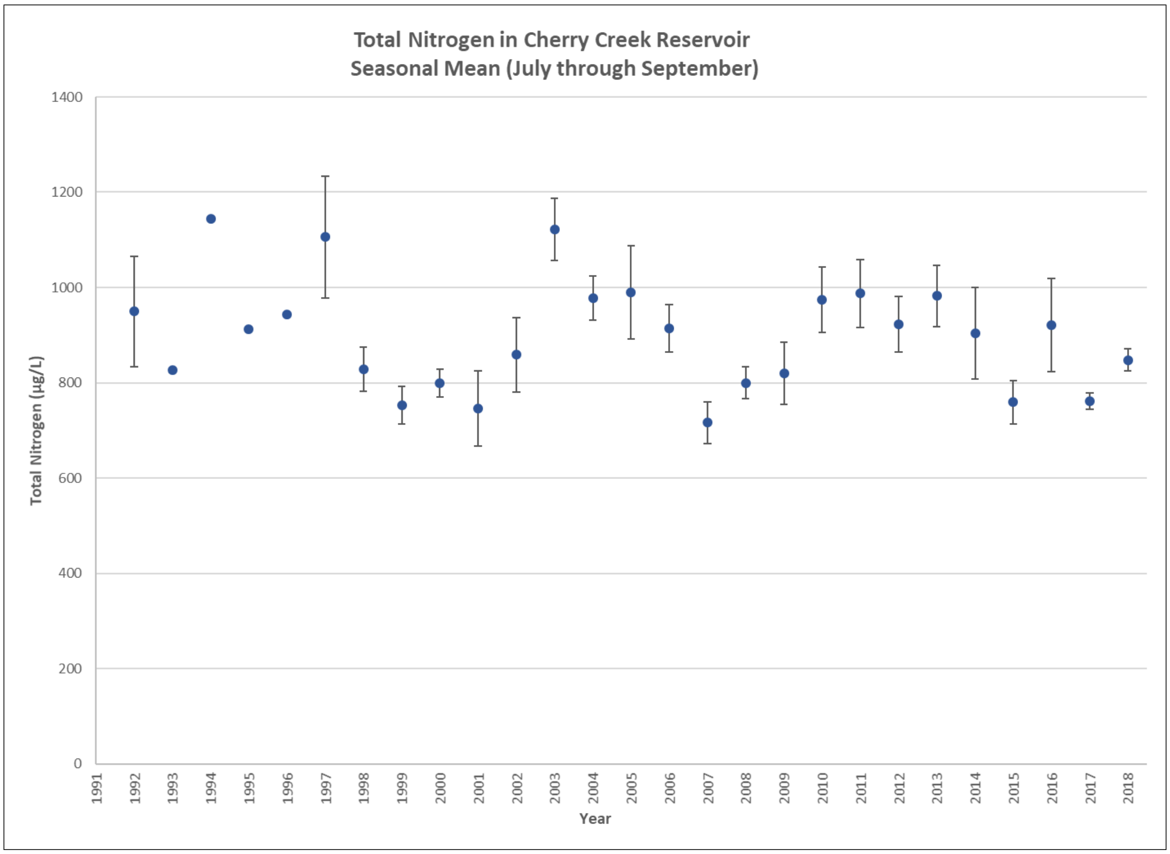


Figure 47. Historical Seasonal Mean TN Concentrations in Photic Zone of Cherry Creek Reservoir 1992-2018.

During the 2018 WY, TN concentrations ranged between 540 µg/L and 1013 µg/L with a mean value of 741 µg/L (Figure 48.). The highest values were present in the July 2018 samples and the lowest values in December of 2017.

During WY 2018, TN levels were elevated throughout the water column during the April 26th and July 10th and 23rd monitoring events (Figure 49). These events correlate with two of the monitoring events where samples collected at 7 m had values of TP that were also elevated: April 25th and July 2018.

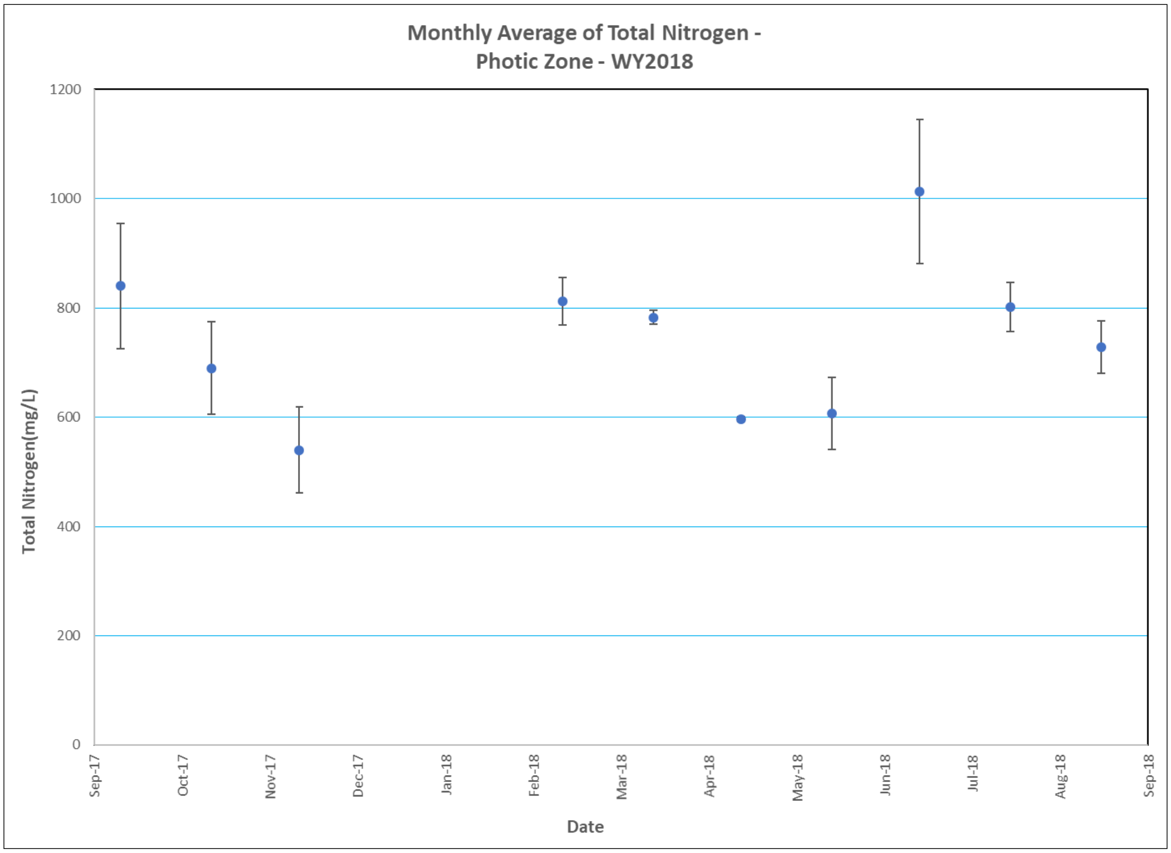


Figure 48. Monthly Average TN Concentrations in Photic Zone, Cherry Creek Reservoir, WY 2018.

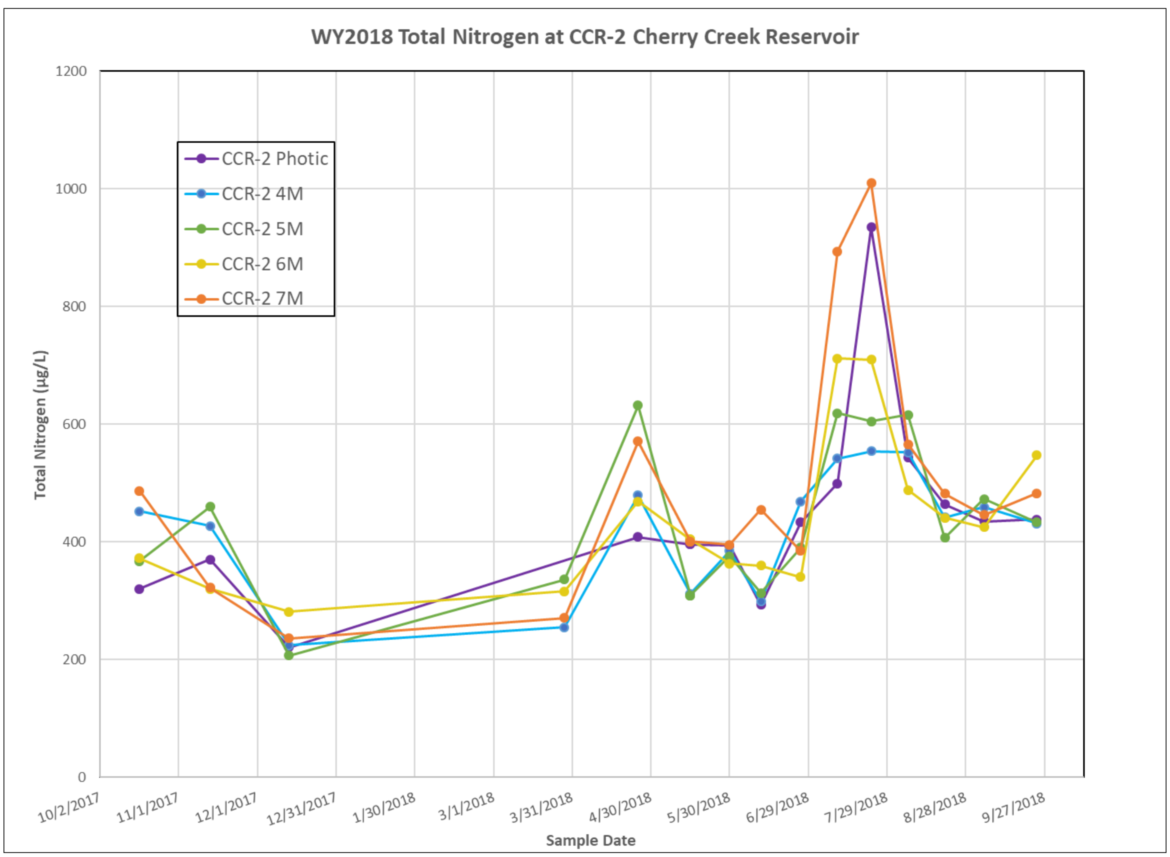


Figure 49. Total Nitrogen Profile at CCR-2 in Cherry Creek Reservoir, WY 2018

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. TIN concentrations were elevated in June and July at the deeper sampling sites (Figure 50). Possible reasons for the high TIN concentrations in the hypolimnion are decomposition processes and internal nitrogen loading.

