# Water Year 2017
# Cherry Creek Monitoring Report

**PREPARED FOR:**

**Cherry Creek Basin Water Quality Authority**
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# EXECUTIVE SUMMARY

The *Water Year 2017 Cherry Creek Monitoring Report* provides a comprehensive update of monitoring efforts conducted in Cherry Creek Reservoir (Reservoir) and its watershed during the 2017 water year, October 1, 2016 to September 30, 2017. The Reservoir and watershed monitoring program ("program") is conducted in the Cherry Creek basin (Figure ES-1) in accordance with Control Regulation No. 72 (CR72) and the Cherry Creek Sampling and Analysis Program and Quality Assurance Procedures and Protocols (SAP/QAPP, 2016). The program is comprised of routine and continuous monitoring of physical, chemical and biological conditions, including evaluations of:

- Attainment of long-term water quality goals and compliance with water quality standards, including the growing season chlorophyll-a (chl-*a*) water quality standard in the Reservoir, pursuant to CR72.
- Water quality characterization of inflows and the Reservoir.
- Effectiveness of the pollutant reduction facilities (PRFs) within the Cherry Creek basin owned and operated by the Cherry Creek Basin Water Quality Authority (Authority).
- Streamflow measurements during base flow and stormflow conditions.
- Flow weighted total phosphorus (TP) and total nitrogen (TN) concentrations conveyed to the Reservoir from Cherry Creek and Cottonwood Creek.
- Trends observed over the long-term since 1987 when the Authority began collecting data, including flow based concentration of phosphorus.

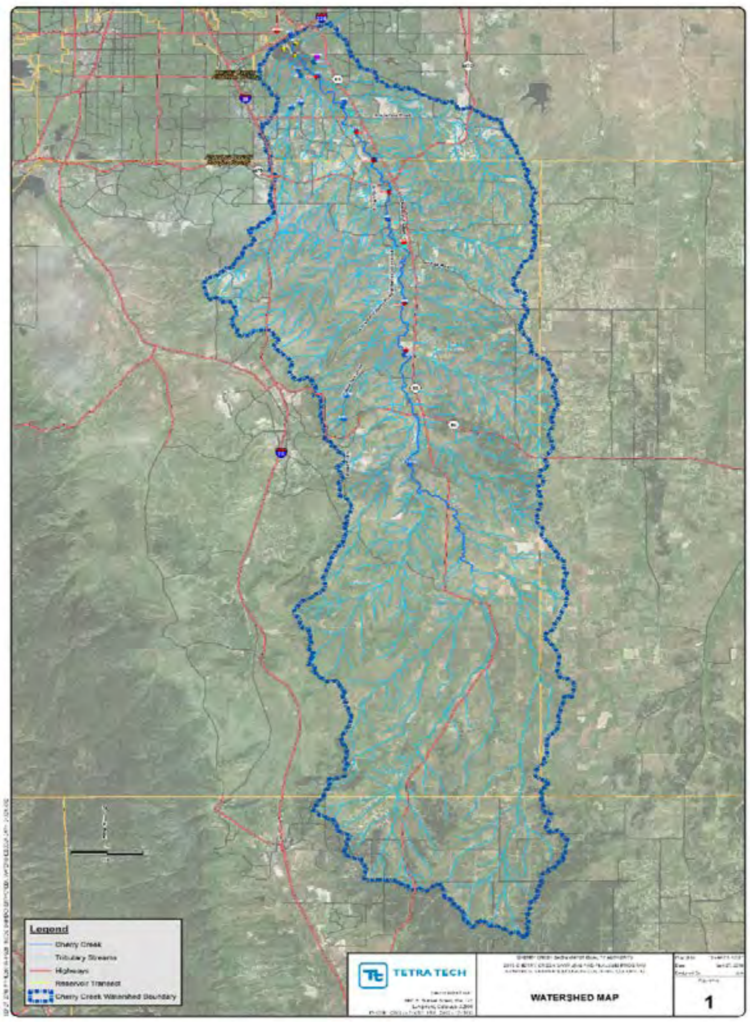


**Figure ES-1. Cherry Creek Watershed Map.** The Cherry Creek Basin is generally located in the Denver metropolitan area, south of Interstate 225 and east of Interstate 25. (Graphic Source: Tetra Tech, Inc.)

Key findings from the 2017 Water Year (WY2017) monitoring season are summarized herein. The Cherry Creek Data Portal and appendices D through G provide 2017 data detail.

2017 REGULATORY HIGHLIGHTS

- Temperature and pH met water quality standards for Cherry Creek Reservoir.
- Cherry Creek Reservoir did not meet the 5.0 mg/L dissolved oxygen standard at one of three vertical profiles in Reservoir.
- The seasonal average chl-*a* concentration in 2017 was 18.8 ug/L, in exceedance of the 18.0 ug/L Cherry Creek Reservoir water quality standard.

## 2017 Regulatory Overview

**Reservoir met temperature and pH water quality standards; Dissolved oxygen (DO) standard was not achieved at monitoring station CCR-1.** Cherry Creek Reservoir temperature and pH were within the water quality standards for aquatic life in Warm Water 1 Lakes (WQCC Regulation #31, effective 01/31/2018). The Reservoir was not in compliance with the DO standard. An average value of 4.62 mg/L was observed in the Reservoir's upper portion (0.5m-2.0m) on August 8, 2017 at monitoring station CCR-1. Reservoir monitoring station locations are depicted on Figure ES-2. Other station profiles, CCR-2 and CCR-3, were in attainment of the DO standard. Average upper layer oxygen levels at CCR-2 and CCR-3 were 5.08 mg/L and 5.32 mg/L, respectively, on the same day.

**Chlorophyll-*a* growing season standard was exceeded.** The Reservoir chl-*a* growing season (July through September) concentration was 18.8 µg/L, improved from WY2016, but in excess of the 18 µg/L growing season average regulated for chl-*a*. The seasonal mean concentration is measured in the upper three meters of the water column (photic zone), with an allowable exceedance frequency of once in five years. The Reservoir has exceeded the chl-*a* standard in four of the last five years (Figure ES-3).

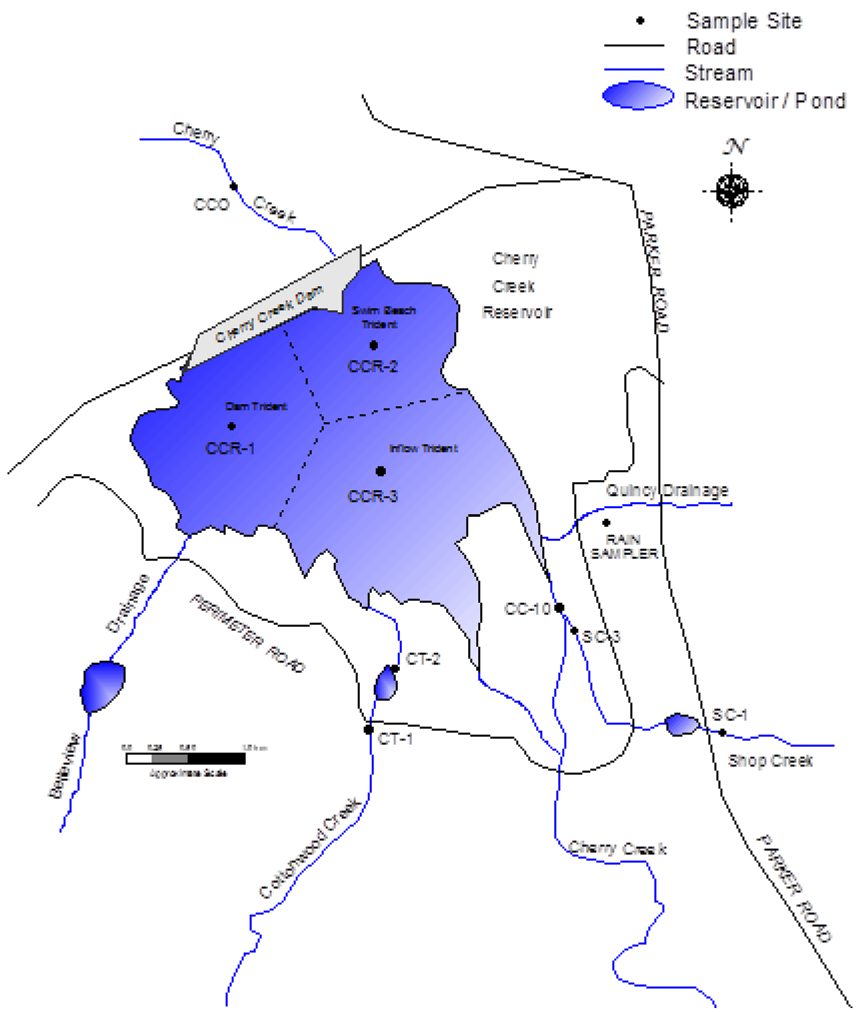


**Figure ES-2 – General Location Map of Sampling Sites in Vicinity of Reservoir** (Graphic Source: GEI Consultants, Inc.)

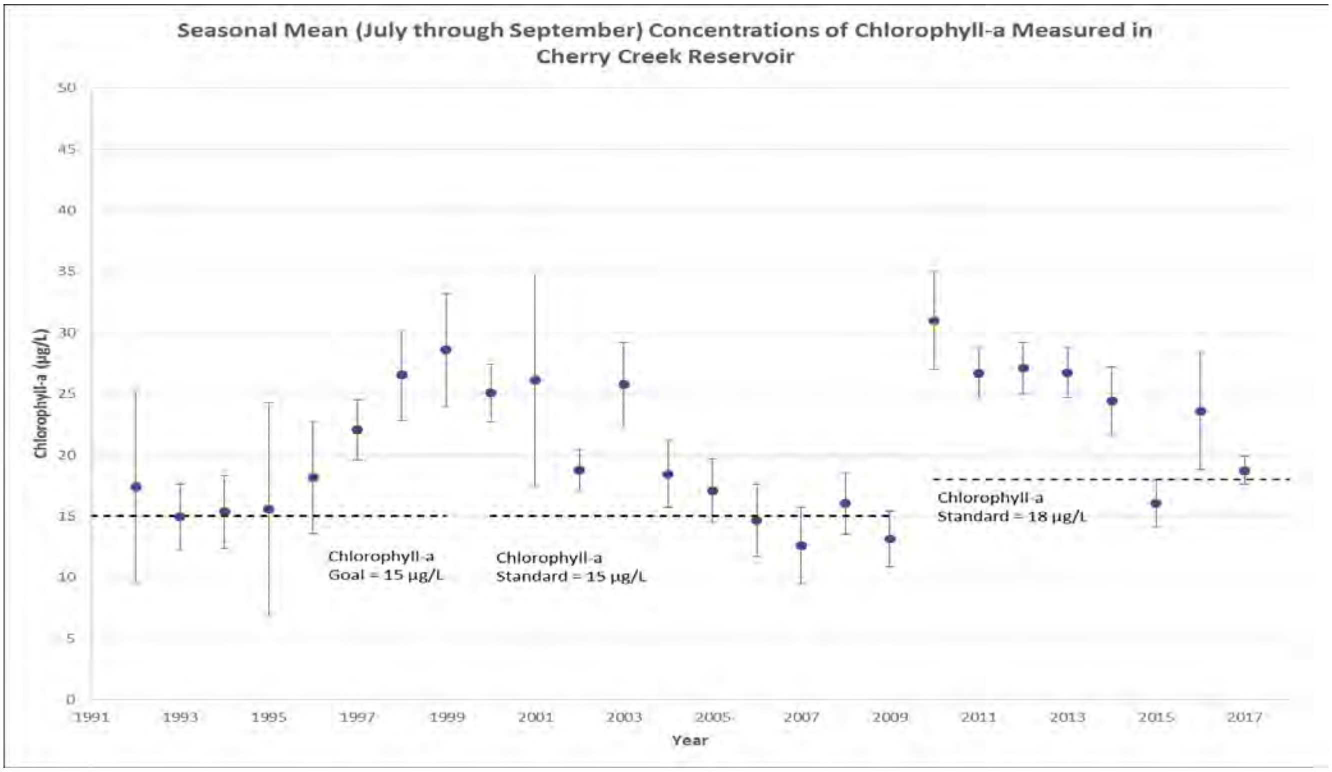


**Figure ES-3. Chl-*a* Growing Season Concentrations in Cherry Creek Reservoir, 1992–2017.** (Sources of Data: IEH Analytical (2016 -2017); GEI Consultants (2006 – 2015); Chadwick Ecological Consultants (1995 – 2006); University of Missouri (1992 – 1994).

## 2017 Reservoir Overview

**The best water quality conditions were observed in the Reservoir in early June**. The best water quality condition observed in June was reflected in the data, including planktonic communities, as well as low concentrations of chl-*a* and TP, and greater transparency. This was following a period of higher than normal precipitation and resultant increased Reservoir inflow and releases and during a period of destratification system operation.

**Increased flushing rate of the Reservoir provided water quality benefits to the Reservoir.** The US Army Corps of Engineers (USACE) operates Cherry Creek Reservoir for flood control purposes. The higher 2017 inflows from the Cherry Creek watershed resulted in a higher than average annual pass through volume from the Reservoir outlet works, an average of 28.6 cubic feet per second (cfs), or approximately 20,700 acre-feet. This was three times the 56-year average daily discharge of 9.2 cfs. The increased flushing rate of the Reservoir helped water quality in WY2017. While the Reservoir continued to retain much more nitrogen and phosphorus on a mass basis than it was flushing, the increased flush in the outflow provided a

### 2017 RESERVOIR HIGHLIGHTS

- The best water quality conditions were observed in the Reservoir in early June, as demonstrated by the plankton data, low chl-*a* and TP, and greater transparency.
- Increased flushing rate provided water quality benefits to the Reservoir.
- Plankton data are indicative of over productive and nutrient rich conditions in the Reservoir (Figures ES- 4, 5 and 6).
- No harmful algal blooms observed.

temporal improvement that would have otherwise resulted in greater water quality impacts to the Reservoir.

**Phytoplankton and zooplankton data are characteristic of an over-productive and nutrient rich Reservoir.** The Reservoir continued to exhibit characteristics of an over-productive, nutrient rich waterbody as indicated by WY2017 planktonic communities. As shown on Figure ES-4, the phytoplankton taxa of biggest concern included an abundance of Cyanophyta (cyanobacteria or "blue green algae", depicted in red) and Chlorophyta (green algae, depicted in orange). Cell concentrations in excess of eutrophic levels, >100,000 cells/mL and > 10,000 cells/mL, for Cyanobacteria and Chlorophyta, respectively, can cause water quality issues in the Reservoir throughout the summer, including elevated chl-*a* concentrations.

Chl-*a* accounted for the total phytoplankton community biomass in WY2017and this biomass was dominated by Chlorophyta (green algae) and Bacillariophyta (diatoms) although different phytoplankton briefly dominated the community, as depicted in Figure ES-5. A significant amount of biomass energy from phytoplankton and bacteria was also stored in the sediments as organic carbon, which contributed to excess nutrient production during this timeframe.

The WY2017 zooplankton community structure was generally illustrative of a hypereutrophic system and not overly productive (biomass) relative to food base for fisheries (Figure ES-6). A generally higher Daphnid biomass was present in May and June, and again in August and September, indicating this preferred fish food was available and abundant for the fishery.

**No harmful algal blooms (HABs) observed in Reservoir.** During WY2017 there were no HAB observations and no beach closures.

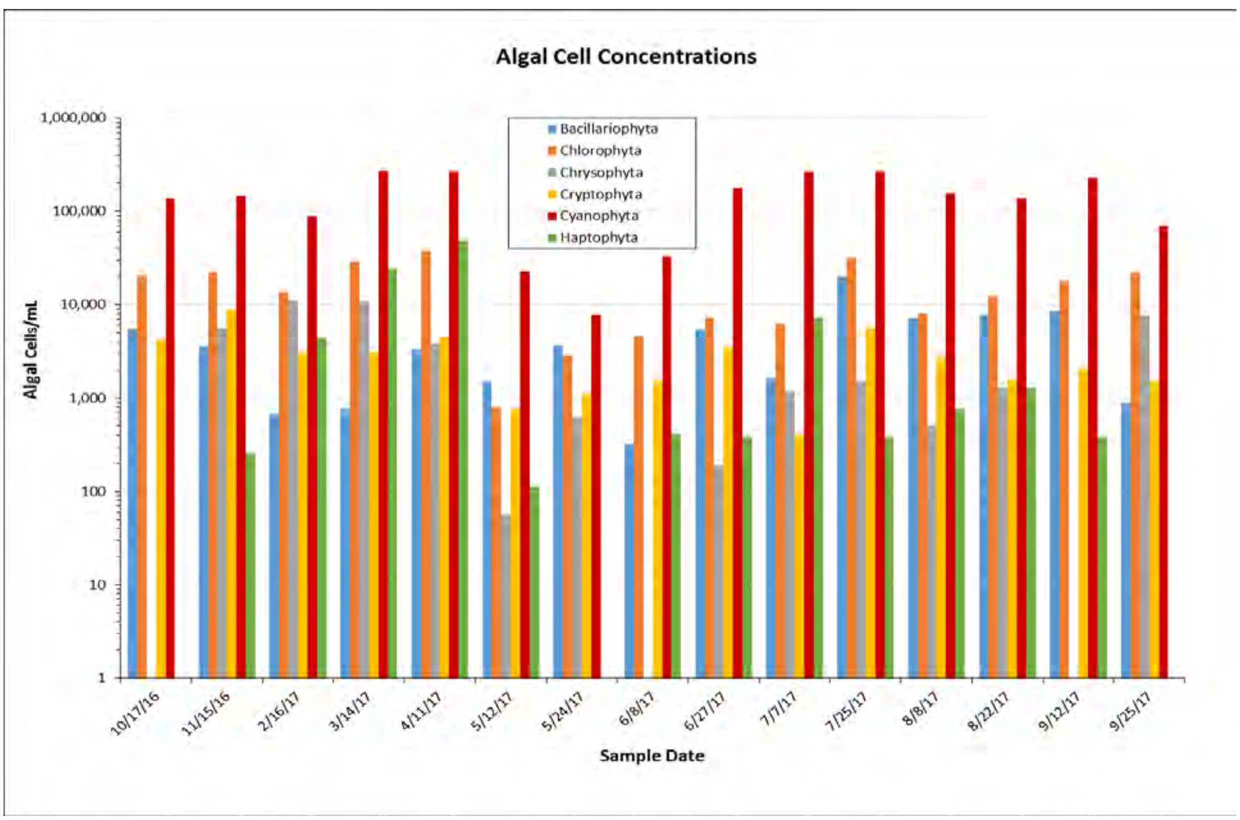


**Figure ES-4. Algal Cell Concentrations Measured in Cherry Creek Reservoir in 2017.** (Source of Data: PhycoTech, Inc.)

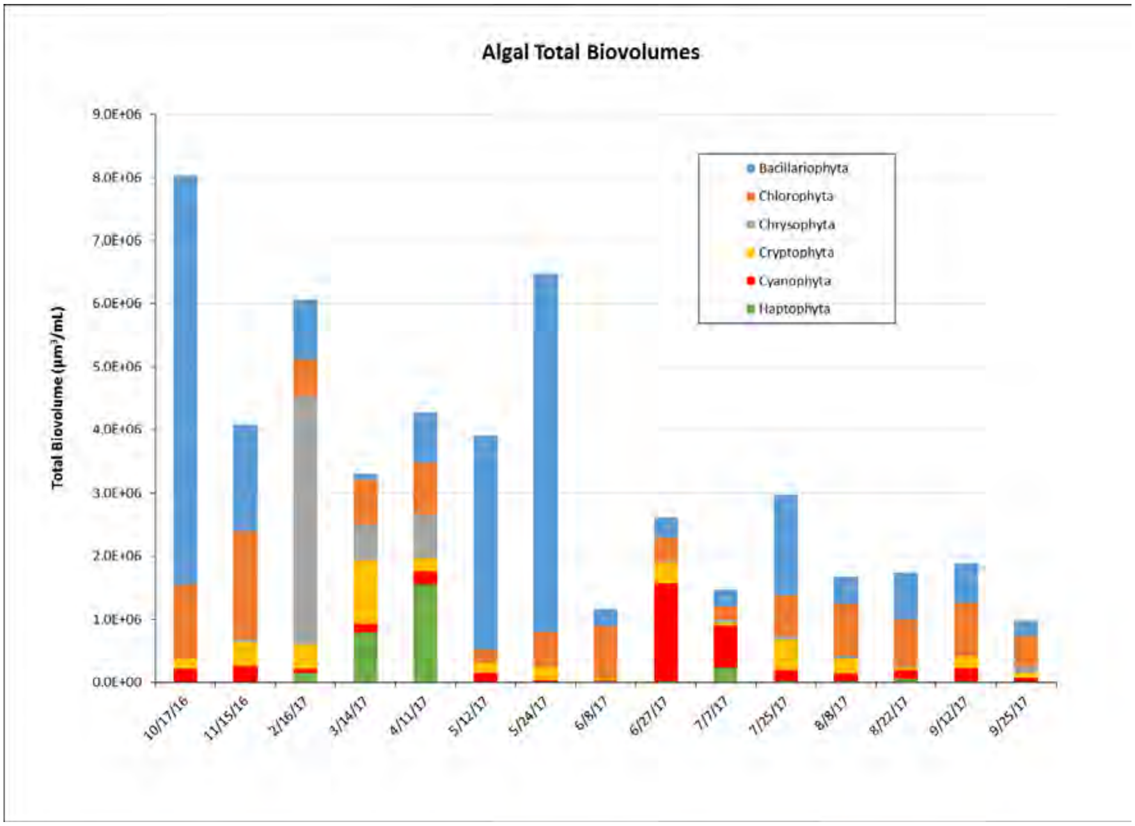


**Figure ES-5. Algal Community Biomass in WY2017.** (Source of Data: PhycoTech, Inc.)

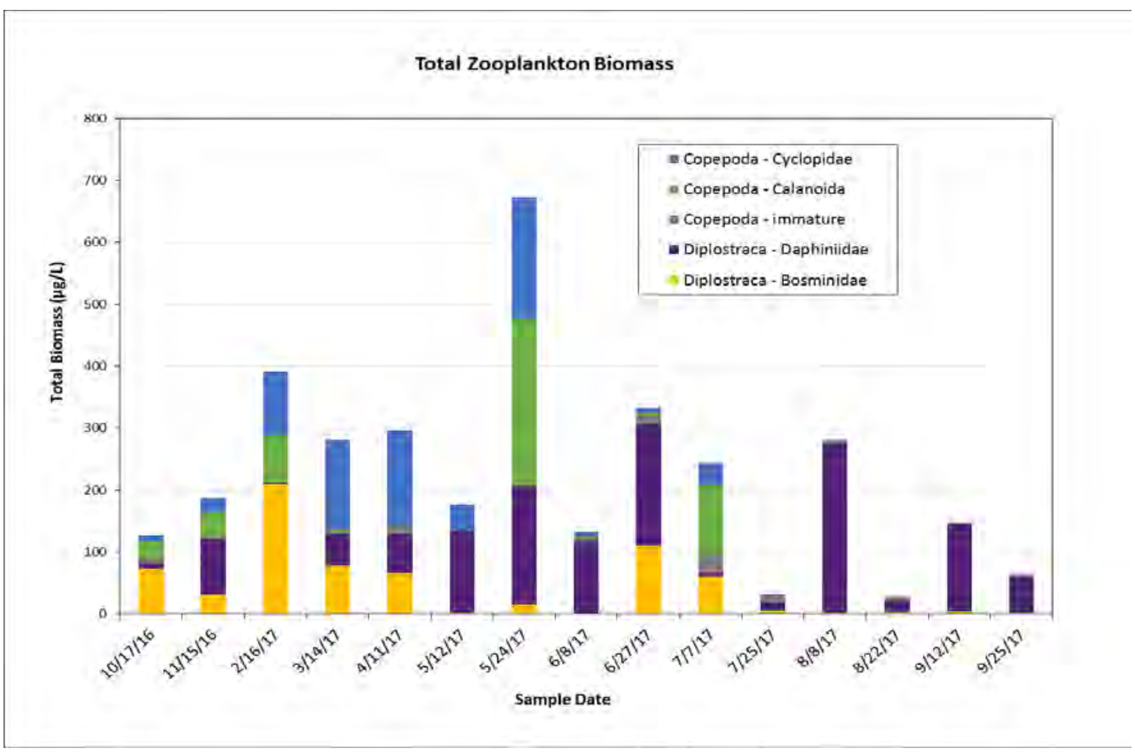


**Figure ES-6. Zooplankton Biomass in WY2017.** (Source of Data: PhycoTech, Inc.)

**OTHER RESERVOIR HIGHLIGHTS**

- While the basin population continues to grow and has nearly doubled 2000 – 2015 (US Census Bureau), the seasonal chl-a concentration since 2000 does not suggest an increasing or decreasing trend (Figure ES-7).
- Since 2000 the median seasonal chl-a concentration in the Reservoir is 18.8 ug/L.

**Cherry Creek watershed population growth nearly doubles, 2000-2015, reflecting the overall population increase trends observed in front range Colorado.** During the period 2000 - 2015, US Census Bureau data estimates an 82% increase in the Cherry Creek basin population. The highest percentage growth areas, greater than 75% population increase, are observed in the vicinity of Castle Rock, Centennial and Parker. Population increases generally impact water quality with increased runoff and point and nonpoint source pollutants.

**No increasing or decreasing trends in seasonal chlorophyll-a concentration since 2000.** Due to the natural progression of man-made lakes, reservoir nutrient water quality becomes more productive as time goes on. Nutrient concentrations observed in the inflows and within Cherry Creek Reservoir (particularly recycled nutrients in the Reservoir sediments that are 2-100 times that from Cherry Creek itself), coupled with the reduced flushing rate under current operating conditions of the Reservoir contribute to water quality impacts. While these impacts affect water quality, the median seasonal average chl-a concentration in the Reservoir, 2000 - present, is 18.8 µg/L, with no apparent increasing or decreasing trend. A comparison of seasonal chl-a concentrations to population growth since 2000 is depicted on Figure ES-7.

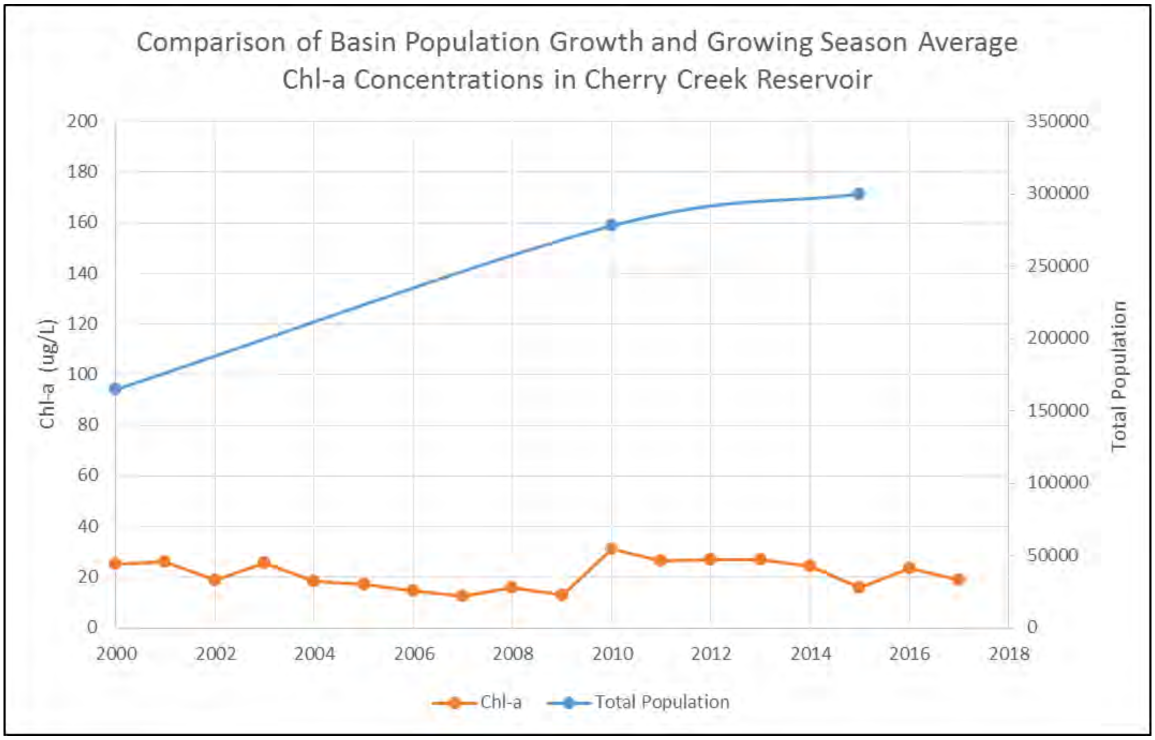


**Figure ES-7 – Comparison of Basin Population and Seasonal Chl-a Concentration in Reservoir since 2000** (Source of Data: US Census Bureau, GEI Consultants, Inc. (2000 – Feb 2016); IEH Analytical, Inc. (March 2016 -2017)

**2017 WATERSHED HIGHLIGHTS**

- Higher than normal flows were measured at Cherry Creek, with below average precipitation observed at Centennial Airport precipitation station (Figures ES-8 and ES-9).
- The Cottonwood Creek PRF generally provided total phosphorus (TP) and sediment (TSS) concentration reductions during stormflows, however, during base flow conditions TP and TSS concentrations increased. Soluble reactive phosphorus (SRP) concentrations and TN concentrations increased during both base flow and stormflow events (Table ES-1).
- Phosphorus was generally present at CC-10 in the dissolved form with the exception of during storm-related high flows. Approximately 90% of the dissolved phosphorus in Cherry Creek is SRP, a more readily available form of phosphorus for algae growth (Figure ES-11).
- During WY2017 the average TP concentration at CC-10 was 233 µg/L, 10% less than the WY2016 TP average of 256 µg/L. During the period 2000 -2017, Cottonwood Creek TP concentrations measured upstream of the Reservoir at CT-2 are approximately one-fourth the average TP measured in Cherry Creek (Figure ES-13).
- Over the past 23 years, the concentration of SRP in the alluvial groundwater upstream of the Reservoir (well MW-9) appears to be gradually increasing to concentrations of approximately 220 µg/L (Figure ES-15).

## 2017 Watershed Overview

**Higher than normal streamflow was measured in Cherry Creek in 2017.** Throughout the majority of WY2017, the streamflow was above the historical median measured in Cherry Creek near Parker, CO (Figure ES-8). Annual precipitation, 12.4 inches, was 77 percent (%) of average at the Centennial Airport weather station with only one month, May, experiencing above-average precipitation (Figure ES-9).

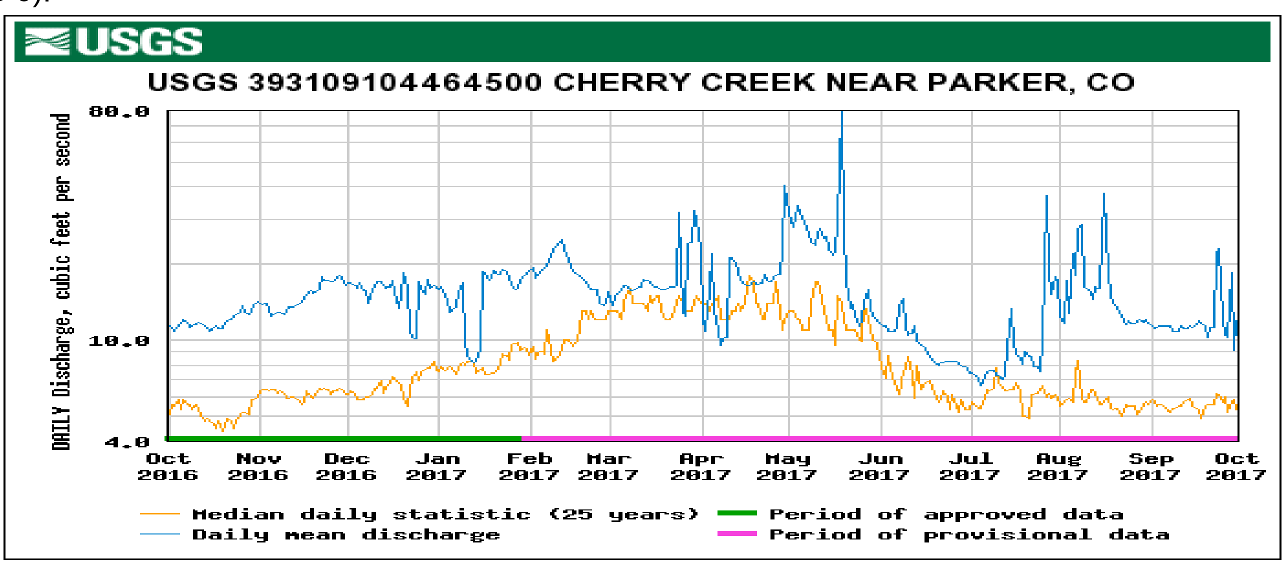


**Figure ES-8. WY2017 Cherry Creek Streamflow near Parker, CO.** WY 2017 streamflow data are compared to the past 25 year median daily statistic. The majority of the flows were considerably greater than the historic record (Source: USGS).

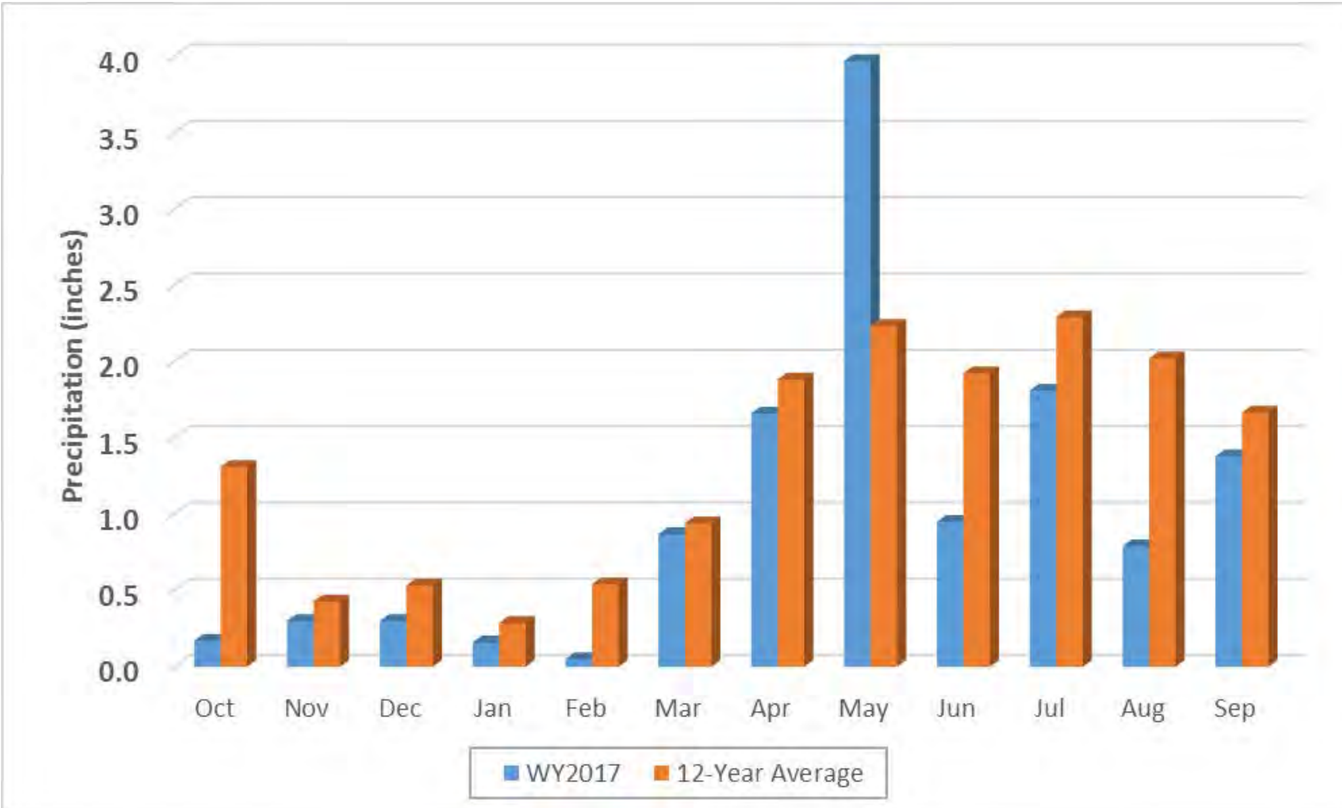


**Figure ES-9. Monthly Precipitation near Cherry Creek Reservoir**. Comparison of WY2017 precipitation and 12-year average (Data Source: NOAA Precipitation Station at Centennial Airport - KAPA).

**Cottonwood Creek Pollutant Reduction Facility (PRF) provided phosphorus and sediment reduction during storm events.** Stream reclamation and wetland detention systems have been a passive treatment train approach widely implemented by the Authority throughout the basin since the 1990's as an effective water quality strategy. The Cottonwood Creek PRF continues to provide for a phosphorus reduction strategy as measured across the entire PRF system between the upstream station CT-P1 and the downstream station CT-2 (Figure ES-10), reducing median TP concentration during stormflow conditions by 74% (Table ES-1). Median total suspended solids concentration (TSS, a quantification of sediment concentration) was reduced 92% during stormflow conditions. This is important, as the phosphorus content in sediments in the creek have been measured to contain high phosphorus content, on average of 0.9 lbs/yd$^3$ (Ruzzo, 2000).


**Figure ES-10. Cottonwood Creek PRF**. CT-P1 (upstream) to CT-2 (downstream). (Graphic: GEI)

During base flow conditions, there was an increase in median TP and TSS concentrations in this reach of Cottonwood Creek between CT-P1 and CT-2. Median soluble reactive phosphorus (SRP) concentrations and TN concentrations increased during both base flow and stormflow events. The complete data set and data variability is presented in Appendices D and F.

**Table ES-1. Pollutant Reduction Effectiveness of the Cottonwood PRF in WY2017.**

| Analyte | Median Concentrations under Base Flow Conditions | | Median Concentrations during Storm Flow Events | |
|---|---|---|---|---|
| | Upstream | Downstream | Upstream | Downstream |
| | CT-P1 (n = 7) | CT-2 (n = 12) | CT-P1 (n = 5) | CT-2 (n = 5) |
| TP, µg/L | 37 | 53 | 242 | 64 |
| SRP, µg/L | 2.0 | 3.5 | 8.5 | 25.5 |
| TN, µg/L | 1,270 | 1,920 | 1,450 | 1,490 |
| TSS, mg/L | 9.0 | 13.7 | 93 | 7.5 |

**Cherry Creek nutrient and sediment (TSS) concentrations upstream of Reservoir reduced in WY2017.** Total dissolved phosphorus (TDP), TP and TSS concentrations measured upstream of the Reservoir at Cherry Creek monitoring station CC-10 since 2016 are depicted in Figure ES-11. In WY2017, phosphorus was generally present at CC-10 in the dissolved form with the exception of storm-related high flows. Orthophosphate (SRP) is the chemically active dissolved form of phosphorus that is taken up directly by plants. In 2017, approximately 90% of the dissolved fraction was SRP readily available for uptake by algae and plants. During the higher flow generated by storm runoff, large amounts of sediment (and associated phosphorus) were transported in Cherry Creek. Particulate phosphorus is calculated as the difference between the total and the dissolved phosphorus concentrations.

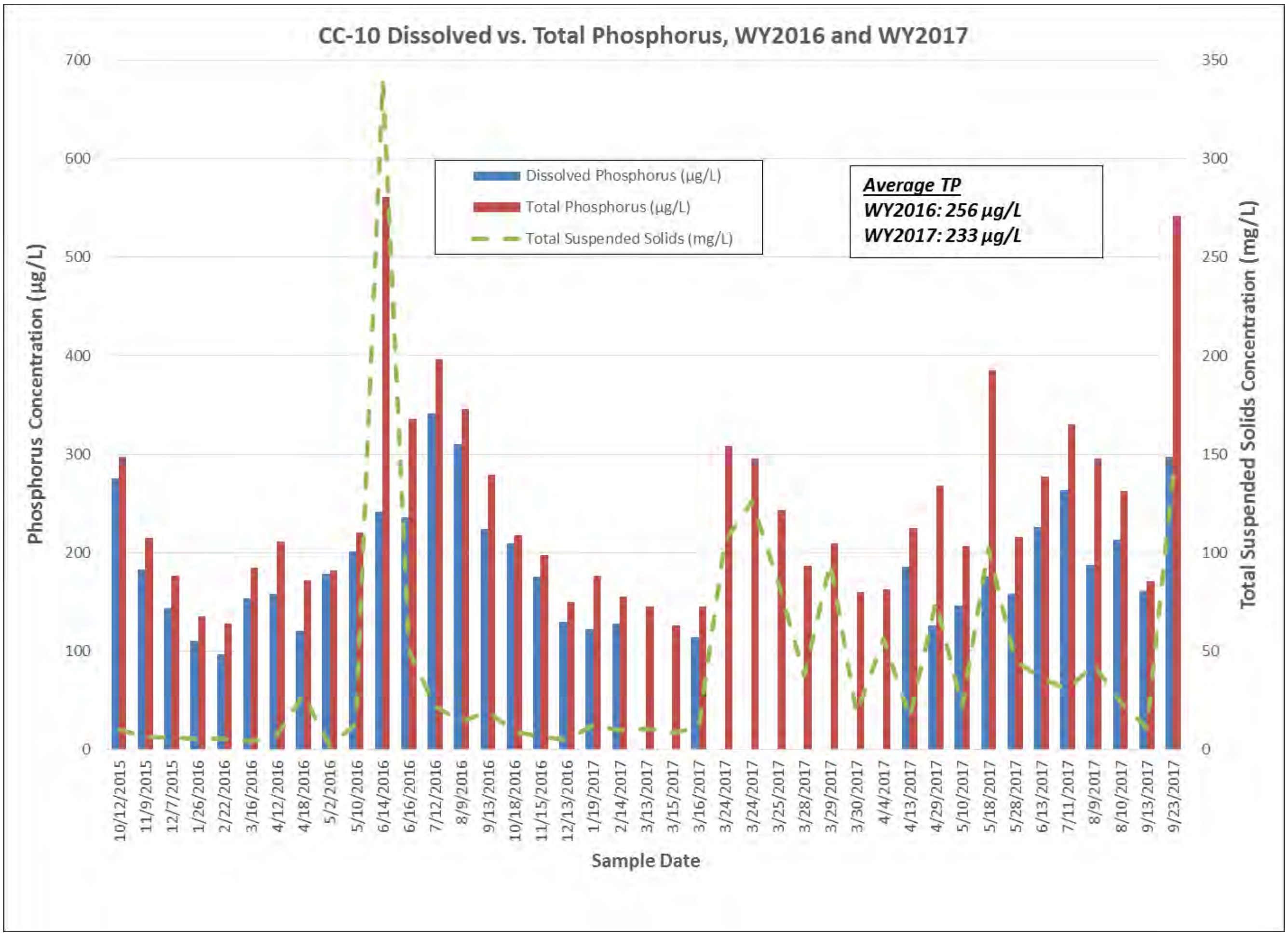


**Figure ES-11. TP, TDP and TSS Concentrations at Cherry Creek upstream of Reservoir (CC-10) (WY2016 and WY2017).** (Source of Data: IEH Analytical, Inc.)