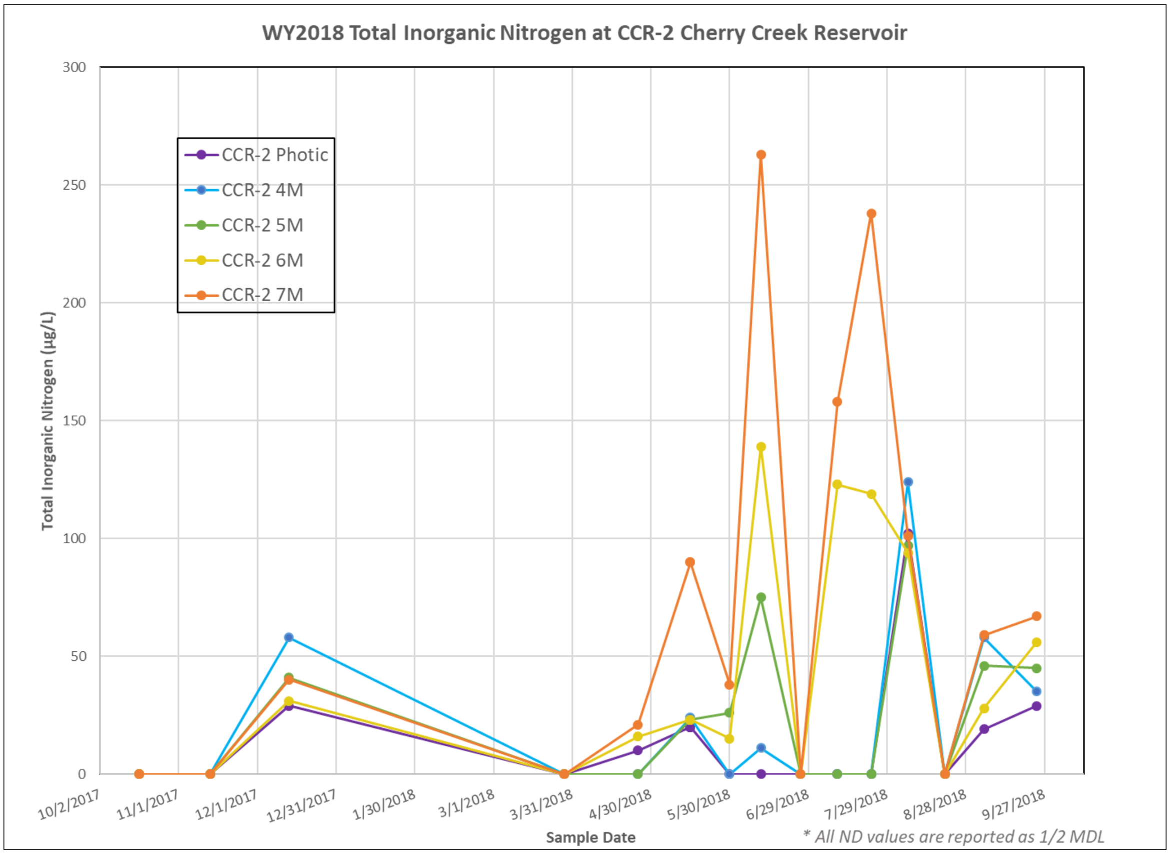


Figure 50. Total Inorganic Nitrogen Profile at CCR-2 in Cherry Creek Reservoir, WY 2018

Figures 51 and 52 illustrate NO_3+NO_2-N and NH_3-N concentrations separately. In general, nitrate concentrations are favored when DO is present and nitrates are converted to ammonia in the absence of oxygen. Nitrates were generally absent from the photic zone of Cherry Creek Reservoir throughout WY 2018, which may be an indication that algal growth in the Reservoir is limited by nitrogen concentrations.

Ammonia concentrations (Figure 52) were elevated at depth throughout most of the year and were also often present in surface waters. This is an indication of a highly productive reservoir. The increases in ammonia concentrations in the deeper layers (5, 6, and 7 m) were most pronounced in June and July, which correlated to the periods of lower oxygen at the bottom of the Reservoir.

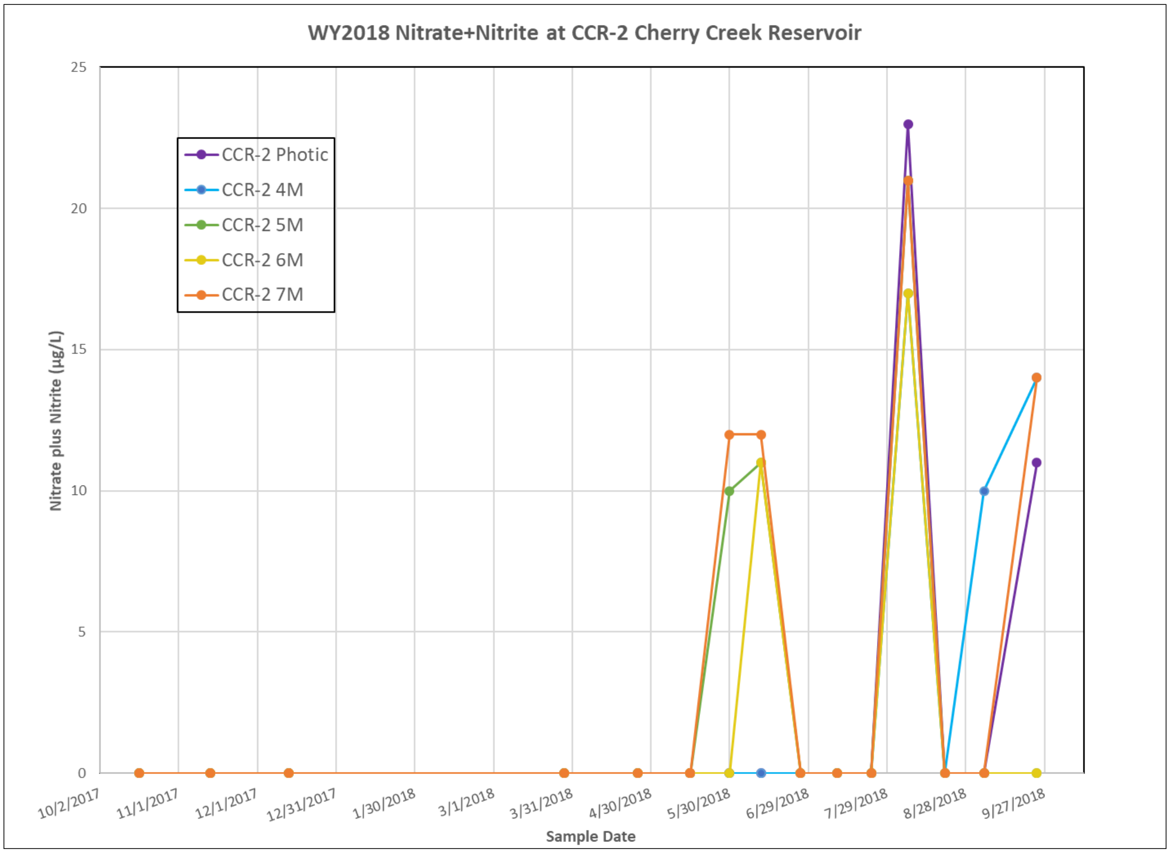


Figure 51. Nitrate and Nitrite Profile at CCR-2 in Cherry Creek Reservoir, WY 2018

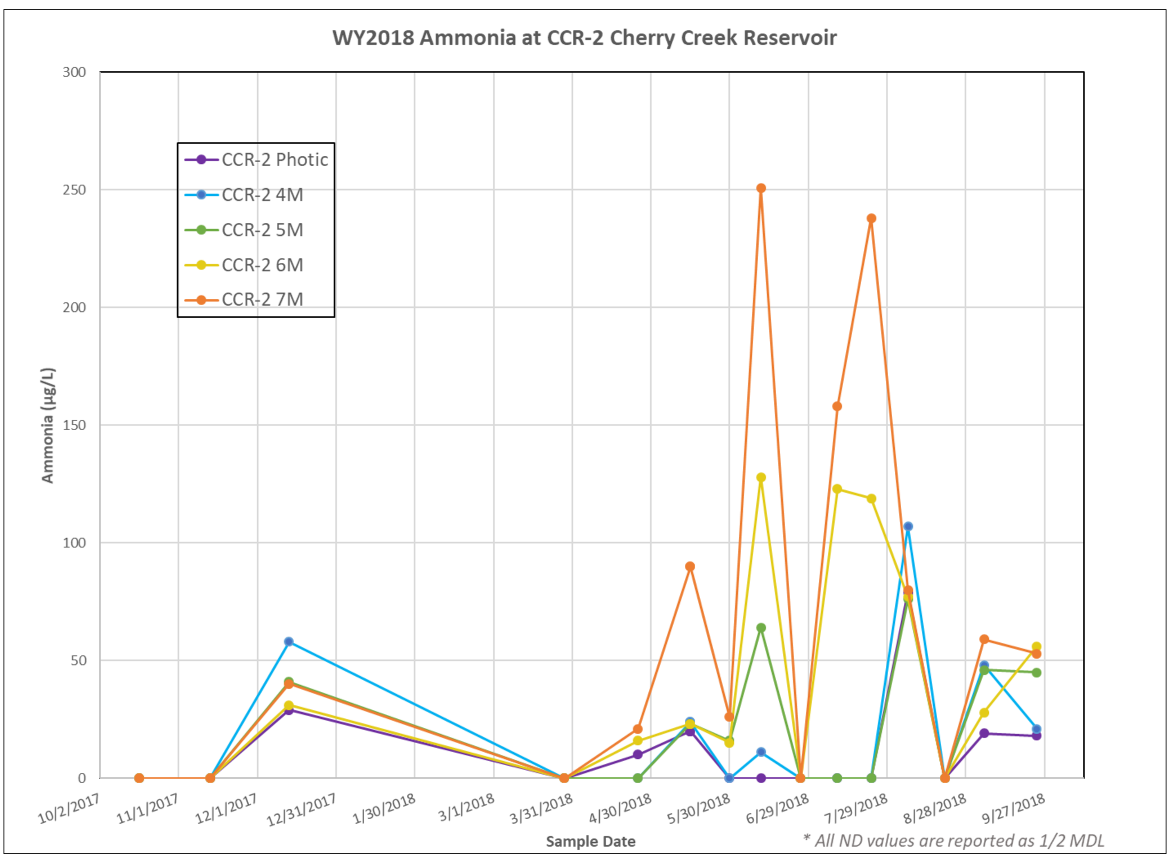


Figure 52. Ammonia Profile at CCR-2 in Cherry Creek Reservoir, WY 2018.

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 N:P ratio of healthy, growing algal cells is about 7 to 1 by weight (or between 15 and 16 to 1 by molar ratio). This value, known as the Redfield ratio, is generally assumed to be the ratio in which these nutrients are ultimately required by algal cells (Reynolds, 1986). Generally, large N:P ratios (>7) indicate that the growth of the phytoplankton community will be limited by the concentration of phosphorus present, while small N:P ratios (<7) indicate that growth will be limited by nitrogen concentrations (Schindler, 1977). The ratios of total inorganic nitrogen (TIN = nitrate+nitrite-N + ammonia-N) to soluble reactive phosphate (SRP) may be more meaningful than the ratio of total nitrogen to total phosphorus because the inorganic nutrient forms are more directly available to support the growth of aquatic organisms. Figure 53 plots the nutrient ratios of TN:TP, TIN:SRP and TDN:TDP. The line indicates the mass ratio of nitrogen to phosphorus indicating whether nitrogen or phosphorus is limiting and chl-*a* is plotted on the secondary axis. The TN:TP line indicates that TN was limiting in late fall of 2017 and in June and early July of 2018. The TIN:SRP ratio indicates a biologically available nitrogen limiting environment throughout the entire 2018 WY. In contrast the TDN:TDP indicates that dissolved phosphorus is limiting for the majority of the year with the exception of one measurement collected in late June of 2018.

Based on the data here and the correlation to the concentrations of chl-*a* at site CCR-2 during WY 2018, it appears that the biologically available forms of nitrogen may limit algal growth in Cherry Creek Reservoir. Due to the potential for cyanobacteria to fix atmospheric nitrogen, this may be one of the main factors leading to a phytoplankton community dominated by cyanobacteria (see Section 5.1).

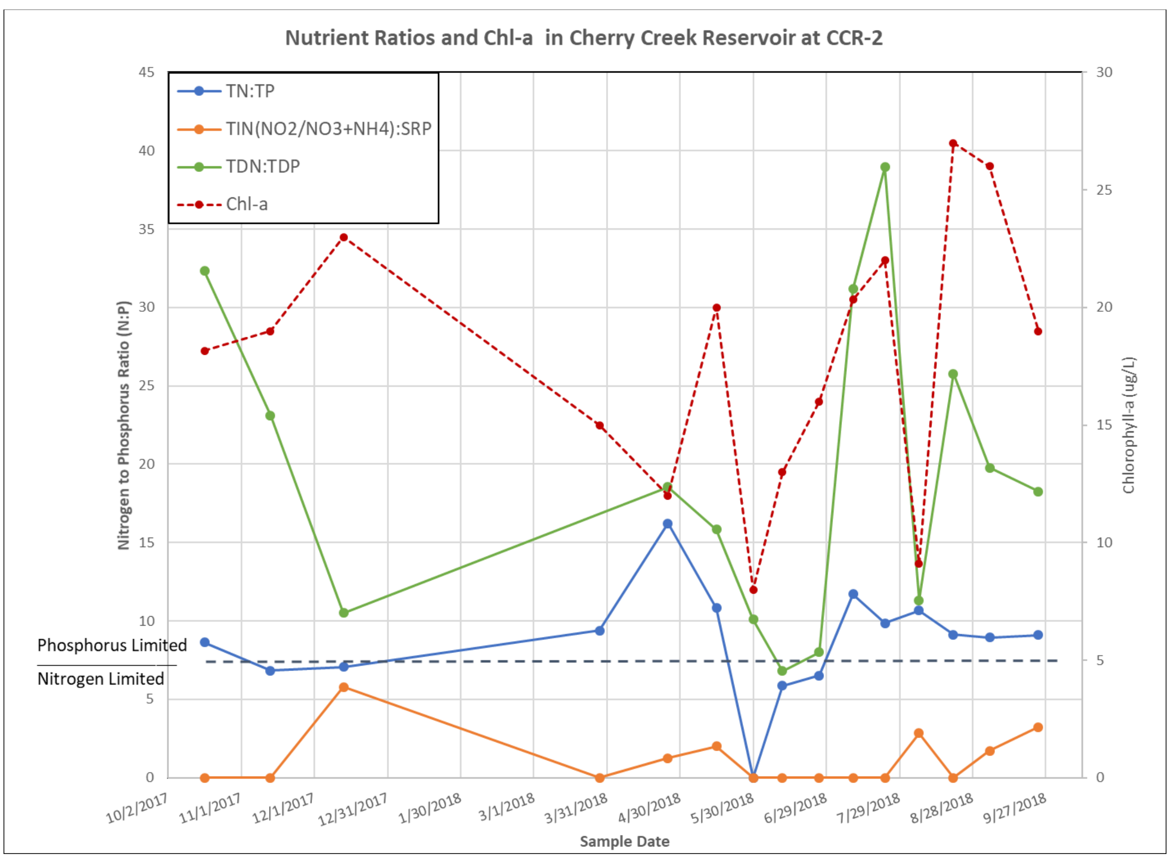


Figure 53. Nutrient Rations for and Chlorophyll-*a* in Cherry Creek Reservoir in WY 2018.

4.14 TROPHIC STATE ANALYSIS

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

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

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

Table 13. Trophic State Indices for Cherry Creek Reservoir WY 2018.

Station	Trophic State Index (TSI)		
	Total P	Secchi Depth	Chlorophyll-*a*
CCR-2	69	58	59

Trophic state can also be assessed by comparing monitoring data to trophic state criteria, such as those developed by the U.S. EPA (1980). Table 14 presents a comparison of Cherry Creek Reservoir monitoring data from WY 2018 to EPA trophic state criteria. Values for the various parameters were the same averages used to calculate the trophic state indices.

Table 14. Comparison of Cherry Creek Reservoir Monitoring Data to Trophic State Criteria WY 2018.

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	**0.089**	**18.4**	**1.2**	**High**

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

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

4.12 PLANKTON SAMPLES

Analyses of phytoplankton and zooplankton samples were used to assess biological conditions in Cherry Creek Reservoir during WY 2018. Both numbers of individuals (cells/mL for phytoplankton and animals/L for zooplankton) and biomass or biovolume (μm^3/mL for phytoplankton and µg/L for zooplankton) were reported.

4.12.1 PHYTOPLANKTON

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

Phytoplankton samples were collected at site CCR-2 from the photic zone and analyzed to identify and quantify the populations present. The results from WY 2018 indicate high productivity with diverse populations.

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 populations in Cherry Creek Reservoir were very diverse, with 40 or more species present on most sampling dates. Cell counts were dominated by the Cyanophytes, which were responsible for 75% or more of the total phytoplankton population throughout the year (Figure 54). Cyanophytes are probably responsible for the majority of algal blooms that occur in freshwater ecosystems. They have the ability to use atmospheric nitrogen as a nutrient source and regulate their position within the water column by altering their buoyancy with the use of gas vacuoles. These characteristics give cyanobacteria a competitive advantage over other groups of phytoplankton. Nuisance blooms of cyanobacteria usually occur in neutral to alkaline waters that are still, relatively warm, and have low N:P ratios, which are all characteristics of Cherry Creek Reservoir.

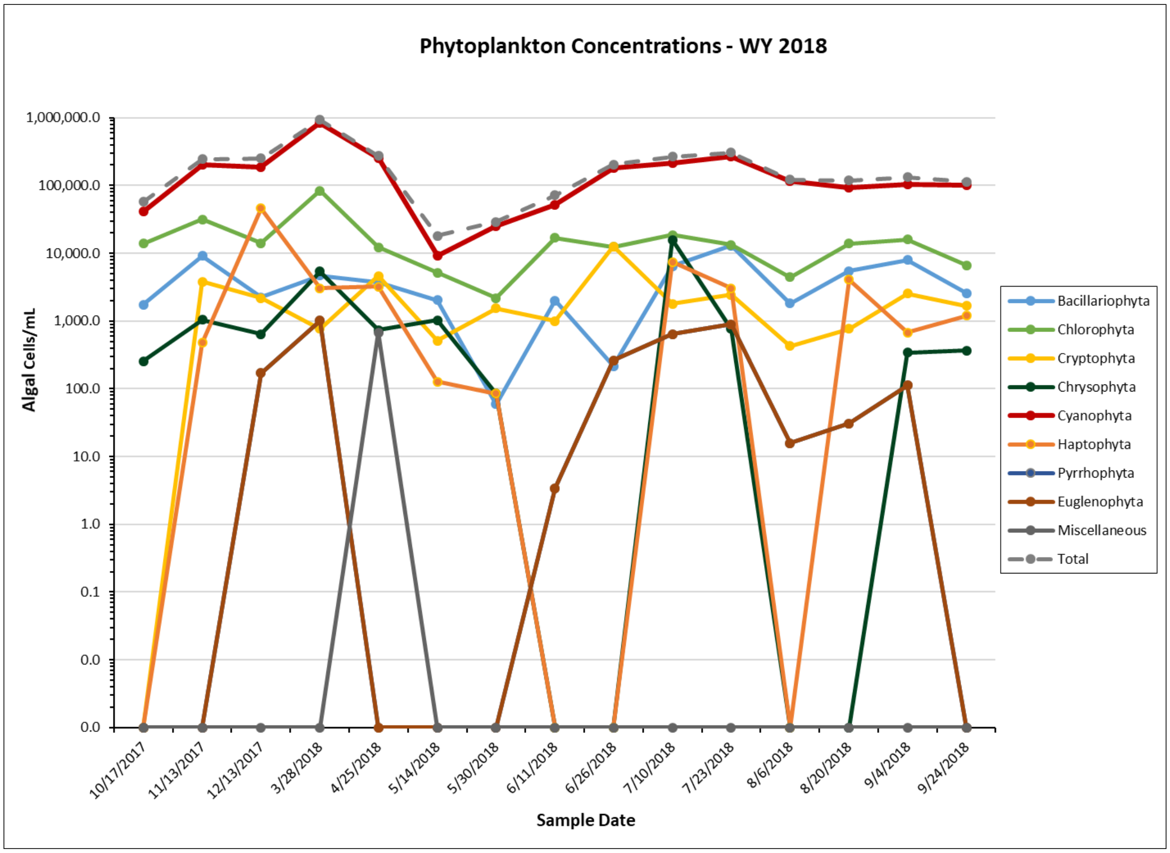


Figure 54. Phytoplankton Concentrations in Cherry Creek Reservoir, WY 2018.