As depicted in Figure ES-12, there is a strong relationship ($R^2$=0.96) between particulate phosphorous and TSS conveyed in Cherry Creek. The Authority's long-standing water quality management strategy to reclaim streambanks is based on this strong relationship.

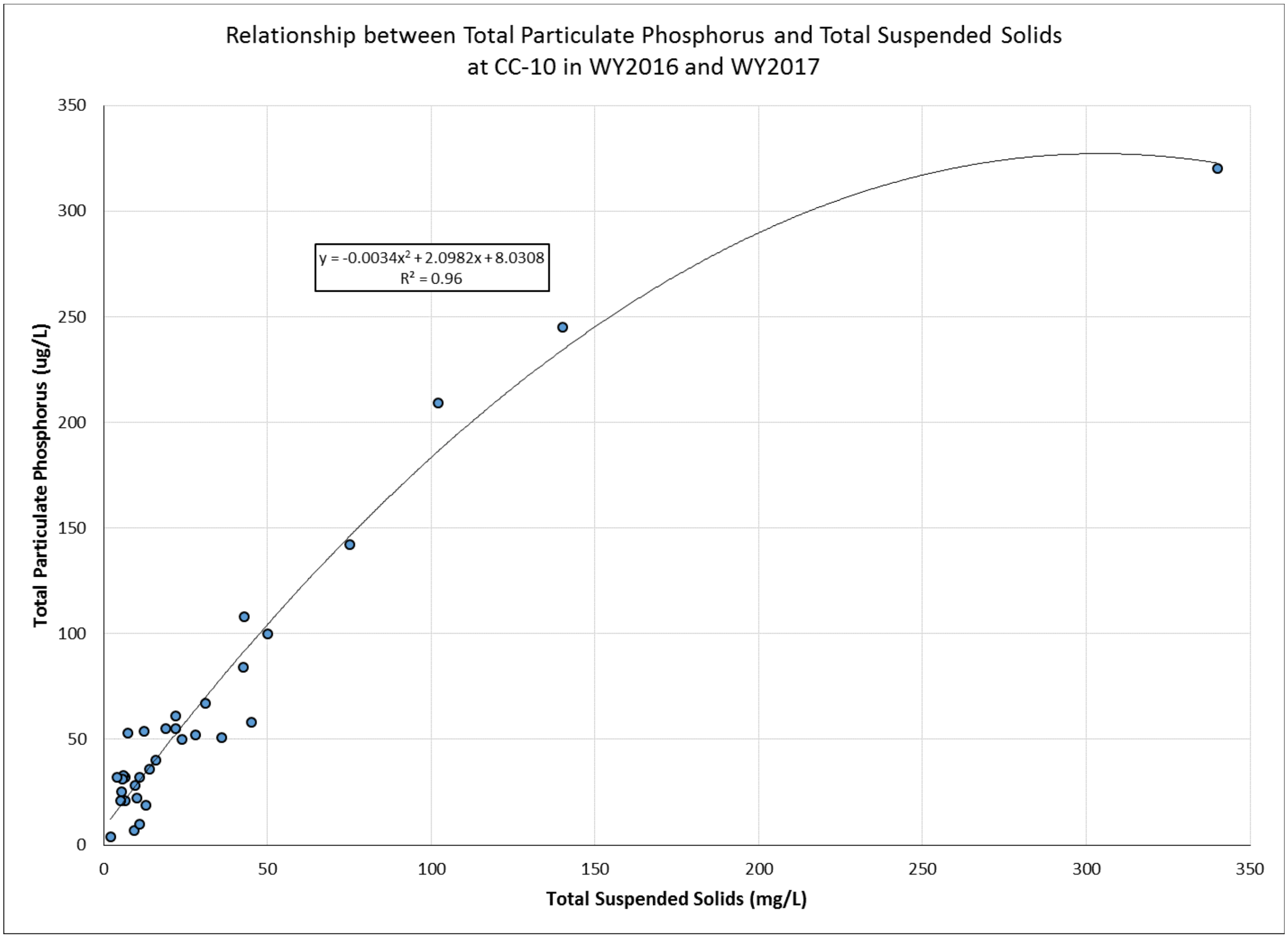


**Figure ES- 12. Relationship between Total Particulate Phosphorus and TSS at CC-10.** (Source of Data: Tetra Tech, Inc., 2016-2017)

The average TP concentrations in Cherry Creek and Cottonwood Creek upstream of the Reservoir are compared in Figure ES-13. During WY2017 the average TP concentration at CC-10 was 233 µg/L, 10% less than the WY2016 TP average of 256 µg/L. During the period 2000 -2017, Cottonwood Creek TP concentrations measured upstream of the Reservoir at CT-2 are approximately one-fourth the average TP measured in Cherry Creek. Since 2008, when the Cottonwood PRFs were completed, the CT-2 station demonstrates a decreasing trend in TP concentration (Figure ES-13). During the last 17 years, the Cherry Creek station CC-10 does not appear to indicate a decreasing or increasing trend.

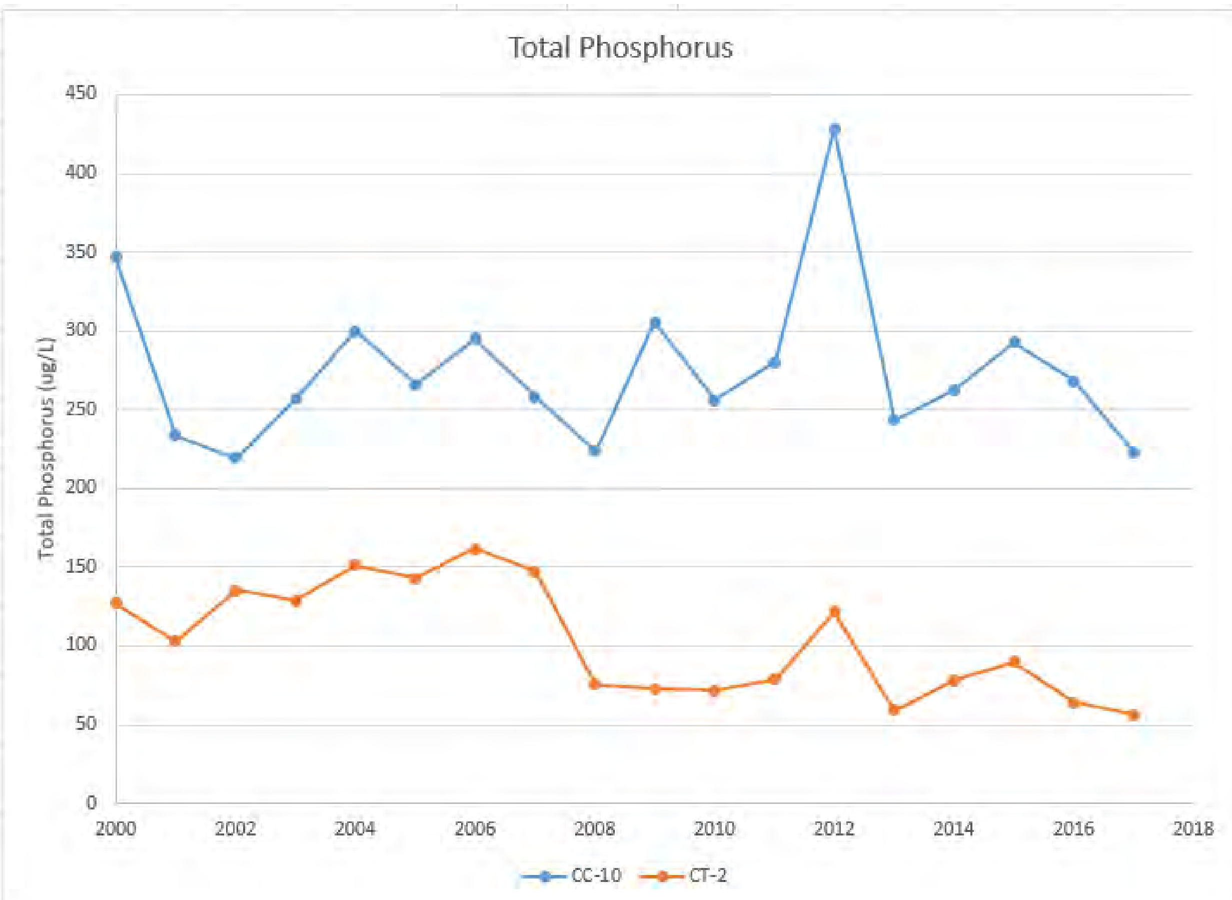


**Figure ES-13. Comparison of Annual Average TP Concentrations Upstream of Reservoir at Cherry Creek (CC-10) and Cottonwood Creek (CT-2), 2000-2017.** (Source of Data: GEI Consultants, Inc., January 2000 February 2016; IEH Analytical, Inc., March 2016 – October 2017)

Median soluble reactive phosphorus (SRP) levels in the Cherry Creek alluvial groundwater (2010 – present) were generally similar to median concentrations observed in nearby Cherry Creek surface water. The Cherry Creek alluvial SRP data support the TP trend observed in WY2017. In general, upstream of the Reservoir the median SRP levels (the horizontal line located in rectangle of each box and whisker plot) in the alluvial groundwater were similar to median concentrations observed in nearby surface water (Figure ES-14). The observed Cherry Creek surface water inflow SRP concentrations were approximately ten times eutrophic levels.

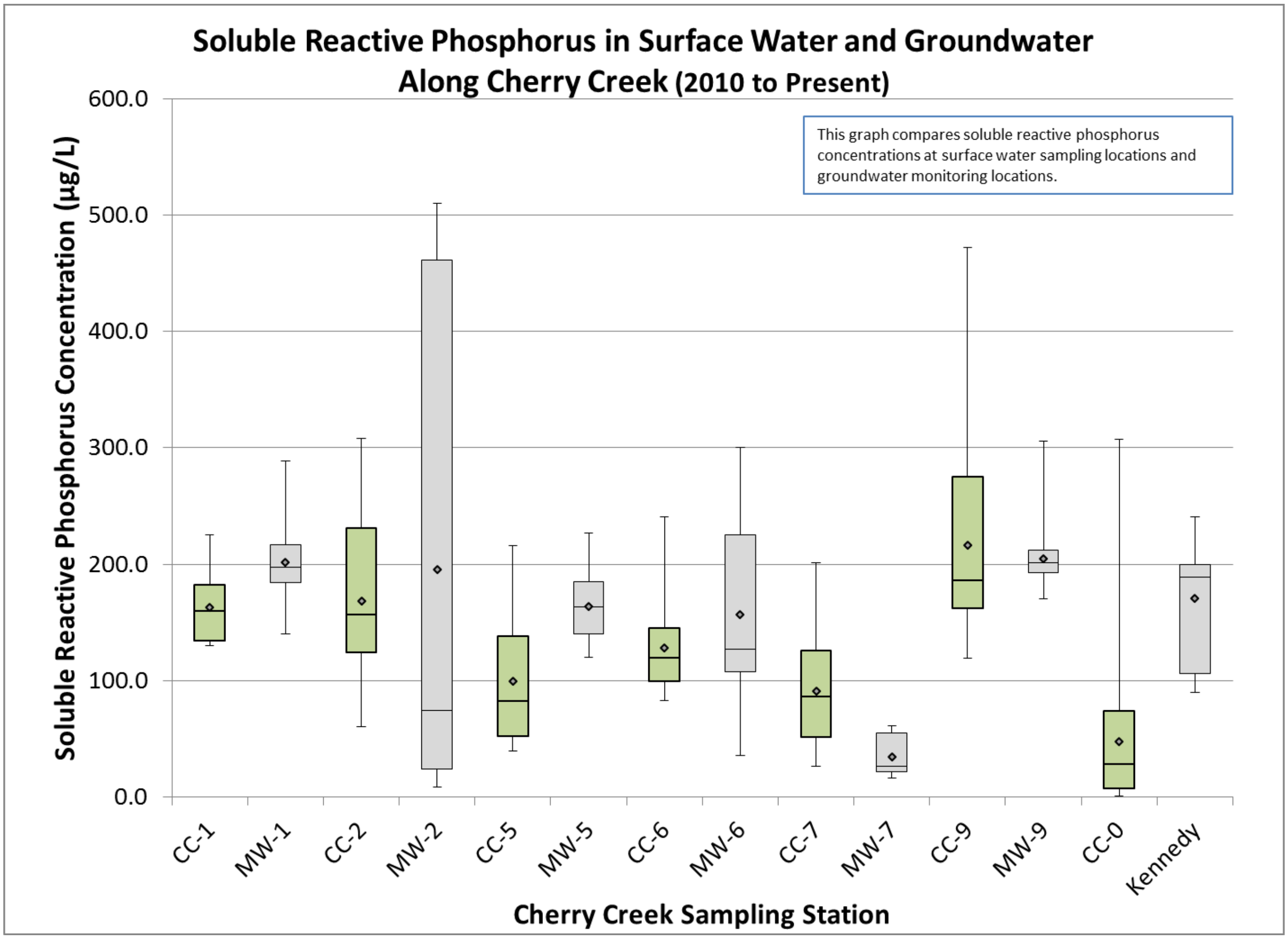


**Figure ES-14. Soluble Reactive Phosphorus in Surface Water and Groundwater along Cherry Creek (2010 to 2017)**.
(Source of Data: GEI Consultants, Inc., 2010 – 2015; IEH Analytical, Inc., 2016 – 2017)

Over the past 20 years, the concentration of SRP in the alluvial groundwater upstream of the Reservoir (well MW-9) appears to be gradually increasing (ES-15). Due to the geochemistry of the area, higher in phosphorus, the groundwater is expected to have a higher SRP concentration than the surface water. However, what was observed at some sampling stations (i.e. CC-7 and CC-9) is that the groundwater SRP levels were less variable than the surface water.

With limited exception, the SRP concentrations in surface water released from the Reservoir (CC-O) has historically been lower than Reservoir inflows and that in alluvial groundwater downstream of the Reservoir (alluvial well at Kennedy Golf Course).

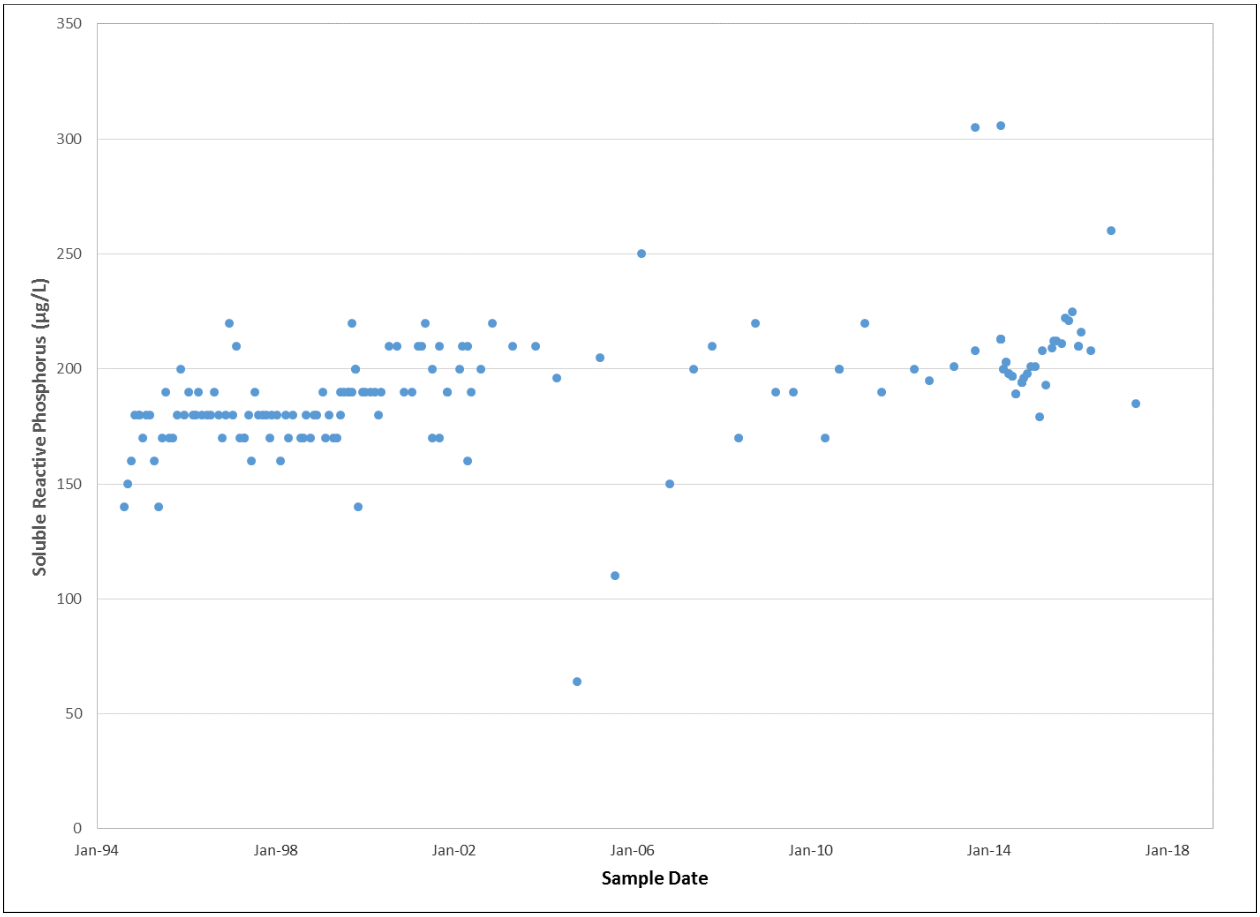


**Figure ES-15. Historic SRP Concentrations in Alluvial Well MW-9 (1994 – 2017).** (Sources of Data: IEH Analytical (2016 - 2017); GEI Consultants (2006 – 2015); Chadwick Ecological Consultants (1995 – 2006); University of Missouri (1994).

## 2017 Flow Weighted Nutrients and Mass Loadings

**Dominant inflow source of nutrients was from Cherry Creek.** Surface water inflow from Cherry Creek was the dominant source of water (and TP load) to the Reservoir. In WY2017, Cherry Creek provided 73% of the 23,804 acre-ft of water that flowed into the Reservoir, with Cottonwood Creek providing an additional 14%. The relative contribution of the inflows to the Reservoir in WY2017 is illustrated in Figure ES -16. Outflows from the Reservoir exceeded inflows in WY2017, with the year-end reservoir storage 364 ac-ft less than it began the water year with.

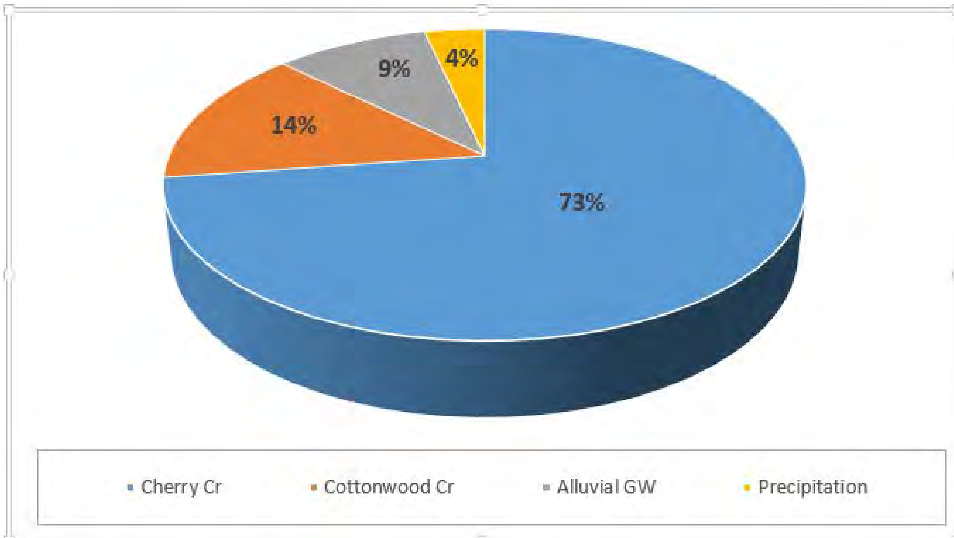


**Figure ES-16. Relative Contribution of Cherry Creek Inflows to Reservoir Water Balance in WY2017.**

Over 3 tons of TP was retained in the Reservoir in 2017. During WY2017 the flow weighted TP concentration from the watershed was 197 µg/L (below the flow weighted concentration goal of 200-ug/L), and an estimated 12,795 pounds (6.4 tons) of phosphorus was delivered to the Reservoir.

The relative contributions of the phosphorus loads to the Reservoir in WY2017 are illustrated in Figure ES-17. The relative contribution of Cherry Creek to phosphorus loads, 84%, exceeded its relative water contribution, while that of Cottonwood Creek was less. A net 6,702 pounds (3.4 tons) of TP was estimated to have been retained in the Reservoir in WY2017, and was available for TP recycling within the Reservoir. The WY2017 total phosphorus inflow and outflow loads were lower than those in WY2015 and WY2016, but were larger than those exhibited in the long-term dataset. The mass of phosphorus retained in the Reservoir in WY2017 was also greater than the long-term average.

**FLOW WEIGHTED NUTRIENTS and MASS LOADINGS**

- Cherry Creek was the dominant inflow source (73%).
- The overall flow-weighted TP inflow concentration was 197 µg/L, lower than the WY2016 value (213 µg/L). The flow weighted TP concentration in Cottonwood Creek and Cherry Creek was 62 ug/L and 229 ug/L, respectively. Flow weighted SRP, readily available for plant uptake, was 155 ug/L.
- Over 3 tons of TP was retained in the Reservoir (an estimated 6.4 tons was delivered to Reservoir and 3.4 tons released).
- The overall flow-weighted TN concentration of 1,284 µg/L is higher than the WY2016 value of 1,175 µg/L. The flow weighted TN concentration in Cottonwood Creek and Cherry Creek was 1809 ug/L and 1260 ug/L, respectively.
- An estimated 42 tons of TN was delivered to the Reservoir. 20 tons of nitrogen was retained in the Reservoir (similar to WY2016).

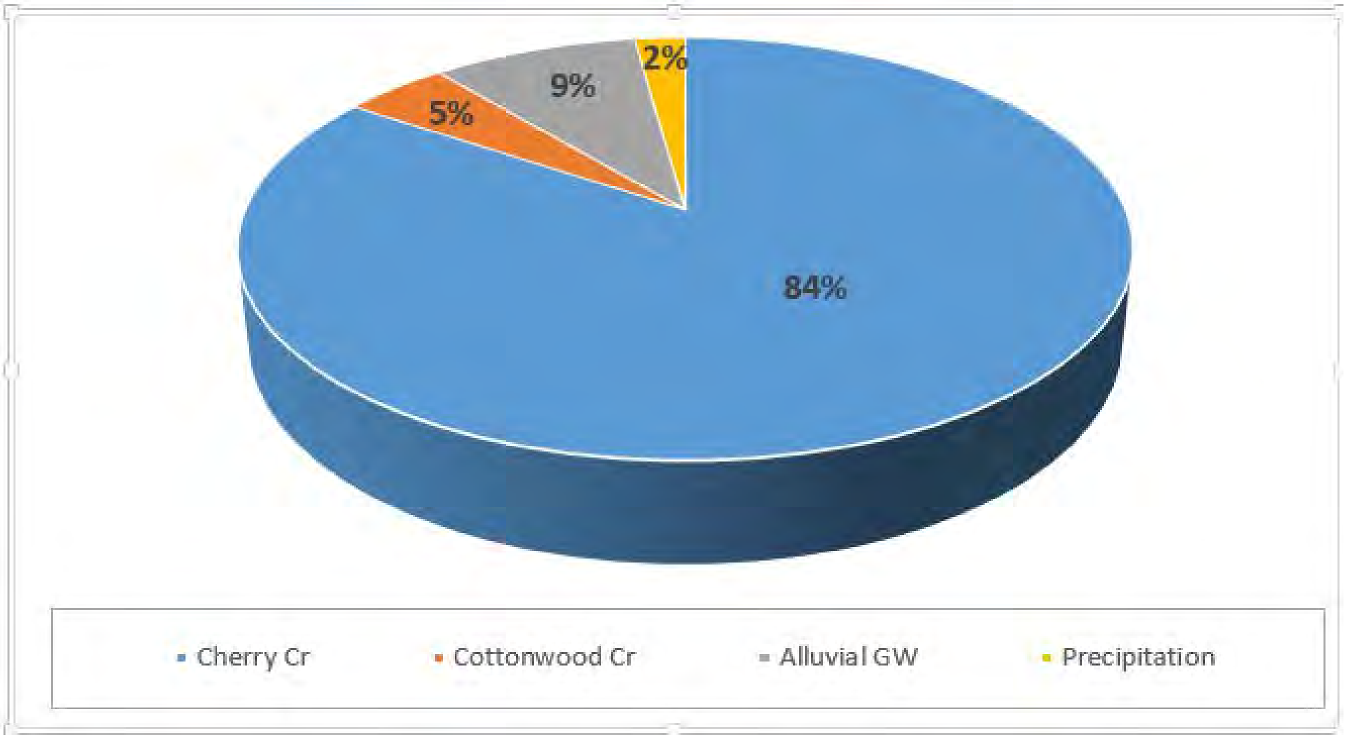


**Figure ES-17. Relative Contribution of Cherry Creek Inflows to Reservoir Phosphorus Balance in WY2017.**

Twenty tons of nitrogen was retained in the Reservoir in WY2017. An estimated 83,588 pounds (42 tons) of nitrogen was delivered to the Reservoir, with a flow-weighted concentration of 1,284 µg/L, which is below the 2011-2015 median of 1,344 µg/L. The relative contributions of the nitrogen loads to the Reservoir are illustrated in Figure ES-18. The relative contribution of Cherry Creek to nitrogen is roughly equivalent to its relative water contribution, while that of Cottonwood Creek is much greater.

A net 40,688 pounds (20 tons) of nitrogen was estimated to have been retained in the Cherry Creek Reservoir in WY2017. The overall WY2017 flow-weighted total nitrogen concentration of 1,284 µg/L was higher than the WY2016 value of 1,175 µg/L. Like phosphorus, the WY2017 total nitrogen loads were similar to those calculated in WY2016 and the surface water loads in both WY2016 and WY2017 were larger than those observed in long-term trends. The mass of nitrogen retained in the Reservoir in WY2017 was much greater than that indicated in the long-term trends.

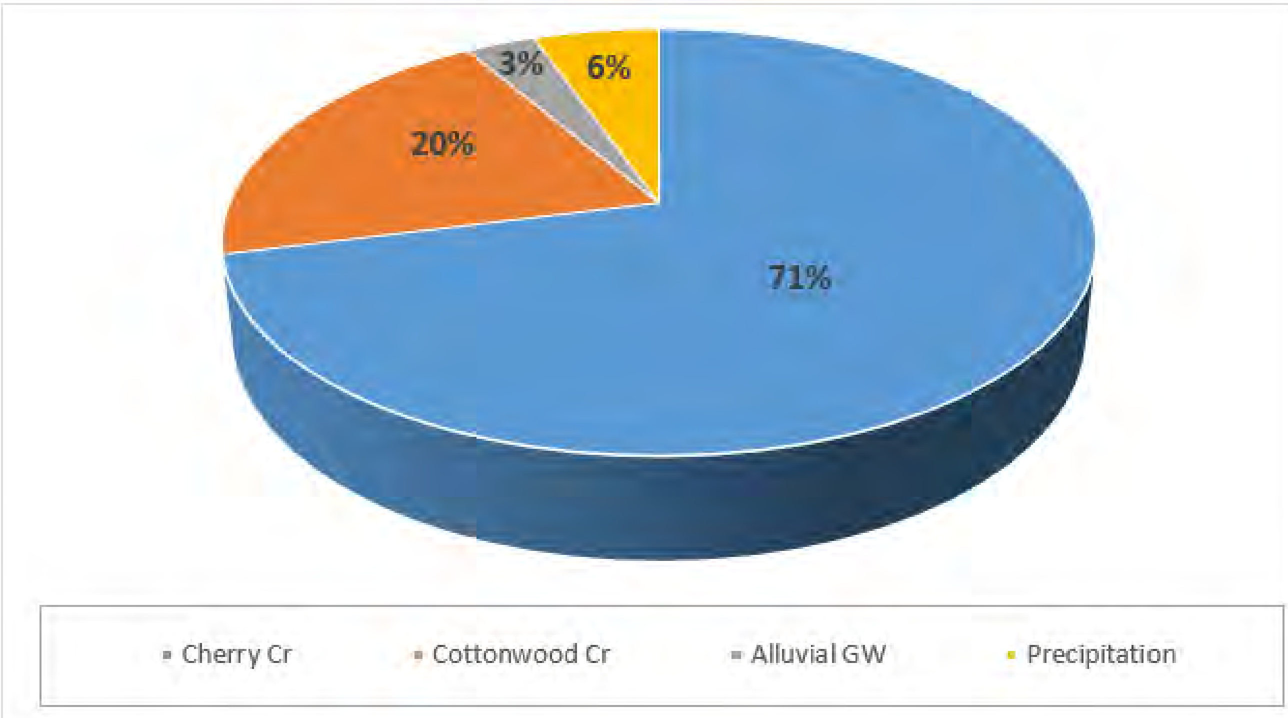


**Figure ES-18. Relative Contribution of Cherry Creek Inflows to Reservoir Nitrogen Balance in WY2017.**

As summarized in Table ES-2, the overall WY2017 flow-weighted TP inflow concentration of 197 µg/L is lower than the WY2016 value (213 µg/L), but very close to the 2011-2015 median of 200 µg/L. A majority of the phosphorus (155 µg/L) is SRP and in a dissolved form, readily available for plant uptake. The overall WY2017 flow-weighted TN concentration of 1,284 µg/L is higher than the WY2016 value of 1,175 µg/L, but still below the 2011-2015 median of 1,344 µg/L.

**Table ES-2. WY2017 Flow-Weighted TP, SRP, and TN Concentrations**

| Nutrient | Inflows (µg/L) | | | | |
|---|---|---|---|---|---|
| | Cherry Creek | Cottonwood Creek | Alluvial Groundwater | Precipitation | Total |
| Total Nitrogen | 1,260 | 1,809 | 430 | 1,977 | **1,284** |
| Total Phosphorus | 229 | 62 | 190 | 119 | **197** |
| Soluble Reactive Phosphorus | 163 | 16 | 185 | 19 | **155** |

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# ACRONYMS/ABBREVIATIONS

| Acronyms/Abbreviations | Definition |
|---|---|
| Ac-ft | Acre-feet |
| CCR | Code of Colorado Regulations |
| CDPHE | Colorado Department of Public Health and Environment |
| CPW | Colorado Parks and Wildlife |
| cfs | Cubic feet per second |
| Chl-*a* | Chlorophyll a |
| CR72 | Control Regulation 72 |
| DO | Dissolved Oxygen |
| HPLC/MS | High performance liquid chromatography combined with mass spectrometry |
| LC-MS/MS | Liquid chromatography followed by a combination of two mass spectrometry analyzers |
| mg/L | Milligrams per liter |
| µg/L | Micrograms per liter |
| ND | Non-detect |
| % | Percent |
| POR | Period of record |
| PRF | Pollutant Reduction Facilities |
| QA/QC | Quality Assurance/Quality Control |
| QAPP | Quality Assurance Project Plan |
| SAP | Sampling and Analysis Plan |
| SM | Standard Methods |
| SRP | Soluble Reactive Phosphorus |
| TDP | Total Dissolved Phosphorus |
| TN | Total Nitrogen |
| TP | Total Phosphorus |
| USACE | U.S. Army Corps of Engineers |
| US EPA | U.S. Environmental Protection Agency |
| USGS | U.S. Geological Survey |
| WQCC | Water Quality Control Commission |
| WQCD | Water Quality Control Division |

# 1.0 INTRODUCTION

The Cherry Creek watershed (watershed) includes over 386 square miles of land and 600 stream miles (Figure 1). The 875-acre Cherry Creek Reservoir (Reservoir), located at the downstream terminus of the study area, is one of the most productive fisheries and widely enjoyed recreational areas in Colorado. The Reservoir was constructed between 1948 and 1950 and is operated by the U.S. Army Corps of Engineers (USACE) for flood control. In addition to its flood control purpose and recreational use, 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.

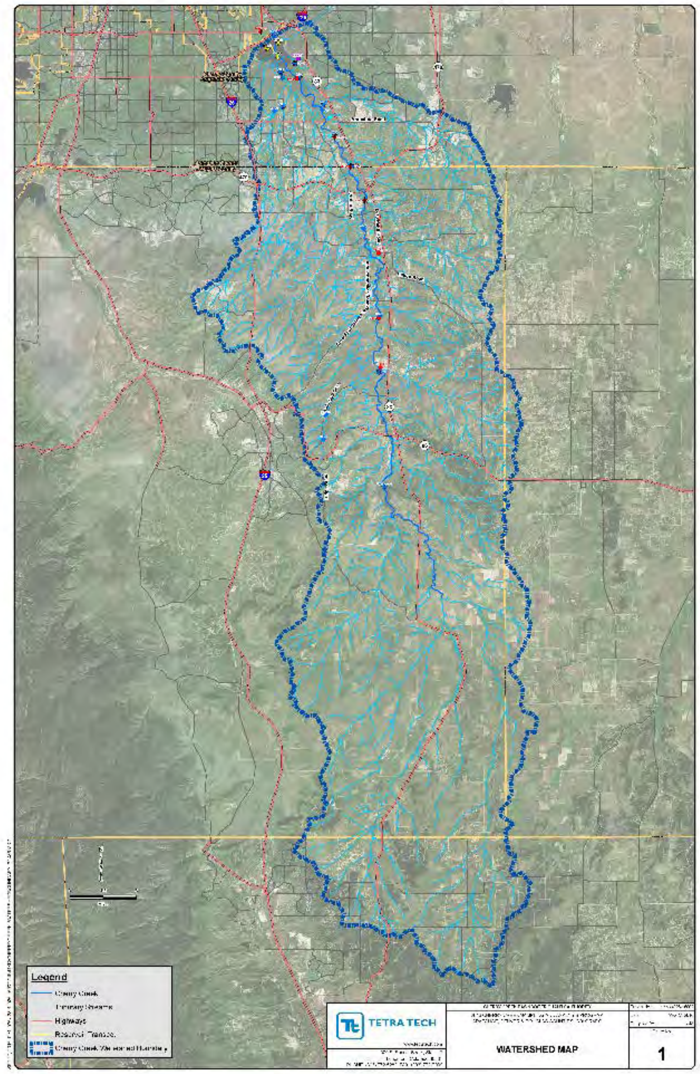



**Figure 1. Cherry Creek Basin Watershed Map. The watershed is 386 square miles in size, with over 600 stream miles.**

The Water Quality Control Commission (WQCC) has adopted specific water quality standards for the Reservoir, Cherry Creek, Cottonwood Creek and other watershed tributaries to protect recreation, aquatic life, agriculture, and water supply uses. Excerpts from Regulation #38, (5 CCR 1002-38, effective June 30, 2017) summarizing water quality standards pertinent to the Cherry Creek Basin are provided in Appendix A.

In accordance with Cherry Creek Reservoir Control Regulation #72 (5 CCR 1002-72, (CR72), the Authority implements water quality monitoring program in the watershed and Reservoir to characterize water quality of inflows and of the Reservoir to determine regulatory compliance. This report describes the Authority's monitoring effort, the 2017 data, and evaluation of results.

# 2.0 MONITORING PROGRAM

The WY2017 monitoring program ("program") was conducted in accordance with the Cherry Creek Sampling and Analysis Plan and Quality Assurance Project Plan (SAP/QAPP, updated in 2016 and 2017; Appendix B). The program includes characterization of the Reservoir water quality, inflow volumes, alluvial water quality, nonpoint source flows, and pollutant reduction facilities (PRF). The reservoir, precipitation, and watershed (surface water, groundwater, and PRF) sampling locations are depicted on Figure 2. Tables 1, 2, and 3 summarize program analyses at each monitoring site and sampling frequency.

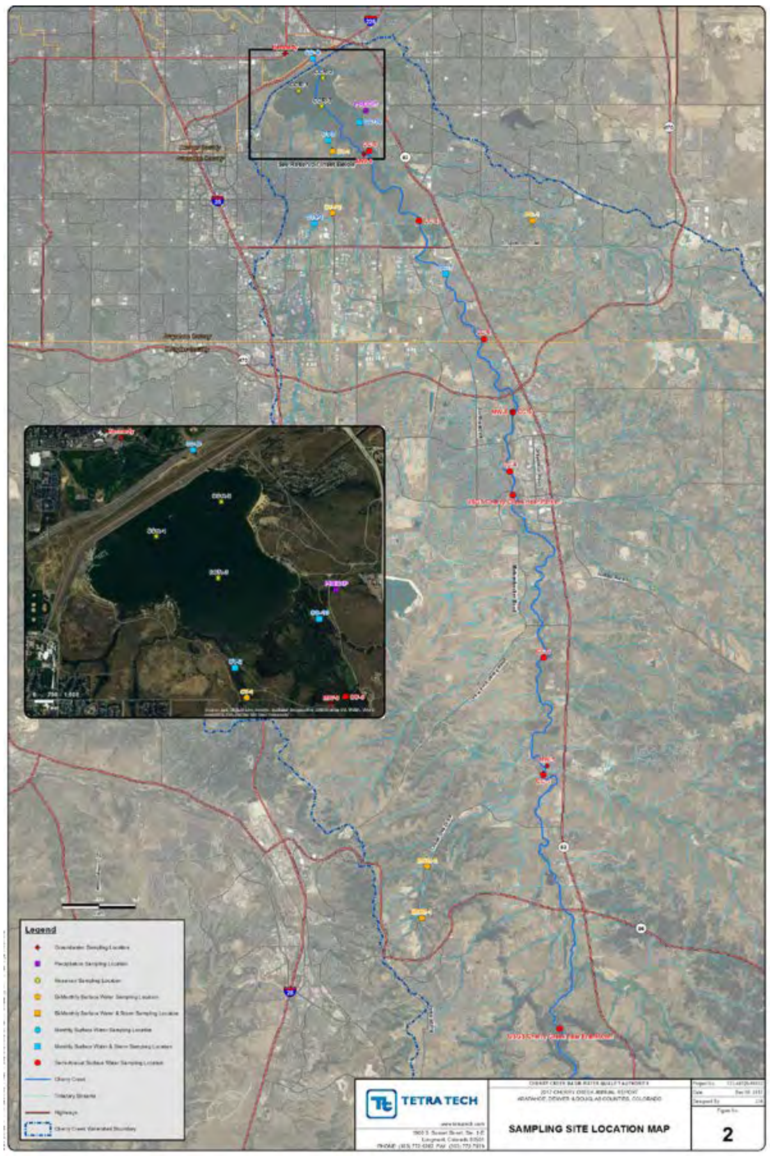



**Figure 2 Sampling Location Map**

**Table 1. Reservoir Sampling Parameters, Frequency, and Sites**

| 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 | √ | √ | √ | √ |
| Total Dissolved Nitrogen | √ | √ | √ | √ |
| Ammonia as N | √ | √ | √ | √ |
| Nitrate + Nitrite as N | √ | √ | √ | √ |
| Total Phosphorus | √ | √ | √ | √ |
| Total Dissolved Phosphorus | √ | √ | √ | √ |
| Orthophosphate as P | √ | √ | √ | √ |
| Total Organic Carbon | | √ | √ | √ |
| Dissolved Organic Carbon | | √ | √ | √ |
| Total Volatile Suspended Solids | √ | √ | | √ |
| Total Suspended Solids | √ | √ | | √ |
| Chlorophyll *a* | √ | √ | | √ |
| Phytoplankton | | √ | | √ |
| Zooplankton | | √ | | √ |

**Table 2. Rain Gage Sampling Parameters**

| Analyte | CCR-Precipitation |
|---|---|
| Total Nitrogen | √ |
| Total Phosphorus | √ |

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

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

## 2.1 MONITORING OBJECTIVES

The 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 and determination of the total annual flow-weighted concentration of nutrients to the Reservoir, evaluation of watershed nutrient sources and transport mechanisms, and effectiveness of PRFs and BMPs in the basin.