Some species of cyanobacteria are capable of producing toxins, but those species were not commonly observed during sampling in Cherry Creek Reservoir in WY 2018. *Chroococcaceae* spp., a relatively small species, was the most common cyanobacteria on most sampling dates and the cyanobacteria as a whole usually made up less than 10% of the total algal biovolume (Figures 55 and 56).

Bacillariophyta (diatoms) and Chlorophyta (green algae) were present in high numbers throughout the year and were responsible for most of the total algal biovolume on most sampling dates (Figure 55), usually providing more than 50% of the total algal biovolume (Figure 56).

Nuisance blooms of diatoms are not as common as nuisance cyanobacteria blooms; however, when they do occur, it tends to be during the late spring or early summer months when water temperatures are still relatively low. Several species of diatoms and green algae were included in both high algal populations and high algal biovolume on most sampling dates. An exception was May 14, 2018, when a single species, the diatom *Asterionella formosa*, accounted for 10.5% of the total cell counts and 78.8% of the total algal biovolume.

Along with the Cyanophytes, Bacillariophytes, and Chlorophytes, members of the Cryptophtye group (cryptomonads) were often present at levels of 1,000 or more cells/mL (Figure 36), a level associated with eutrophic conditions. The cryptomonads have two flagella that can be used for propulsion and can also form resting stages (cysts) to survive unfavorable conditions.

Phyrrophyta (dinoflagellates) bloomed in late fall 2017 and again in summer 2018. Dinoflagellates are responsible for the majority of algal blooms that occur in marine ecosystems and can cause "red tides". The toxins produced by marine dinoflagellates are extremely toxic to humans and cause paralytic shellfish disease. While such deadly blooms usually do not occur in freshwater systems, dinoflagellate blooms do occur in lakes and have been reported to be responsible for the deaths of fish, waterfowl, and livestock. Dinoflagellates of the genera *Peridinium* and *Ceratium* are also known to be responsible for taste and odor problems in freshwater ecosystems when present in high concentrations. The frequency of dinoflagellate blooms appears to be highly correlated to levels of organic pollution. Pyrrophytes made up about 28% of the total algal biovolume on June 26, 2018, and 62% of the biovolume on July 10, 2018 (Figure 56), with single species responsible for most of those totals on both dates. *Ceratium brachyceros* was responsible for 25% of the biovolume on June 26th and *Peradinium polonicum* contributed 61% of the algal biovolume on July 10th.

Other groups present at various times during the year included the Chrysophtes (yellow-brown algae), Euglenophytes, and Haptophytes (golden algae). All of these groups include some large species that made up relatively large portions of the total algal biovolume on some sampling dates (Figure 56).

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 known toxin producer, was first noted in Cherry Creek Reservoir in March 2016 and has been present in most samples since that date. Although concentrations of *Chrysochromulina parva* are usually relatively low, they peaked on December 13, 2017, when this species accounted for 18% of the total algal population and 48% of the algal biovolume.

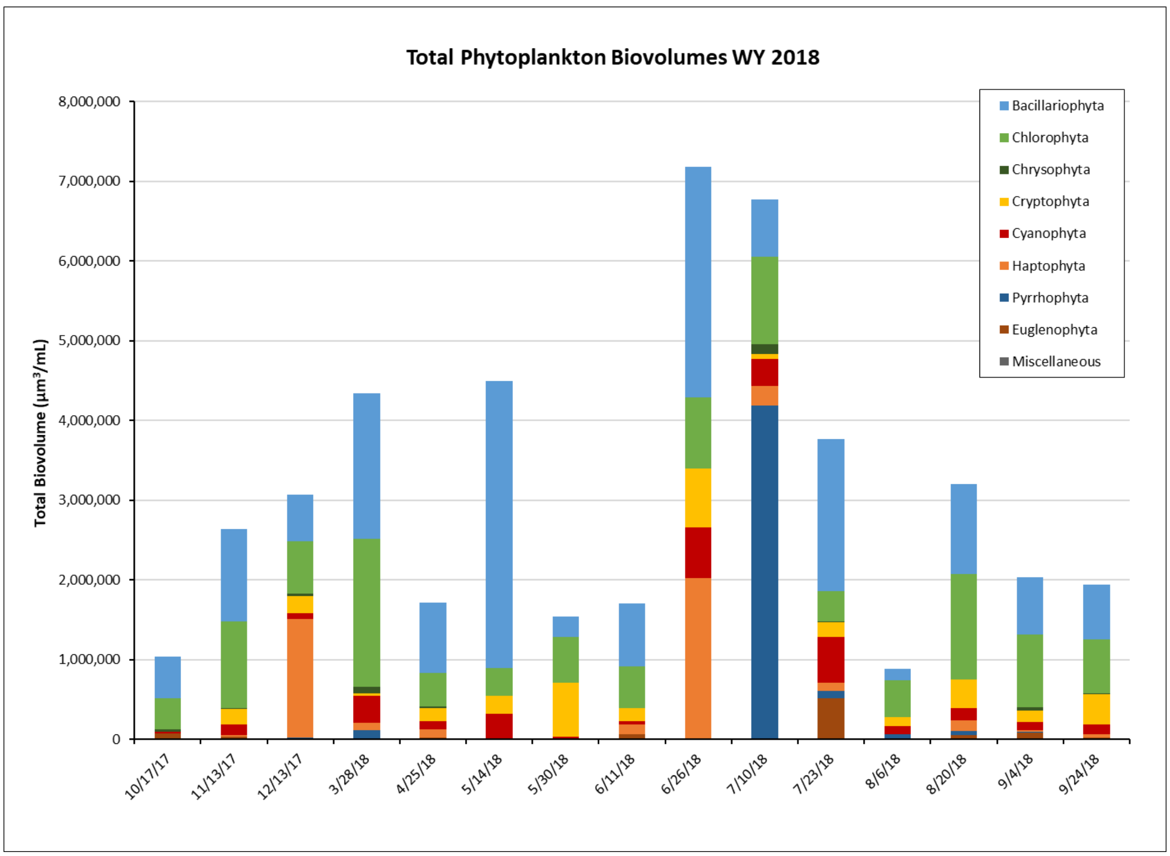


Figure 55. Phytoplankton Biovolumes in Cherry Creek Reservoir in WY 2018.

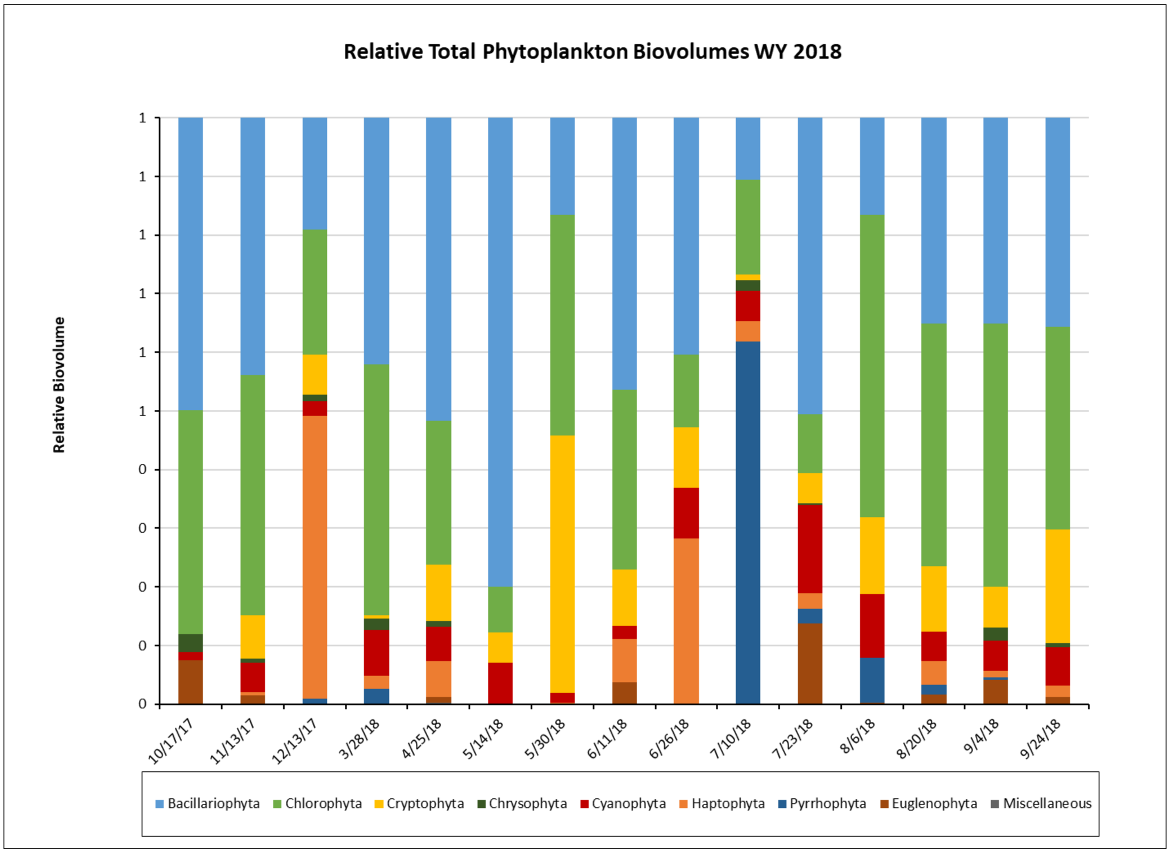


Figure 56. Relative Phytoplankton Biovolumes in Cherry Creek Reservoir in WY 22018.

4.12.2 ZOOPLANKTON

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

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

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

The zooplankton population in Cherry Creek Reservoir was much less diverse than the phytoplankton population. There were often less than 10, and never more than 17 species, including immature forms, present on any sampling date. This is typical of Colorado lakes. A classic study by Pennak (1957) found that there were rarely more than 1-3 copepods, 2-4 cladocerans, and 3-7 rotifers present in any given lake.