The specific objectives of the program include the following:

- Assess protection of beneficial uses and compliance with CR72 water quality standards.
- Calculate base flow and storm flow concentrations for nitrogen and phosphorus in tributary inflows, as well as concentrations in the Reservoir and the outflow.
- Calculate the hydrological inflows and nutrient loads entering the Reservoir, including Reservoir exports.
- Calculate the annual flow-weighted phosphorus concentration and changes to the concentrations entering the Reservoir from streams and precipitation and the phosphorus export from the Reservoir via the outlet structure.
- Assess biological productivity in the Reservoir, as measured by algal biomass (chl-*a* concentration), and species composition of the plankton community.
- Evaluate relationships between the biological productivity and nutrient concentrations within the Reservoir and total inflows.
- Assess the effectiveness of pollutant reduction facilities (PRFs) on Cottonwood Creek and McMurdo Gulch to reduce phosphorus loads into the Reservoir.

The program has also supported other complementary Authority activities over the years, such as calibration of the Reservoir water quality model, determining water quality effectiveness of Authority owned 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 SAP/QAPP

The 2015 SAP/QAPP (Sample and Analysis Plan/Quality Assurance Project Plan) provides the foundation for the sampling and analysis program activities, including sampling methods, QA/QC (quality assurance/quality control) protocols, etc. Monitoring and analytical work are performed in accordance with this document, provided in Appendix B.

In 2016 and again in 2017, a variety of field procedure refinements were implemented (e.g., improved sampling methodology for plankton samples, discontinuance of certain monitoring locations due to access issues, discontinuance of redundant analytical parameters). Modifications made to the 2015 SAP/QAPP for the 2016 monitoring program are described in the WY2016 Annual Monitoring Report (Tetra Tech, 2017) and documented in Appendix B. Additional modifications to the SAP/QAPP implemented as part of the 2017 program included:

- Reduction of the seasonal deployment of thermistor strings in the Reservoir from three profile locations to one (CCR-2).
- Analysis of only TP and TN in rain gage samples (Table 2).
- Elimination of dissolved nitrogen, chloride, and sulfate analyses in stream samples (Table 3).
- Change in the frequency of collection of stream samples from monthly to every other month in McMurdo Gulch (MCM-1 and MCM-2) and at two intermediate locations in Cottonwood Creek (CT-P2 and CT-1) (Table 3).
- Elimination of two groundwater monitoring sites (MW-2 and MW-7a).
- Reduction of the seasonal stormwater monitoring sites from six to four (CC-7, CC-10, CT-P1 and CT-2).

The 2017 modifications are documented in Appendix B.

Stream reclamation activities continued in Piney Creek in WY2017. Consequently, the planned flow and water quality monitoring station in this sub-basin, PC-1 (Figure 2; Table 3), was not constructed in WY2017.

### 2.2.1 Laboratory Analyses

Analytical services were provided by a variety of accredited laboratories in accordance with laboratory QA/QC protocols outlined in the QAPP prepared by each respective laboratory to meet state certification requirements. Table 4 summarizes laboratories utilized during the 2017 program.

**Table 4. Laboratories Responsible for Analyzing Samples (2017 Labs)**

| 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. |
| GEI Consultants, Inc., Ecological Division, Ms. Sarah Skigen | Nutrients and chl-*a*. |

As part of the QA/QC protocol, nutrient and chl-*a* samples were split between IEH Analytical and GEI Consultants in WY2016 to understand lab variability and data comparability. A preliminary evaluation of the comparability of TP and TN between labs indicated that the results from the two labs were within margin of error, approximately 20%, for these two parameters. However, chl-*a*, TDP, and SRP concentrations were more variable amongst the two laboratories. In addition, the WY2016 report (Tetra Tech, 2017), noted differences between the laboratories in their method of analysis for chl-*a* [SM 10200 H (IEH) and modified SM 10200 H with hot ethanol extraction (GEI)] and sampling containers provided by the lab [amber plastic (IEH) and clear plastic cubitainer (GEI)] that may contribute to differences in chl-*a* results. The chl-*a* standard methods of analysis employed by IEH and GEI are both approved by the Colorado Department of Public Health and Environment (WQCC Regulation No. 85, effective 12/30/17). Additional split sampling of nutrients and chl-*a* was performed in WY2017 to help understand the inter-laboratory variability for nutrient parameters and chl-*a*.

The results of the split sample analyses for WY2016 and WY2017 are discussed in Appendix C. In summary, Tetra Tech provided split samples to IEH and GEI during two sampling events each in WY2016 and WY2017. All split samples were collected from the Reservoir photic zone, with samples collected at CCR-1, CCR-2 and CCR-3 during each of the four sampling events. The influence of sample container type and color (amber versus clear) on chl-*a* results was evaluated during the May 24, 2017 sampling event by submitting split samples preserved in amber and clear containers to both laboratories.

Tetra Tech evaluated the 87 paired data sets using the relative percent difference (RPD) or control limit methods. Pairs were judged to exhibit acceptable levels of precision if the RPD was ≤ 20% or, in instances where the RPD method is not appropriate, if the absolute value of the difference between the primary and replicate samples was less than or equal to the detection limit (DL). Sample pairs not meeting these criteria were judged to have anomalous levels of precision.

The results of the split sample evaluation suggest a systematic difference between the data generated by the two laboratories, although the WY2017 data compare more favorably than the WY2016 data. The differences between the paired results were also evaluated for bias (i.e., IEH results consistently higher than GEI results or visa-versa). The results of this evaluation indicate that, with the exception of the May 24, 2016 monitoring event, the GEI laboratory results are generally higher than the IEH results. Based on the available data, it is not clear if IEH laboratory results are biased low or if the GEI laboratory results are biased high. With respect to the chl-*a* analyses, the WY2017 results were more comparable than the WY2016 results; in WY2017 five of six split samples exhibited RPD values within acceptable limits (although GEI results were generally higher than the IEH results). In the clear versus amber container test, five of six samples exhibited RPD values within acceptable limits (although the amber container results were generally higher than the clear container results).

# 3.0 DATA AND RESULTS

The WY2017 monitoring program review is comprised of an assessment of data and results from the watershed, including water quality and quantity of surface water, groundwater, stormwater, and pollutant reduction effectiveness of PRFs (Section 3.1) and the Reservoir (Section 3.2). The 2017 water quality data and results are described herein and made available on the Authority's website, www.cherrycreekbasin.org.

## 3.1 WATERSHED

The watershed-wide water quality monitoring program evaluated the location, timing, magnitude, quantity and quality of nutrient sources to the Reservoir. The surface water and groundwater monitoring program data contains the following elements:

- Routine (monthly, every other month, bi-annual) surface water sampling results, including PRF effectiveness.
- Storm event sampling results.
- Groundwater (bi-annual) sampling results.

During WY2017, 19 surface water sites were monitored at a frequency ranging from monthly to bi-annual (Table 3) and four stations were included in a storm event monitoring program.

The USACE performed its annual operational check and flushing of the Cherry Creek Reservoir outlet works on May 24, 2017. The USACE individually operated the gates between approximately 0900 and 1200 on May 24, and the discharge in Cherry Creek downstream of the Reservoir increased from approximately 42.8 cfs to approximately 260 cfs in five separate pulses. An estimated 6.3 ac-ft of water was released from the Reservoir during the test, approximately 4.8 ac-ft more than would have been released under steady state discharge. The Reservoir level decreased approximately 0.05 feet as a result of the releases.

### 3.1.1 Surface Water

During WY2017 the Cherry Creek surface water monitoring sites were routinely sampled monthly, every other month or twice per year (Table 3). Additionally, four of the monitoring sites were included in the storm event program. In the WY2017 storm event program, runoff generated from seven separate storm events was sampled up to six times at two locations in Cottonwood Creek and/or two locations in lower Cherry Creek. Additional sampling at surface water site CC-10 occurred from mid-March through early April with analyses limited to TP and TSS, and samples collected on March 16$^{th}$ at CC-10 and CT-2 were both analyzed for total iron.

#### 3.1.1.1 Stream Flows

The U.S. Geological Survey (USGS) has operated two gaging stations on Cherry Creek upstream of the Reservoir for numerous years. The Cherry Creek near Franktown gage (number 0671200) has a 76-year period of record (POR) and the Cherry Creek near Parker gage (number 393109104464500) has a 25-year POR. The Authority operates two gaging stations upstream of the Reservoir at surface water monitoring sites CC-7 (Eco Park) and CC-10. The Authority's gage locations are illustrated on Figure 2.

The USGS's Cherry Creek near Franktown gage is located within Castlewood Canyon State Park and has a drainage area of 169 mi$^2$. The WY2017 preliminary flows at the USGS Franktown gage totaled

4,845 ac-ft, with an average daily discharge rate of 6.7 cfs. The WY2017 average rate was approximately 73 percent of the long-term (WY1940-WY2017) average daily rate of 9.2 cfs. The preliminary WY2017 daily hydrograph for the Cherry Creek near Franktown gage is illustrated, along with the 76-year POR mean daily flow, on Figure 3.

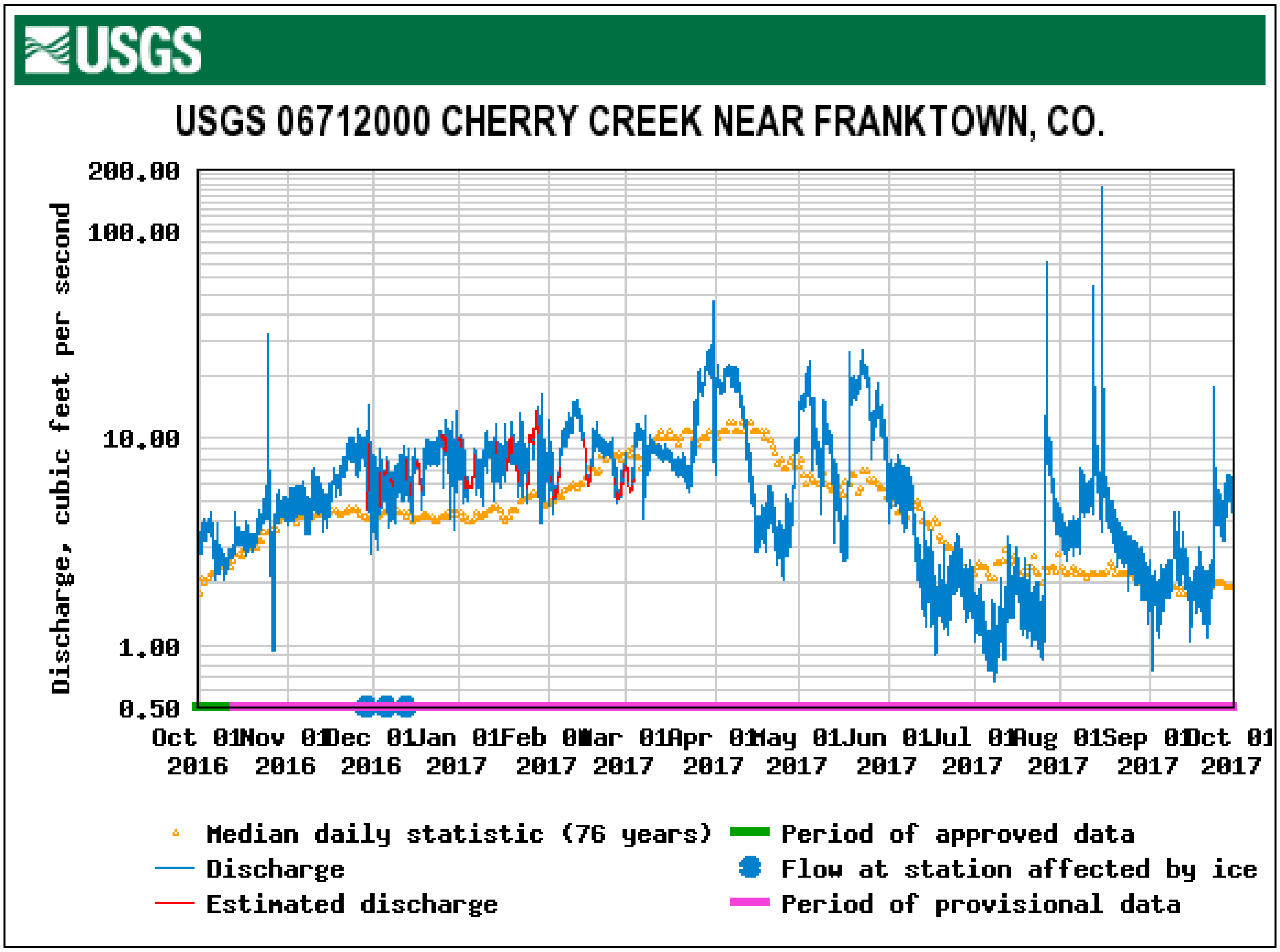



**Figure 3. WY2017 Hydrograph and Historical Median Flows for USGS Gage near Franktown**

The USGS Cherry Creek near Parker gage is located approximately nine miles upstream of the Reservoir, about ½-mile upstream of Authority monitoring site CC-4, and has a drainage area of 287 mi$^2$. The WY2017 preliminary flows at the USGS Parker gage totaled 11,052 ac-ft, with an average daily discharge rate of 15.3 cfs. The preliminary WY2017 average rate was approximately 37 percent higher than the long-term (WY1992-WY2017) average daily rate of 11.1 cfs. The WY2017 daily hydrograph for the USGS Parker gage is illustrated, along with the 25-year POR mean daily flow, on Figure 4.

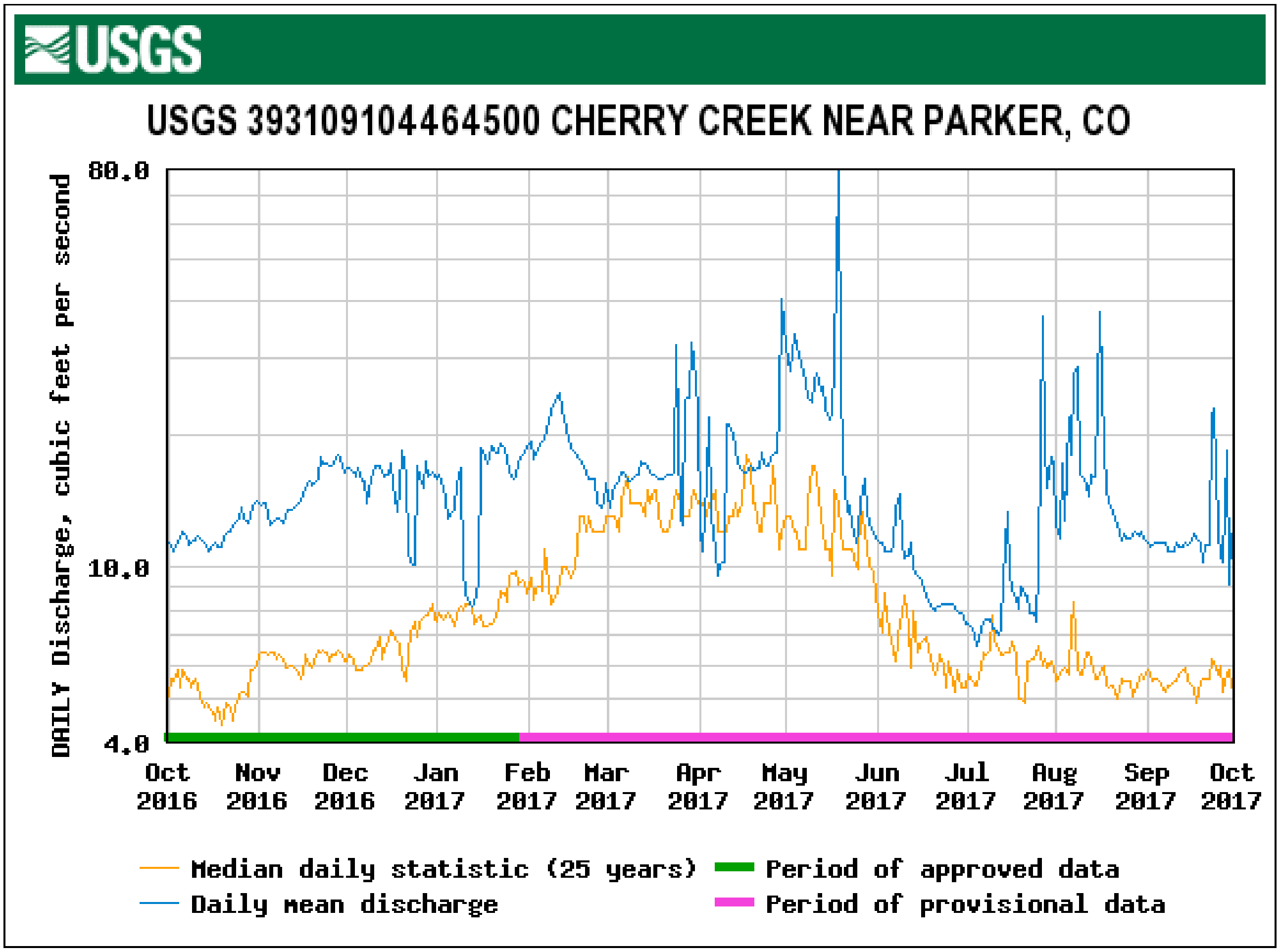



**Figure 4. WY2017 Hydrograph and Historical Median Flows for USGS Gage near Parker (Source of Data: USGS)**

Precipitation measured at the Centennial Airport weather station (KAPA) in WY2017, 12.4 inches, was 77 percent of the 12-year average. Only during one month, May 2017, was precipitation above-average (Figure 5), yet streamflow at the USGS gage near Parker remained above the historical mean for the majority of the year (Figure 4). Review of precipitation data for the entire basin (http://water.weather.gov/precip/) suggests that the southern (upper) portion of the basin may have received above-average precipitation in WY2017 while the northern portion of the basin, where the Authority's monitoring efforts are focused, received below-average precipitation.

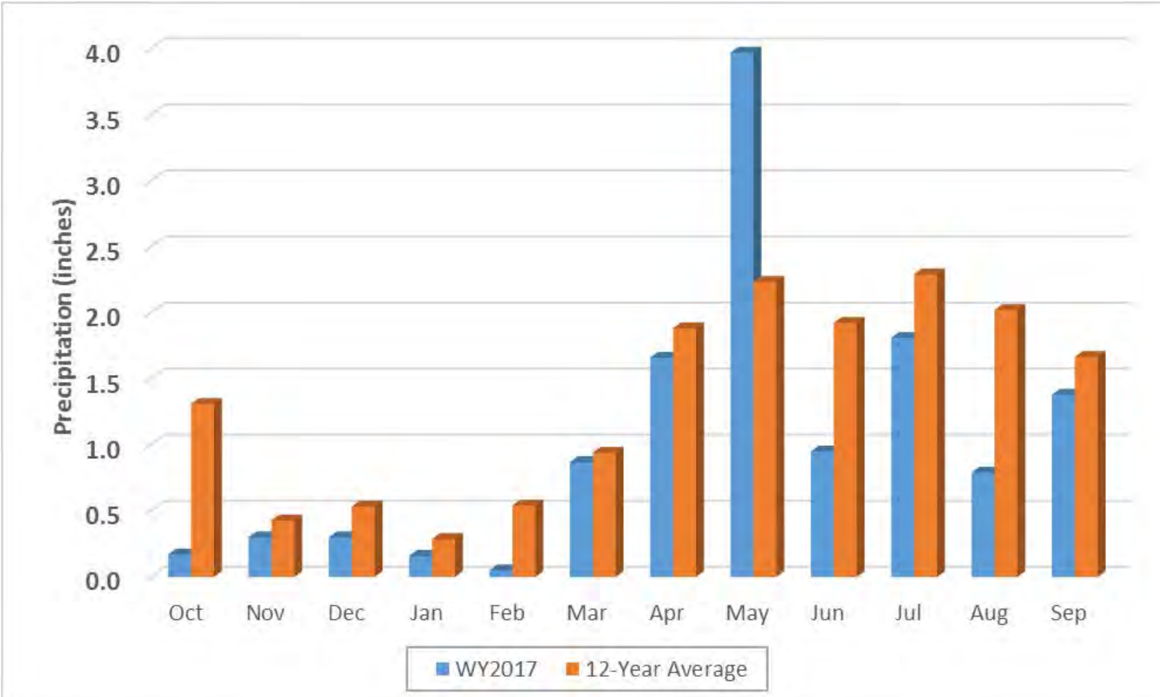



**Figure 5. WY2017 Monthly Precipitation near Cherry Creek Reservoir.** (Source of Data: Centennial Airport, KAPA Precipitation Station)

The Authority operates and maintains two continuous recording stations on Cherry Creek at CC-7 (Eco Park) and CC-10 (Figure 2). Data for these stations are provided in Appendix D. The estimated WY2017 flows at the Authority's CC-10 monitoring site totaled 17,362 ac-ft, with an average daily discharge rate of 24.0 cfs (Figure 6). These values are approximately 57 percent greater than those observed 9 miles upstream at the USGS gage near Parker (Figure 4).

The Authority also operates continuous recording equipment at the two monitoring sites on Cottonwood Creek. Monitoring site CT-P1 monitors the inflow of the PRF located west of Peoria Street. Monitoring site CT-2 monitors the outflow of the PRF located just upstream of the Reservoir inside the Park boundary (the "Perimeter Pond"). Streamflow data and hydrograph for these stations are provided in Appendix D. The estimated WY2017 flows at the Authority's CT-2 monitoring site totaled 3,431 ac-ft, with an average daily discharge rate of 4.7 cfs. The WY2017 daily hydrograph for the CT-2 gage, which reflects the flow of water entering the Reservoir from Cottonwood Creek, is illustrated on Figure 7.

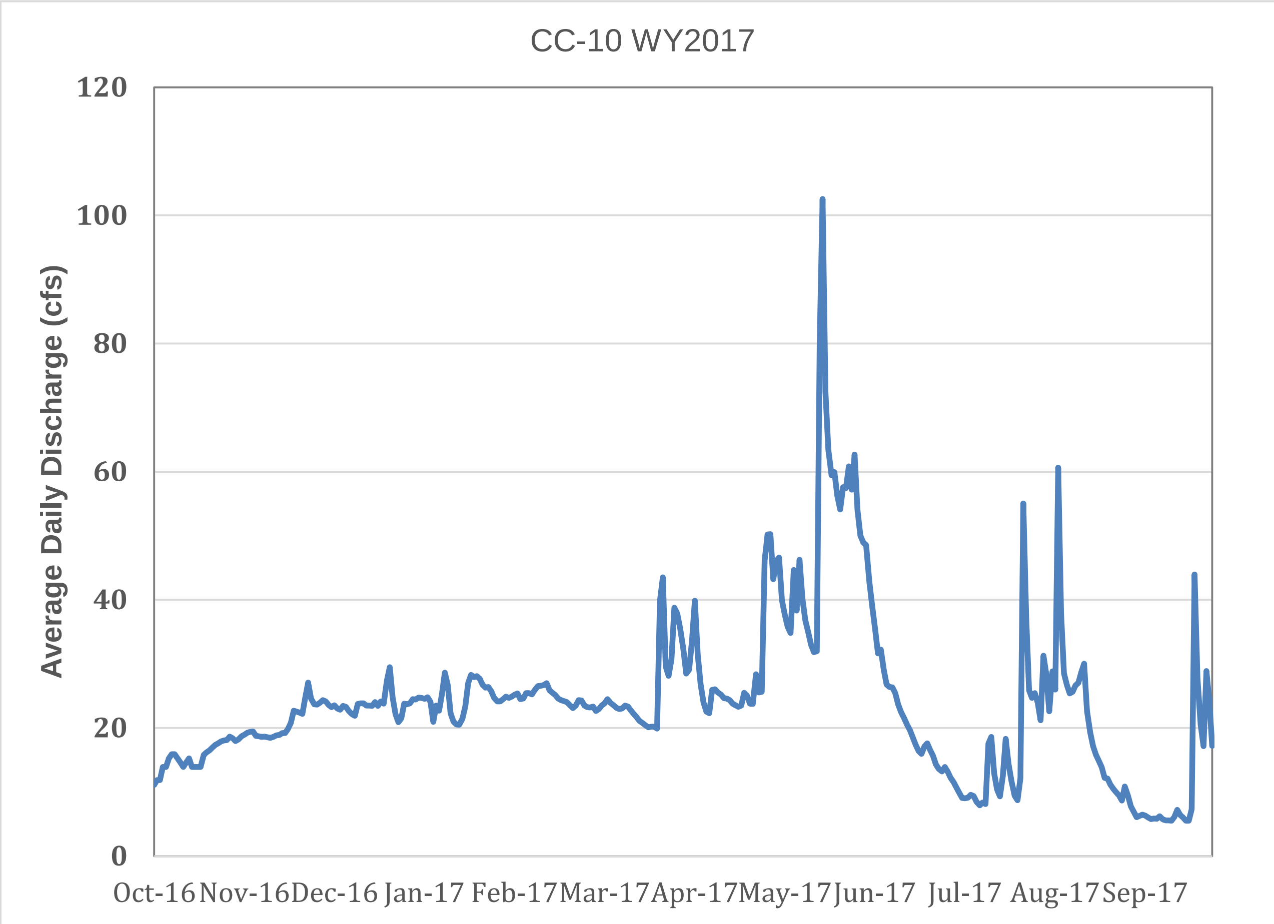



**Figure 6. WY2017 Hydrograph for the Authority's Cherry Creek CC-10 Gage** (Source of Data: Tetra Tech, Inc.)

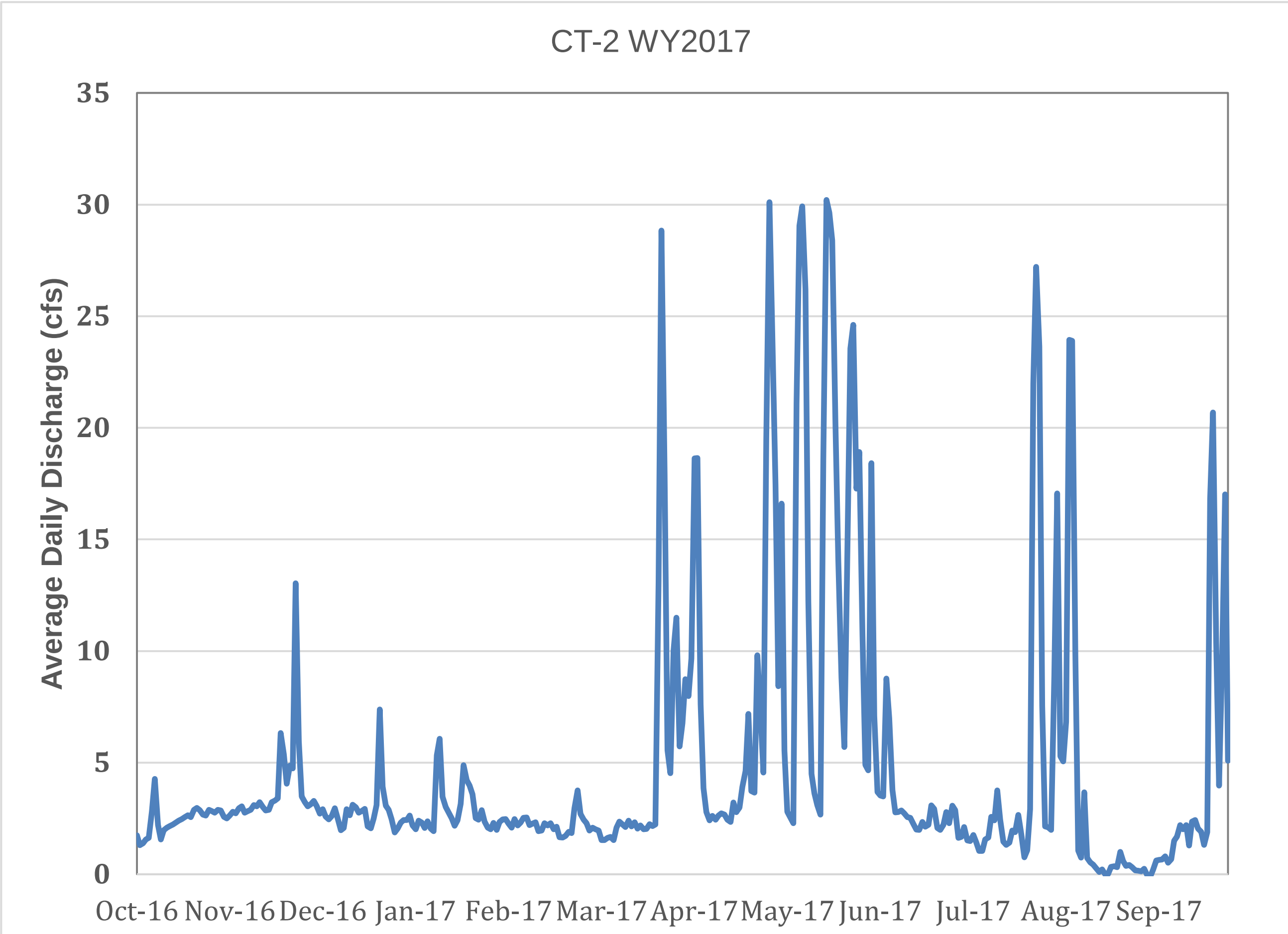



**Figure 7. WY2017 Hydrograph for the Authority's Cottonwood CT-2 Gage** (Source of Data: Tetra Tech, Inc.)

The USACE also calculates net daily inflow into the Cherry Creek Reservoir by estimating the change in reservoir storage and then accounting for losses (measured releases from outlet works, estimated evaporation) and gains (precipitation based on reservoir surface area). The USACE's net daily inflow calculation combines the flows from Cherry Creek, Cottonwood Creek, other minor tributaries, and alluvial groundwater gains/losses. The USACE's WY2017 daily inflow estimates are included in Appendix E.

As discussed in the WY2016 report (Tetra Tech, 2017), the Authority began augmenting the aging ISCO recorders at key inflow stations CC-10 and CT-2 in summer 2017 with Sutron Accubar Constant Flow (CF) bubbler systems (Photo 1) to measure stream stage (which is converted to discharge as with the pressure transducer data). The pressure transducer and

**Photo 1 – Sutron Accubar Constant Flow (CR) Bubbler System Controller.**

bubbler systems will be operated in parallel through at least part of WY2018 at CC-10 and CT-2 to ensure comparable data are generated by the CF bubbler systems.

### 3.1.1.2 Cherry Creek Water Quality

The Cherry Creek sub-basin is significantly larger, at 234,000 acres, than the Cottonwood Creek sub-basin at 9,050 acres. The larger Cherry Creek sub-basin area, with greater runoff volume and different land uses, permitted discharges, etc. produces surface water of a different quality than the Cottonwood Creek sub-basin. The Cherry Creek basin surface water has higher TP concentrations; whereas, the Cottonwood Creek basin surface water is higher in TDS and TN. WY2017 water quality data are provided in Appendix F.

The pH and specific conductance (surrogate for total dissolved solids (TDS)) of water in Cherry Creek both increase as surface water moves from the upper basin downstream to the Reservoir. In the case of specific conductance, during the October 2016 basin-wide monitoring event specific conductance values increased approximately four-fold from the upper monitoring stations (Castlewood and CC-1) to those in Cherry Creek State Park (CC-10) (Figure 8). A similar trend was noted in the May 2017 basin-wide event specific conductance data, although the increase was less (Figure 9).

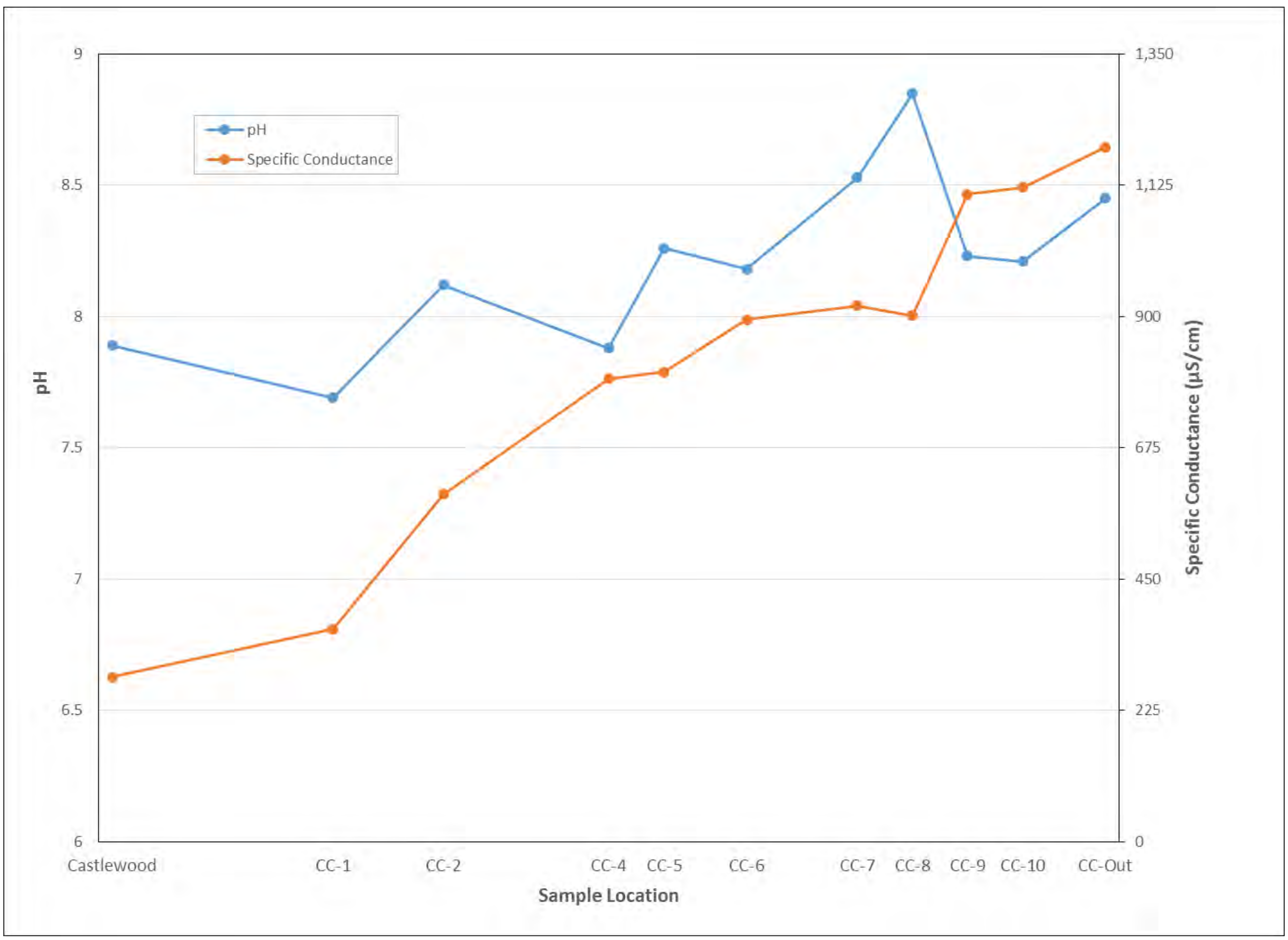



**Figure 8. Specific Conductance and pH in Cherry Creek Basin, October 2016.** (Source of Data: Tetra Tech, Inc.)

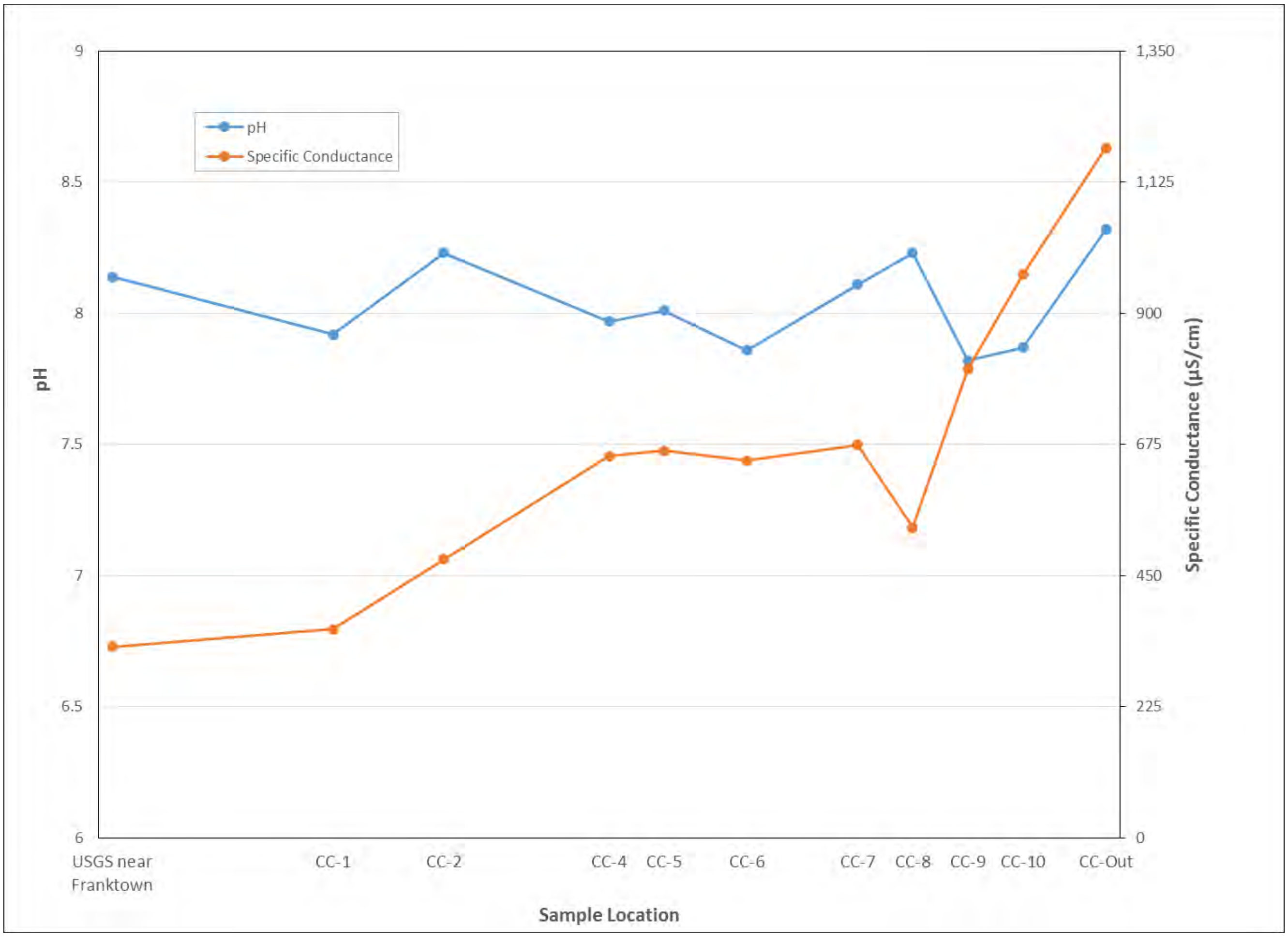



**Figure 9. Specific Conductance and pH in Cherry Creek Basin, May 2017.** (Source of Data: Tetra Tech, Inc.)

The pH values were relatively consistent through the watershed in May 2017 (Figure 9) although a slight downstream increase in pH has been observed in prior events (e.g. Figure 8). Review of the historic pH values measured at CC-10 suggests that the pH of surface water entering the Reservoir at CC-10, after slowly declining from 2009 through 2015, appears to have rebounded to previous levels in 2016 and 2017 (Figure 10).

Review of the historic specific conductance values measured at CC-10 indicates that surface water quality in Cherry Creek has also changed (Figure 11). Since the mid-2000s, specific conductance values at CC-10 appear to have approximately doubled although the WY2016 and WY2017 values are slightly lower than the longer-term trend.

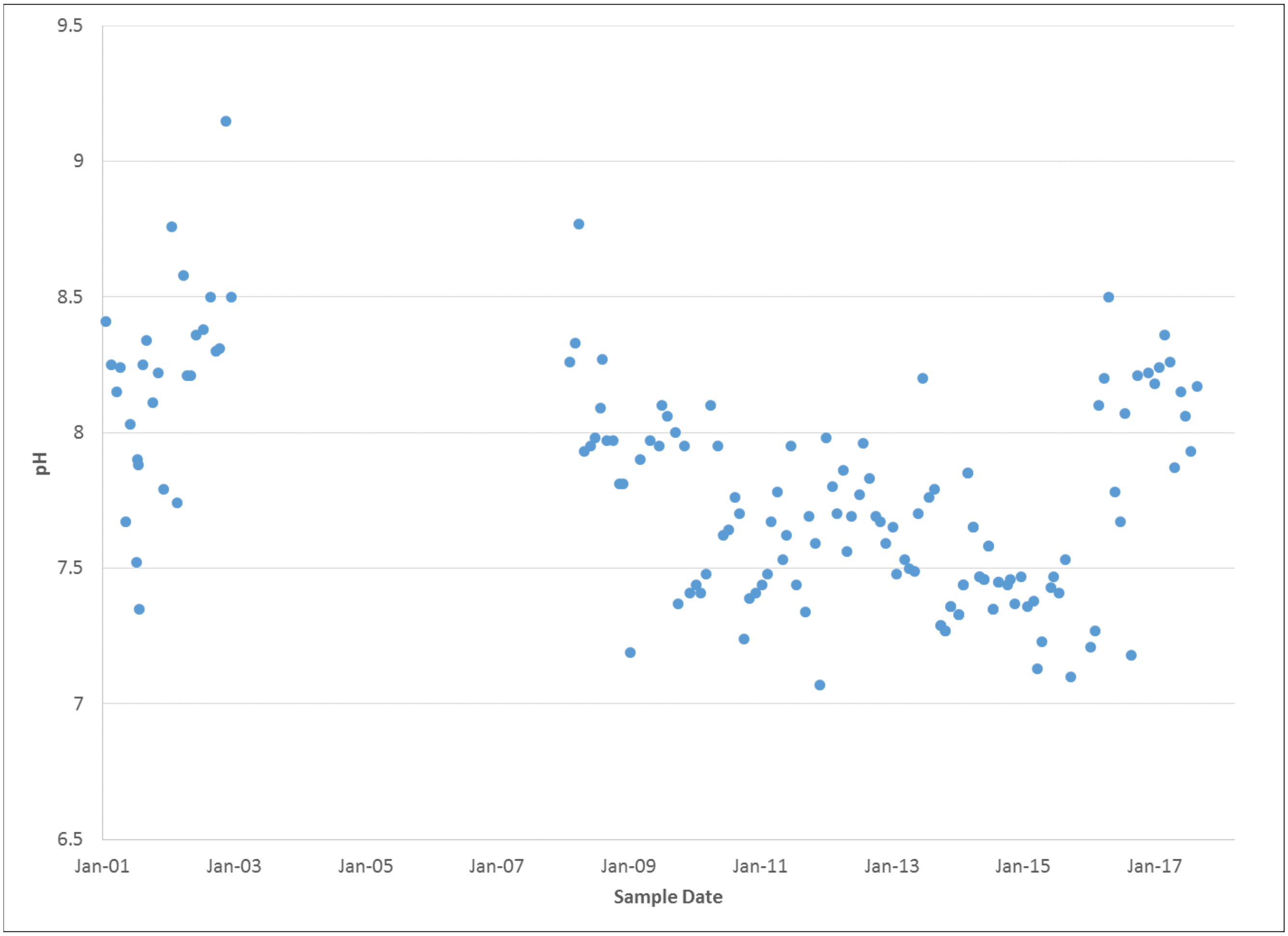



**Figure 10. Historic pH values at Cherry Creek Monitoring Site CC-10.** (Source of Data: Tetra Tech, Inc.)

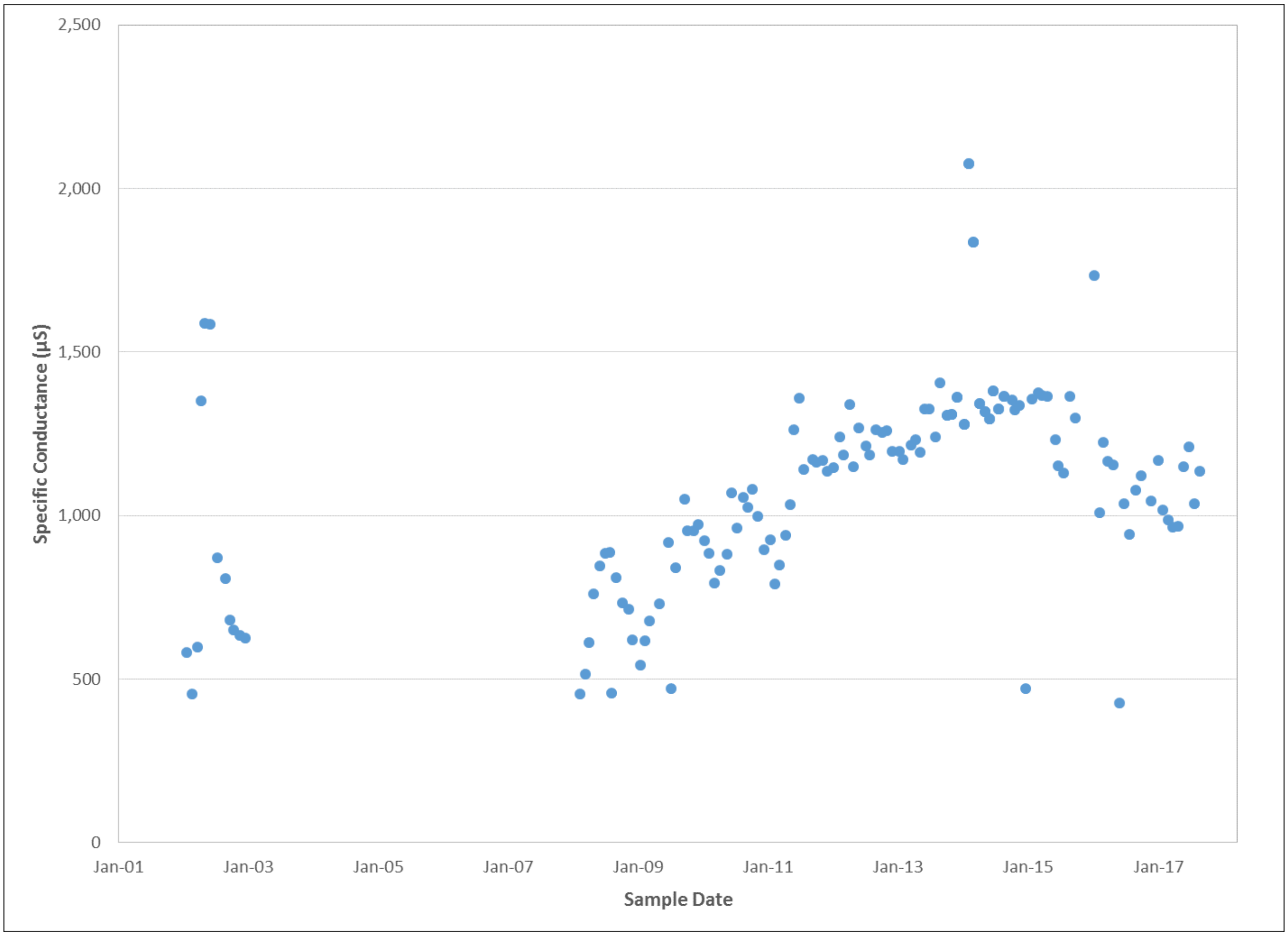



**Figure 11. Historic specific conductance values at Cherry Creek Monitoring Site CC-10.** (Source of Data: Tetra Tech, Inc.)

During the October 2016 basin-wide surface water sampling event, the level of total phosphorus (TP) remained relatively constant upstream of the Reservoir while total nitrogen (TN) increased from the Castlewood State Park downstream to CC-2, remained relatively constant to CC-6, and then decreased through the Cherry Creek State Park (Figure 12).

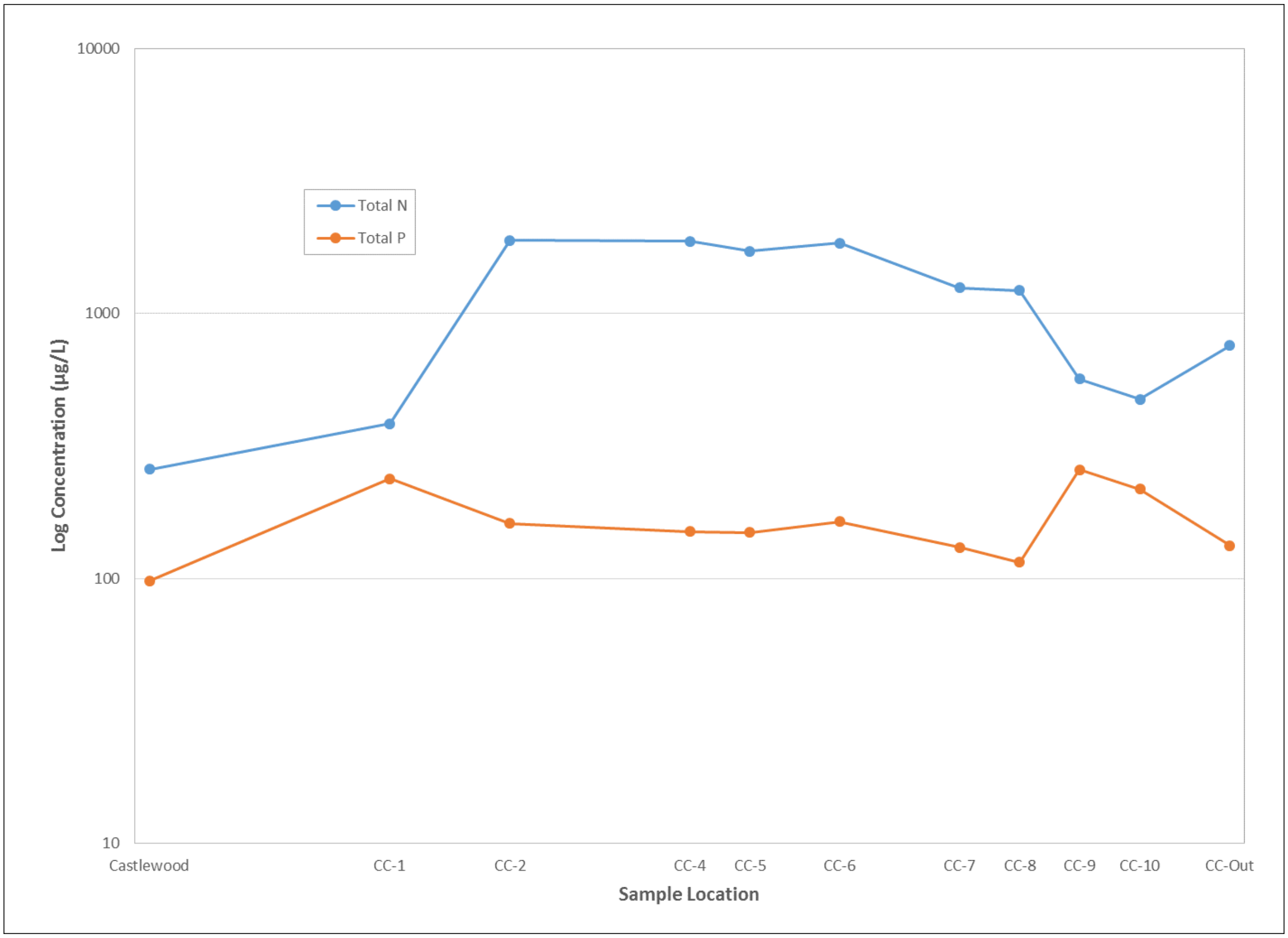



**Figure 12. TN and TP Concentrations in Cherry Creek Basin, May 2017.** (Source of Data: IEH Analytical, Inc.)

In the May 2017 basin-wide surface water sampling event, the level of total phosphorus also remained relatively constant upstream of the Reservoir while total nitrogen again increased from the Castlewood State Park downstream to CC-2 but remained relatively constant further downstream than the previous fall, before again decreasing through the Cherry Creek State Park (Figure 13).

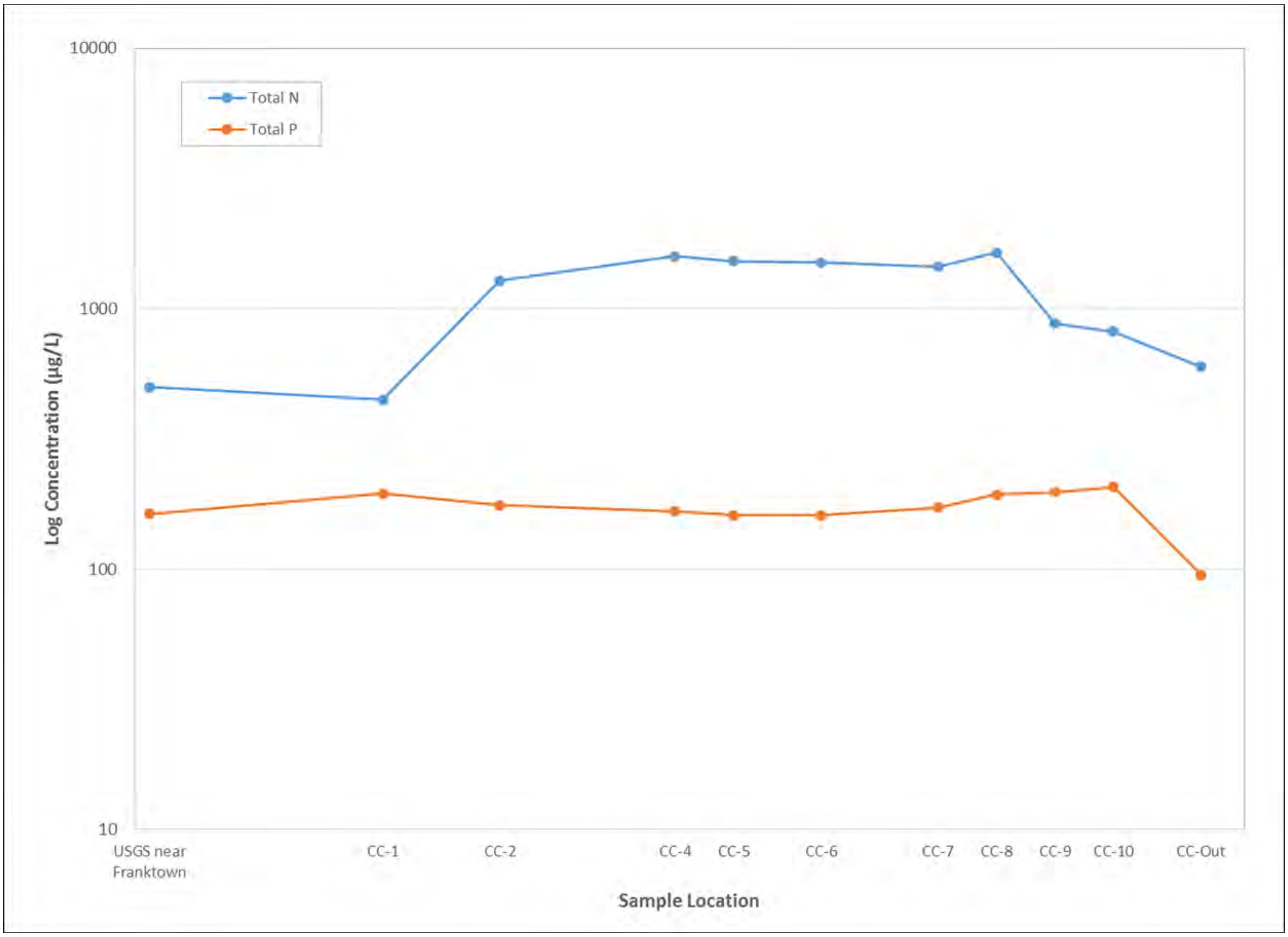



**Figure 13. TN and TP Concentrations in Cherry Creek Basin, May 2017.** (Source of Data: IEH Analytical, Inc.)

The levels of TP leaving the Reservoir (CC-Out) were lower than those entering the Reservoir (CC-10) during all WY2017 monitoring events. As will be discussed in Section 4, this is due to the retention of phosphorus in the Reservoir. TN levels leaving the Reservoir (CC-Out) were lower than those entering the Reservoir (CC-10) in nine of the 12 (75%) WY2017 monitoring events, with the TN levels higher at CC-Out than at CC-10 in October 2016 (Figure 12), and in July and September 2017.

In both the October 2016 and May 2017 basin-wide surface water sampling events, ammonium accounted for less than five percent of the TN present in Cherry Creek, with nitrate/nitrite comprising a larger component of the total nitrogen load. Soluble reactive phosphorus (SRP, also referred to as orthophosphate) comprised the majority of the total phosphorus in Cherry Creek upstream of the Reservoir in both the October 2016 and May 2017 basin-wide surface water sampling events. SRP is is the chemically active dissolved form of phosphorus that is taken up directly by plants. In 2017, approximately 65%-85% of the total fraction was SRP readily available for uptake by algae and plants. The relative distribution of the various nitrogen and phosphorus species measured during the October 2016 basin-wide surface water sampling event are illustrated in Figure 14. Note that a significant level of soluble N and P as it is taken up by biota within the Reservoir. The relative distribution of the nitrogen and phosphorus species measured during the May 2017 basin-wide surface water sampling event is illustrated in Figure 15. The speciation of both nitrogen and phosphorus changes within the Reservoir, as reflected in the change between CC-10 and CC-Out (Figures 14 and 15).

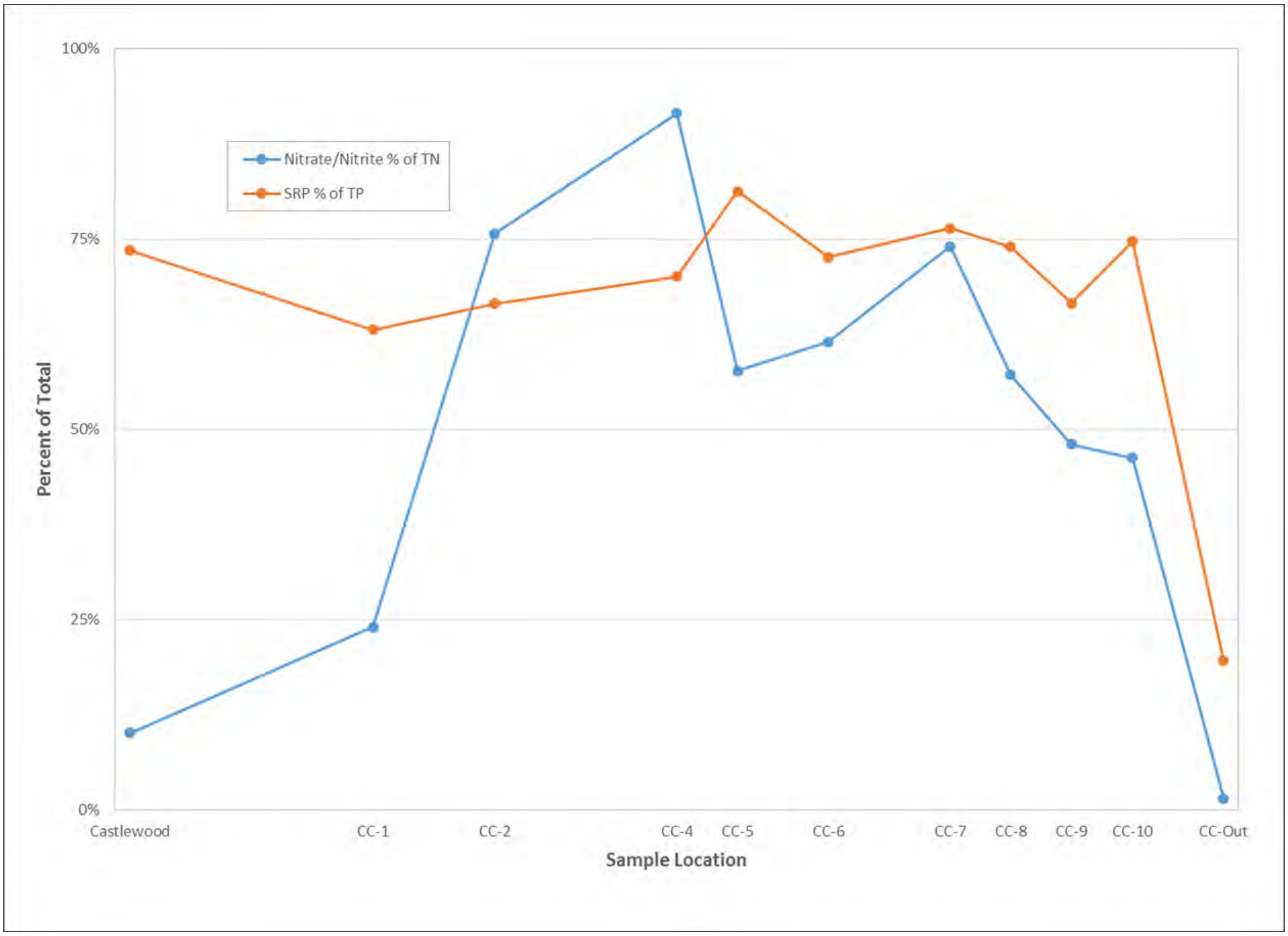



**Figure 14. Nitrogen and Phosphorus Species in Cherry Creek Basin, October 2016.** (Source of Data: IEH Analytical, Inc.)

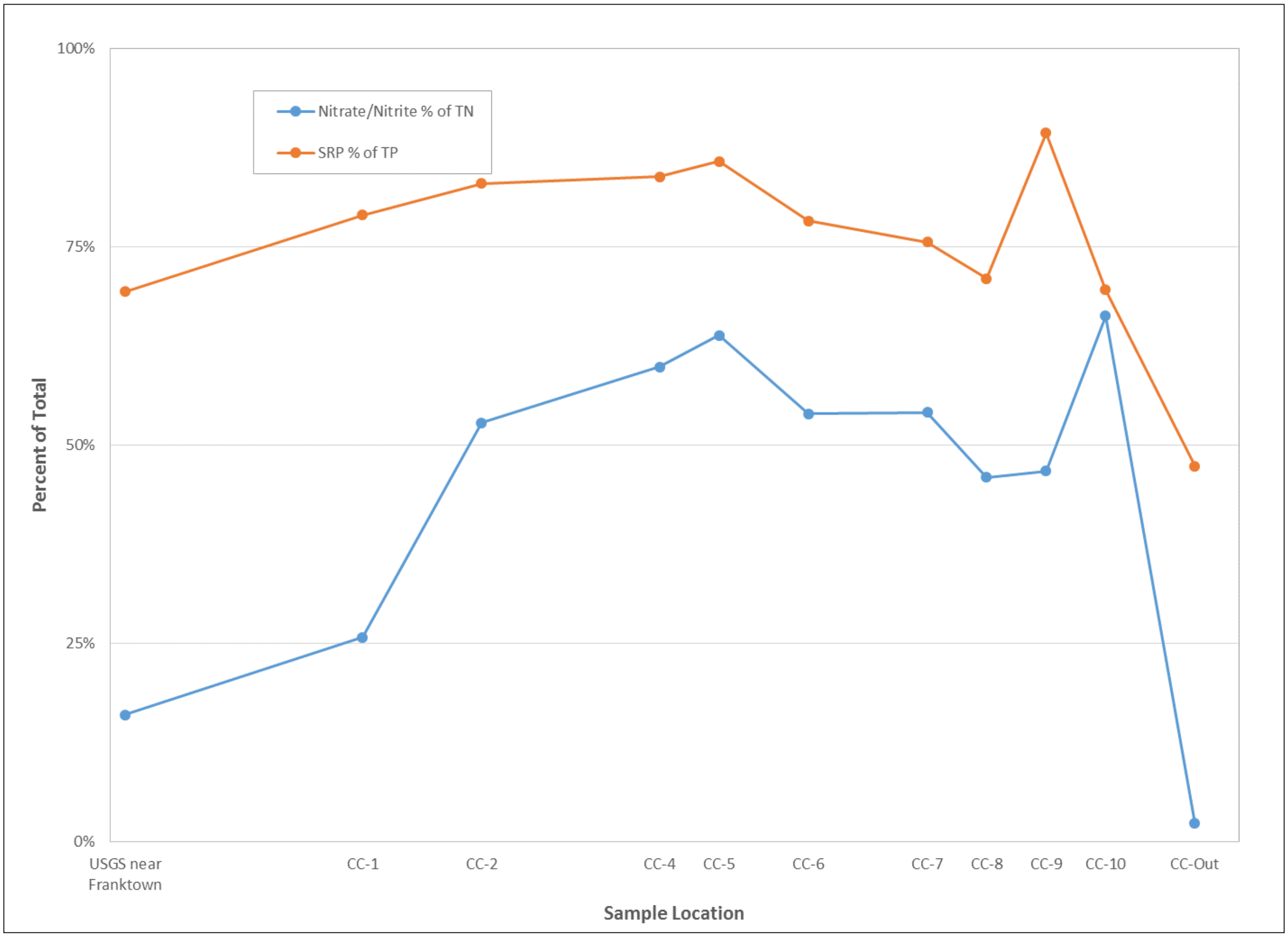



**Figure 15. Nitrogen and Phosphorus Species in Cherry Creek Basin, May 2017.** (Source of Data: IEH Analytical, Inc.)

Just upstream of the Reservoir, phosphorus was generally present at CC-10 in the dissolved form, which includes SRP, with the exception of during storm-related high flows when large amounts of suspended sediment are transported (e.g., June 14, 2016, May 18, 2017, September 23, 2017) (Figure 16). As illustrated on Figure 16, the arithmetic average TP concentration at CC-10 was slightly lower in WY2017 than in WY2016.

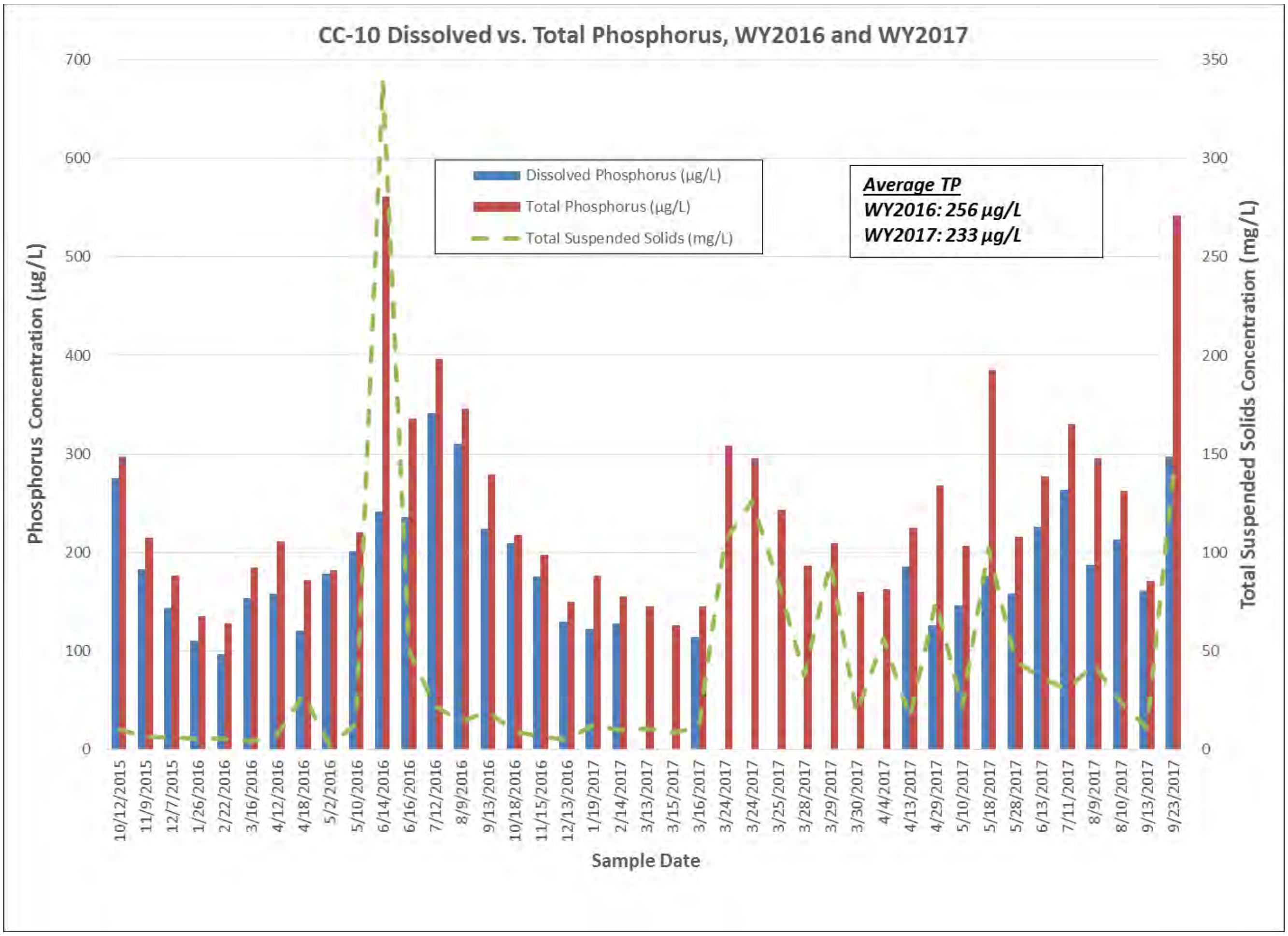



**Figure 16. Comparison of Dissolved and Total Phosphorus and TSS at CC-10, WY2016 and WY2017.** (Source of Data: IEH Analytical, Inc.)

There is a very strong relationship between particulate phosphorus and suspended sediment conveyed by Cherry Creek. Particulate phosphorus is calculated as the difference between the total and the dissolved phosphorus concentrations (or the difference in the height of the red and blue bars in Figure 16). The relationship between particulate phosphorus and TSS at CC-10 in WY2016 and WY2017 is illustrated in Figure 17.

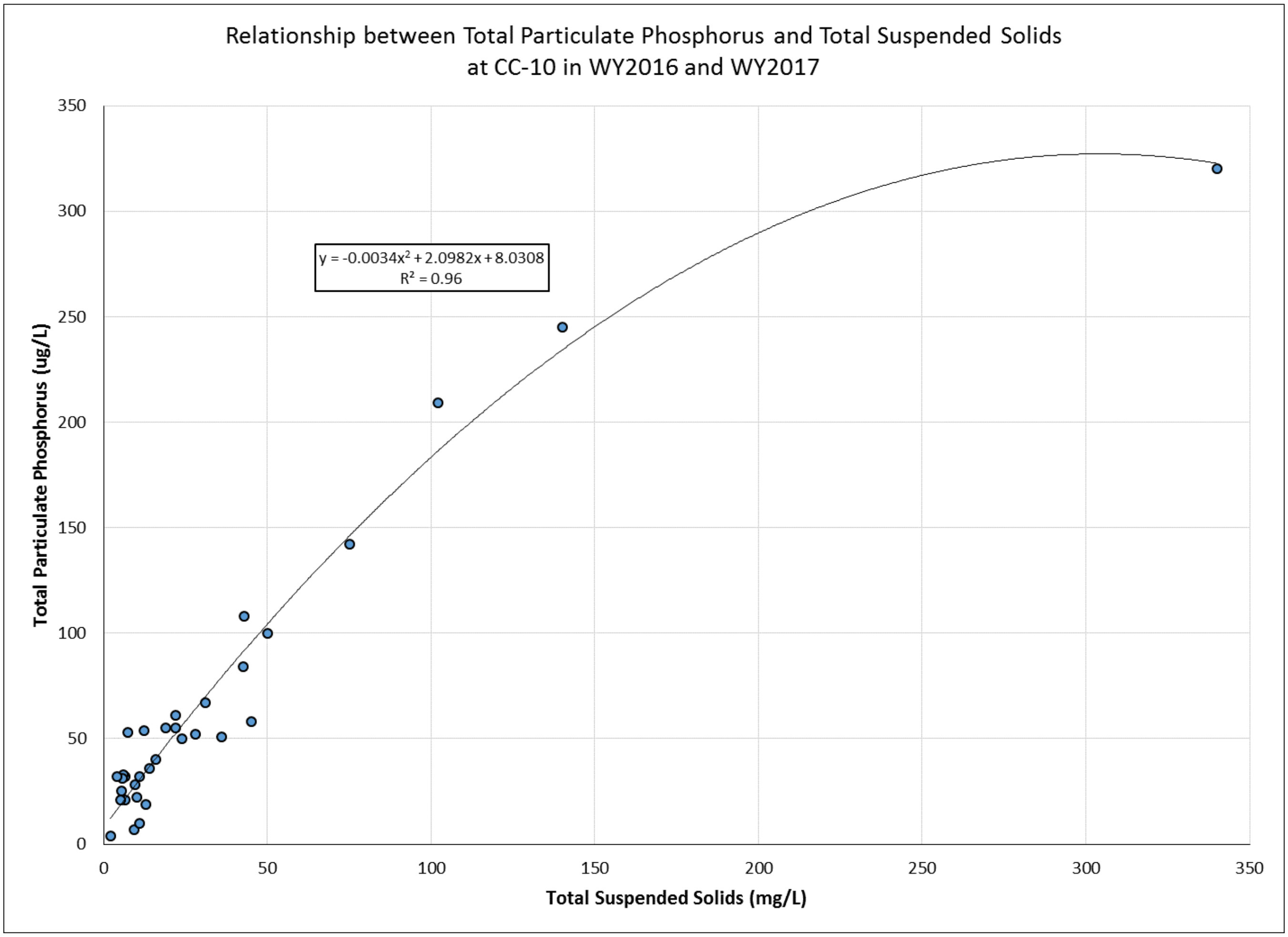



**Figure 17. Particulate Phosphorus versus TSS at CC-10, WY2016 and WY2017.** (Source of Data: IEH Analytical, Inc.)

The positive relationship between phosphorus and suspended sediment concentrations is reflected in the difference between the median total phosphorus concentrations in samples collected at CC-10 during storm events versus those in samples collected during base-flow (non-storm) sampling events. Summary statistics for total phosphorus concentrations at CC-10 in WY2016 and WY2017 under these two flow regimes are provided in Table 5.

**Table 5. Summary Statistics for Total Phosphorus Samples Collected at CC-10 during Base Flow (Routine) and Storm Events, WY2016 and WY2017.**

| Total Phosphorus Statistic | Base Flow Sampling Events (Routine, Non- Storm) | Storm Sampling Events |
|---|---|---|
| Count | 26 | 16 |
| Minimum (µg/L) | 126 | 163 |
| Maximum (µg/L) | 396 | 561 |
| Mean (µg/L) | 213 | 292 |
| Median (µg/L) | 202 | 282 |

The flow weighted total phosphorus concentration at CC-10 for WY2017 was 229 µg/L, which was lower than the WY2016 flow-weighted concentration (250 µg/L) and lower than the recent (2011 – 2015) flow weighted total phosphorus concentration of 263 µg/L published in GEI (2016). However, the WY2017 flow-weighted average concentration for Cherry Creek station CC-10 remains much higher than the WY2017 flow weighted total phosphorus concentration of 62.2 µg/L calculated for station CT-2 in lower Cottonwood Creek (Section 3.1.1.3).

Because of the very strong relationship between particulate phosphorus and TSS, Tetra Tech conducted a field test of continuous turbidity meters in spring 2017 to explore the relationship between total phosphorus concentration and turbidity. If field turbidity were to prove a reliable surrogate measurement of TSS, then installation of turbidity meters at CC-10 and CT-2 could provide a continuous record of total phosphorus entering the Reservoir from Cherry and Cottonwood Creeks. The 7 samples collected during the spring testing demonstrated a very strong relationship between TP and turbidity at CC-10 (Figure 18).

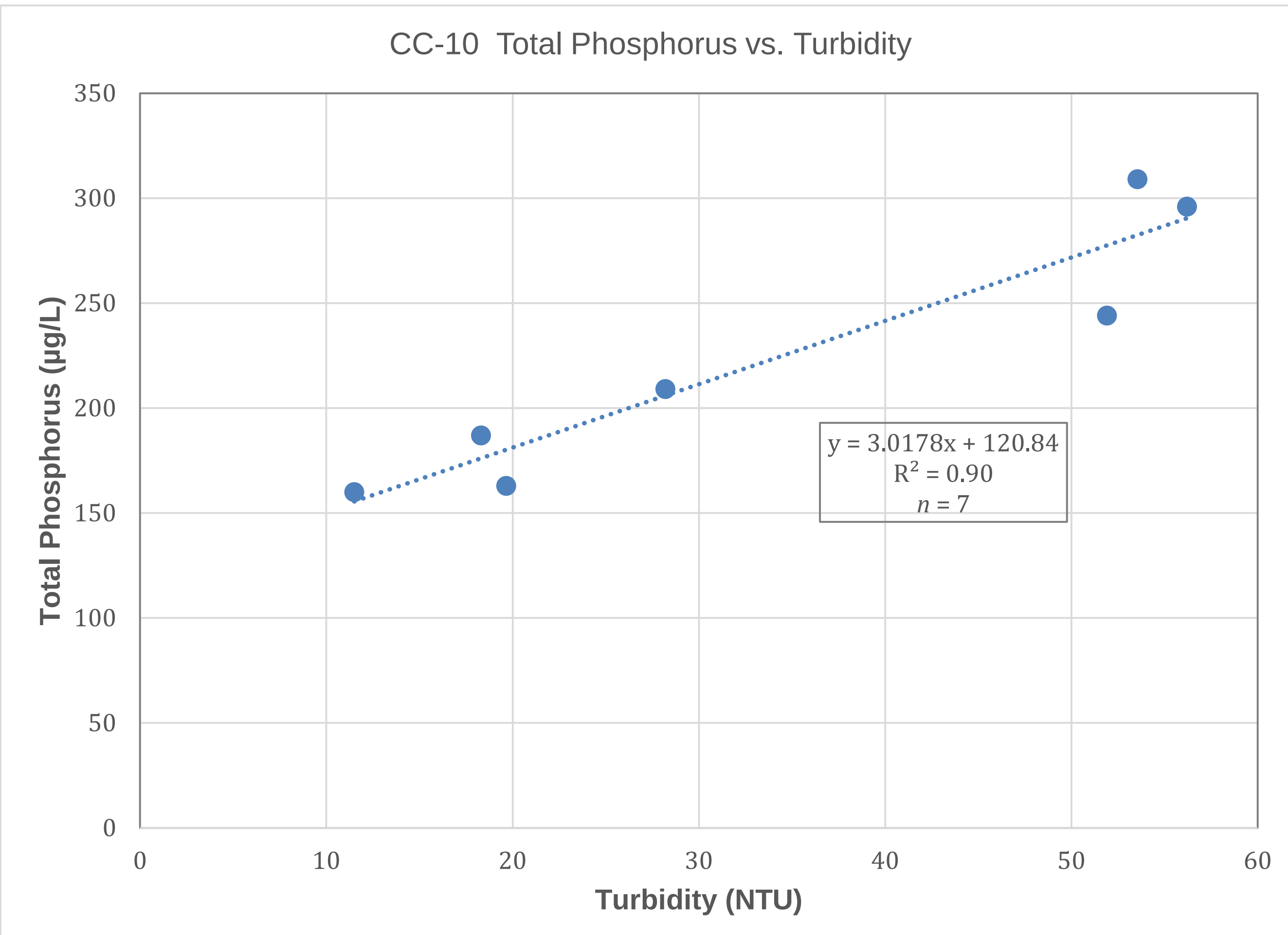



**Figure 18. Total Phosphorus versus Turbidity at CC-10, Spring 2017 Testing Program.** (Source of Data: IEH Analytical, Inc. and Tetra Tech, Inc.)

As a result of the positive spring testing, and with the donation of surplus water monitoring equipment from Pioneer Natural Resources, Inc. to the Authority, Tetra Tech installed Hydrolab (OTT) DS5 Sondes at CC-10 and CT-2 during the summer 2017. The DS5 Sondes measure and record pH, specific conductance, temperature and turbidity at 15-minute intervals. Daily average data for these parameters are provided in Appendix F. Since their deployment, two (2) additional routine water quality samples were collected at CC-10 in WY2017. Two storm event samples were also collected but, because storm event samples are time-composited samples, they are not included in the TP versus turbidity assessment. With the addition of the two additional (August and September 2017) samples, the strength of the TP versus turbidity relationship decreased, but remains strong (Figure 19).

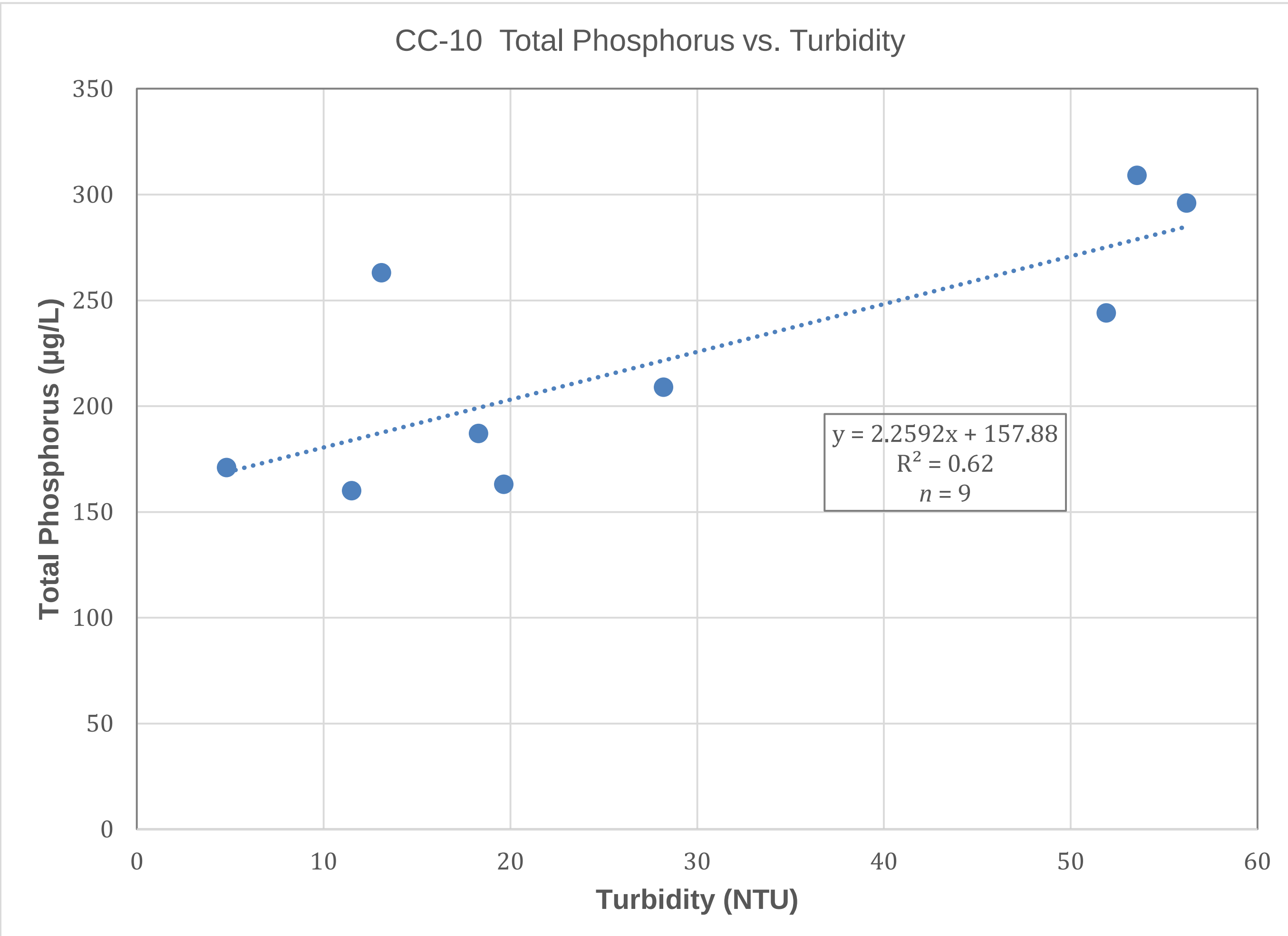



**Figure 19. Total Phosphorus versus Turbidity at CC-10, WY2017** (Source of Data: IEH Analytical, Inc. and Tetra Tech, Inc.)