Copepods were typically the zooplankton present in the highest numbers in Cherry Creek Reservoir and accounted for over 50% of the total population throughout the summer months (Figure 57). Immature forms of calanoid and cyclopoid copepods accounted for the majority of the organisms present. Diachyclops thomasi and/or Leptodiaptomus ashlandi were present on most sampling dates and were often the only adult copepods present.

Cladocerans frequently comprised over half of the zooplankton biomass (Figures 58 and 59), although the species present in Cherry Creek Reservoir typically did not include large-bodied *Daphnia* that are an important source of fish food in many lakes. The lack of larger zooplankton may be related to the presence of high populations of gizzard shad (*Dorosoma cepedianum*). Gizzard shad are an important part of the food base for the Cherry Creek Reservoir walleye (*Sander vitreus*) fishery, but they are also effective filter feeders, especially at the larval stage (Johnson, 2014).

The most common cladocerans were *Daphnia ambigua*, *Bosmina longirostris*, and *Daphnia lumholtzi*. *Daphnia ambigua* is one of the smaller *Daphnia* and the bosminads, in general, are small cladocerans. No daphnia were present in zooplankton samples collected on March 28 and August 20, 2018. The absence of *Daphnia* on two sampling dates and the general small size of the cladocerans present is likely due to predation by gizzard shad.

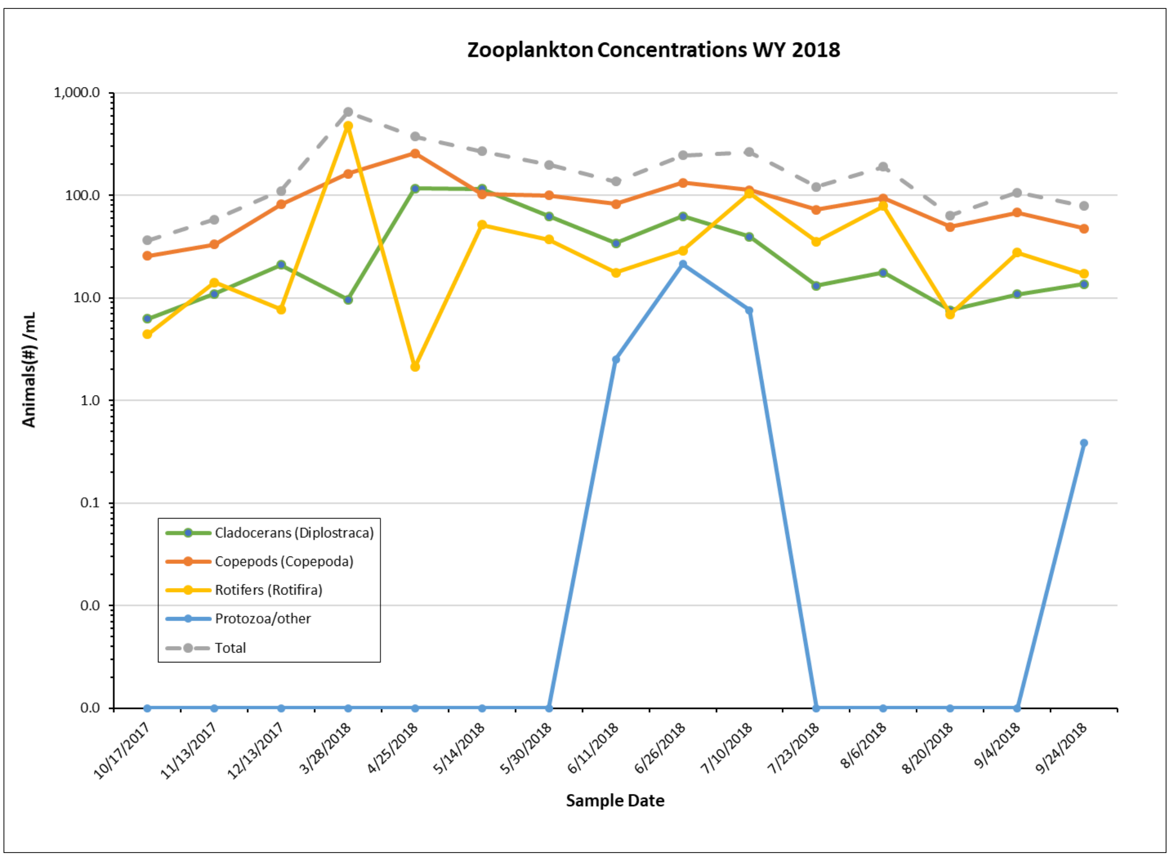


Figure 57. Total Zooplankton Concentrations – WY 2018.

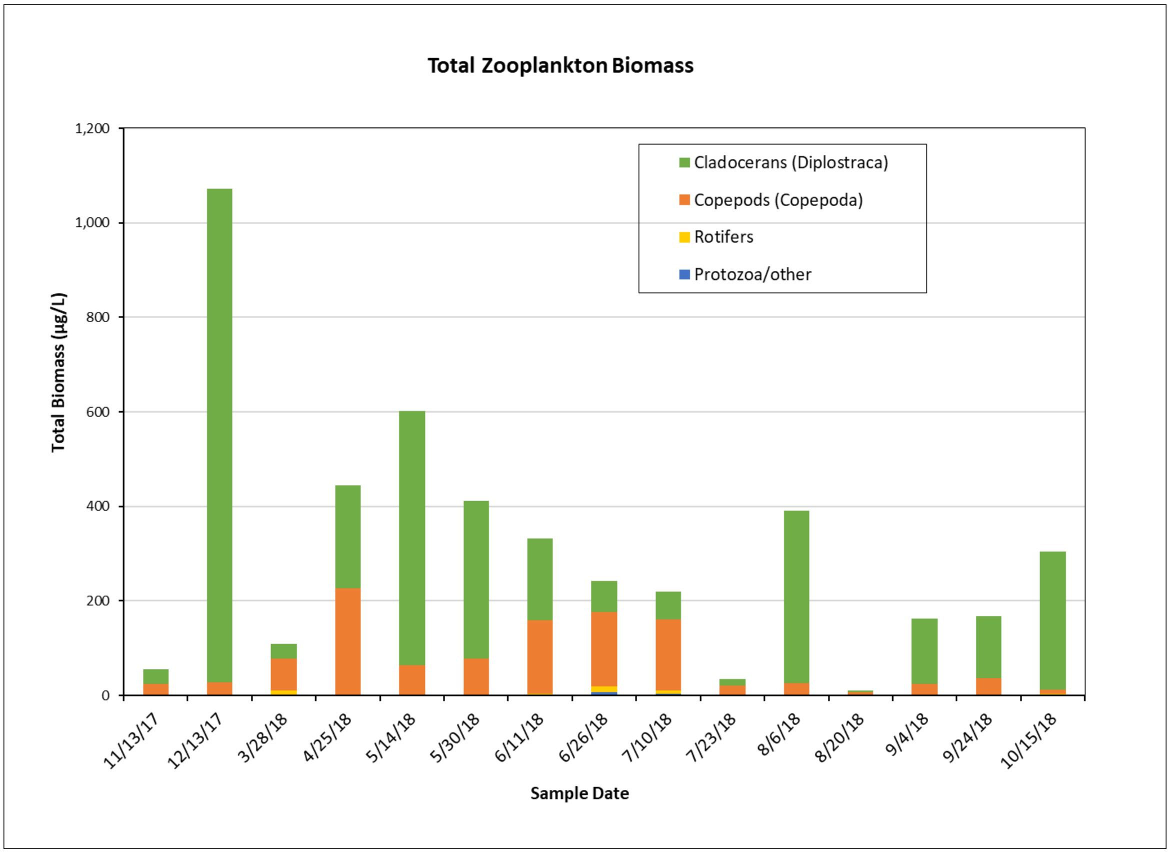


Figure 58. Total Zooplankton Biomass – WY 2018

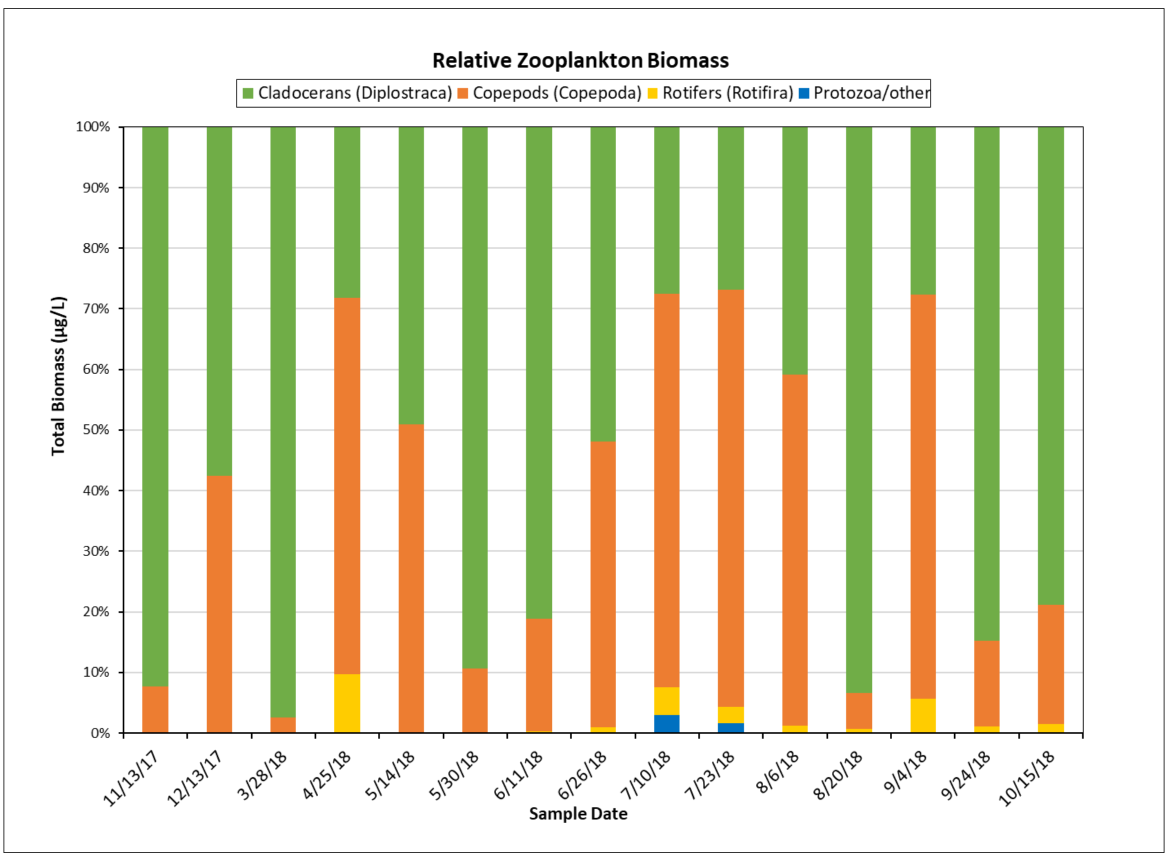


Figure 59. Relative Zooplankton Biomass in Cherry Creek Reservoir in WY 2018.