In contrast to phosphorus, the historic data indicate that there is not a strong relationship between particulate nitrogen and TSS. Summary statistics for total nitrogen concentrations at CC-10 in WY2016 and WY2017 under storm and base-flow (non-storm) flow regimes are provided in Table 6.

**Table 6. Summary Statistics for Total Nitrogen Samples Collected at CC-10 during Base Flow (Routine) and Storm Events, WY2016 and WY2017.**

| Total Nitrogen Statistic | Base Flow Sampling Events (Routine, Non- Storm) | Storm Sampling Events |
|---|---|---|
| Count | 23 | 10 |
| Minimum (µg/L) | 444 | 562 |
| Maximum (µg/L) | 2,146 | 2,950 |
| Mean (µg/L) | 1,040 | 1,250 |
| Median (µg/L) | 837 | 1,060 |

The flow weighted total nitrogen concentration at CC-10 for WY2017 was 1,260 µg/L, which was higher than that calculated in WY2016 (1,012 µg/L) but essentially equal to the recent (2011 – 2015) flow weighted TN concentration of 1,261 µg/L published in GEI (2016). However, the WY2017 flow-weighted total nitrogen concentration for Cherry Creek station CC-10 remains much lower than that calculated for site CT-2 (1,809 µg/L) in lower Cottonwood Creek in WY2017 (Section 3.1.1.3).

### 3.1.1.3 Cottonwood Creek Water Quality

The quality of surface water in lower Cottonwood Creek just above the Reservoir (monitoring site CT-2) is discussed in this section. The water quality at the other Cottonwood Creek monitoring sites is discussed in Section 3.1.1.4 in the context of PRF performance. WY2017 water quality data are provided in Appendix F.

The pH of water in lower Cottonwood Creek ranged from 6.1 to 8.6, with a median value of 7.9. This pH range is generally consistent with the pH values observed in lower Cherry Creek (see Figure 9), although the December 2016 pH value of 6.1 represents the lowest observed pH measured at CT-2. The concentration of dissolved solids, as inferred by specific conductance values, is higher in Cottonwood Creek than in Cherry Creek. In WY2017, the specific conductance at CT-2 ranged from approximately 990 to 4,150 µS/cm with a median value of 1,707 µS/cm. Compared to the specific conductance of water entering the Reservoir from Cherry Creek (Figure 10), water entering the Reservoir from Cottonwood Creek contains approximately 60 percent more dissolved solids. As discussed in Tetra Tech (2017), this higher specific conductance is due, in part, to elevated levels of chloride and sulfate present in Cottonwood Creek.

The concentrations of TP and TN measured at CT-2 in WY2017 are shown in Figure 20. The level of nitrogen present in lower Cottonwood Creek is higher than that observed in Cherry Creek, but the level of phosphorus is lower in Cottonwood Creek than in Cherry Creek.

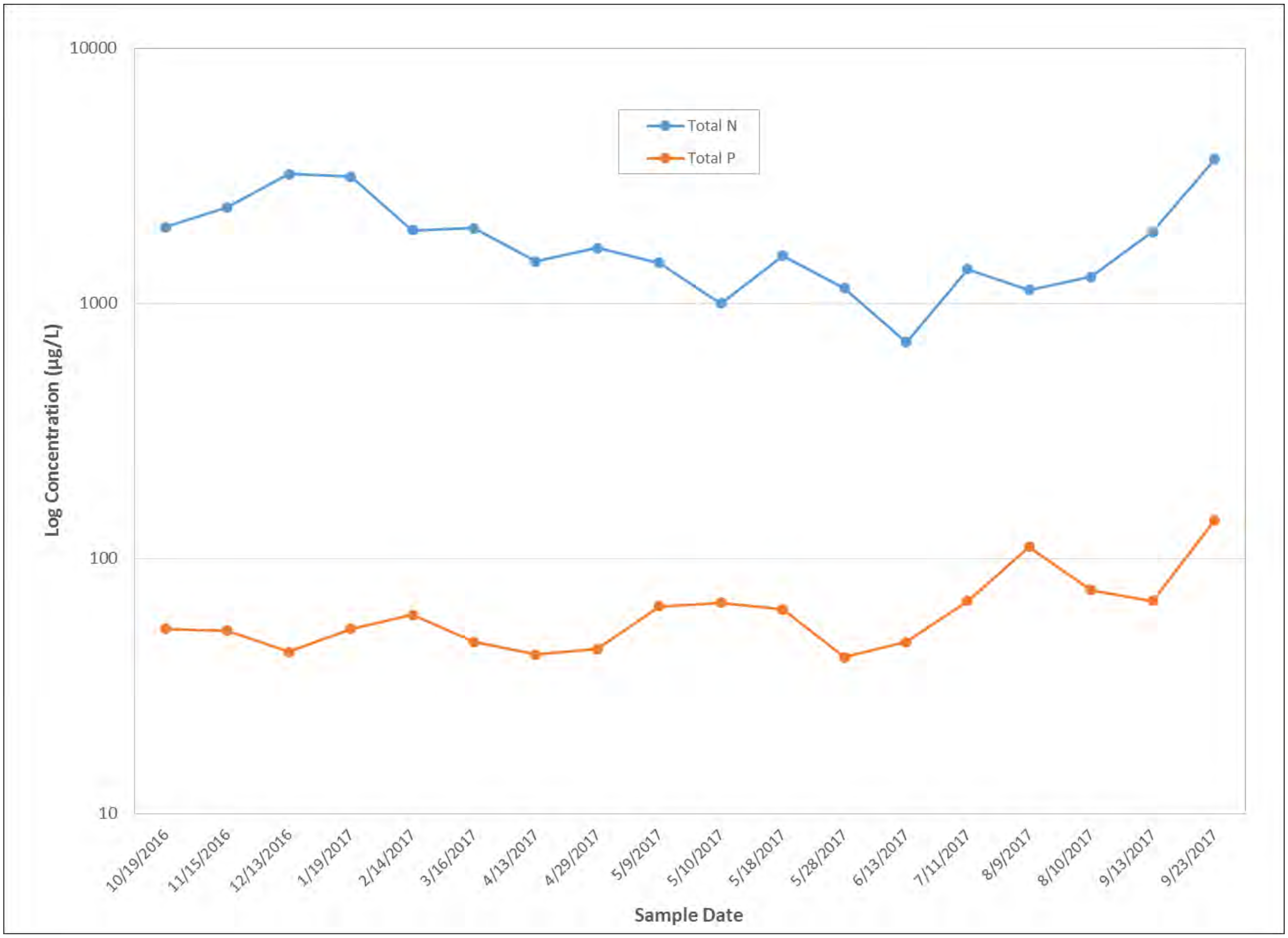



**Figure 20. Comparison of Total Nitrogen and Total Phosphorus at CT-2, WY2017.** (Source of Data: IEH Analytical, Inc.)

There is a moderately strong relationship between particulate phosphorus and TSS in Cottonwood Creek (Figure 21) although, based on R-squared values, the relationship is not as strong as that observed in Cherry Creek (Figure 17). As discussed in Section 3.1.1.2, a water quality Sonde was installed at lower Cottonwood Creek station CT-2 in summer 2017. The DS5 Sonde installed at CT-2 measures and records pH, specific conductance, temperature, and turbidity at 15-minute intervals. Daily average data for these parameters are provided in Appendix F. Since the deployment of the Sonde, only two routine water quality samples were collected at CT-2 in WY2017. Additional data will be collected in 2018 to establish the relationship between total phosphorus and turbidity in Cottonwood Creek.

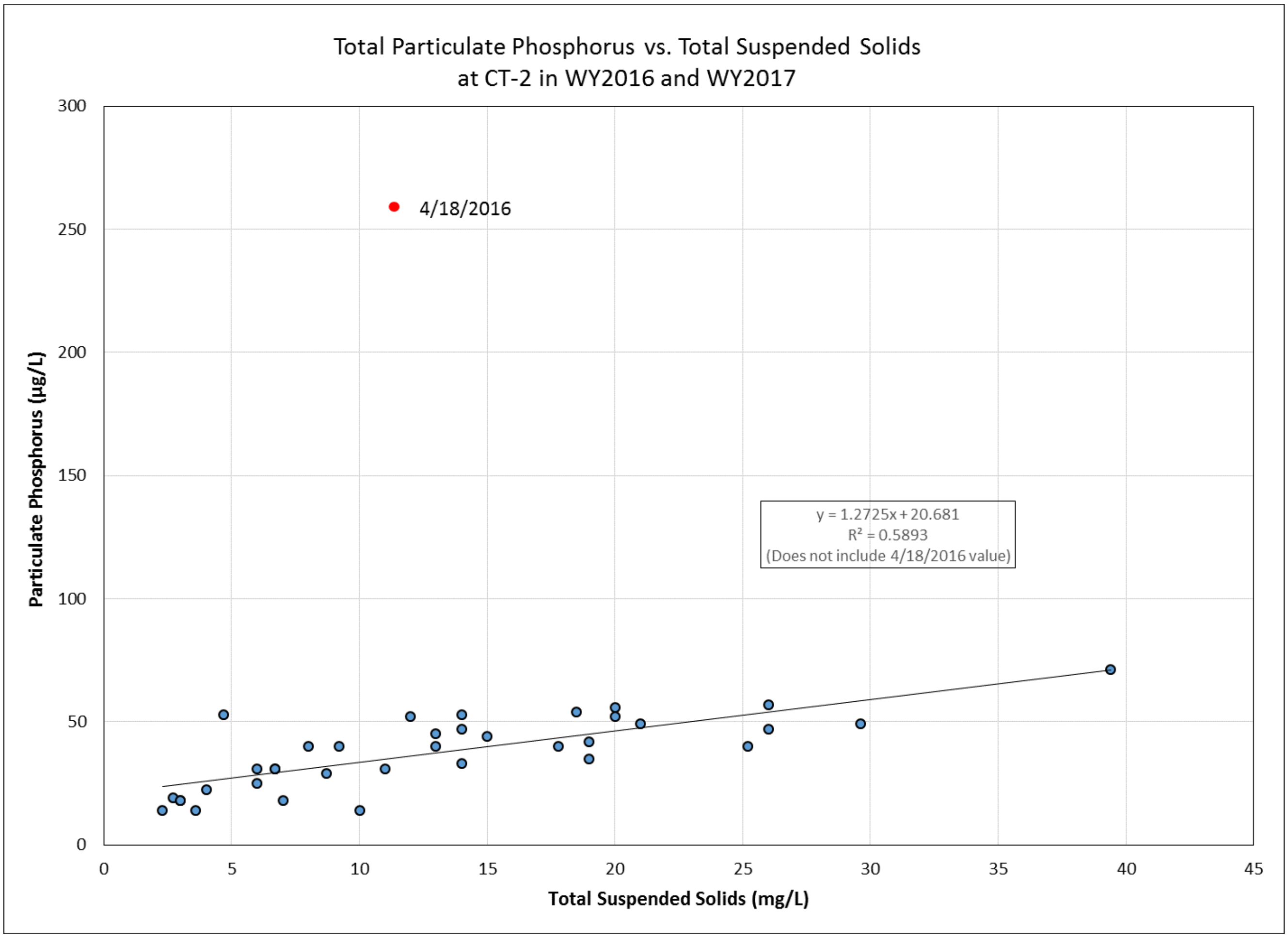



**Figure 21. Particulate Phosphate versus TSS at CT-2, WY2016 and WY2017.** (Source of Data: IEH Analytical, Inc.)

Summary statistics for total nitrogen and total phosphorus concentrations at CT-2 in WY2016 and WY2017 under storm and non-storm (routine sampling) flow regimes are provided in Table 7.

**Table 7. Summary Statistics for TN and TP Samples Collected at CT-2 during Base Flow (Routine) and Storm Events, WY2016 and WY2017.**

| Statistic | Total Phosphorus | | Total Nitrogen | |
|---|---|---|---|---|
| | Base Flow Sampling Events (Routine, Non-Storm) | Storm Sampling Events | Base Flow Sampling Events (Routine, Non-Storm) | Storm Sampling Events |
| Count | 24 | 13 | 24 | 13 |
| Minimum (µg/L) | 33 | 29 | 705 | 1,130 |
| Maximum (µg/L) | 78 | 275 | 4,085 | 3,670 |
| Mean (µg/L) | 57 | 81 | 1,890 | 1,953 |
| Median (µg/L) | 54 | 65 | 1,920 | 1,650 |

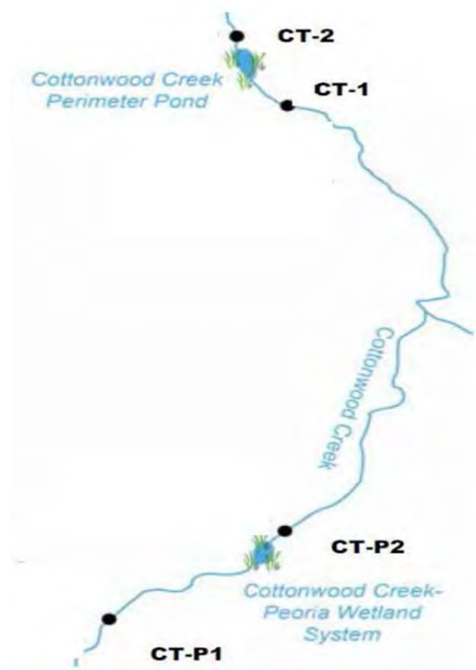
The flow weighted total phosphorus concentration at CT-2 for WY2017 was 62.2 µg/L, which is lower than the recent (2011 – 2015) flow weighted total phosphorus concentration of 75 µg/L reported in GEI (2016) and well below the WY2017 flow weighted total phosphorus concentration of 229 µg/L calculated at site CC-10 in lower Cherry Creek (Section 3.1.1.2).

The flow weighted total nitrogen concentration at CT-2 for WY2017 was 1,809 µg/L, which is higher than the recent (2011 – 2015) flow weighted total nitrogen concentration of 1,592 µg/L reported in GEI (2016) and much higher than the WY2017 flow weighted total nitrogen concentration of 1,260 µg/L calculated at site CC-10 in lower Cherry Creek (Section 3.1.1.2).

### 3.1.1.4 Select Pollutant Reduction Facility Performance

A variety of pollutant reduction facility (PRF) systems have been constructed throughout the Cherry Creek basin. The Authority's current monitoring program targets two tributaries with PRFs, McMurdo Gulch and Cottonwood Creek, to assess the effectiveness of PRFs in decreasing nutrient and sediment loading to surface water. Results from the WY2017 monitoring program in each tributary are discussed below.

The Cottonwood Creek PRF relies on a passive treatment train approach that includes a series of wetland detention systems combined with stream reclamation. The Authority collects water quality samples under both routine (monthly and every other month) and storm (spring and summer) flow conditions at four monitoring sites on Cottonwood Creek (Table 3). As shown in the schematic to the right, monitoring sites CT-P1 and CT-P2 monitor the inflow and outflow, respectively, of the PRF located west of Peoria Street (the "Peoria Pond"). Monitoring sites CT-1 and CT-2 monitor the inflow and outflow, respectively, of the PRF located just upstream of the Reservoir inside the Park boundary (the "Perimeter Pond"). Data for these stations are provided in Appendix F.




Historically, the Authority evaluated the effectiveness of the Peoria and Perimeter Ponds separately. Beginning in WY2016, the combined effectiveness of these two PRFs was evaluated by comparing the data from the uppermost monitoring site in Cottonwood Creek, CT-P1, to data from the lowermost monitoring site in Cottonwood Creek, CT-2, providing an assessment of the net impact of the passive treatment approach on nutrient concentrations in Cottonwood Creek.

In WY2017, the passive treatment approach provided for an effective phosphorus reduction strategy under stormflow conditions, reducing the median TP concentration by 74 percent (Table 8). Median total suspended solids (TSS) concentration, a quantification of sediment concentration in streamflow, was also reduced 92 percent during storm flows. This TSS reduction is important, as the phosphorus content in sediments in Cottonwood Creek has been documented to contain high levels, on average of 0.9 pounds/cubic yard (Ruzzo, 2000), as illustrated in Figure 21. During base flow conditions, there was an increase in TP and TSS concentrations between CT-P1 and CT-2. Soluble reactive phosphorus (SRP) concentrations increased during both base flow and stormflows. TN concentrations also increased during both base flow and stormflows.

**Table 8. Pollutant Reduction Effectiveness of the Cottonwood PRFs in WY 2017**

| Analyte | Median Concentrations under Base Flow Conditions | | Median Concentrations during Storm Flow Events | |
|---|---|---|---|---|
| | CT-P1 (n = 7) | CT-2 (n = 12) | CT-P1 (n = 5) | CT-2 (n = 5) |
| TP, µg/L | 37 | 53 | 242 | 64 |
| SRP, µg/L | 2.0 | 3.5 | 8.5 | 25.5 |
| TN, µg/L | 1,270 | 1,920 | 1,450 | 1,490 |
| TSS, mg/L | 9.0 | 13.7 | 93 | 7.5 |

The PRF developed in McMurdo Gulch is a stream reclamation project. The Authority collected water quality samples only under routine flow (base flow) conditions at two monitoring sites on McMurdo Gulch. Monitoring site MCM-1 is located upstream of the steam reclamation project area while monitoring site MCM-2 is located downstream of the stream reclamation project area. Data for these stations are provided in Appendix F.

In WY2017, the McMurdo Gulch Stream Reclamation Project reduced the median TP, SRP and TN concentrations by 18 percent, 22 percent and 17 percent, respectfully (Table 9). TSS concentrations were essentially unchanged through the stream reclamation project area in McMurdo Gulch in WY2017.

**Table 9. Pollutant Reduction Effectiveness of the McMurdo Gulch in WY2017**

| Analyte | Median Concentrations under Base Flow Conditions | |
|---|---|---|
| | MCM-1 (n = 7) | MCM-2)\ (n = 7) |
| TP, µg/L | 304 | 250 |
| SRP, µg/L | 251 | 196 |
| TN, µg/L | 551 | 456 |
| TSS, mg/L | 1.2 | 2.5 |

## 3.1.2 Groundwater

The Cherry Creek alluvial groundwater is currently monitored twice per year (Table 3). Many of the wells in the Authority's alluvial groundwater monitoring network have been regularly sampled since 1994. The wells are located throughout the basin, including just upstream (MW-9) and just downstream (Kennedy) of the Reservoir (Figure 2). The depths of the wells range from approximately 27 to 60 feet. WY2017 groundwater quality data are provided in Appendix F.

#### 3.1.2.1 Groundwater Levels

Groundwater levels are scheduled to be measured twice per year (spring and fall). Monitoring well MW-9 was also equipped with a continuous water level and temperature monitoring device from April 14, 2016 through WY2017. The Kennedy well is owned by the City and County of Denver, whose employees "purge" the well prior to sampling; consequently, water levels obtained from the Kennedy well are not representative of static groundwater levels as Denver personnel initiate well pumping prior to arrival of Authority sampling personnel.

Hydrographs illustrating the groundwater levels in the Authority's alluvial wells are provided in Appendix D. The historic groundwater level data for the Authority monitoring wells provided on these hydrographs dates from the mid-1990s. In general, the groundwater level trends in many of the Authority wells were similar during the first decade of monitoring; groundwater levels decreased from highs in the early- to mid-1990s to lows in the early- to mid-2000s. Beginning in the early- to mid-2000s the groundwater levels in some of the wells exhibit different trends. From upstream to downstream, general trends exhibited in wells with the most continuous records are summarized below.

- After decreasing from the mid-1990s through the early-2000s, alluvial groundwater levels observed in well MW-1 have increased slightly but are not back to the mid-1990 levels. The depth to groundwater in this well, currently about 25 feet below ground surface, is much deeper than the other Authority wells where groundwater levels are less than 10 feet below ground surface.
- After decreasing from the mid-1990s through the mid-2000s, alluvial groundwater levels observed in wells MW-2 and 5 have increased to the highest levels historically measured.
- After decreasing from the mid-1990s through the early- to mid-2000s, alluvial groundwater levels in wells MW-6 and MW-9 fluctuated with no major apparent recent trends.

Well MW-9 was equipped with a continuous data logger starting on April 14, 2016 to monitor shorter-term changes in alluvial groundwater levels and temperature. The continuous water level data collected from well MW-9 are illustrated in Figure 22.


**Figure 22. WY2016 and W2017 Mean Daily Alluvial Groundwater Elevation in Well MW-9.** (Source of Data: Tetra Tech, Inc.)

As anticipated, the alluvial groundwater level monitored at MW-9 exhibits seasonality with groundwater levels decreasing one to two feet from spring highs to fall lows. This seasonal decrease was larger and more abrupt in WY2017 than that observed the prior year. WY2017 daily average groundwater level and temperature measurements from MW-9 are provided in Appendix D.

### 3.1.2.2 Groundwater Quality

Based on the review of the historic pH and specific conductance data collected from the Authority wells, the quality of the alluvial groundwater appears to be slowly evolving through time. The pH of the alluvial groundwater is generally near neutral, predominately ranging from approximately 6.5 to 7.5. The data from some wells (e.g., MW-9) suggest a slight decrease in pH over the past 20 years. The historic pH values measured in samples collected from well MW-9 are illustrated in Figure 23.

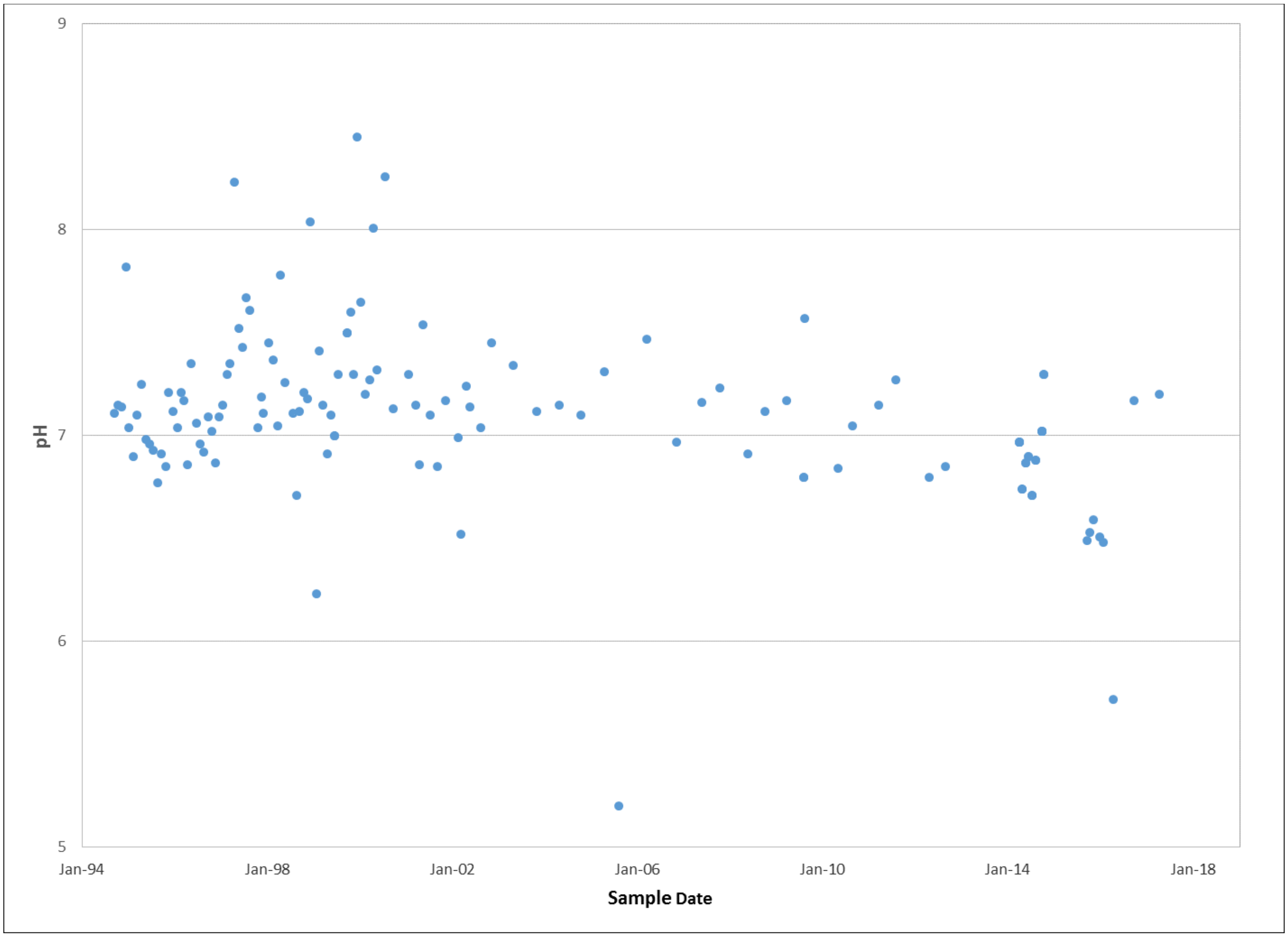



**Figure 23. Historic pH values in Well MW-9.** (Source of Data: GEI Consultants, 1994 –February 2016; Tetra Tech, March 2016-2017)

The pH values in well Kennedy, located downstream of the Reservoir, have remained relatively constant through time.

Specific conductance, a surrogate of the total dissolved solids (TDS) content of the alluvial groundwater, has increased in several wells over time (e.g., MW-9). The historic specific conductance values measured in samples collected from well MW-9 are illustrated in Figure 24. During this same period, chloride concentrations increased in well MW-9 samples from less than 50 µg/L to more than 150 µg/L.

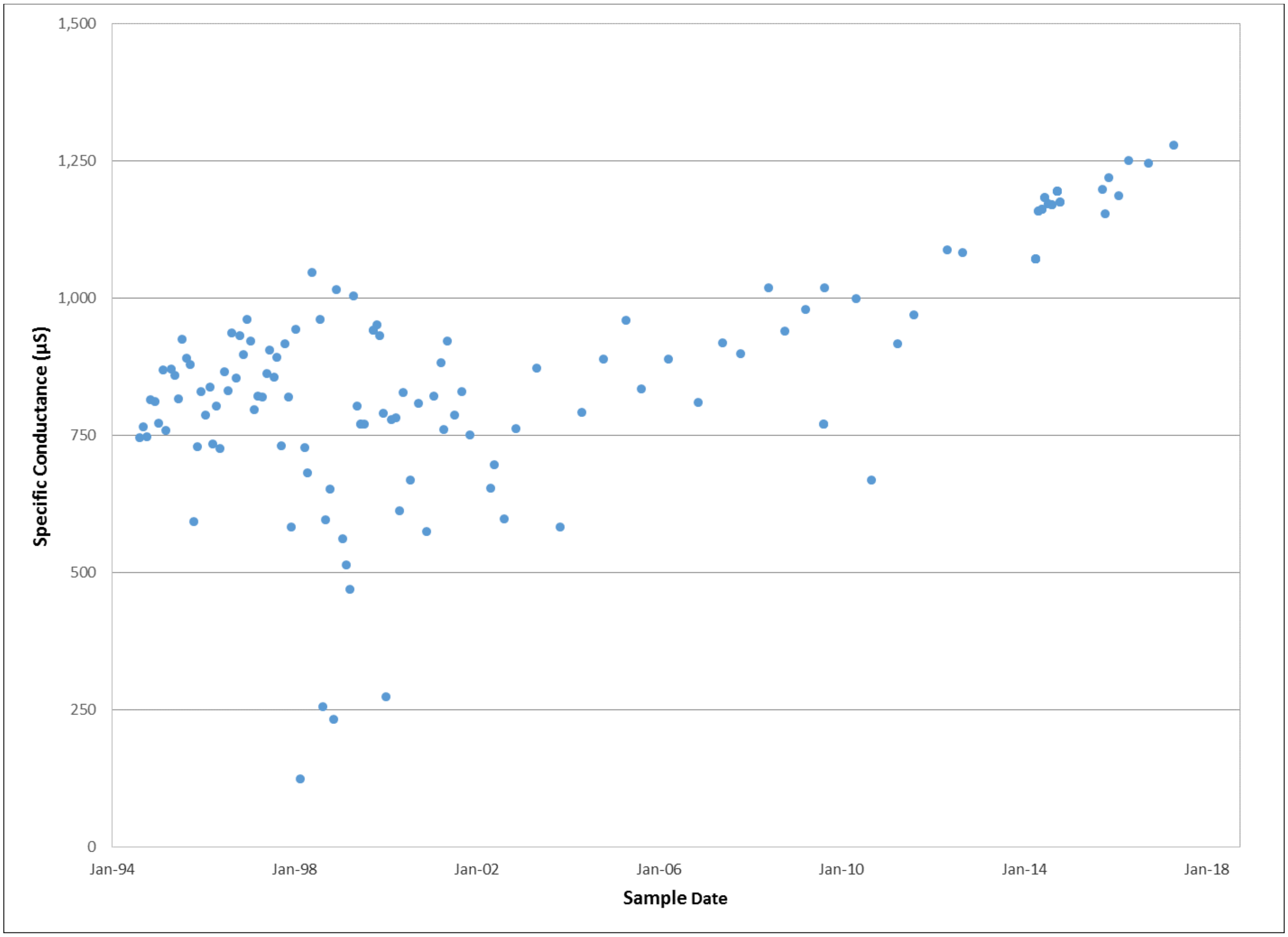



**Figure 24. Historic specific conductance values in Well MW-9.** (Source of Data: GEI Consultants, 1994 –February 2016; Tetra Tech,Inc. March 2016-2017)

Data from the October 2016 and May/June 2017 basin-wide alluvial groundwater sampling events indicated that the concentrations of chloride and sulfate in all the wells were below the applicable state groundwater (domestic water supply) standards of 250 µg/L (5 CCR 1002-41.8, Table 2).

Comparison of Cherry Creek surface water and alluvial groundwater data from the May 2017 basin-wide sampling event suggests a difference in total nitrogen concentrations between the two media (Figure 25). The median concentrations of TN in May 2017 were 1.28 mg/L in surface water and 0.67 mg/L in alluvial groundwater. The exception to this pattern was in the upper basin at well MW-1, where the total nitrogen level was much greater than that in the adjacent surface water. Note that nitrate/nitrite concentration in well MW-1, 8.77 mg/L, was below the state groundwater (domestic water supply) standard of 10 mg/L (5 CCR 1002-41.8, Table 1).

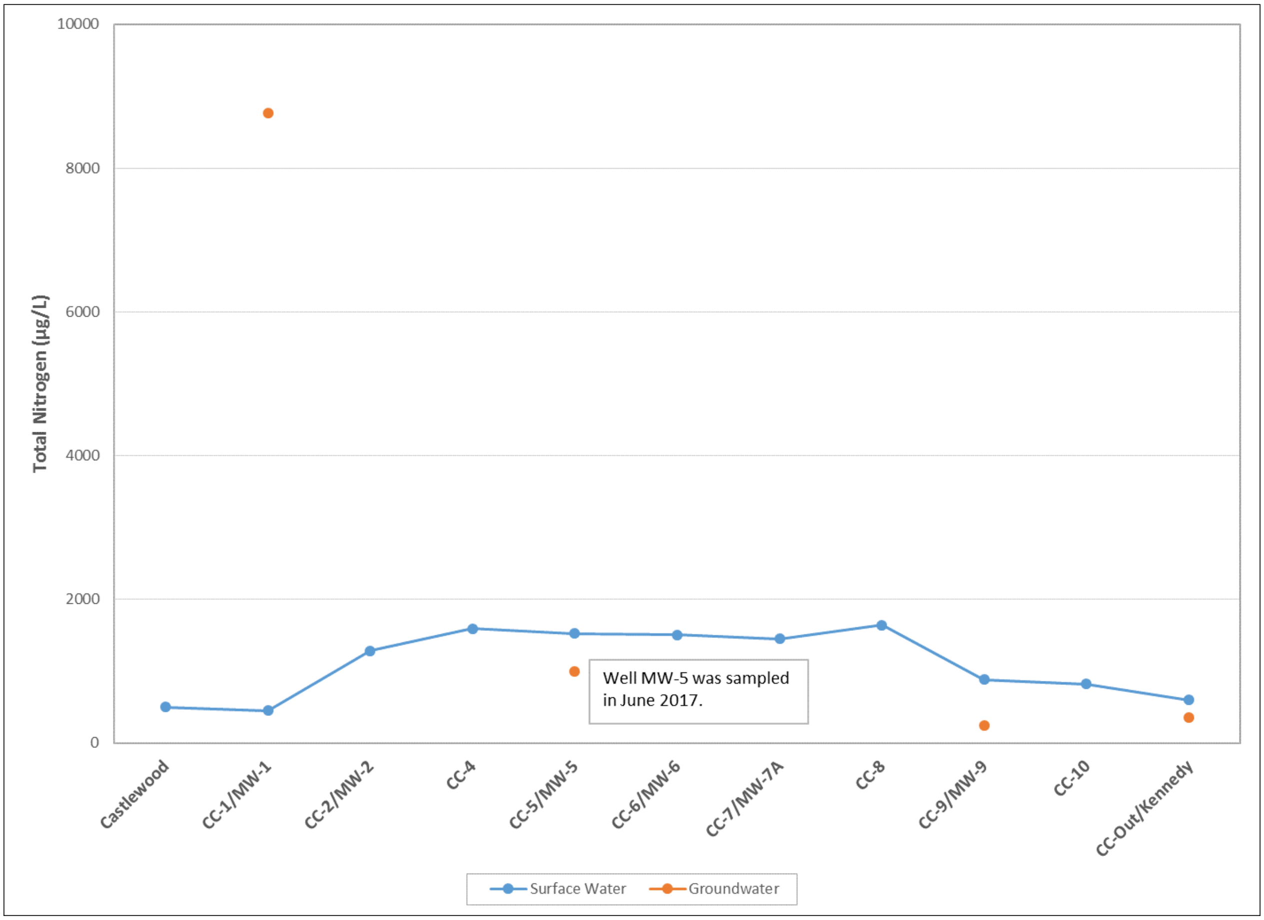



**Figure 25. Total Nitrogen concentrations in Cherry Creek Surface Water and Alluvial Groundwater, May 2017. (Source of Data: IEH Analytical, Inc.)**

In contrast to TN, comparison of Cherry Creek surface water and alluvial groundwater data from the May 2017 basin-wide sampling event suggests little difference in total phosphorus concentrations between the two media (Figure 26). The median concentrations of total phosphorus differed little between the two media in May 2017, 172 µg/L in surface water and 178 µg/L in alluvial groundwater.

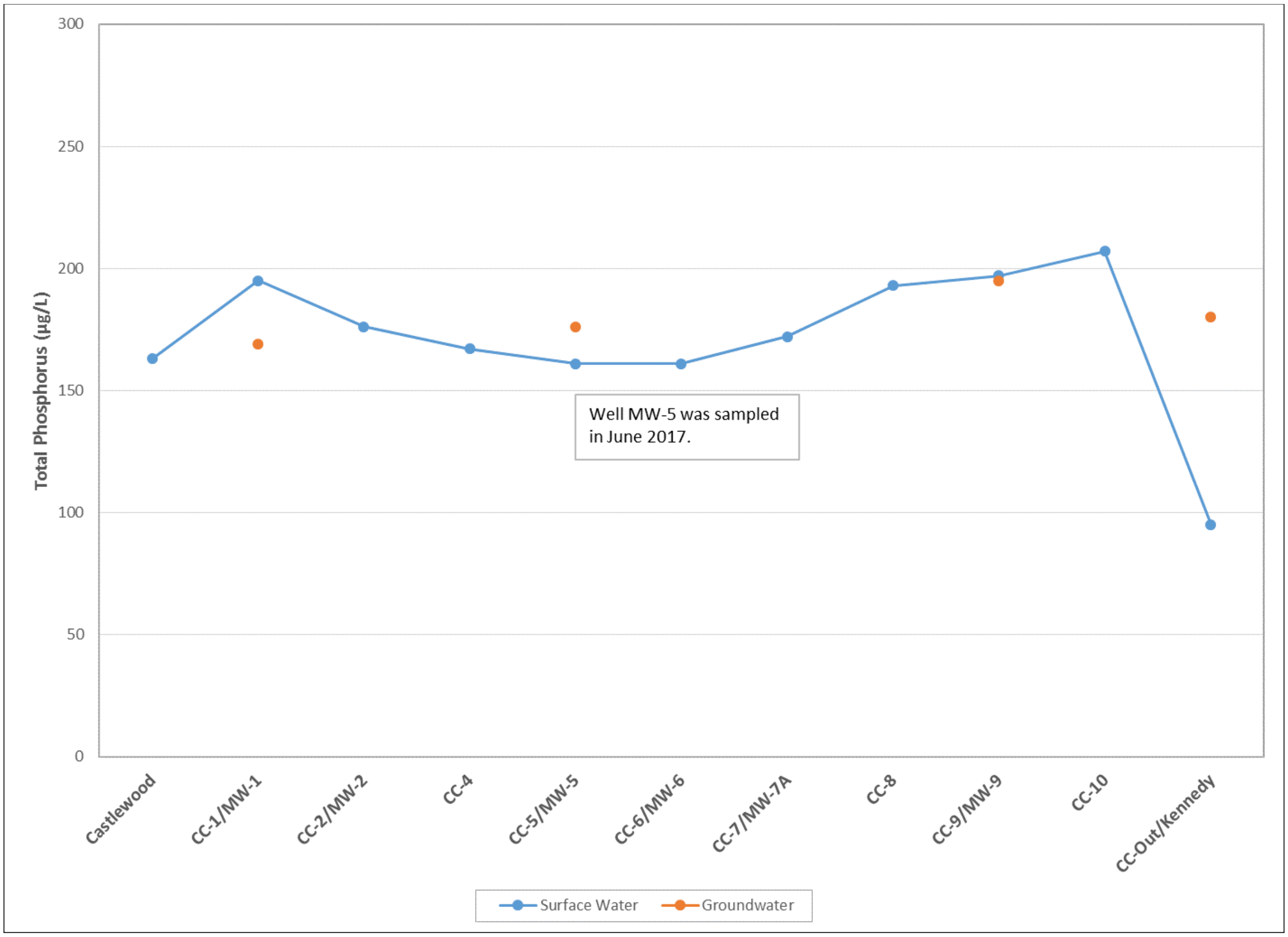



**Figure 26. TP concentrations in Cherry Creek Surface Water and Alluvial Groundwater, May 2017. (Source of Data: IEH Analytical, Inc.)**

Recent (2010 to 2017) SRP data support the TP trend observed in May 2017, although some wells (e.g., MW-2) historically exhibit a wide range in SRP levels. In general, upstream of the Reservoir the SRP levels in the alluvial groundwater are similar to that in nearby surface water (Figure 26). However the SRP level in surface water released from the Reservoir (CC-Out) has historically been lower than that in alluvial groundwater downstream of the Reservoir (alluvial well Kennedy) (Figure 27).