Daphnia lumholtzi is an invasive species is a larger daphnia, but it is characterized by long spines that help it avoid predation. This species was first identified in Colorado in 2008 (USGS, NonIndigenous Aquatic Species fact sheet, https://nas.er.usgs.gov/queries/FactSheet.aspx?speciesID=164) and in Cherry Creek Reservoir in 2011 (Johnson, 2014). *Daphnia lumholtzi* was identified in Cherry Creek Reservoir during WY 2018 from October through December 2017 and July through September 2018. *Daphnia lumholtzi* peaked on August 6, 2018, when it contributed 3.4% of the zooplankton population and 92.6% of the zooplankton biomass, and again on September 24, 2018, when it contributed 5.4% of the zooplankton population and 73.8% of the zooplankton biomass.

5.0 WATER BALANCE

The calculated WY 2018 water balance for Cherry Creek Reservoir was calculated from the following equation:

$\text{Ending Storage}_{9/30/2018} + \sum\text{Reservoir Inflows} - \sum\text{Reservoir Outflows} - \text{Starting Storage}_{10/1/2017} = \Delta\ \text{Storage}$

Storage was based on daily surface elevations and area-capacity tables for Cherry Creek Reservoir provided by the USACE (Appendix C). The lake surface area and volume were 5549.2 ft and 11,897 AF on October 1, 2017, and 5548.6 ft and 11,414 AF on September 30, 2018. This results in a loss in storage of 483 AF (-Δ Storage) during WY 2018.

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) is estimated from the acreage of the Reservoir and the amount of precipitation recorded at the nearby Centennial Airport (KAPA) precipitation gauge (Section 3.1). The surface area of Cherry Creek Reservoir during WY 2018 varied between 798 acres at the end of September 2018 and 878 acres on May 7 and 9, 2018, with a median value of 828 acres. The median surface area was based on elevations and area-capacity tables for Cherry Creek Reservoir provided by the USACE. The median surface elevation for WY 2018 was 5546.8 ft and the area-capacity tables were based on a 2009 survey of the lake.

A total of only 9.51 inches (0.972 feet) of precipitation was recorded at the Denver-Centennial Airport weather station (KAPA) during WY 2018. This was the lowest rainfall total in the last 12 years (Figure 4). The total volume of water contributed to Cherry Creek Reservoir during WY 2018 was calculated by multiplying the daily precipitation amounts measured at the KAPA station by the corresponding lake surface areas on those dates, as determined by the USACE area-capacity tables. Based on these calculations, precipitation contributed an estimated 666 AF of water to the Reservoir during WY 2018.

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 to flows (Inflow 3) and weir calculations provided by Bill Ruzzo (2014. unpublished, included in Appendix D of GEI, 2016) were used to calculate flows from the recorded elevations at Station CT-2 (Inflow 4). The average of the 15-minute flows for each date were averaged to produce daily flows that could be used to provide a daily time step for Cherry Creek modeling efforts.

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 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 WY 2018 net inflow was 16,629 AF.

Due to instrument failure, water levels were not recorded at Station CT-2 from December 13, 2017, through April 12, 2018. Flows for the missing dates were estimated by calculating flows at CT-2 as a percentage of flows at CC-10 for the dates when flows were measured. Although there was considerable variability, flows at CT-2 averaged 19.7% of the flow at CC-10 in WY 2018. Data provided in the WY 2017 monitoring report (TetraTech, 2018) indicated flows at CT-2 averaged 19.8% of the flow at CC-10 in WY 2017, indicating this estimation should provide reasonable values for the missing flow data.

The estimated volumes of surface flow entering the Reservoir from surface water sources in WY 2018 are:

- Cherry Creek: 16,407 AF
- Cottonwood Creek: 3,228 AF

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

Evaporation estimates (outflow 1) are provided by the USACE. The USACE indicated they had some problems with their evaporation model during WY 2018 and provided SLM with the evaporation data they used as a substitute to the modeled data (Katie Seefus, USACE, personal communication with Erin Stewart, SLM, Nov. 26, 2018). The estimated evaporative losses from the reservoir were 3,042 AF during WY 2018, or approximately 44.1 inches (3.67 feet) per acre at the median surface area of 828 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 60). The gauge is located approximately 2,300 ft downstream of the Reservoir. Other than releases from the reservoir, there are no major surface water contributions to flow measured at this gauge. Preliminary WY 2018 flows at the USGS gauge totaled 15,653 AF.

The Reservoir WY 2018 water balance is summarized in Table 15. Following methods developed by TetraTech (2018), the net ungauged inflows(+)/outflows(-) was mathematically calculated to result in the Reservoir change in storage to equal the -552 ac-ft reported by the USACE for WY 2018 (Appendix C). Components included in this calculated term are ungauged surface water inflows into the reservoir, groundwater seepage from the reservoir through the dam, and measurement uncertainties. Net ungauged outflows for WY 2018 were 4,358 AF. Based on previous practice, this large change was apportioned between the Cherry Creek and Cottonwood Creek inflows to calculate nutrient loading (Section 6). Cherry Creek contributed 83.6% of the combined inflow and Cottonwood Creek contributed 16.4%, resulting in reductions surface inflows of 3,642 AF for Cherry Creek and 717 ac-ft for Cottonwood Creek. The adjusted inflows are included in Table 15.

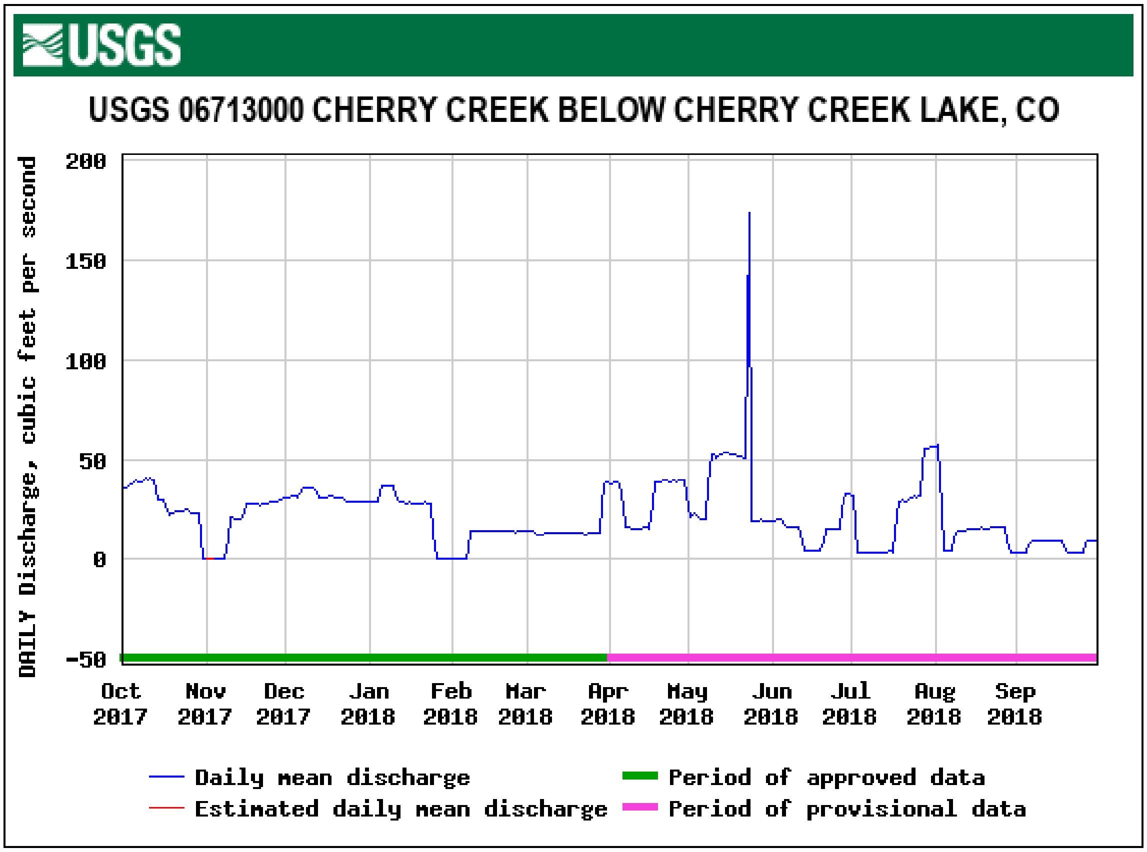


Figure 60. WY 2018 Preliminary Hydrograph and Historical Median Flows for USGS Gauge Cherry Creek below Cherry Creek Lake.