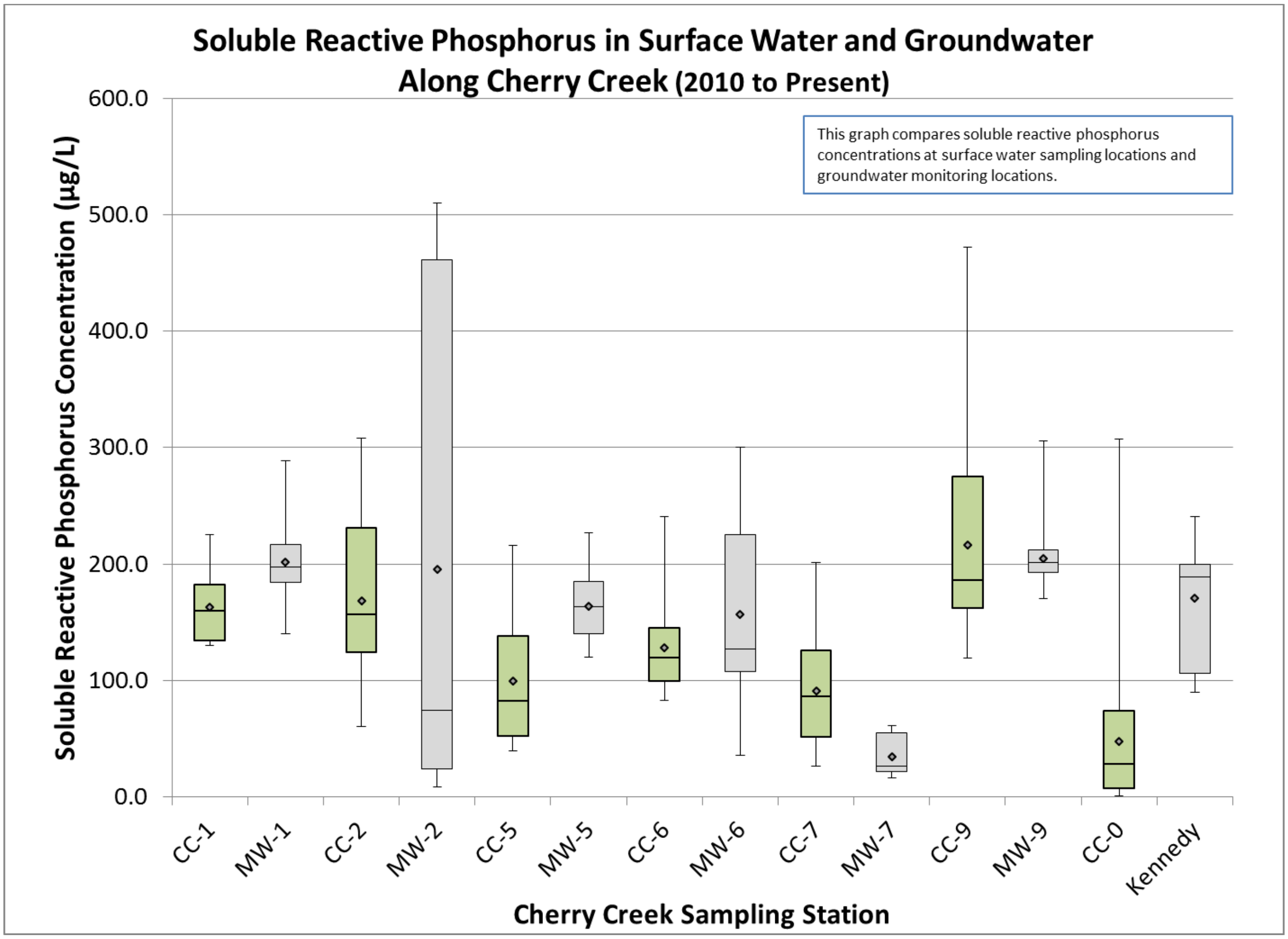



**Figure 27. Soluble Reactive in Surface Water and Groundwater along Cherry Creek (2010 to 2017) (Source of Data: GEI Consultants, Inc. 2010 – February 2016; IEH Analytical, Inc., March 2016 – 2017)**

Over the past 20 years, the concentration of SRP in the alluvial groundwater upstream of the Reservoir appears to have increased, adding to the Reservoir nutrient source pool (Figure 28).

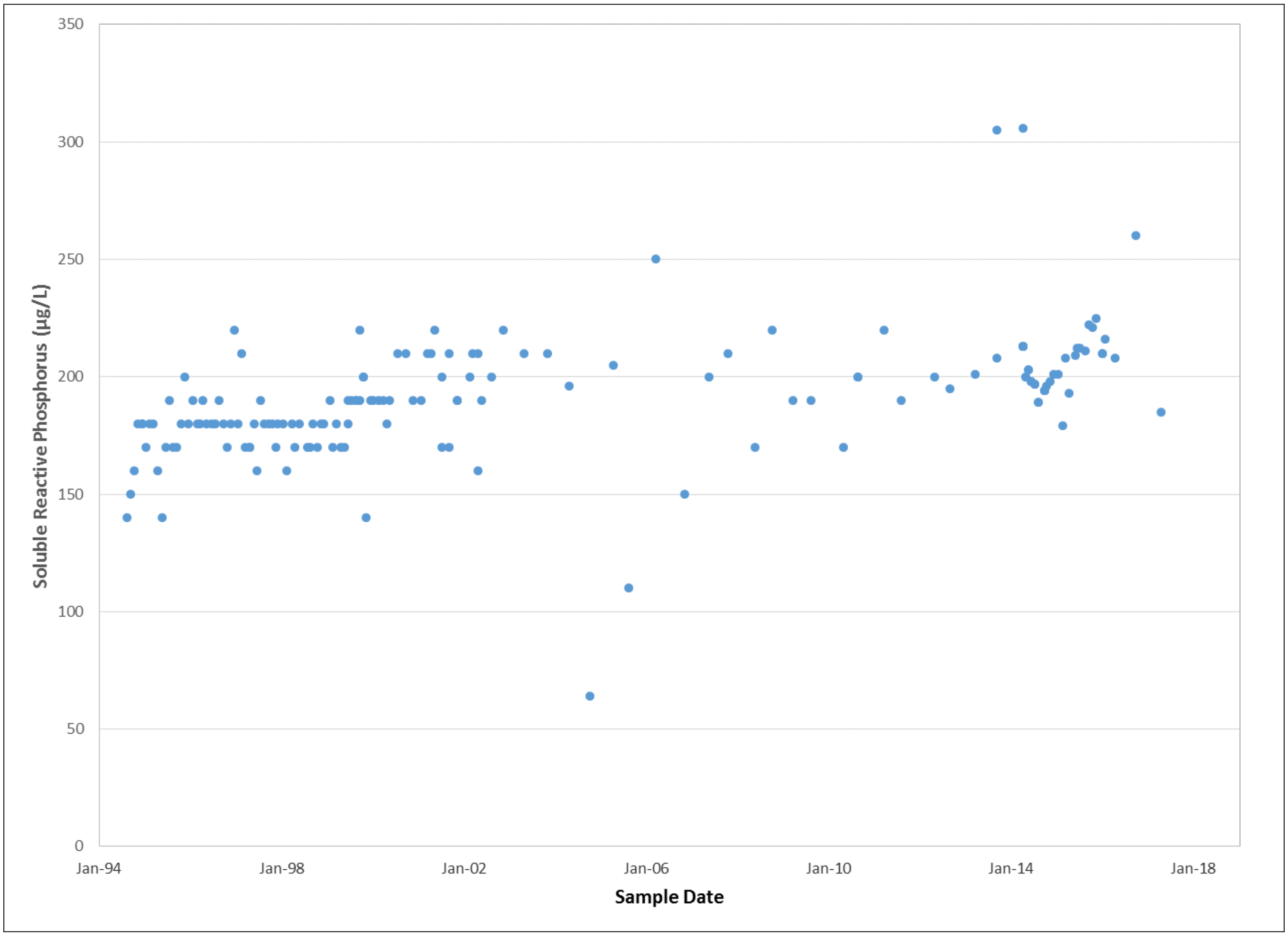



**Figure 28. Historic SRP Concentrations in Alluvial Well MW-9 (1994 – 2017). (Source of Data: GEI Consultants, Inc. 1994 – February 2016; IEH Analytical, Inc., March 2016 – 2017)**

Well MW-9 was sampled and analyzed for the total and dissolved forms of organic carbon (TOC and DOC, respectively) twice during WY2017. The historic TOC and DOC results from MW-9 samples are illustrated in Figure 29.

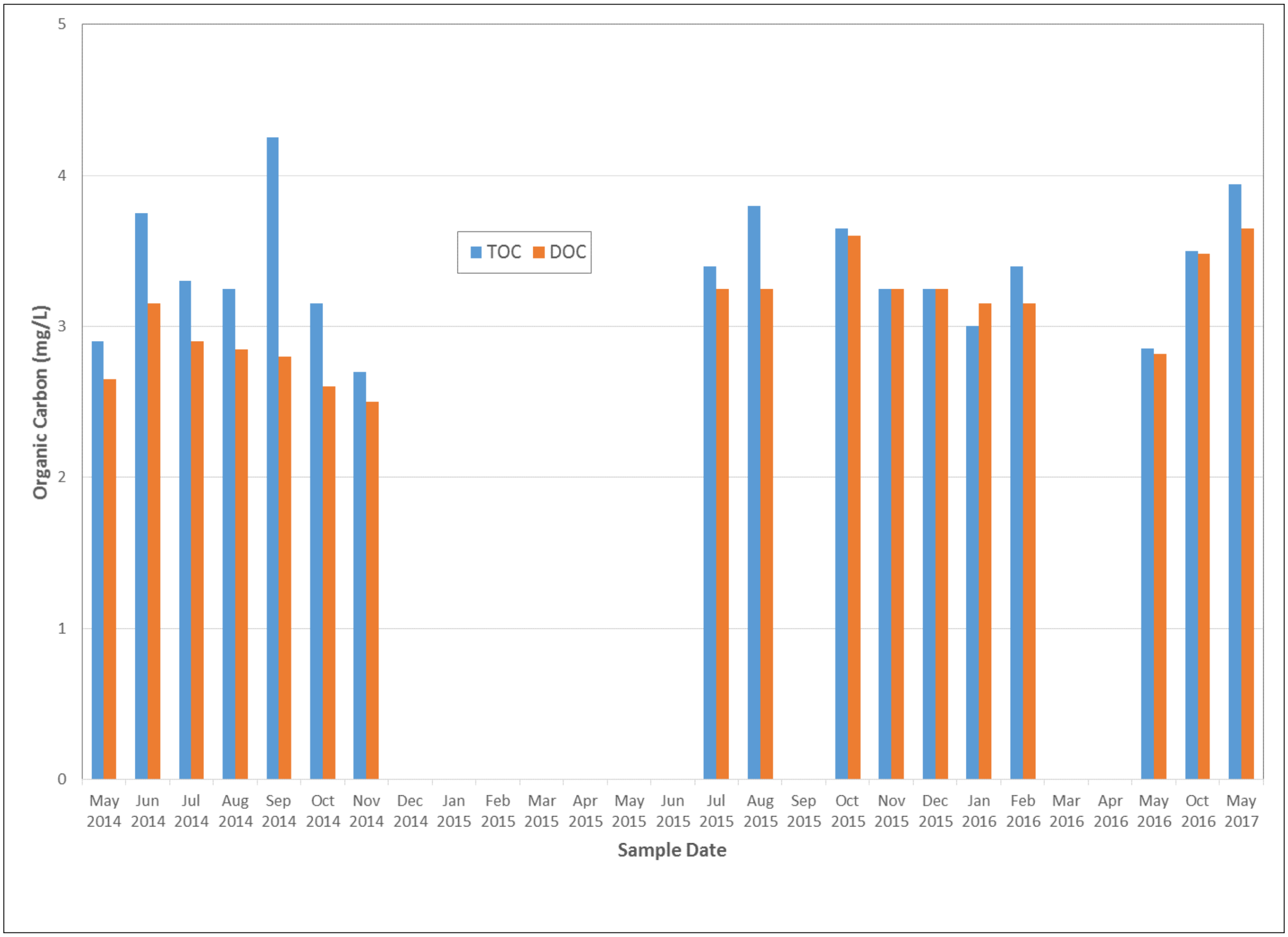


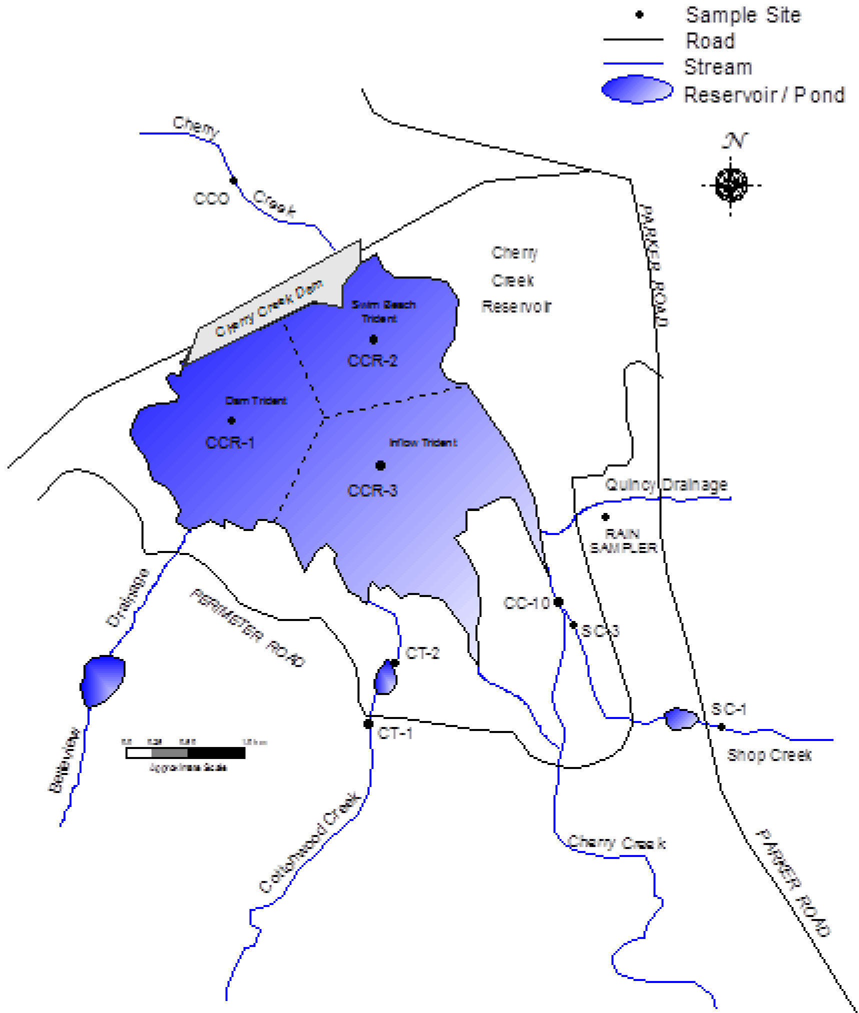

**Figure 29. Total and Dissolved Organic Carbon Data from MW-9, May 2014 – May 2017. (Source of Data: GEI Consultants, Inc. May 2014 – February 2016; IEH Analytical, Inc., March 2016 – May 2017)**

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. The TOC concentrations measured in the two samples collected in WY2017 were both slightly higher than the long-term average.

As illustrated in Figure 29, the dissolved fraction historically comprises between 66 percent and 100 percent of the total organic carbon present in the alluvial groundwater samples collected from well MW-9, with a long-term average of 92 percent.

## 3.2 RESERVOIR

Three Reservoir monitoring stations (general locations depicted on page 40) have focused on data to support regulatory requirements and attaining beneficial uses; aquatic life, recreation and indirect downstream uses, water supply and agriculture. As such, the primary constituents of concern are phosphorus, nitrogen, and chl-*a*. Nutrients, TP and TN, are often the contributing or limiting factor in the growth of algae (Cole 1979; Horne and Goldman 1994; Wetzel 2001; Cooke, et al. 1993). Excessive amounts of these nutrients in aquatic systems often result in algal blooms that create an imbalance in the Reservoir, aesthetic problems, as well as potentially unsuitable conditions for aquatic life. High external nutrient loading from the watershed, coupled with internal phosphorus loading in the Reservoir itself, impact water quality in the Reservoir. Chl-*a*, a regulated indicator of algae, affects aquatic life, fishing, swimming and other recreational uses. Ultimately, lower nutrient concentrations are necessary to greatly reduce algal biomass as measured by chl-*a*.




The phycology data provides an excellent biological indicator of what plankton species are thriving in the Reservoir and helps determine ecological stressors, overall health of the Reservoir, and an understanding of the basis for some water quality issues. Other physical parameters described in this section include transparency, dissolved oxygen, temperature, and pH, all which support protection of aquatic life and recreational uses.

### 3.2.1 Transparency

Secchi disk depth and a LI-COR water sensor provided a measurement of Reservoir water clarity or transparency in WY2017. Transparency is a basic indicator of the health of an aquatic ecosystem and the level of biological productivity.

Figure 30 depicts mean Secchi disk depth in the Reservoir at CCR-2 during WY2016 and WY2017. The average WY2017 Reservoir Secchi disk depth was approximately the same as that in WY2016. The mean Secchi disk depth was as high as 1.2 meters (m) in early-June 2017, representing the highest clarity condition which coincided with:

- Above average precipitation the previous month (Figure 5) and highest Reservoir release rates of the WY2017 (Section 4.1),
- Low phytoplankton cell counts, low algal biomass and the lowest average chl-*a* concentration (7.1 µg/L), and
- The lowest average TP concentration (50 µg/L).

The mid- to late-summer Secchi disk depth measurements represented hypereutrophic conditions and reduced clarity. The greatest chl-*a* and TP concentrations were also measured during this timeframe, but were lower than those observed in WY2016. Secchi disk depth from 1992 to present is depicted in Figure 31. Since the late-1990s, the annual mean Secchi disk depth has fluctuated between approximately 0.75 m to 1.25 m, firmly in the eutrophic zone.

The LI-COR sensor measured light attenuation to determine transparency and the depth at which 1 percent of photosynthetically active radiation penetrated the water column (i.e., photic zone depth). The depth of 1 percent light attenuation ranged from 2.1 to 2.2 m in the late summer to a maximum depth 5 m in early-June. Figure 32 depicts the direct relationship between Secchi disk depth and 1 percent light attenuation ($R^2$=0.72). A stronger relationship is observed with Secchi disk depth up to 1.8 m and 1 percent light attenuation up to 5 m.

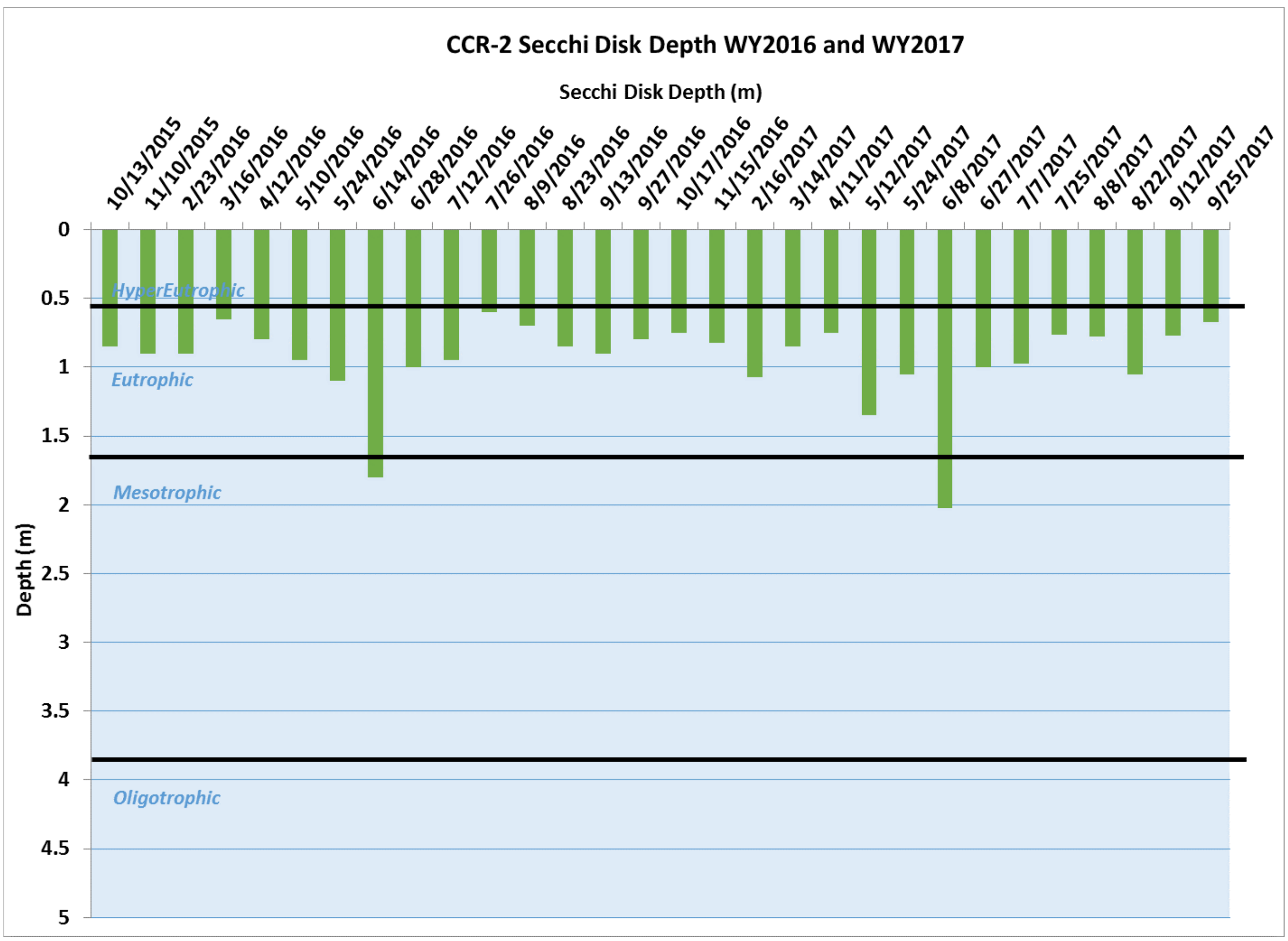



**Figure 30. WY2016 and WY2017 Secchi Disk Depth in Cherry Creek Reservoir, Station CCR-2** (Source of Data: Tetra Tech, Inc., 2016-2017)

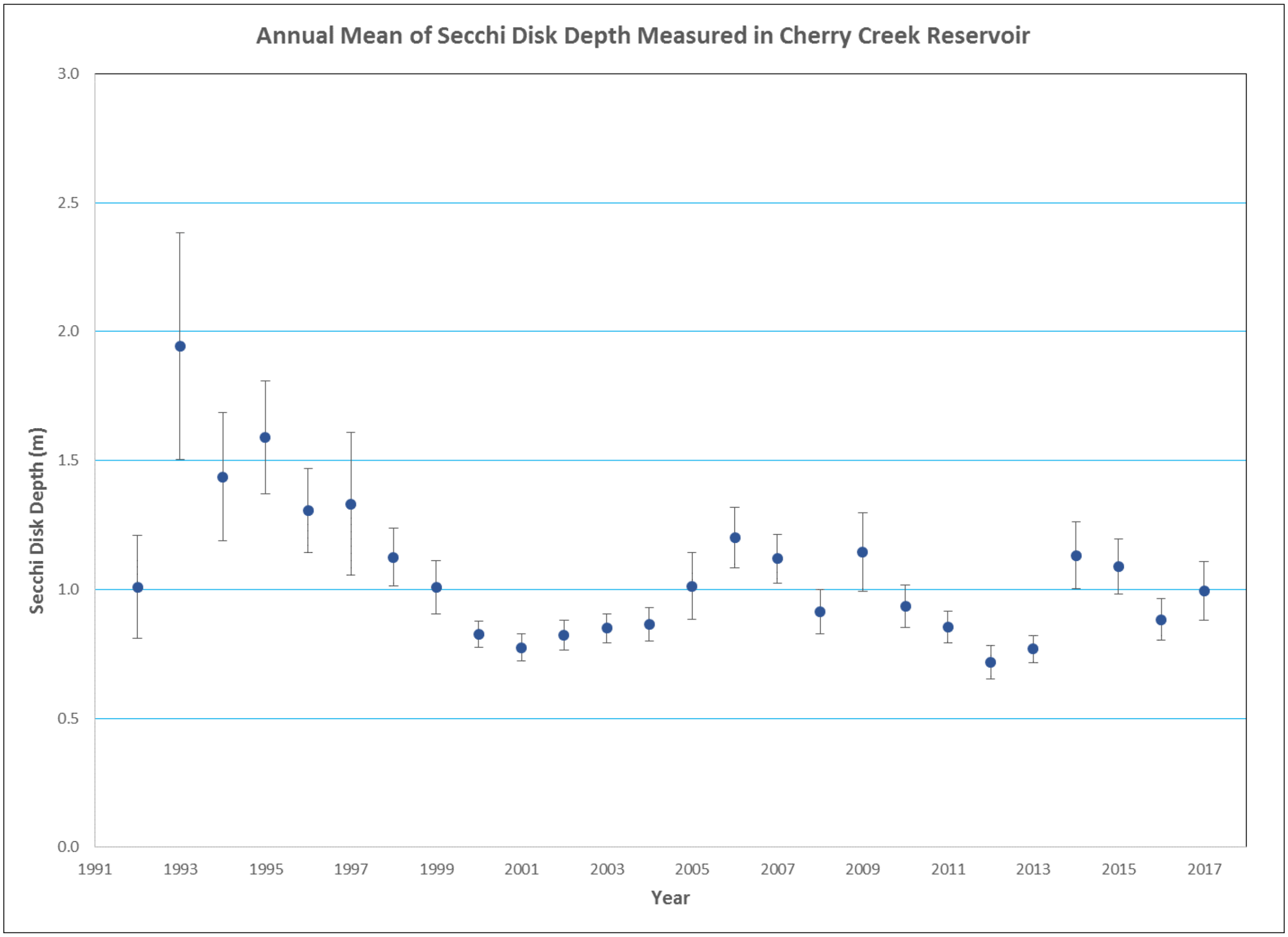



**Figure 31. Annual Mean Secchi Disk Depth Measured in Reservoir, 1992 – 2017.** (Sources of Data: IEH Analytical (2016 - 2017); GEI Consultants (2006 – 2015); Chadwick Ecological Consultants (1995 – 2006); University of Missouri (1992 – 1994).

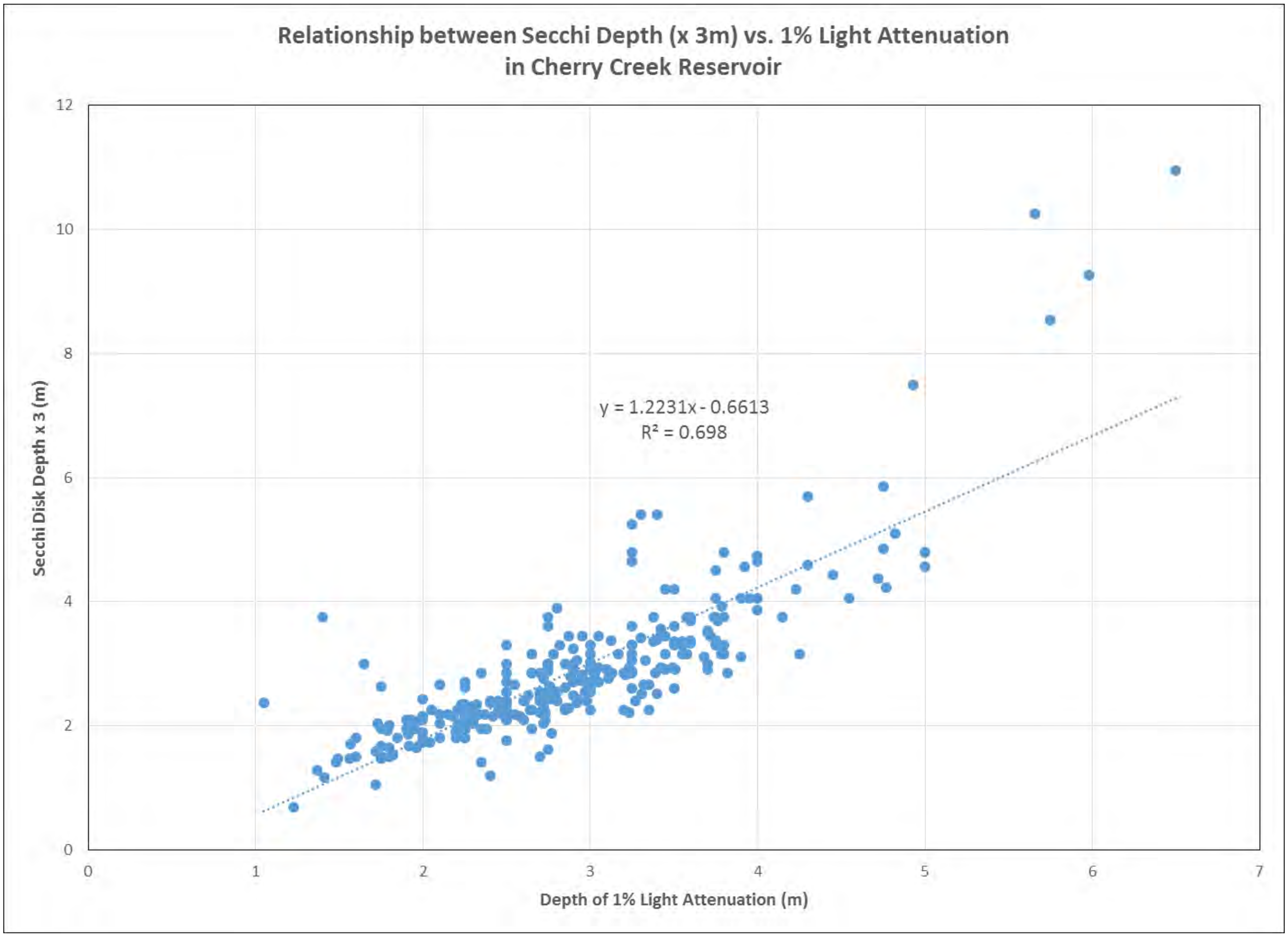



**Figure 32. Historic Relationship between Secchi Disk Depth X 3 (m) and Depth of 1% Light Attenuation in Reservoir (m).** (Sources of Data: Tetra Tech, Inc., 2016-2017; GEI Consultants, Inc., 2000-2015)

## 3.2.2 Total Phosphorus

The WY2017 TP concentrations measured in the photic zone ranged between 45 µg/L and 166 µg/L (Figure 33). The 2017 growing season mean TP concentration was 115 µg/L, slightly lower than the WY2016 value (126 µg/L). The lowest average photic zone TP concentration of 50 µg/L was measured on June 8, 2017. This low value was most likely due to above-average precipitation in May (Figure 5) and increased Reservoir outflow (Section 4.1) effectively flushing some of the algal biomass with organic-P out of the Reservoir, coupled with sedimentation of the algal bloom biomass that transported TP to the Reservoir sediments.

Data collected throughout the growing season indicated an overabundance of TP in the Reservoir, resulting in a eutrophic waterbody that continues to age and even show hypereutrophic tendencies. Therefore, it appears that light and hydraulic residence time (flushing rate) were the limiting factors in controlling phytoplankton productivity in the Reservoir.

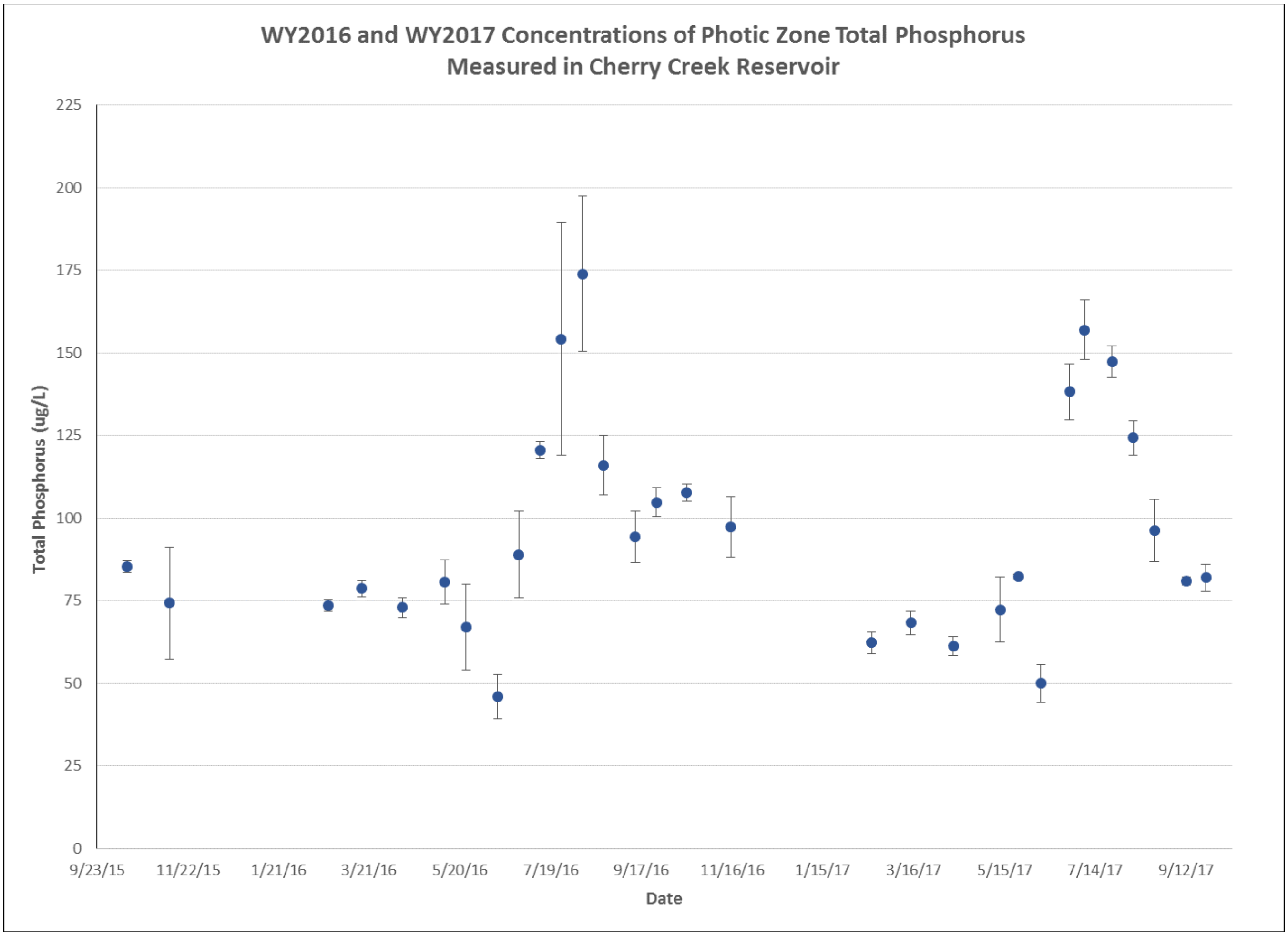



**Figure 33. Total Phosphorus in Cherry Creek Reservoir, WY2016 and WY2017.** (Sources of Data: IEH Analytical (2016 - 2017); GEI Consultants (2006 – 2015); Chadwick Ecological Consultants (1995 – 2006); University of Missouri (1992 – 1994).

An evaluation of seasonal mean TP concentrations (1992 – 2017) in the Reservoir indicates an increasing pattern in the last 30 years (Figure 34).

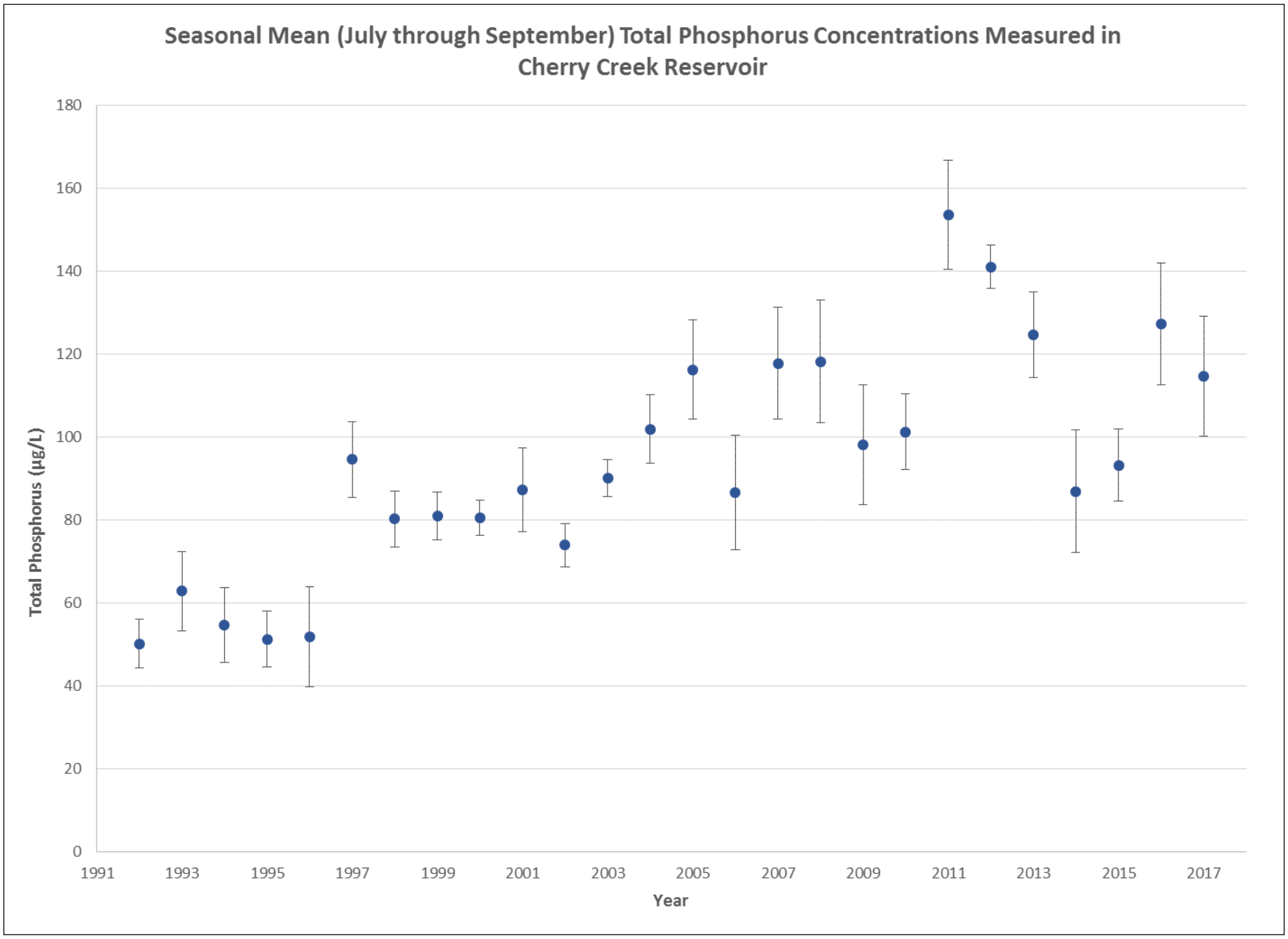



**Figure 34. Seasonal Mean TP Concentrations in Cherry Creek Reservoir, 1992 – 2017.** (Sources of Data: IEH Analytical (2016 -2017); GEI Consultants (2006 – 2015); Chadwick Ecological Consultants (1995 – 2006); University of Missouri (1992 – 1994).

TP profiles at Reservoir monitoring station CCR-2 in WY2017 at depths 1.5 meters to 7 meters are depicted in Figure 35. Internal TP loading was observed and more prevalent during the summer. As shown, the TP concentration at 7 m was measured above 200 µg/L on June 8, 2017 and again on July 7, 2017. The internal nutrient release of phosphorus from bottom sediments occurred when the bottom of the Reservoir becomes anoxic (very low DO concentrations) as discussed in Section 3.2.9. The sediment phosphorus load accumulates over time from external sources, including from the Reservoir, and is geochemically transformed and released when the sediment surface becomes anoxic (Nürnberg and LaZerte, 2008). This internal release of phosphorus facilitates the growth of all algae; increasing the seasonal mean chl-*a* concentrations and the production of cyanobacteria (blue green algae). Throughout July, DO concentrations at depths greater than 6 m were generally less than the upper threshold that facilitates internal loading (2 mg/L) and created an anoxic environment near the water/sediment boundary (see Figure 43) which resulted in elevated phosphorus concentrations at depth (Figure 34). Phosphorus can be released at rates as much as 1,000 times faster during anoxic conditions than during well oxygenated conditions (Horne and Goldman, 1994). Although the rate of exchange of nutrients (mainly phosphorus) at the water/sediment interface remains unknown for the Reservoir, this internal nutrient loading component of the Reservoir has been estimated to account for approximately 25 percent of the cumulative TP load from 1992 to 2006 (Nürnberg and LaZerte, 2008).

However, the total amount of TP loading to the Reservoir is not the only factor that was important in WY2017, the timing of the load and bioavailability of TP was also critical. Given Cherry Creek Reservoir is a polymictic reservoir[1] (Section 3.2.7) and the rapid influx of TP and SRP (Figures 35 and 36) during periods of robust biological activity (shown by pH and DO changes) (Sections 3.2.8 and 3.2.9), internal cycling of P within the Reservoir is one of the foremost drivers enabling excessive phytoplanktonic productivity. The WY2017 data illustrated in Figure 35 indicate that overall levels of phosphorus in the Reservoir were very high, given the eutrophic-hypereutrophic boundary for TP is 100 µg/L and the eutrophic boundary starts at 25 µg/L (Nürnberg, 1996).