Table 15. Cherry Creek Reservoir WY 2018 Water Balance

Water Source	Water Volume (AF)
Inflows	
Cherry Creek (CC-10)	16,407
Cottonwood Creek (CT-2)	3,228
Precipitation	666
Alluvial groundwater	2,200
Total Inflows	**22,501**
Outflows	
Evaporation	-3,042
Reservoir releases	-15,653
Total Outflows	**-18,695**
Net Ungauged Inflows/Outflows	
Calculation	-4,358
WY 2018 Change in Storage	**-552**

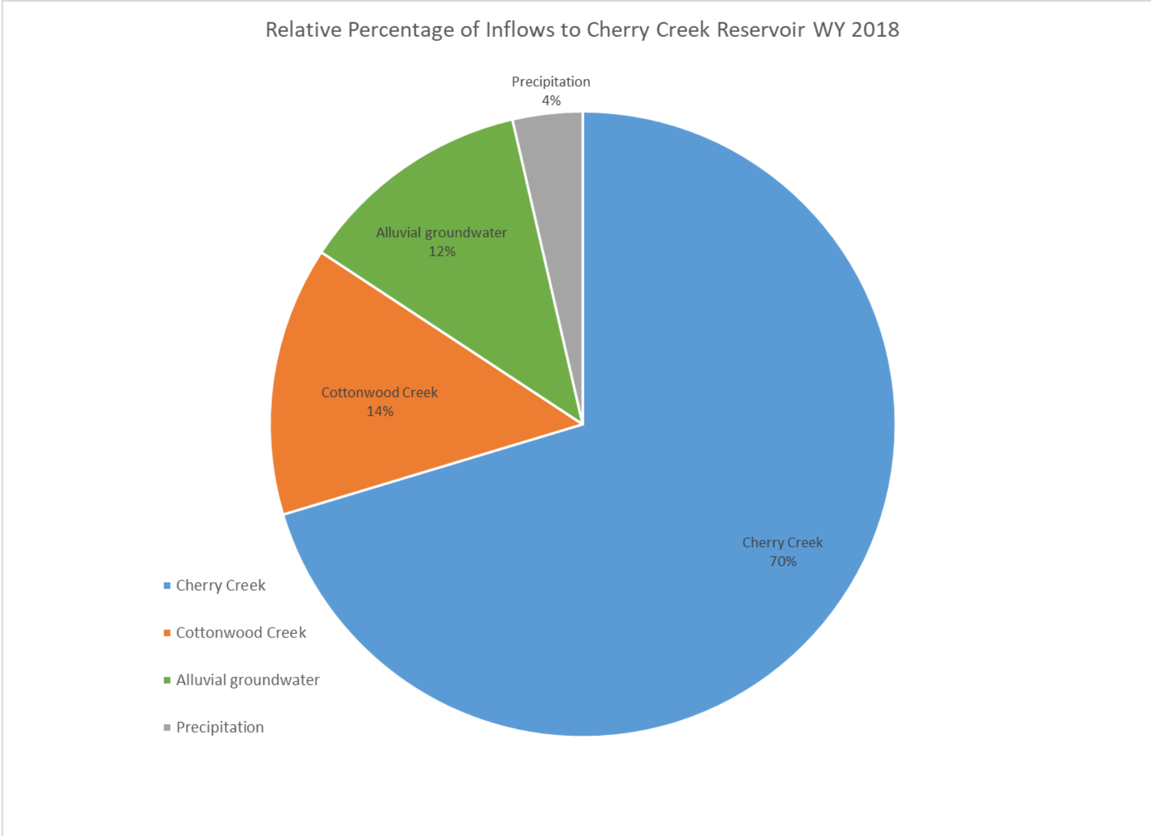


Figure 61. Relative Inflows to Reservoir Water Balance in WY 2018

The relative inflows to the Reservoir from Cherry Creek, Cottonwood Creek, groundwater, and precipitation are pictured in Figure 61.

6.0 FLOW WEIGHTED NUTRIENT CONCENTRATIONS

Daily nutrient concentrations for Cherry Creek and Cottonwood Creek were calculated by interpolating concentrations between sampling dates and multiplied by the daily flows at CC-10 and CT-2 to provide nutrient loading on a daily time step. The sum of the daily nutrient loads was divided by the annual inflows to calculate the annual flow-weighted inflow concentration. The flow weighted nutrient concentrations for WY 2018 as well as the concentrations from previous years are outlined in Table 16.

The WY 2018 flow-weighted phosphorus concentration for Cherry Creek was 236 µg/L, which was higher than WY 2017 (229 µg/L) but lower than WY 2016 (250 µg/L) and the recent (2011 – 2015) flow-weighted total phosphorus concentration of 263 µg/L published in GEI (2016).

The WY 2018 flow-weighted nitrogen concentration was 1,883 µg/L, which was higher than WY 2017 (1,260 µg/L), WY 2016 (1,012 µg/L), and the recent (2011 – 2015) flow-weighted total phosphorus concentration of 1,261 µg/L published in GEI (2016).

The WY 2018 flow-weighted phosphorus concentration for CT-2 was 79 µg/L, which was higher than WY 2017 (62.2 µg/L) and the 2011 – 2015 flow-weighted total phosphorus concentration of 75 µg/L calculated by GEI in 2016, but lower than WY 2016 (88 µg/L).

The WY 2018 flow-weighted nitrogen concentration for CT-2 was 1,984 µg/L, which was higher than WY 2017 (1,809 µg/L), and the 2011 – 2015 flow weighted total phosphorus concentration of 1,592 µg/L calculated by GEI in 2016, but lower than WY 2016 (2,020ug/L).

The WY 2018, and recent historical flow-weighted phosphorus concentrations for CT-2 on Cottonwood Creek were much lower than at CC-10   However, the WY 2018 and recent historical flow weighted nitrogen concentrations at CT-2 are higher than at CC-10.

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

Location	**Cherry Creek**		**Cottonwood Creek**	
Nutrient	Total Phosphorus	Total Nitrogen	Total Phosphorus	Total Nitrogen
Water Year	Concentration (µg/L)			
WY 2018	236	1,833	79	1,984
WY 2017	229	1,260	62	1,809
WY 2016	250	1,012	88	2,020
WY 2011-2015	263	1,261	75	1,592

The median groundwater nutrients concentrations of 190 µg/L of total phosphorus and 430 µg/L of total nitrogen for the period 1993-2018 was multiplied by the assumed annual alluvial groundwater inflow of 2200 AF/yr (Section 5.0) to calculate nutrient load groundwater loads.

Nutrient loads from precipitation were calculated by multiplying the observed WY 2018 precipitation of 666 AF/yr by the 1992-2018 median nutrient concentrations of 155 µg/L of total phosphorus and 2,009 µg/L of total nitrogen. Flow-weighted nutrient concentrations for all inflows and the weighted total concentration based on the relative inflow contribution to Cherry Creek for WY 2018 are summarized in Table 17.

Table 17. Flow-Weighted TP and TN Concentrations, WY 2018

	Nutrient	Source				
		Cherry Creek	Cottonwood Creek	Alluvial Groundwater	Precipitation	Weighted Total
Inflow Concentration (µg/L)	Total Phosphorus	236	79	190	155	
	Total Nitrogen	1,833	1,984	430	2,009	
% of Total Inflow		70.4%	13.8%	12.1%	3.7%	
Weighted Concentration (µg/L)	**Total Phosphorus**	**166**	**11**	**23**	**6**	**206**
	Total Nitrogen	**1,290**	**274**	**52**	**74**	**1,691***

**Variability due to rounding to nearest decimal point.*

The WY 2018 flow-weighted TP concentration of all inflows of 206 ug/L is higher than WY 2017 (197 µg/L) and the 2011-2015 median of 200 µg/L but lower than WY 2016 (213 µg/L). In addition, the WY 2018 flow-weighted TN inflow concentration of 1,691 µg/L is higher than WY 2017 (1,284 µg/L), WY 2016 (1,175 µg/L), and the 2011-2015 median of 1,344 µg/L.

Table 18 indicates the flow-weighted nutrient concentrations for the outflow (losses) during WY 2018. In addition to the above sources, nitrogen can be added to Cherry Creek Reservoir through the process of nitrogen fixation. Cyanobacteria can use atmospheric nitrogen as a nutrient source and incorporate it into algal cells. This process is not easy to measure and no estimates for nitrogen fixation in Cherry Creek Reservoir are available. This source is probably small relative to the other sources listed.

Table 18. Flow-Weighted TP and TN Concentrations at CC-0 and Evaporation, WY 2018

Nutrient	Concentration (µg/L)	
	Cherry Creek Outflow	Evaporation
Total Phosphorus	109	0
Total Nitrogen	831	0

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

7.0 NUTRIENT BALANCE

The calculated WY 2018 phosphorus and nitrogen balances in the Cherry Creek Reservoir were calculated using a mass-balance approach:

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

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

The reservoir inflows (nutrient loads) considered in the WY 2018 nutrient balance are:

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

The only physical release mechanism considered from the Reservoir in the WY 2018 nutrient mass balance is surface water released through the dam's outlet works. Nutrient loss through evaporation is considered zero as the evaporating water is assumed to not contain any nutrients. The net ungauged outflows were accounted for in Table 15 and in the nutrient loads calculated in Table 18 based on the flow adjustments described in Section 6.0.

7.1 SURFACE WATER LOADS

The Authority collects water quality samples on a monthly basis at surface water monitoring stations CC-10, CT-2, and CC-Out (Table 3). The Authority also periodically collects storm event samples at CC-10 and CT-2 (Table 3). These samples were analyzed for the parameters indicated in (Table 3), which include total phosphorus and total nitrogen.

The nutrient concentrations in samples collected at CC-10, CT-2 and CC-Out in WY 2018 are summarized in Tables 17 and 18. Nutrient concentrations in were combined with the WY 2018 daily flows to calculate annual total phosphorus and total nitrogen loads for the surface water inflows and outflows (releases) to/from the reservoir (Table 19). The Cherry Creek and Cottonwood Creek loads presented in Table 19 were adjusted to apportion the ungauged inflows as discussed in Section 5.0.

Table 19. Surface Water Nutrient Loads to Cherry Creek Reservoir, WY 2018.

	WY 2018 Nutrient Loading	
Site	Total Phosphorus (Pounds)	Total Nitrogen (Pounds)
Inflows		
Cherry Creek @ CC-10	8,192	63,625
Cottonwood Creek @ CT-2	539	13,548
Releases		
USGS Gage & CC-Out	- 4,622	- 35,378

7.2 PRECIPITATION LOADS

In WY 2018, total phosphorus and total nitrogen were measured at the PRECIP site located in Cherry Creek State Park during storm sampling events. Seven precipitation samples were collected after storm events during WY 2018 which were analyzed for total phosphorus and total nitrogen concentrations. These values represent atmospheric loading and dry deposition. Table 20 lists the statistics of the concentration, maximum, minimum and mean value and the addition to the historical mean values which was used to calculate the total loading from precipitation during WY 2018.