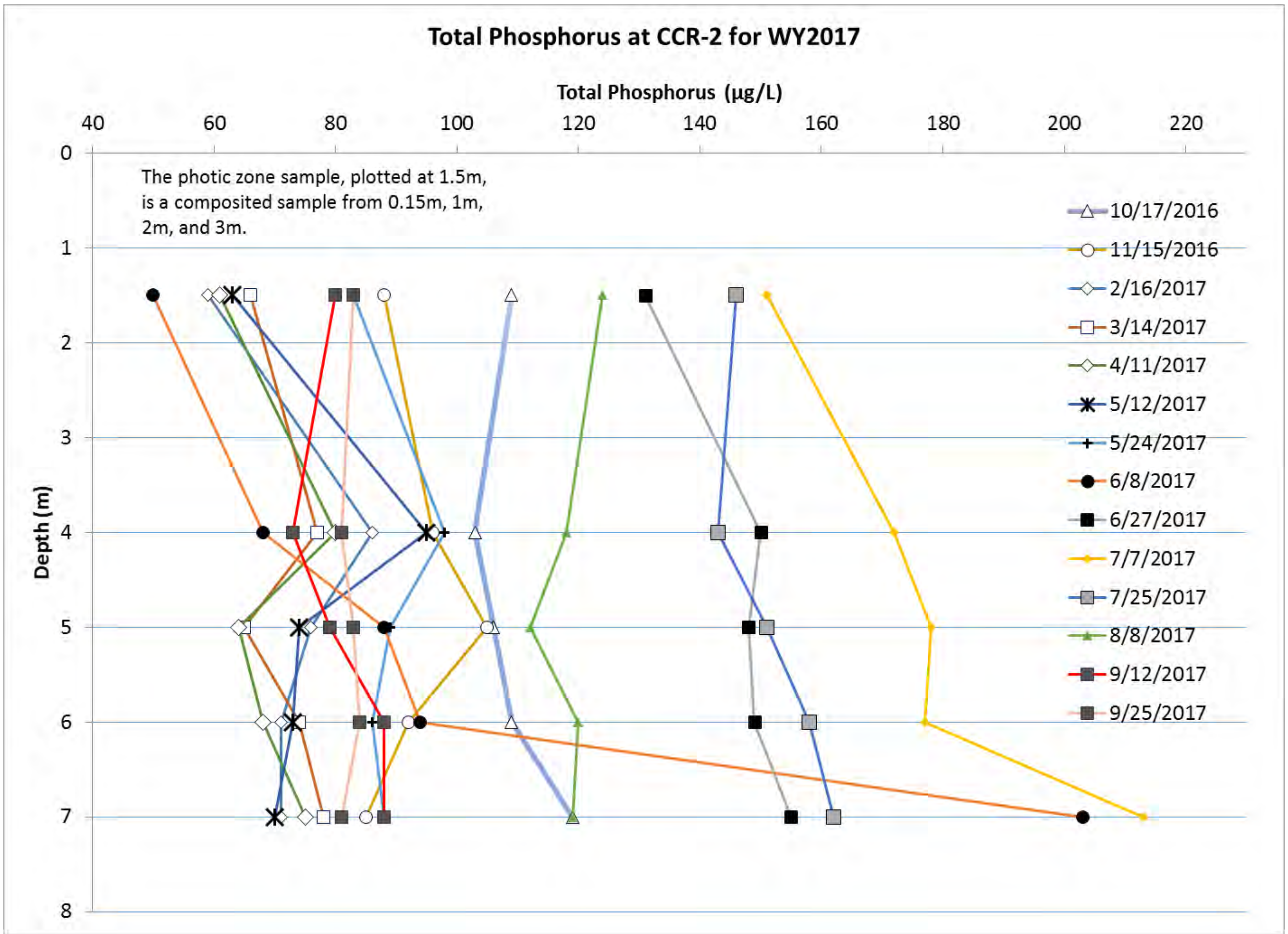



**Figure 35. WY2017 TP at Monitoring Station CCR-2** (1.5 – 7 meter depth profiles).

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[1] Polymictic reservoirs and lakes are too shallow to develop strong thermal stratification. Consequently, their waters tend to mix from top to bottom, many times through the ice-free period.

### 3.2.3 Soluble Reactive Phosphorus

Soluble reactive phosphorus (SRP) represents the bioavailable form of phosphorus. Figure 36 depicts SRP data collected at Reservoir monitoring station CCR-2 during profile sampling in WY2017. As shown, the Reservoir was well-mixed in October 2016 through April 2017. During June through early-August, elevated bioavailable phosphorus, up to 137 µg/L, were observed at depths below 6 meters, indicating an extended period of nutrient release from bottom sediments. The period of observed heightened nutrients near the Reservoir bottom suggest that even a few centimeters of anoxic water at the water/sediment interface, which the Sonde monitoring device may not have captured, is sufficient for creating a reducing environment and internal load release of nutrients (GEI, 2015). There may also be significant aerobic and anaerobic mineralization of organic-P to SRP with the decay of phytoplankton that has settled to the bottom. The elevated SRP at these depths show a rapid and dramatic spike in concentration of SRP at deeper reservoir depth, confirming soluble phosphorus was released from sediments during this time. This also indicates that phosphorus recycling is occurring within the reservoir at a rapid rate and through multifaceted processes due to the history of nutrient retention within the Reservoir over the past several decades.

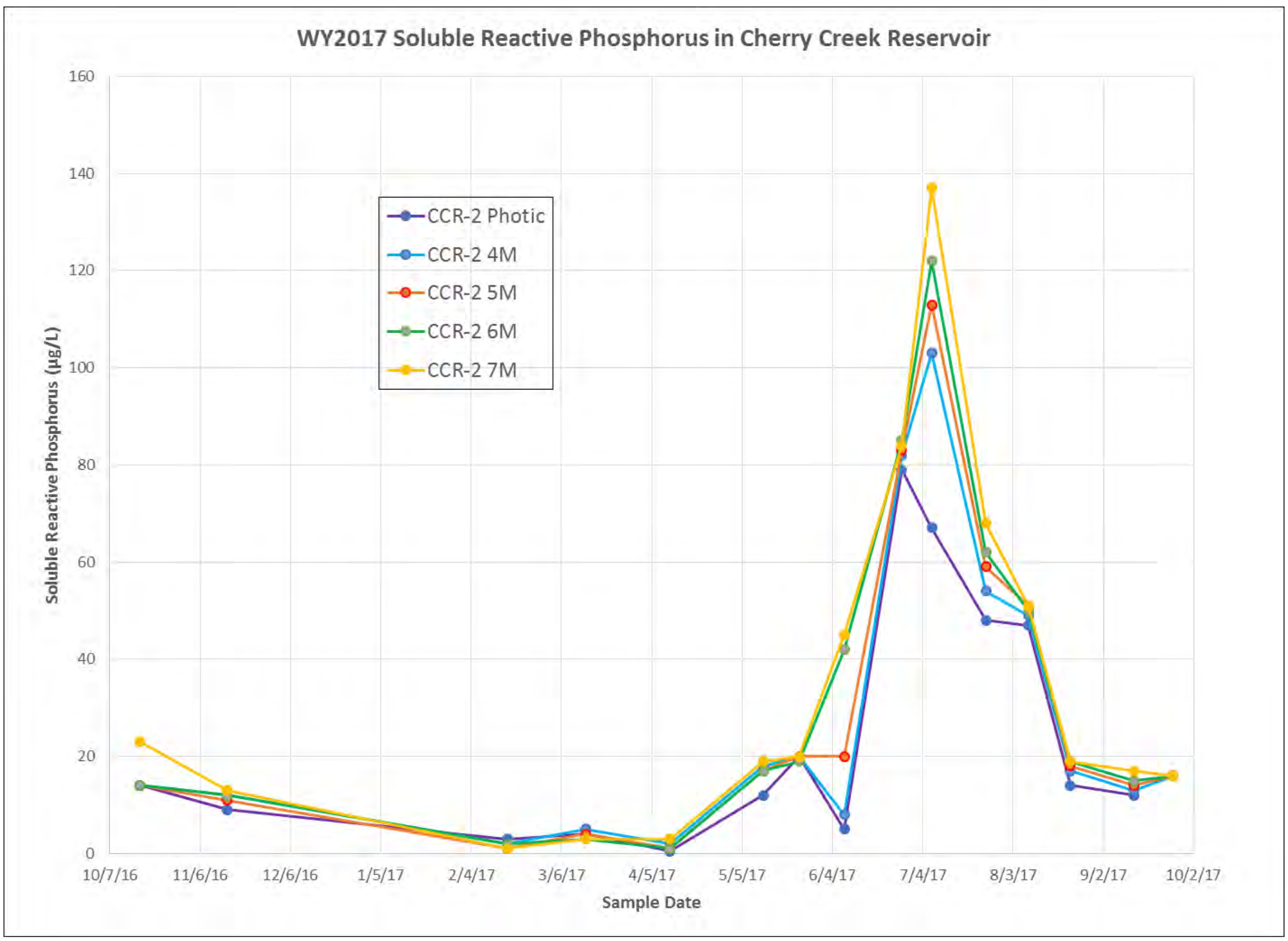



**Figure 36. SRP Variability in Reservoir at CCR-2), WY2017.** (Source of Data: IEH Analytical, Inc.)

## 3.2.4 Total Nitrogen

The July – September WY2017 seasonal mean TN in the Reservoir was 761 µg/L, well below the WY 2016 value (910 µg/L). The long-term average from 1992 – 2017 is 931 µg/L and no discernible increasing or decreasing trend was identified with the TN data (Figure 37).

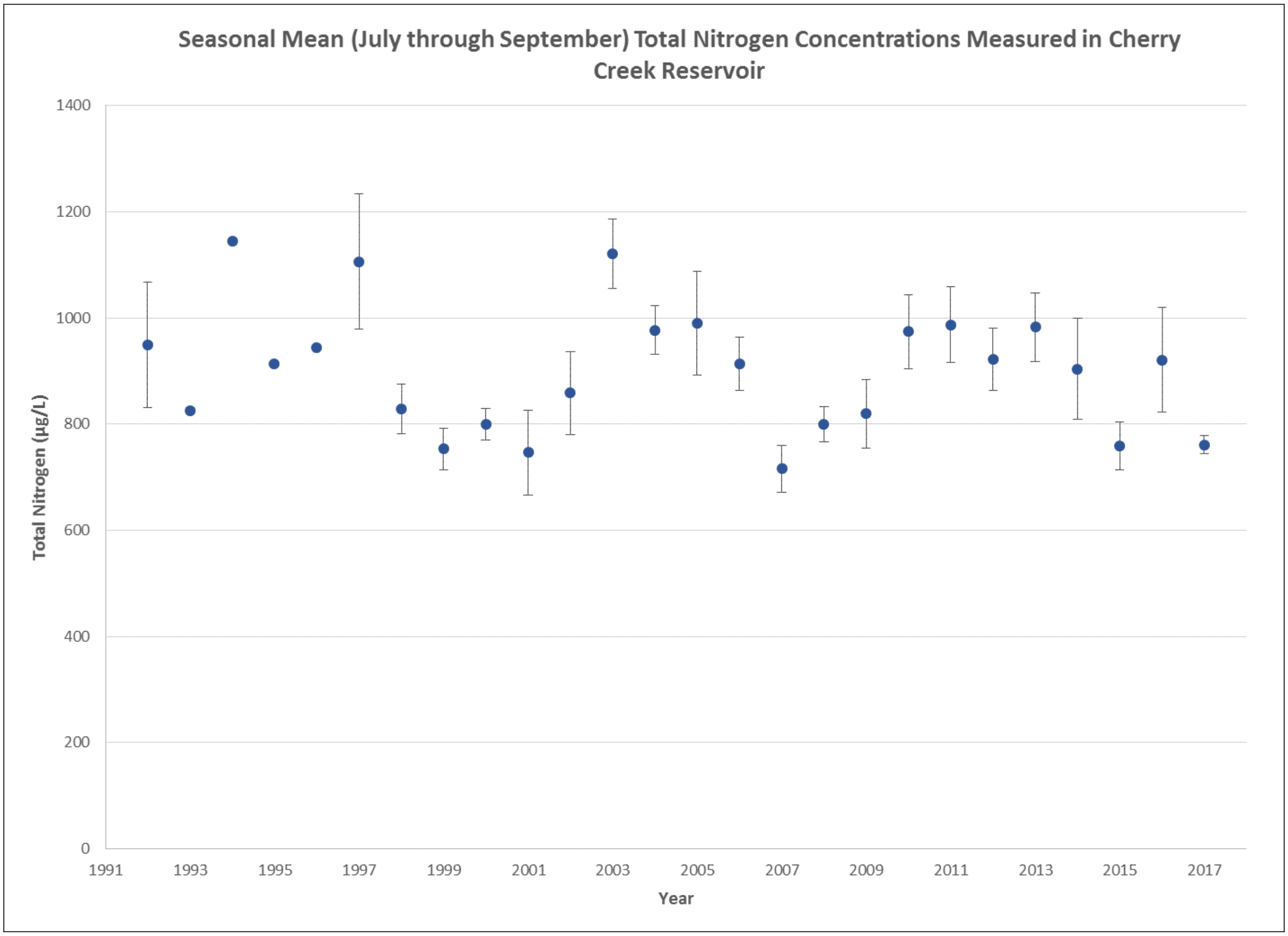



**Figure 37. TN Measured in Cherry Creek Reservoir, 1992 – 2017.** (Source of Data: IEH Analytical, Inc.)

## 3.2.5 Total Inorganic Nitrogen (TIN)

TIN is calculated as the sum of nitrate-nitrite as N and ammonia as N. Similar to SRP, TIN was elevated at depth, specifically during the July timeframe, suggesting the presence of internal nitrogen loading (Figure 38).

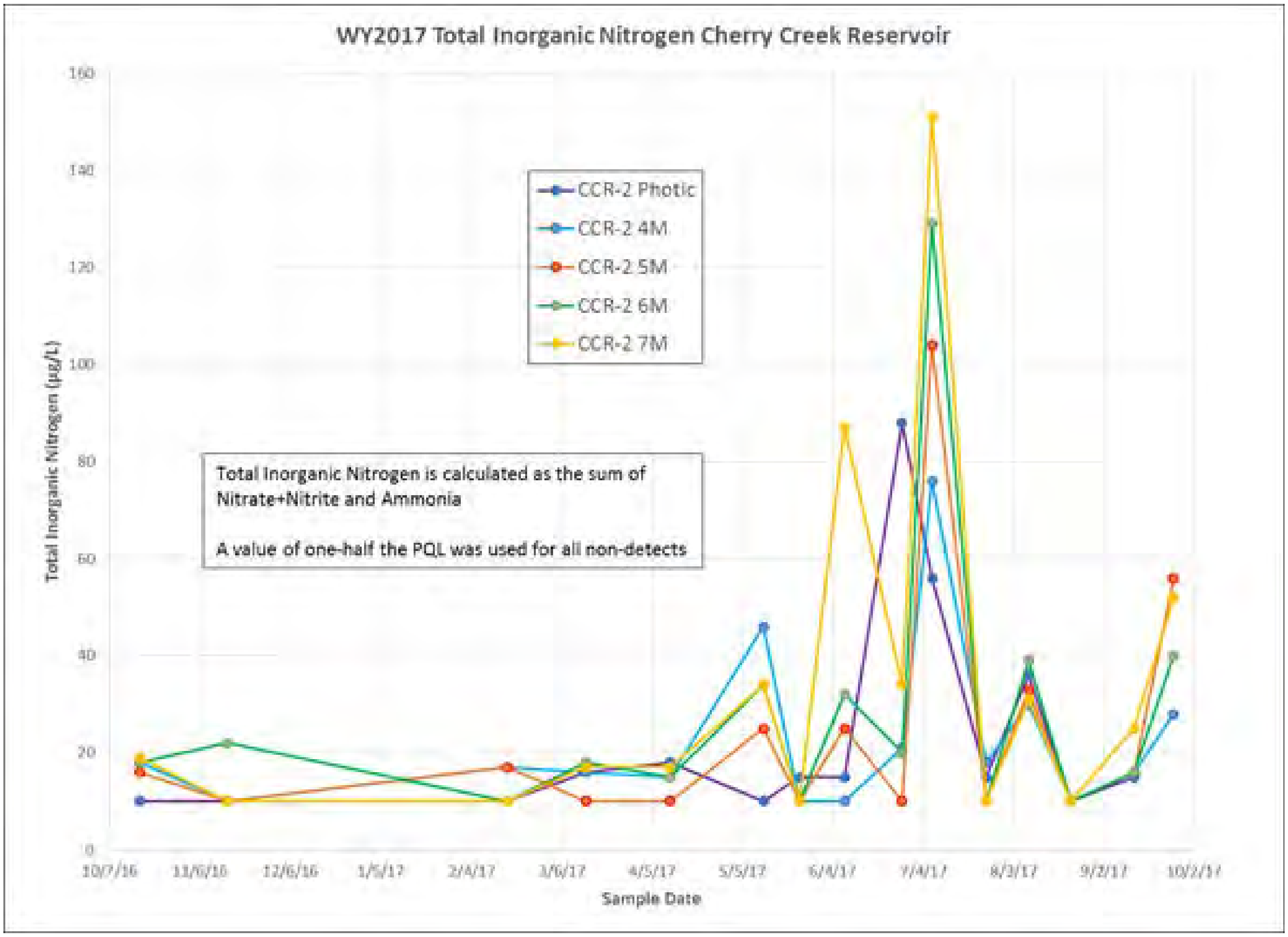



**Figure 38. Total inorganic nitrogen (TIN) Concentrations at CCR-2, Photic Zone – 7 meters.** (Source of Data: IEH Analytical, Inc.)

Figure 39 depicts nitrate-N and ammonium-N separately in the Reservoir at 3-7 meters to determine whether it was decay of organics through aerobic or anaerobic processes that contributed to the N availability. This graphical analysis also serves to support our understanding of N utilization and the potential for N limitation for what algal group and, if so, the timing of this limitation. Of particular note is that cyanobacteria (blue-green algae) can use both ammonium and nitrate and fix atmospheric N to use it directly, while chlorophyta (green algae) and most diatoms require nitrate. Also, blue-greens can be a producer of ammonium. As shown in Figure 39, the highest ammonium concentration coincided with the lowest DO in the bottom water (7m) at CCR-2 (see Figure 45). This indicates sediment degradation with the release of ammonium that cyanobacteria could utilize.

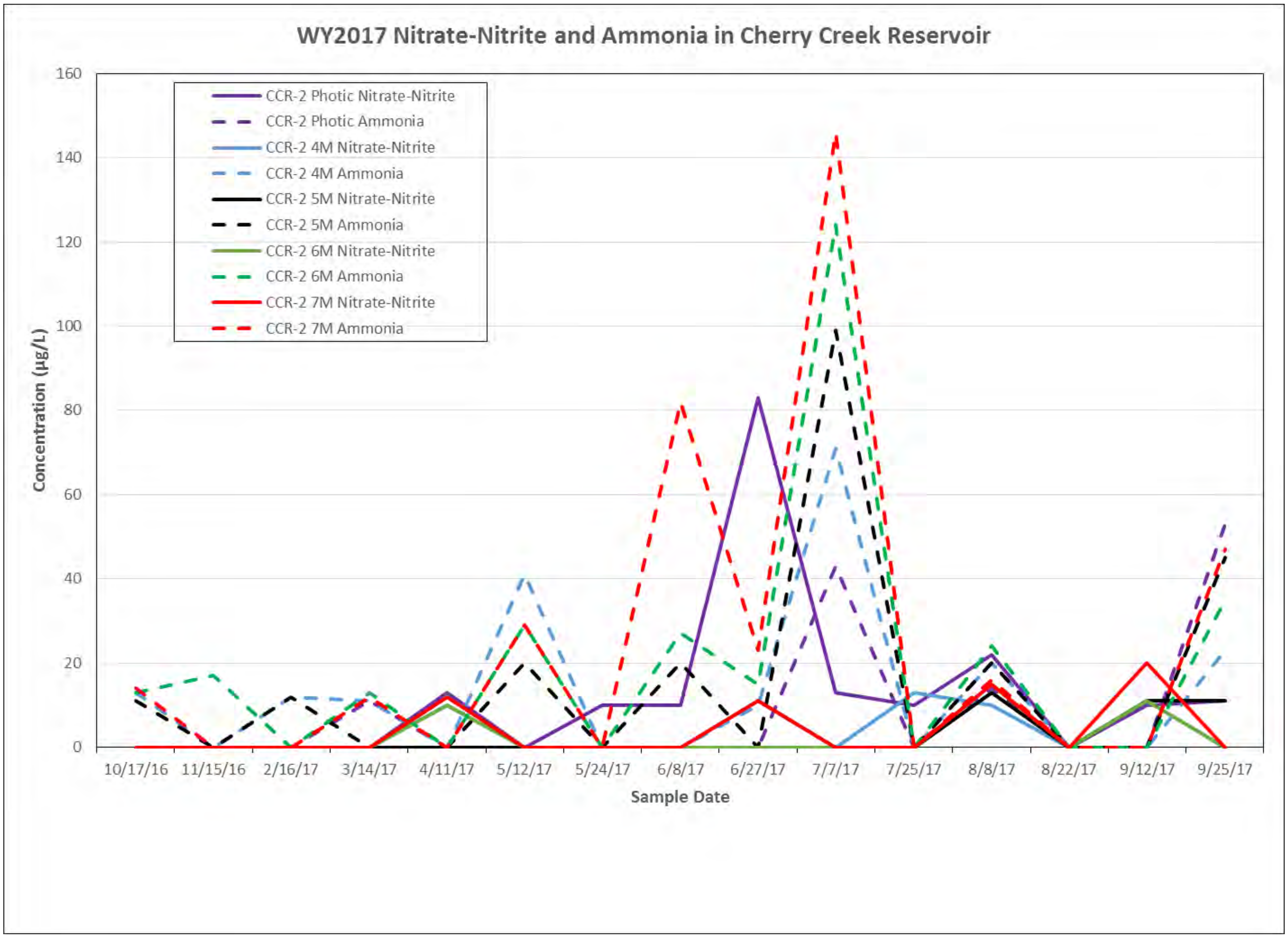



**Figure 39. Nitrate-nitrite and ammonia concentrations at CCR-2, Photic Zone – 7 meters.**

## 3.2.6 Chl-*a*

The WY2017 chl-*a* growing season (July through September) concentration was 18.8 µg/L, lower than the WY 2016 value (23.6 µg/L), but still in exceedance of the 18 µg/L growing season average regulated for chl-*a* (Figure 40). The seasonal mean concentration is measured in the photic zone, with an allowable exceedance frequency of once in five years.

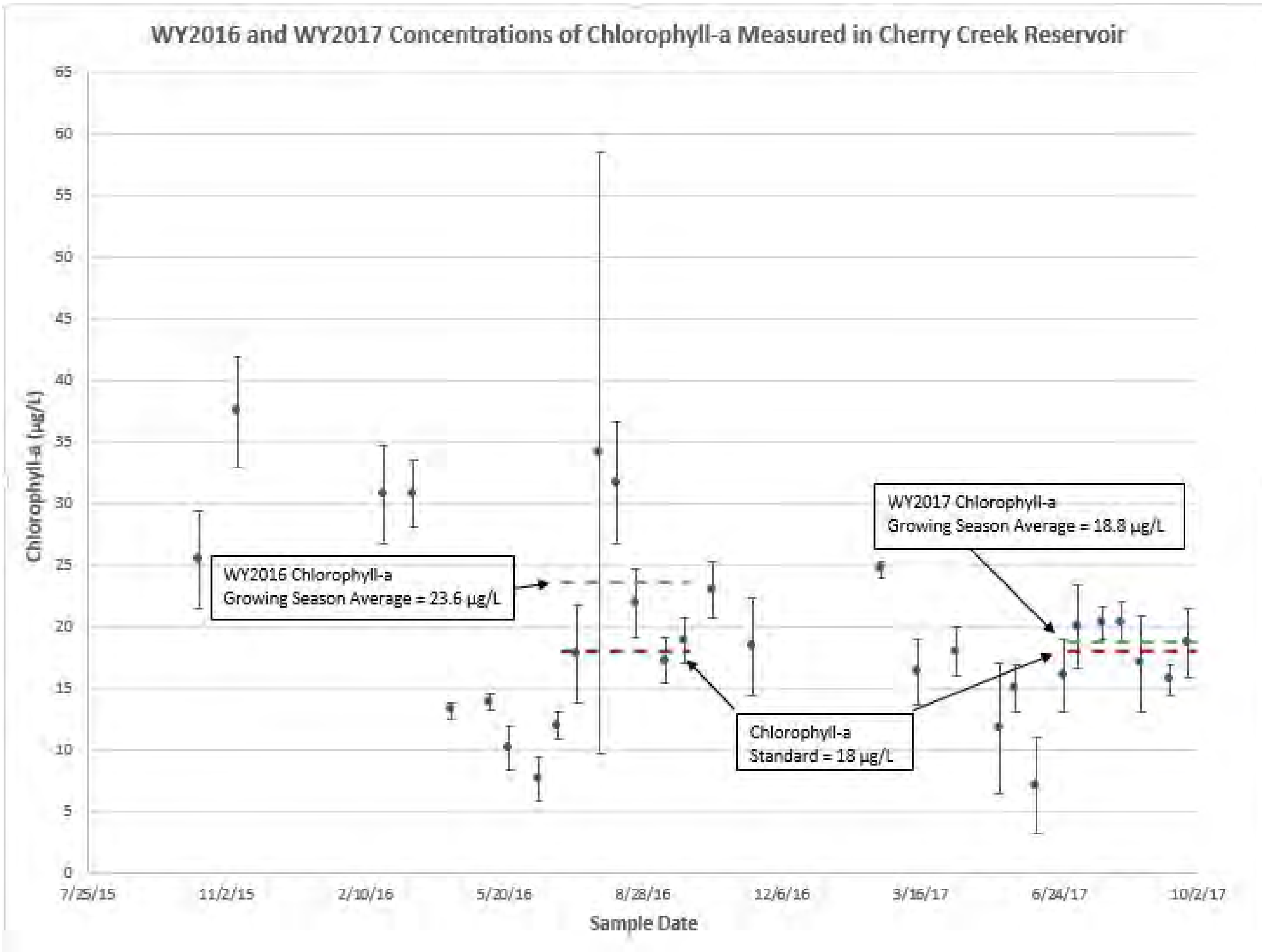



**Figure 40. WY2017 Chl-*a*, Growing Season Average, was 18.8 µg/L, in exceedance of the 18 µg/L standard.** (Source of Data: IEH Analytical, Inc.)

The Reservoir has exceeded the chl-*a* standard in four of the last five years (Figure 41). The Reservoir is in a eutrophic-hypereutrophic state as defined by chl-*a* concentrations of >9 µg/L (eutrophic) and > 25 µg/L (hypereutrophic) and total phosphorus concentrations >25 µg/L (eutrophic) to >100 µg/L (hypereutrophic) (Nürnberg, 1996).

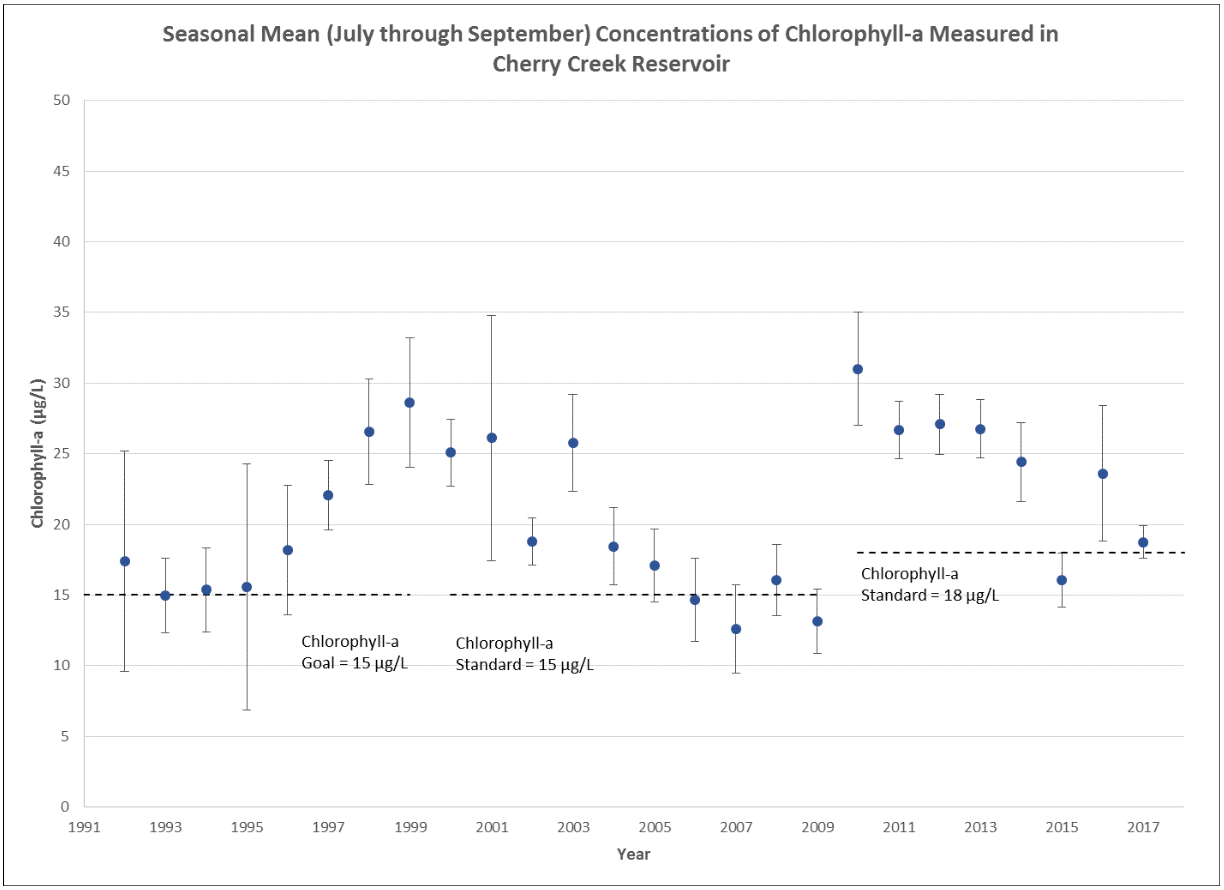



**Figure 41. Seasonal Means of Chl-*a* in Reservoir, 1992 – 2017.**

External phosphorus loading from the watershed, coupled with internal phosphorus loading in the Reservoir, were high enough to result in the generation of excess algal production and chl-*a* levels above the standard in WY2017. The likely control factors for low versus high production summers appear to include internal mixing, flushing rate, and light limitation during the growing season. However, these factors are not really controllable or predictable and the Reservoir is becoming more productive as time goes on due to the natural progression of man-made lakes, elevated nutrient concentrations observed within the watershed, and recycled nutrients in the Reservoir sediments that are 2-100 times that of the flushing rate under current conditions in the Reservoir.

## 3.2.7 Temperature

Figure 42 depicts the temperature variability (in degrees Celsius) at Reservoir station CCR-2. The Reservoir met the temperature standards established for the Reservoir, protective of the warm water fishery (WQCC Regulation No. 31, effective January 31, 2018) including the April–December temperature standards of 26.2 ºC (chronic) and 29.3 ºC (acute) and January–March temperature standards of 13.1 ºC (chronic) and 24.1 ºC (acute). As observed in polymictic lakes, the Reservoir was mixed relative to temperature, with very little vertical thermal stratification (thermal resistance to mixing).

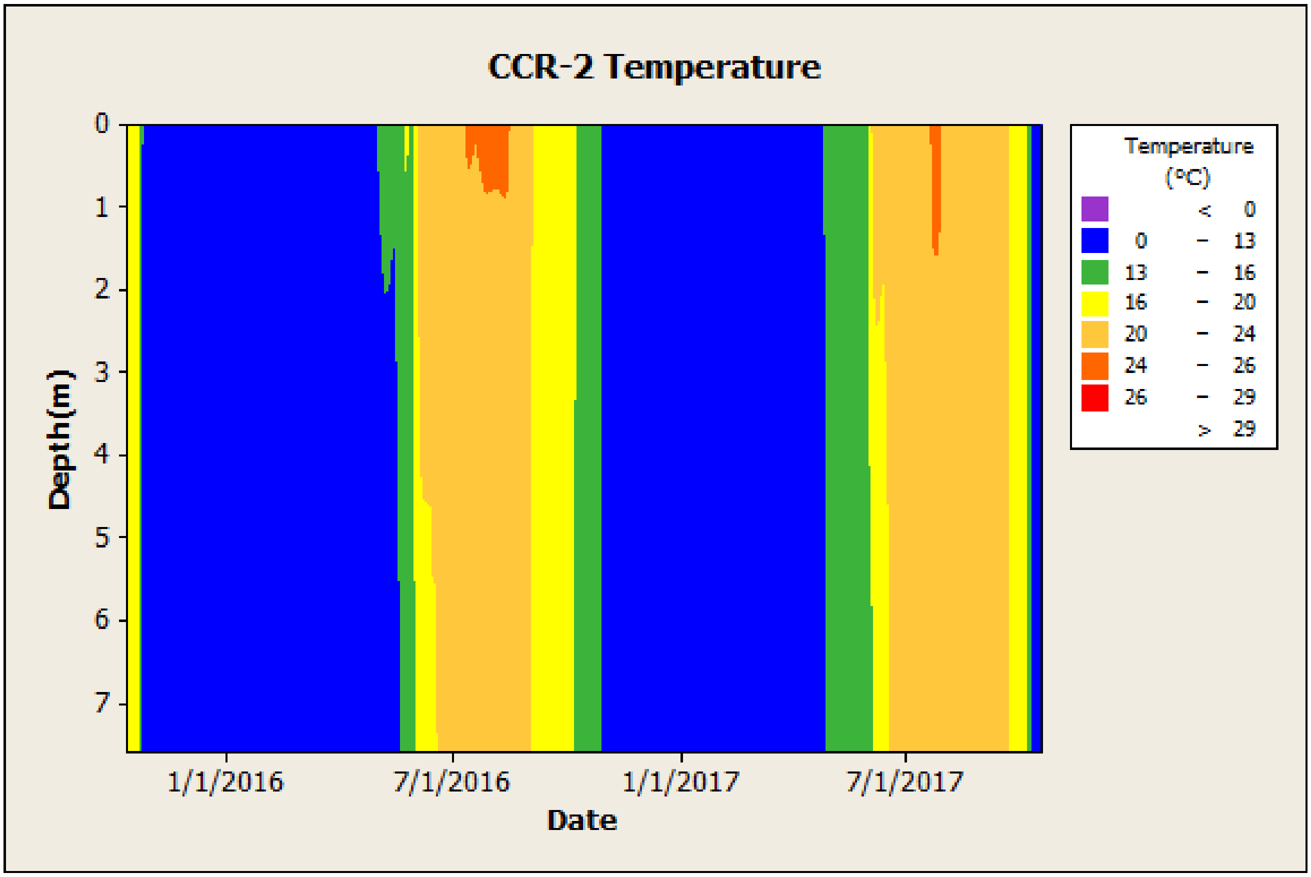



**Figure 42. WY2016 and WY2017 Temperature Profile in Cherry Creek Reservoir, Station CCR-2.** (Source of Data: Tetra Tech, Inc.)

## 3.2.8 pH

The WY2017 pH in the Reservoir ranged from 7.0 to 8.6 (Figure 43). The higher pH observed during April through July and, to a slightly lesser extent, in October 2016, was a direct result of photosynthetic production within the Reservoir. Given the historically higher reservoir releases during WY2017 (section 4.1) that flushed some of the biomass, there was likely less chlorophyll buildup in the Reservoir than there was potential for, given the elevated nutrient levels.

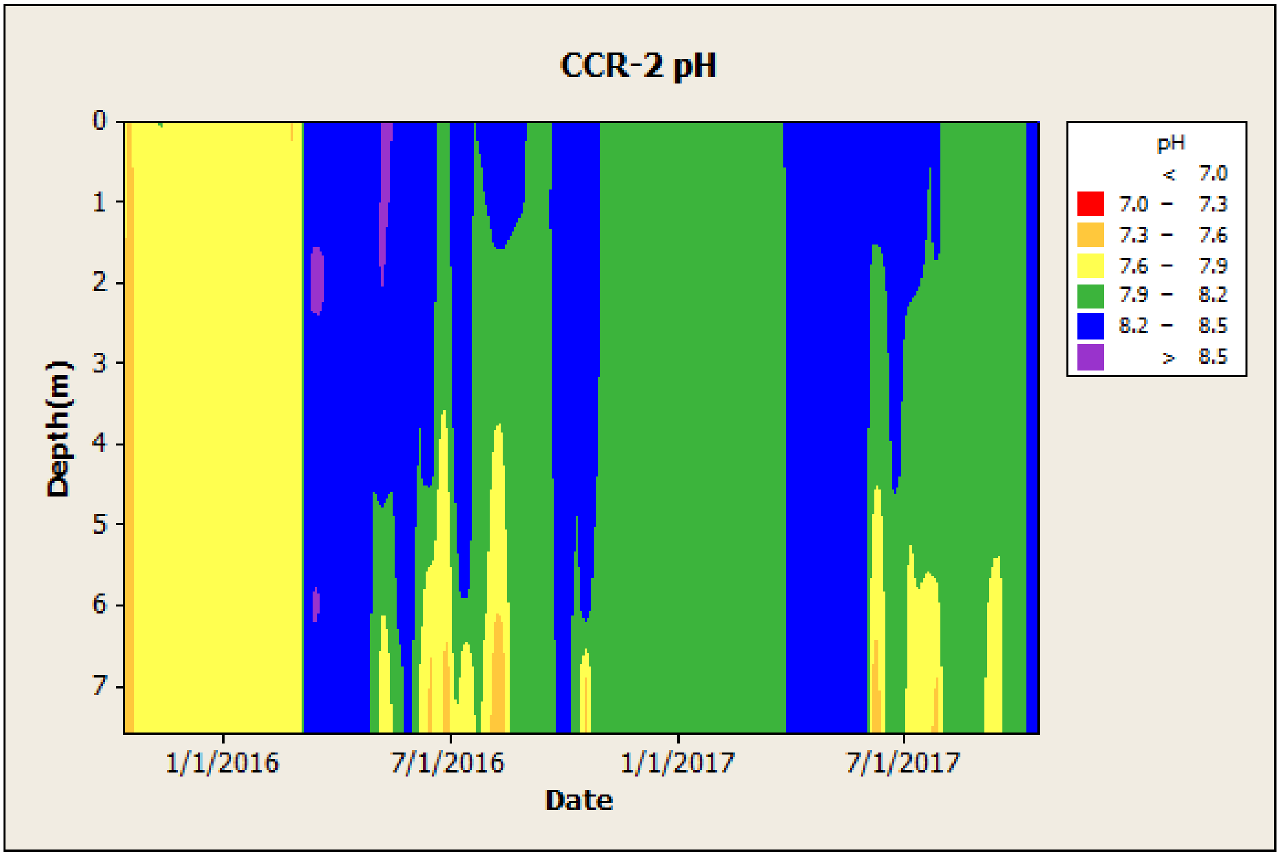



**Figure 43. WY2016 and WY2017 pH Profile in Cherry Creek Reservoir, Station CCR-2 67).** (Source of Data: Tetra Tech, Inc.)

## 3.2.9 Dissolved Oxygen

The DO standard for Cherry Creek Reservoir is 5 mg/L near the surface 0.5m – 2.0m (WQCD 303(d) Listing Methodology, March 2017). The Reservoir was not in compliance with the DO standard. An average value of 4.62 mg/L was observed in the Reservoir's 0.5m - 2.0m profile on August 8, 2017 at monitoring station CCR-1. Other station DO vertical profiles, at CCR-2 and CCR-3, were in attainment of the DO standard. Average upper layer oxygen levels at CCR-2 and CCR-3 were 5.08 mg/L and 5.32 mg/L, respectively, on the same day. Detailed DO data is available on the Cherry Creek Data Portal and Appendix F. Figure 44 depicts DO concentrations at depths 0 – 7 m at CCR-2. The lower DO levels measured at depths from 6-7 m, less than 2.5 mg/L, were a result of the sediment oxygen demand that creates an anoxic layer and promotes internal phosphorus loading. This internal loading occurred even though the water column was thermally mixed most of the time.

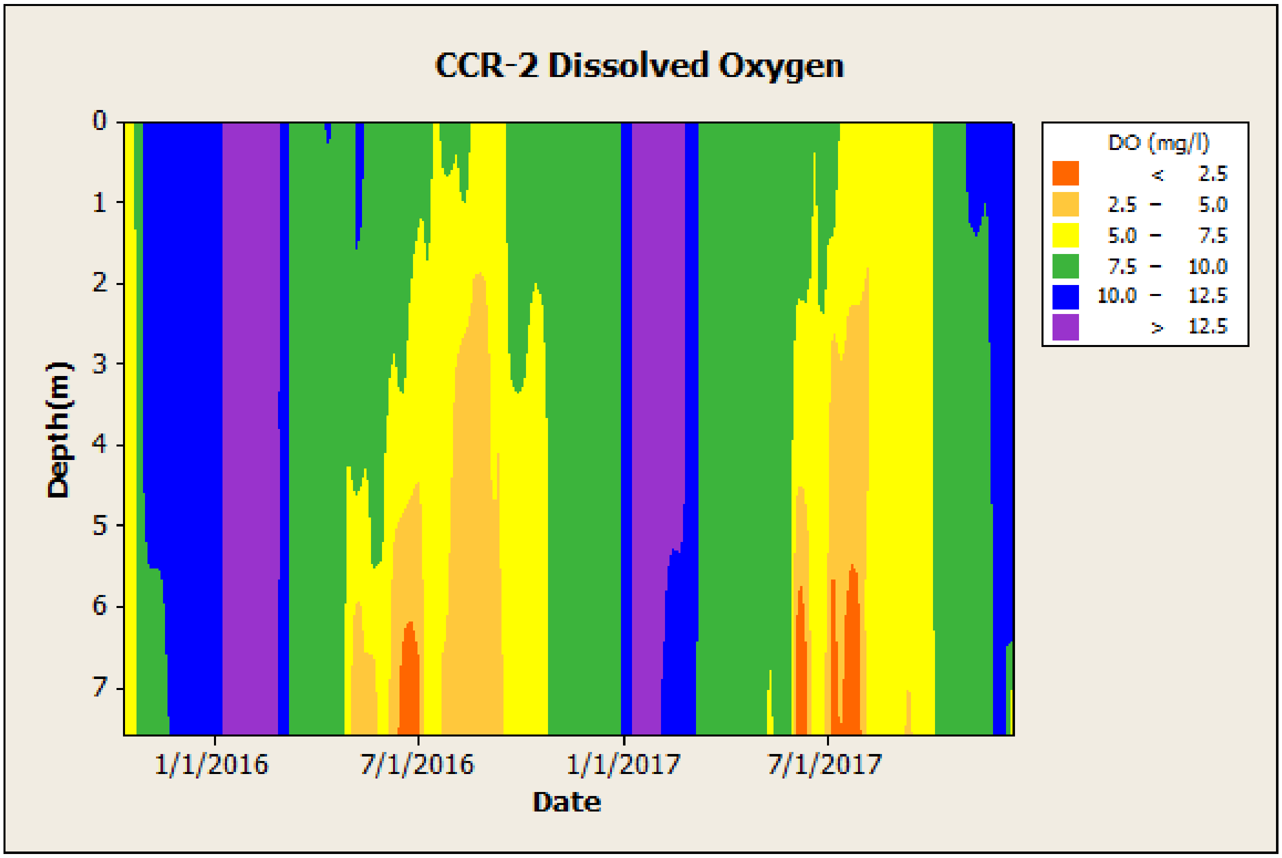


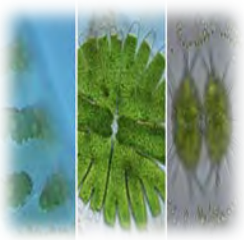
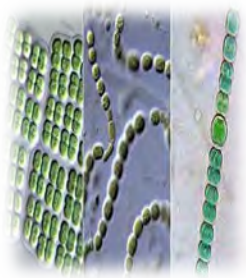

**Figure 44. WY2016 and WY2017 DO Profile at Cherry Creek Reservoir Monitoring Station CCR-2.** (Source of Data: Tetra Tech, Inc.)