Table 20. Cherry Creek Reservoir WY 2018 Precipitation Nutrient Loads

	WY 2018 Nutrient Loading	
PRECIP	Total Phosphorus	Total Nitrogen
Maximum (µg/L)	625	3,770
Minimum (µg/L)	24	1,100
Median (µg/L)	116	2,580
Updated Historical Median(µg/l)	155	2,009
Inflow WY 2018 (AF)	**666**	**666**
Total (lbs)	**280**	**3,637**

- Total phosphorus concentrations ranged from 24 µg/L to 625 µg/L, with a median value of 116 µg/L. The WY 2018 mean value is lower than the historical median of 155ug/L (1991-2018) although it is higher than WY 2017 (28 µg/L) and WY 2016 (60 µg/L).
- Total nitrogen concentrations ranged from 1,100 µg/L to 3,770 µg/L, with a median value of 2,580 µg/L. The WY 2018 value is higher than the historical median of 2,009ug/L (1991-2018) as well as WY 2016 (2,547 µg/L) and WY 2017 (1,170 µg/L).

Based on the 2018 daily precipitation and corresponding Reservoir surface areas and long-term median concentrations, the total loading from precipitation was calculated.

- Total Phosphorus: 279 pounds
- Total Nitrogen: 3,615 pounds

7.3 ALLUVIAL GROUNDWATER LOADS

During WY 2018 (November 2017 and May 2018) water samples from monitoring well MW-9 were collected and analyzed for total phosphorus and total nitrogen. The results are summarized in Table 21.

Table 21. Cherry Creek Reservoir WY 2018 Groundwater Loading

	WY 2018 Nutrient Load	
MW-9	**Total Phosphorus**	**Total Nitrogen**
Maximum WY18 (µg/L)	230	410
Minimum WY18 (µg/L)	225	220
Median WY18 (µg/L)	228	315
Updated Historical Median (µg/L)	*217*	*315*
Inflow WY18 (AF)	*2,200*	*2,200*
Total (lbs)	**1,298**	**1,885**

- The median TP concentration in MW-9 for WY 2018 was 228 µg/L. Using the WY 2018 median, the median from WY 2017 of 237 µg/L, the median from WY 2016 of 206 µg/L and the long-term median of 190 µg/L (GEI, 2016) the historical median TP concentration was updated to 217 µg/L.
- The median TN for WY 2018 was 315 ug/ L. Using the WY 2017 TN median of 241 µg/L and the long-term median of 430 µg/L (GEI, 2016) an updated historical median concentration of 315 µg/L TN was calculated.

The updated long-term median total phosphorus and total nitrogen concentrations were combined with the estimated 2,200 AF of inflow to calculate the nutrient loads from the alluvial groundwater inflow to the Reservoir for WY 2018: 1,298 lbs total phosphorus and 1,885 lbs total nitrogen.

8.0 NUTRIENT MASS BALANCES

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

Nutrient balances for total phosphorous and total nitrogen for Cherry Creek Reservoir are calculated for WY 2018 based off the nutrient calculations for inflow and releases. Internal nutrient loading is not included in the mass balances since data to evaluate values was not collected. Previous studies (Nurnberg and LaZerte, 2008; AMEC et al. 2005) provided estimates of internal phosphorus loading ranging from 810 to 2,000 lbs of phosphorus/year. Internal phosphorus loading in WY 2018 would have been expected to be towards the low end of this range because of the relatively low concentrations of phosphorus in the hypolimnion of Cherry Creek Reservoir during summer 2018. Based on the data presented in Section 7.1 through 7.3, the WY 2018 total phosphorus and nitrogen mass balances are summarized in Table 22. The difference between the inflow and the outflow loads (Δ Storage$_{Nutrients}$) indicate that a net 5,519 pounds of phosphorus and 48,010 pounds of nitrogen were retained in the reservoir in WY 2018.

Table 22. Total Phosphorus and Nitrogen Mass Balance in Cherry Creek Reservoir WY 2018

Source	Total Phosphorus Mass (pounds)	Total Nitrogen Mass (pounds)
Surface Water		
Cherry Creek (CC-10)	8,185	63,625
Cottonwood Creek (CT-2)	539	13,548
Reservoir Release (CC-Out)	-4,622	-35,373
Alluvial Groundwater		
Inflow	1,137	2,572
Atmospheric		
Precipitation	280	3,637
Evaporation	0	0
WY 2018 Change in Storage	**5,519**	**48,010**

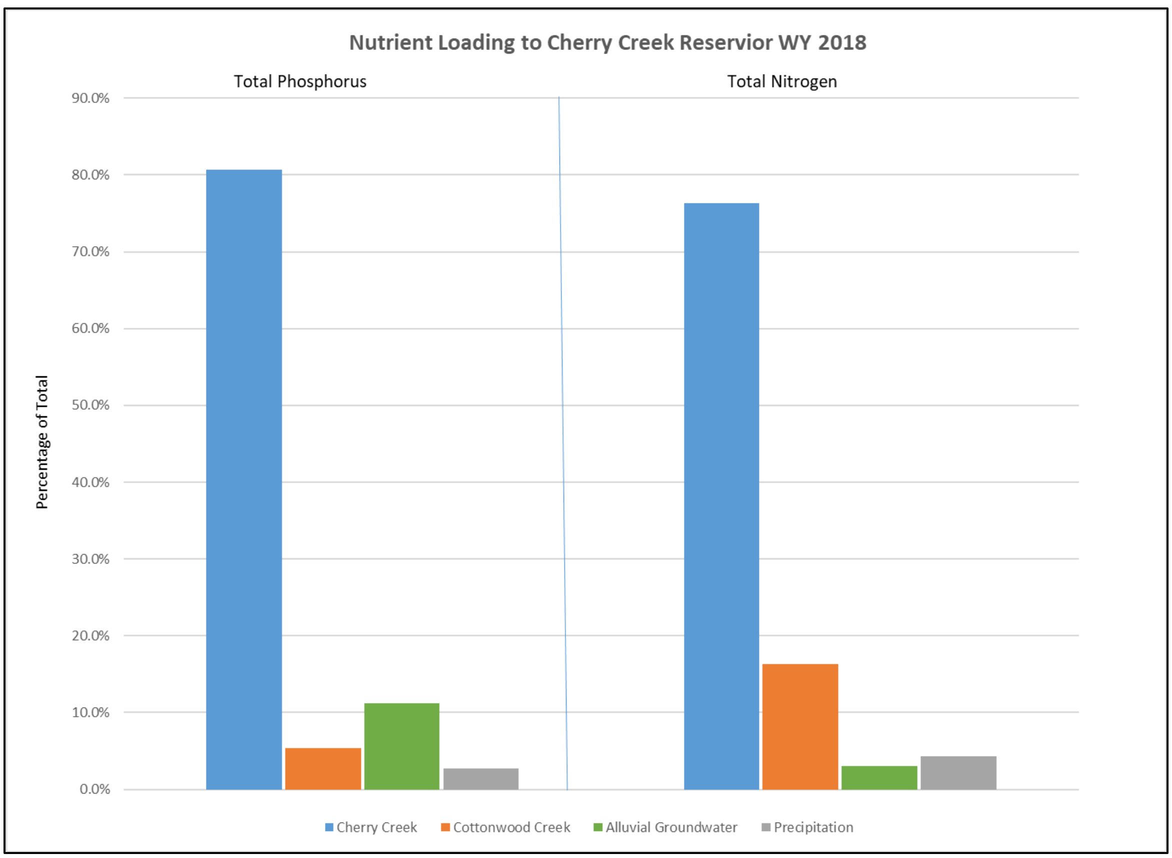


Figure 62. Nutrient Loading Percentages by Source to Cherry Creek Reservoir, WY 2018.

The relative contributions of the inflow sources of phosphorus and nitrogen loading to the Reservoir in WY 2018 are represented in Figure 62.

Table 23 presents the historical total nutrient mass loads, outflows and resulting storage in Cherry Creek reservoir in comparison to WY 2018. The total phosphorus inflow loads calculations for WY 2018 were lower than WY 2017, WY 2016 and WY 2015 as well as the historical means from 1995-2015 but was higher than the historical mean from 2011-2015. The lower outflows during WY 2018 contributed to the higher mass retention of total phosphorus. The total nitrogen loads from WY 2018 are higher than any values from previous years. The lower flows from the outlet during WY 2018 may have contributed to higher retention rates of nitrogen in the Reservoir.

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

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

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

9.0 2018 RECOMMENDATIONS AND CONCLUSIONS

RECOMMENDATIONS AND CONCLUSIONS

Recommendations

During the 2018 monitoring and data analysis efforts, recommendations for improvement and enhancement of the sampling program and analysis were developed. The following recommendations could help facilitate examining long-term water quality trends and additional factors impacting water quality within the watershed and sub-basins of Cherry Creek.

- Install level monitoring and stormwater collection equipment at the Piney Creek Site.
- Continue monitoring nitrogen and phosphorus ratios to determine relationships between chl-*a* and phytoplankton populations and the limiting nutrient in Cherry Creek Reservoir.
- Compare data from USACE Tri-Lakes Monitoring Program.
- Work with Colorado Parks and Wildlife (CPW) and downstream water users to assess attainment of beneficial uses in more detail.
- Continue the split analysis between IEH and High Sierra through 2019 to ensure that the current limits provide the highest quality and accurate information for determination of nutrient ratios in the Reservoir.
- Install a stable cross section at CC-10 monitoring site in order to help obtain more accurate flow measurements, assist in calibration of the watershed model, and reduce chances for storm sampling equipment failure. The damage to the stream banks up stream of the monitoring site has resulted changes to the dynamics in in this section of stream which may have impacts to the sensitivity of the model flows at that site. The bottom of the stream at the level gauge has shown fluctuation and the sampling equipment has been buried causing lost samples and maintenance requirements.
- Evaluate options for analyzing the PRF ponds using a mass balance approach similar to the Reservoir on a smaller scale.

Conclusions

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

The assessment of the destratification system and feasibility of increasing mixing rate could provide important information to determine potential impacts to water quality if results indicate changes to existing operations would be beneficial.

Storm events appear to play a large role in nutrient and sediment loading of the reservoir. The current wetland PRFs appear to reduce sediment and nutrient loads during intermittent high flows. Assessment of these PRFs to determine scale and frequency of maintenance of these wetlands necessary to maintain storage capacity and reduce organic accumulation is vital to maintaining long-term function.

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

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

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APPENDICES

APPENDIX A – SUMMARY OF CHERRY CREEK BASIN DESIGNATED USES AND WATER QUALITY STANDARDS (REGULATION NO. 38)

APPENDIX B – 2018 CHERRY CREEK SAMPLING AND ANALYSIS PLAN/QUALITY ASSURANCE PROTOCOLS AND PRECEDURES SAP/QAPP1

APPENDIX C – USACE DATA - WY 2018