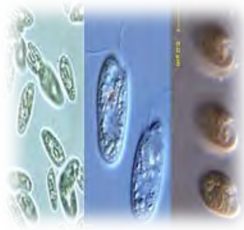
## 3.2.10 Reservoir Phycology

The primary plankton taxa observed in the Reservoir during WY2017 and their significance as an ecological stressor or benefit to the aquatic community is summarized in Table 10. The phytoplankton and zooplankton data indicates nutrient rich Reservoir conditions observed in WY2017. Cherry Creek Reservoir continues to exhibit characteristics of an over-productive, nutrient rich Reservoir.

**Phytoplankton.** The phytoplankton taxa included an abundance of Chlorophyta (green algae), Cyanophyta (cyanobacteria), and Bacillariophyta (diatoms, a great source of food for zooplankton) (Figure 45). The algal abundance (measured as cell counts/mL) for Cyanobacteria (photosynthetic bacteria, “blue green algae”) and Chlorophyta were generally in excess of eutrophic levels, >1,000 algal cells/mL for each group and often in excess of 10,000 cells/mL (Chlorophyta) and 100,000 cells/ML (Cyanophyta). The green algae and diatom community were dominated by species that are indicative of over-enriched conditions and some are not utilized as efficiently as other species as a base of the food web. Also, the densities observed contributed to increased oxygen demand and other poor water quality conditions such as increasing phosphorus recycling and chlorophyll concentrations. Cyanobacteria do not directly contribute greatly to the food web and caused water quality issues such as turbidity, dissolved oxygen depletion, nutrient generation, and elevated chl-*a* concentrations.

**Table 10. Summary of Primary Plankton Taxa Observed, Ecological Benefits and Stressors**

| Phytoplankton or Zooplankton Taxonomic Division and Common Name | Picture *(Photos courtesy of PhycoTech, Inc. and NOAA)* | Period of Occurrence | Ecological Benefits for Reservoir | Ecological Stressors for Reservoir | Abundance (Yes/No) |
|---|---|---|---|---|---|
| Phytoplankton Chlorophyta "Green algae" |  | During periods of high nutrient concentrations; indicates both nitrogen and phosphorus are in excess supply. Higher ratio of desmids to other greens is indication of nitrogen abundance. | Small colonial and single celled greens are a good food source for zooplankton. | Sometimes filamentous green algae and large colonial forms (i.e. volvox) do not add to food web and create water quality problems. Also creates problems when it grows in "cotton candy" type clouds in the water. | Yes. When cell numbers exceed 3,000 to 5,000 cells/mL it is high and in excess of the eutrophic/beneficial use levels, >1,000 cells/mL; Reservoir typically measured over 10,000 cell/mL |
| Phytoplankton Cyanophyta "Cyanobacteria" - "Blue green algae" Note: Truly are bacteria so proper classification is Cyanobacteria. |  | During periods of over abundant enrichment and with very high nutrients, especially phosphorus. Their excess production will lead to water quality problems. | Do not contribute greatly to food web. Few people view cyanobacteria as beneficial organisms in a lake environment. | Blue-greens create water quality problems, i.e. oxygen depletion when their excessive growth produces algae blooms Some species are toxic (cyanotoxins) and result in HABs. | Yes. Cyanophyta, were observed at nearly 75,000 cells/mL; this is too high for a balanced system, keeping the risk for cyanotoxins elevated. |
| Phytoplankton Bacilliaraphyta "Diatoms" |  | Typically, the first algae to bloom in early spring.When conditions in the upper mixed layer (nutrients and light) are favorable (spring), their competitive edge and rapid growth rate enables them to dominate phytoplankton communities | Important contributors to the primary production in aquatic ecosystems. Food resource for zooplankton and also produces atmospheric oxygen. Some diatoms can host nitrogen-fixing cyanobacterial symbionts that are high in protein, which may benefit the organisms grazing these diatoms. | Freshwater diatoms commonly observed in the reservoir are indicators of eutrophic (over enriched conditions) and their densities are greater than a balanced system would support. This contributes to environmental degradation through increased oxygen demand and phosphorus recycling. | Abundant in early June and early August, over 10,000 cells/mL. Predominant biovolume during same timeframe. |

| Phytoplankton or Zooplankton Taxonomic Division and Common Name | Picture *(Photos courtesy of PhycoTech, Inc. and NOAA)* | Period of Occurrence | Ecological Benefits for Reservoir | Ecological Stressors for Reservoir | Abundance (Yes/No) |
|---|---|---|---|---|---|
| Phytoplankton Cryptophyta |  | Cryptophytes are abundant in the phytoplankton and can also live through the winter, under ice-cover and with little solar radiation for photosynthesis. | They are also an important food for zooplankton. Zooplanktons, in turn, are food for fish and other organisms that are part of the aquatic food web. | | Due to proliferation over the winter, Cryptophyta numbers were higher in May and June, tapering off later in the growing season. |
| Zooplankton Daphnids "Water flea", "Daphnia magna" and "Daphnia dubia" |  | Historically conditions are ideal for Daphnids around early June timeframe. These are the most effective phytoplankton harvesters and food source for fish. | Excellent zooplankton that play a significant role in the food web as major source of oils and proteins for fish. Large in size and preferred fish food (over 10 times the size of Bosminids). | | Higher density in June reflects phytoplankton community structure, higher numbers with balance moderate production of phytoplankton. |
| Zooplankton Bosminid |  | High percentage of Bosminids indicates that the Cryptophytes and the single cells, chlorophytes, are the major algal food base. | Provides food base, but because of their small size, not a preferred food source. | Given Bosminids are smaller than the preferred Daphnids for fish food this indicates that most of the primary production is not being used by higher aquatic biota and hence contributes to over enrichment of the reservoir. | |

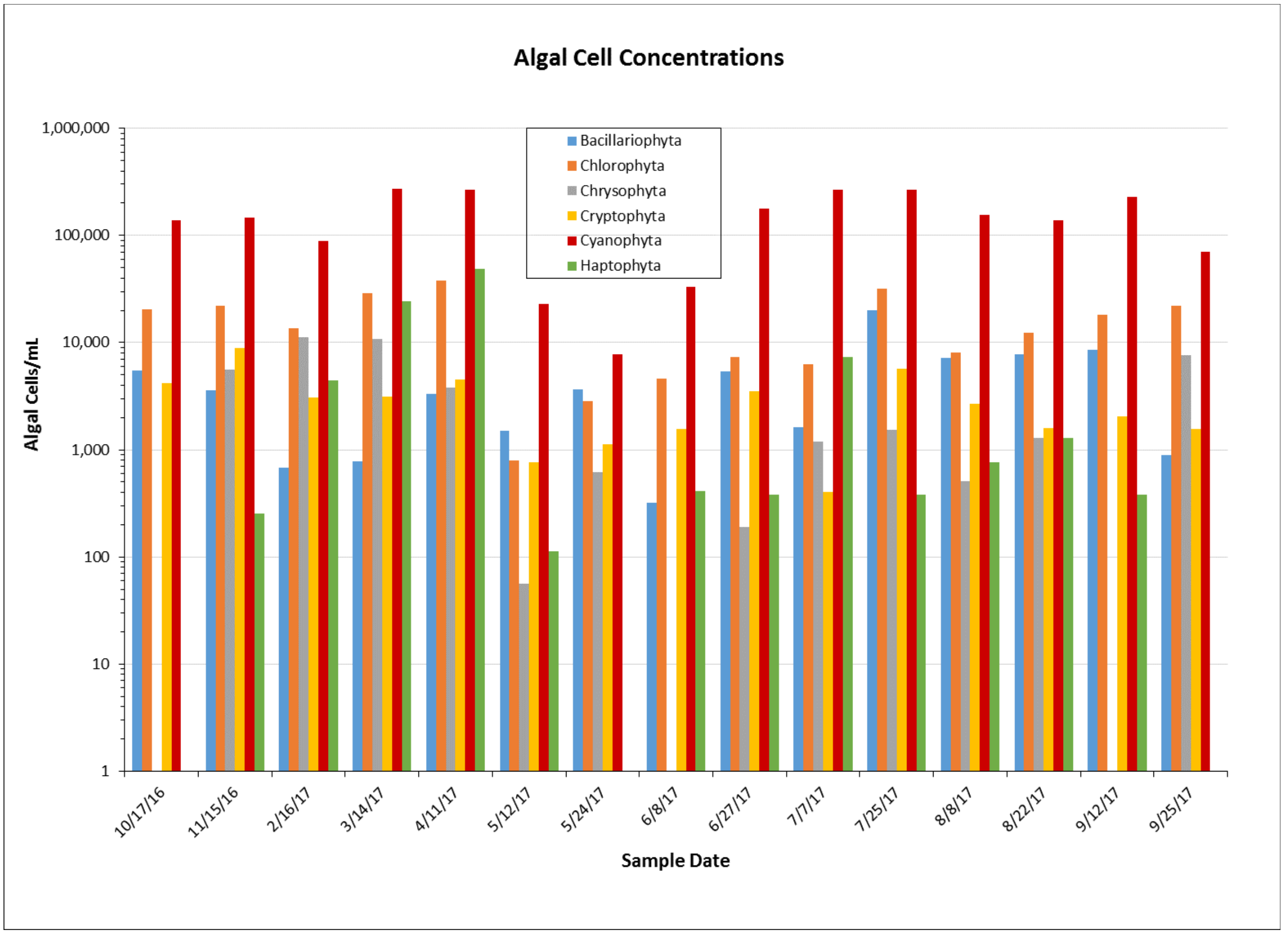



**Figure 45. Algal Cell Concentrations Measured in Cherry Creek Reservoir in WY2017.** (Source of Data: PhycoTech, Inc.)

Chl-*a* accounted for the total phytoplankton community biomass in WY2017and this biomass was dominated by Chlorophyta and Bacillariophyta (diatoms, a significant source of food for zooplankton, however not all of the diatoms species present fit into this function) although different phytoplankton (e.g. Chrysophyta in February through April, Cyanophyta in June and early July) briefly dominated the community, as depicted in Figure 46. A significant amount of biomass energy from phytoplankton and bacteria was also stored in the sediments as organic carbon, which contributed to excess nutrient production during this timeframe.

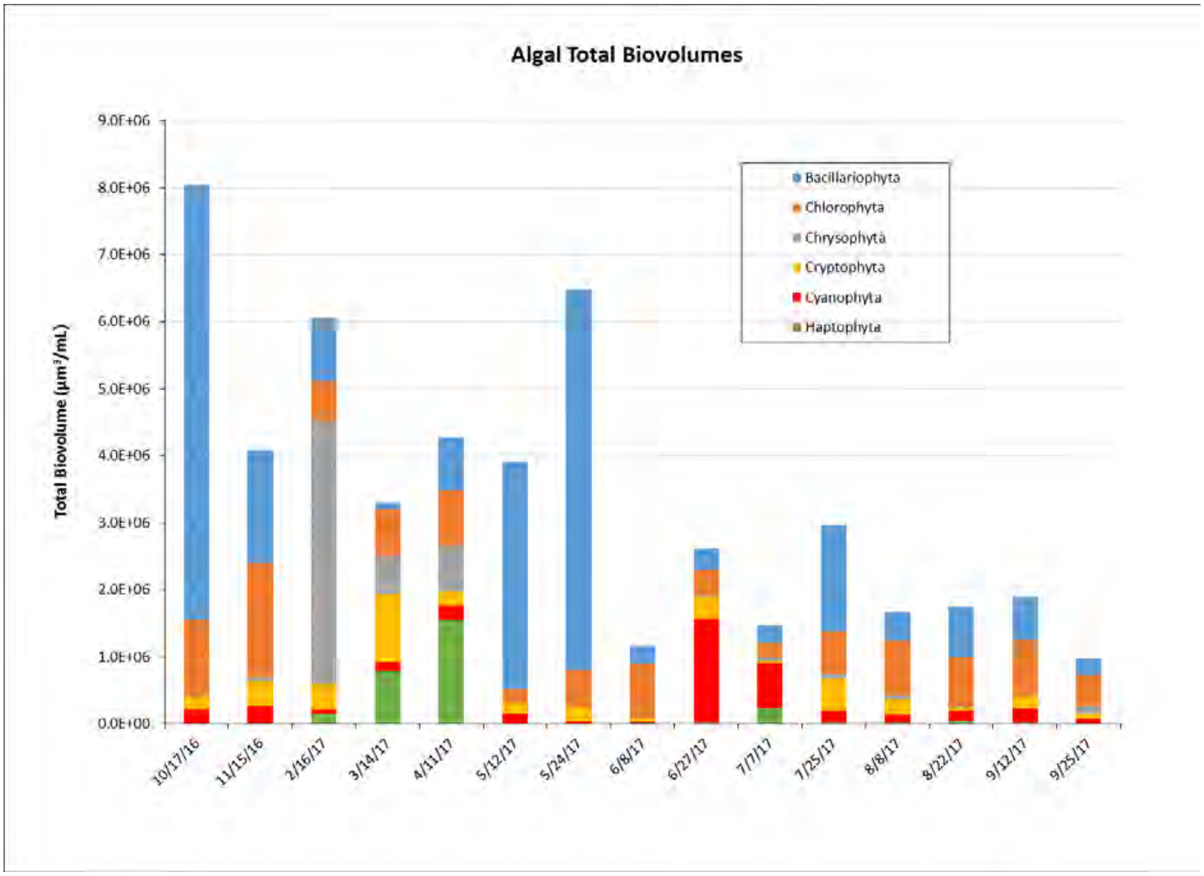



**Figure 46. Algal Community Biomass in WY 2017.** (Source of Data: PhycoTech, Inc.)

**Zooplankton.** The WY2017 zooplankton community structure was generally illustrative of a hypereutrophic system and not overly productive (biomass) relative to food base for fisheries (Figure 47). A generally higher Daphnid biomass was present in May and June, and again in August and September, indicating this preferred fish food was available and abundant for the fishery. However, Bosminids, which are ten times smaller than the preferred Daphnids, were sporadically prevalent throughout WY2017. The dominance of Bosminids indicates that most of the primary production was not being used by higher aquatic biota during these times, which contributes to the over enrichment of the Reservoir.

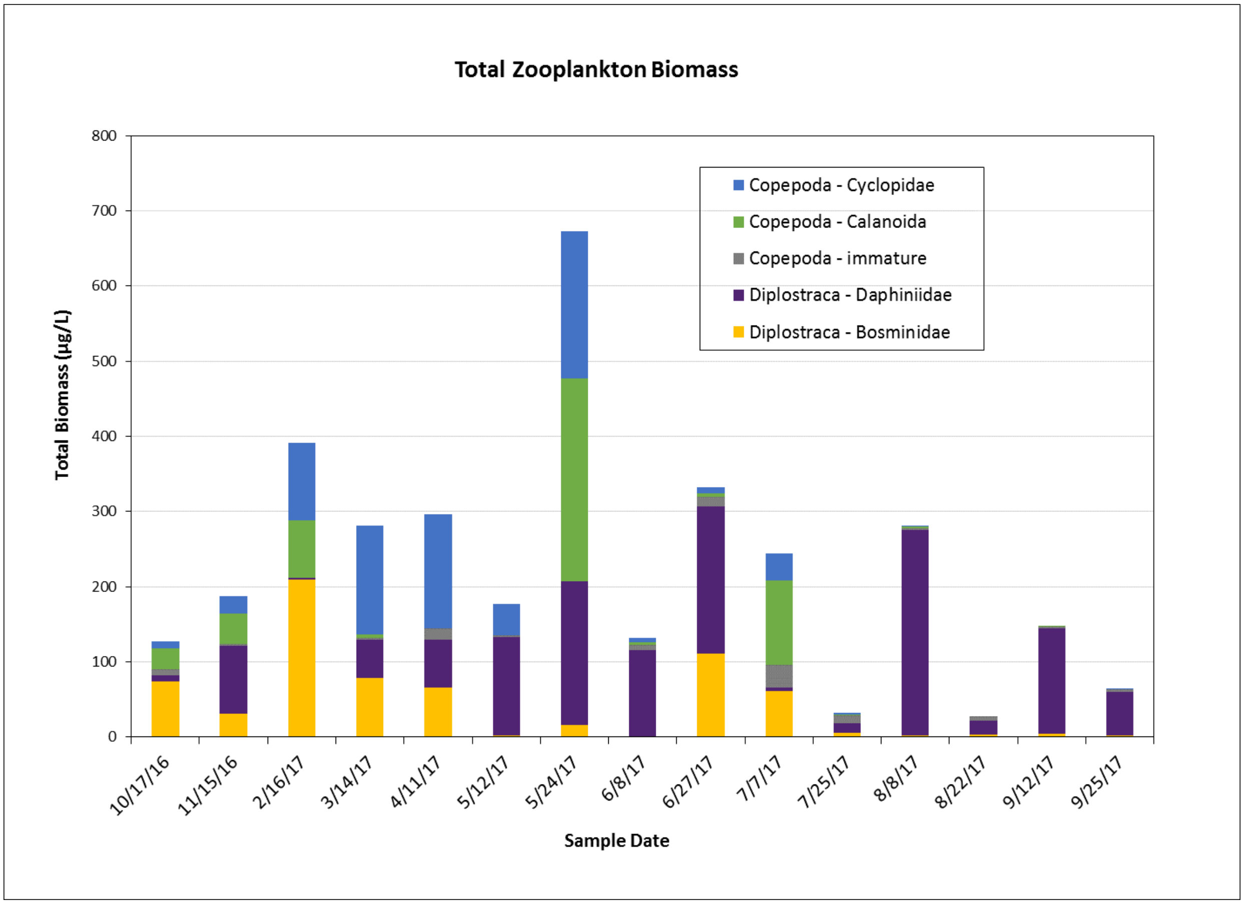



**Figure 47. Zooplankton Biomass WY2017.** (Source of Data: PhycoTech, Inc.)

## 3.2.11 Harmful Algal Blooms

Harmful algal blooms (HABs) were not observed in the Reservoir in WY2017. There were no beach closures.

# 4.0 RESERVOIR NUTRIENT BALANCE

The calculated WY2017 water, phosphorus and nitrogen balances in the Cherry Creek Reservoir are presented in this section.

## 4.1 WATER BALANCE

The calculated WY2017 water balance for Cherry Creek Reservoir is presented in this section. The reservoir water balance can be calculated by the following equation:

$$\text{Ending Storage}_{9/30/2017} + \sum \text{Reservoir Inflows} - \sum \text{Reservoir Outflows} - \text{Starting Storage}_{10/1/2016} = \Delta\ \text{Storage}$$

The USACE's daily storage calculations (Appendix E), which are based on pool elevation, indicate a 364 ac-ft loss in storage (-Δ Storage) from October 1, 2016 (12,339 ac-ft) through September 30, 2017 (11,975 ac-ft).

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

1. Precipitation (incident to the reservoir's surface).
2. Alluvial groundwater.
3. Cherry Creek surface water.
4. Cottonwood Creek surface water.
5. Ungaged inflows.

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

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

The Authority measures surface water inflows (inflow item numbers 3 and 4), while precipitation (inflow item 1) can be estimated from the acreage of the reservoir and the amount of precipitation recorded at the nearby Centennial Airport (KAPA) precipitation gage (Section 3.1.1.1). Alluvial groundwater inflow (inflow item 2) is estimated at a constant 2,200 ac-ft/year based on evaluations conducted by Lewis, et al. (2005) and used by Hydros (2015) in the reservoir model. The USGS measures outflow item number 3 and the USACE provides an estimate of outflow item 1. The net influence of ungagged surface water inflows and alluvial groundwater losses (seepage) (inflow item 5 *less* outflow item 2) is calculated based on the difference between the measured and estimated inflows and outflows, and the USACE calculated WY2017 net inflow of 23,804 ac-ft (Appendix E).

Surface water inflow from Cherry and Cottonwood Creeks are estimated from the continuous flow stations operated by the Authority at monitoring sites CC-10 (Cherry Creek) and CT-2 (Cottonwood Creek) (Figure 2). The estimated volumes of surface flow entering the Reservoir from these two surface water sources in WY2017 are:

- Cherry Creek: - 17,362 ac-ft
- Cottonwood Creek: - 3,431 ac-ft

Flow data from the Authority's gaging stations are provided in Appendix D.

Water is released from the Reservoir through the dam's outlet works. The USGS operates the *Cherry Creek below Cherry Creek "Lake"* gage approximately 2,300 feet downstream of the Reservoir. Other than releases from the Reservoir, there are no major surface water contributions to flow measured at this gage. The preliminary WY2017 flows at the gage totaled 20,703 ac-ft, with the WY2017 mean daily discharge rate of 28.6 cfs exceeding the 56-year POR mean daily rate of 9.2 cfs (Figure 48).

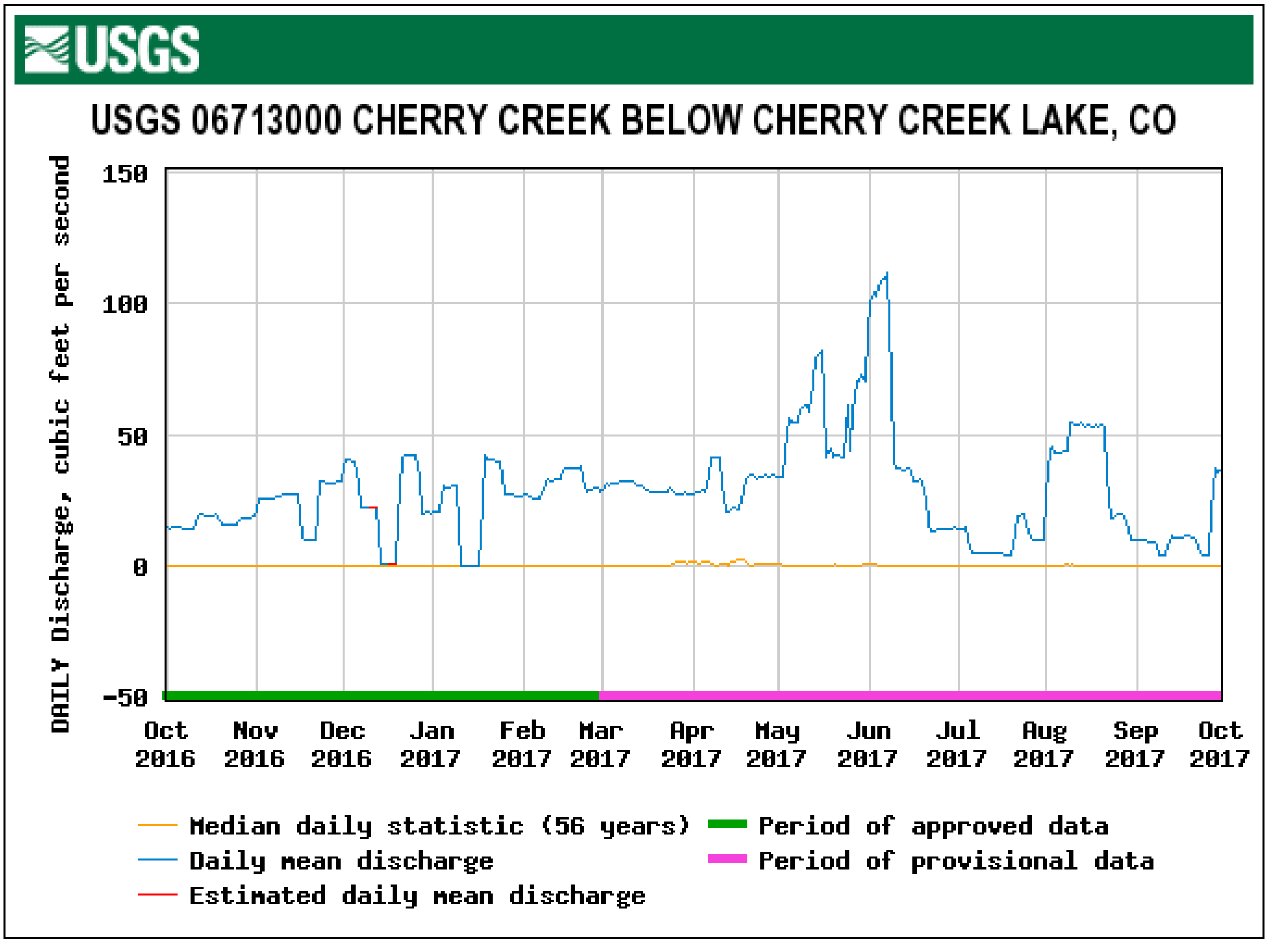



**Figure 48. WY2017 Preliminary Hydrograph and Historical Median Flows for USGS Gage Cherry Creek below Cherry Creek Lake. (Source of Data: USGS)**

During WY2017, the surface area of Cherry Creek Reservoir varied between 812 acres on September 22, 2017 and 883 acres on May 30, 2017, with a median value of 836 acres[2]. During WY2017, 12.41 inches (1.034 feet) of precipitation was recorded at the Denver-Centennial Airport weather station (KAPA). Assuming that 1.034 feet of water fell evenly over 836 acres results in an estimated 865 ac-ft of water contributed to the Reservoir by precipitation.

[2] http://www.dwr.state.co.us/SurfaceWater/data/detail_graph.aspx?ID=CHRRESCO&MTYPE=STORAGE

The USACE estimated evaporative losses from the Reservoir in WY2017 at 3,605 ac-ft (Appendix E), or approximately 51.8 inches (4.3 feet) per acre assuming a median surface area of 836 acres.

The Reservoir WY2017 water balance is summarized in Table 11.

**Table 11. Cherry Creek Reservoir WY2017 Water Balance**

| Water Source | Water Volume (ac-ft) |
|---|---|
| **Surface Water** | |
| Cherry Creek ( CC-10) | 17,362 |
| Cottonwood Creek (CT-2) | 3,431 |
| Reservoir Release (CC-Out) | -20,703 |
| **Alluvial Groundwater** | |
| Inflow | 2,200 |
| **Atmospheric** | |
| Precipitation | 865 |
| Evaporation | -3,605 |
| **Net Ungaged Inflows/Outflows** | |
| Calculation | 86 |
| **WY2017 Change in Storage** | **-364** |

The net ungaged inflows(+)/outflows(-) is mathematically calculated to result in the Reservoir change in storage to equal the -364 ac-ft reported by the USACE (Appendix E). Components included in this calculated term are ungaged surface water inflows into the reservoir, groundwater seepage from the reservoir through the dam, and measurement uncertainties.

The relative contribution of the inflows to the Reservoir in WY2017 are illustrated in Figure 49.

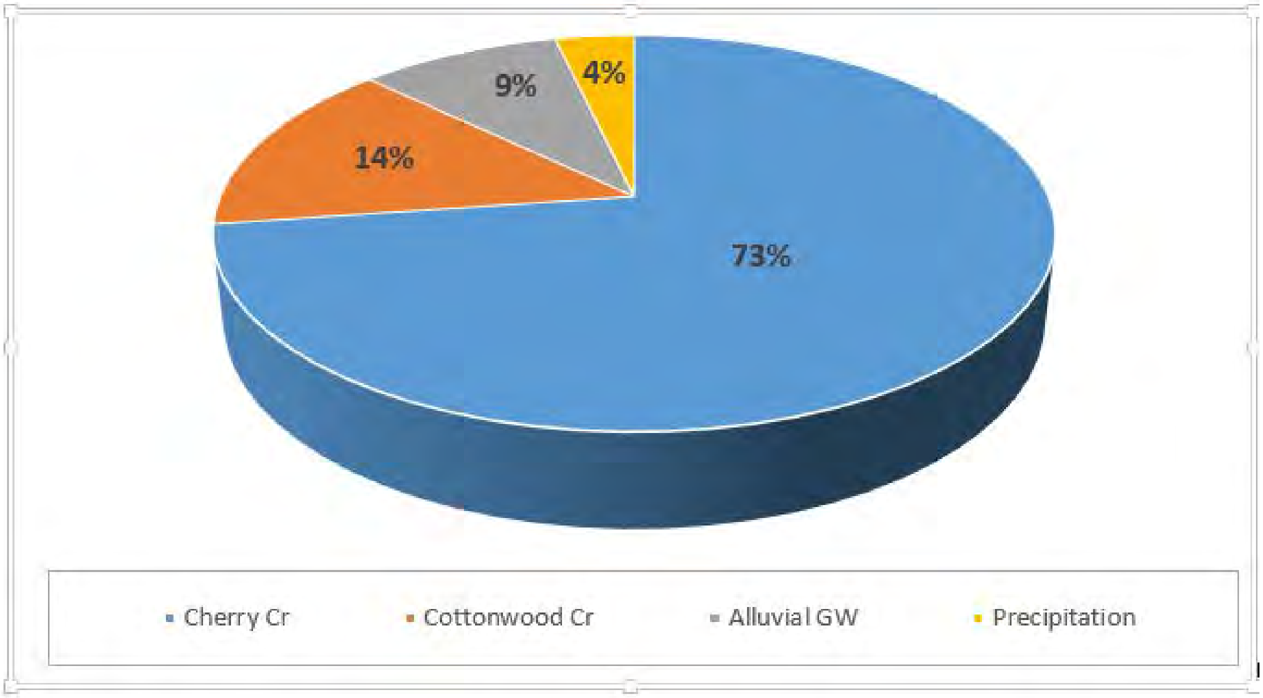



**Figure 49. Relative Contribution of Cherry Creek Inflows to Reservoir Water Balance in WY2017**

In keeping with prior year's nutrient loading calculations, the 86 ac-ft difference between the Authority's and the USACE's calculated inflows was apportioned to the two dominant surface water inflows (Cherry Creek and Cottonwood Creek) for purposes of calculating reservoir nutrient loads (Section 4.2). For WY2017 nutrient loading evaluation (Section 4.2), 83.5 percent of the 86 ac-ft (72 ac-ft) was allocated to the Cherry Creek inflow (CC-10) annual total while the remaining 16.5 percent of the 86 ac-ft (14 ac-ft) was allocated to the Cottonwood Creek inflow (CT-2).

## 4.2 NUTRIENT LOADS

The calculated WY2017 phosphorus and nitrogen balances in the Cherry Creek Reservoir are presented in this section. The reservoir nutrient loading was 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 ($-\Delta\ \text{Storage}_{\text{Nutrients}}$) indicates the opposite and would suggest that previously stored nutrients are being exported from the Reservoir.

The reservoir inflows (nutrient loads) considered in the WY2017 nutrient balance are:

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

The only physical release mechanism considered from the Reservoir in the WY2017 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 ungagged inflow/outflow load was apportioned to the measured WY2017 Cherry Creek and Cottonwood Creek loads based on the flow adjustments described in Section 4.1. Internal loading (nutrient recycling) discussed in Section 3.2 is not included in the mass balance but contributes to the overall nutrients available to the phytoplankton that thrive in the Reservoir.

### 4.2.1 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 4). The Authority also periodically collects storm event samples at CC-10 and CT-2 (Table 4). These samples are analyzed for the parameters indicated in Table 3, which includes total phosphorus and total nitrogen. The nutrient concentrations in samples collected at CC-10, CT-2 and CC-Out in WY2017 are summarized in Section 3.1. When combined with the WY2017 flows, the annual total phosphorus and total nitrogen loads can be calculated for the surface water inflows and outflows (releases) to/from the Reservoir (Table 12). The Cherry Creek and Cottonwood Creek loads presented in Table 12 have not been adjusted to apportion the ungaged inflows as discussed in Section 4.1.

**Table 12. Cherry Creek Reservoir WY2017 Surface Water Nutrient Loads**

| Site | WY2017 Nutrient Load | |
|---|---|---|
| | Total Phosphorus (Pounds) | Total Nitrogen (Pounds) |
| **Inflows** | | |
| Cherry Creek @ CC-10 | 10,799 | 59,487 |
| Cottonwood Creek @ CT-2 | 580 | 16,878 |
| **Releases** | | |
| USGS Gage & CC-Out | - 6,093 | - 42,900 |

## 4.2.2 Precipitation Loads

The WY2017 atmospheric nutrient loading through precipitation and dry deposition was seasonally monitored (May 2017 through September 2017) at the Authority's rain gage located immediately east of the reservoir (see "PRECIP" site on Figure 2). Five precipitation samples were collected in WY2017 and analyzed for total phosphorus and total nitrogen. The results are summarized below:

- WY2017 total phosphorus concentrations ranged from 15 µg/L to 307 µg/L, with a median value of 28 µg/L. The WY2017 median value is lower than both the WY2016 median value (60 µg/L) and the long-term median[3] of 119 µg/L.
- WY2017 total nitrogen concentrations ranged from 362 µg/L to 4,120 µg/L, with a median value of 1,170 µg/L. The WY2017 median value is lower than both the WY2016 median value (2,547 µg/L) and the long-term median of 1,978 µg/L.

The long-term median total phosphorus and total nitrogen precipitation/dry fall concentrations were combined with the estimated 865 ac-ft of precipitation to calculate these nutrient loads from direct precipitation to the Reservoir:

- Total Phosphorus: 280 pounds
- Total Nitrogen: 4,650 pounds

## 4.2.3 Alluvial Groundwater Loads

Water quality samples collected from well MW-9 on two occasions in WY2017 and were analyzed for total phosphorus and total nitrogen. The results are summarized below:

- The median WY2017 total phosphorus concentration was 237 µg/L. The WY2017 median value is higher than both the WY2016 median value (206 µg/L) and the long-term median of 190 µg/L (GEI, 2016).
- The median WY2017 total nitrogen of 241 µg/L is well below the long-term median of 430 µg/L (GEI, 2016).

The long-term median total phosphorus and total nitrogen concentrations reported in GEI (2016) were combined with the estimated 2,200 ac-ft of inflow to calculate these nutrient loads from the alluvial groundwater inflow to the Reservoir:

- Total Phosphorus: 1,136 pounds
- Total Nitrogen: 2,573 pounds

## 4.2.4 Nutrient Balances

The WY2017 total phosphorous and total nitrogen load balance calculations are presented in this section. Internal loads are not included in the mass balances presented in this section.

[3] Available data in the Authority's database for location "Rain Gauge" from 2001, 2008-2010, and 2014-2017 were used to calculate long-term median total nitrogen and total phosphorus statistics.

### 4.2.4.1 Total Phosphorus Mass Balance

Based on the data presented in Sections 4.2.1 through 4.2.3, the WY2017 total phosphorous mass balance is summarized in Table 13.

**Table 13. Cherry Creek Reservoir WY2017 Total Phosphorus Mass Balance**

| Source | Mass (pounds) |
|---|---|
| **Surface Water** | |
| Cherry Creek ( CC-10) | 10,799 |
| Cottonwood Creek (CT-2) | 580 |
| Reservoir Release (CC-Out) | -6,093 |
| **Alluvial Groundwater** | |
| Inflow | 1,136 |
| **Atmospheric** | |
| Precipitation | 280 |
| Evaporation | 0 |
| **WY2017 Change in Storage** | **6,702** |

The difference between the inflow and the outflow loads ($\Delta$ $Storage_{Nutrients}$) indicates that a net 6,702 pounds (3.4 tons) of phosphorus were retained in the Reservoir in WY2017.

The relative contributions of the inflow sources to the Reservoir phosphorus load WY2017 are illustrated in Figure 50.

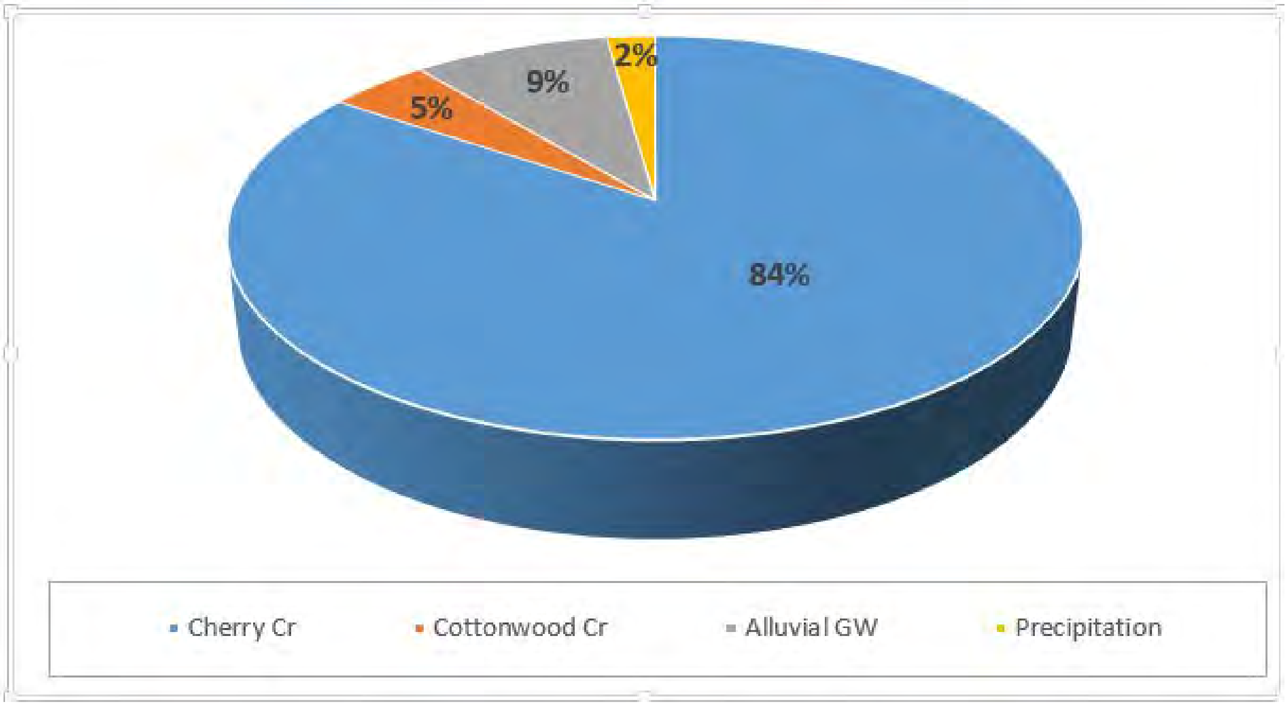



**Figure 50. Relative Contribution of Cherry Creek Inflows to Reservoir Phosphorus Balance in WY2017**

The WY2017 total phosphorus loading data are compared to prior year's loads in Table 14.

**Table 14. Comparison of Cherry Creek Reservoir WY2017 Total Phosphorus Loading to Historic Loads**

| Period | Inflows (pounds) | | | | Outflow (pounds) | Δ Storage (pounds) |
|---|---|---|---|---|---|---|
| | Surface Water | Alluvial Groundwater | Precipitation | Total | | |
| Median (1993 – 2015) | 7,868 | 1,033 | 379 | 9,301 | -4,113 | 5,599 |
| Median (2011 – 2015) | 7,164 | 1,033 | 323 | 8,588 | -4,114 | 5,187 |
| WY 2015 | 15,141 | 1,033 | 526 | 16,701 | -8,222 | 8,479 |
| WY2016 | 13,212 | 1,136 | 435 | 14,783 | -9,156 | 5,627 |
| **WY2017** | **11,379** | **1,136** | **280** | **12,795** | **-6,093** | **6,702** |

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

The WY2017 total phosphorus inflow and outflow loads are lower than those in WY2015 and WY2016, but are larger than those exhibited in long-term dataset. The mass of phosphorus retained in the Reservoir in WY2017 is also greater than the long-term average.

### 4.2.4.2 Total Nitrogen Mass Balance

Based on the data presented in Sections 4.2.1 through 4.2.3, the WY2017 total nitrogen mass balance calculation is presented in Table 15.

**Table 15. Cherry Creek Reservoir WY2017 Total Nitrogen Mass Balance**

| Source | Mass (pounds) |
|---|---|
| **Surface Water** | |
| Cherry Creek ( CC-10) | 59,487 |
| Cottonwood Creek (CT-2) | 16,878 |
| Reservoir Release (CC-Out) | -42,900 |
| **Alluvial Groundwater** | |
| Inflow | 2,573 |
| **Atmospheric** | |
| Precipitation | 4,650 |
| Evaporation | 0 |
| **WY2017 Change in Storage** | **40,688** |

The difference between the inflow and the outflow loads ($\Delta$ Storage$_{Nutrients}$) indicates that a net 40,688 pounds (20.3 tons) of nitrogen were retained in the Reservoir in WY2017.

The relative contributions of the inflow sources to the reservoir nitrogen load WY2017 are illustrated in Figure 51.

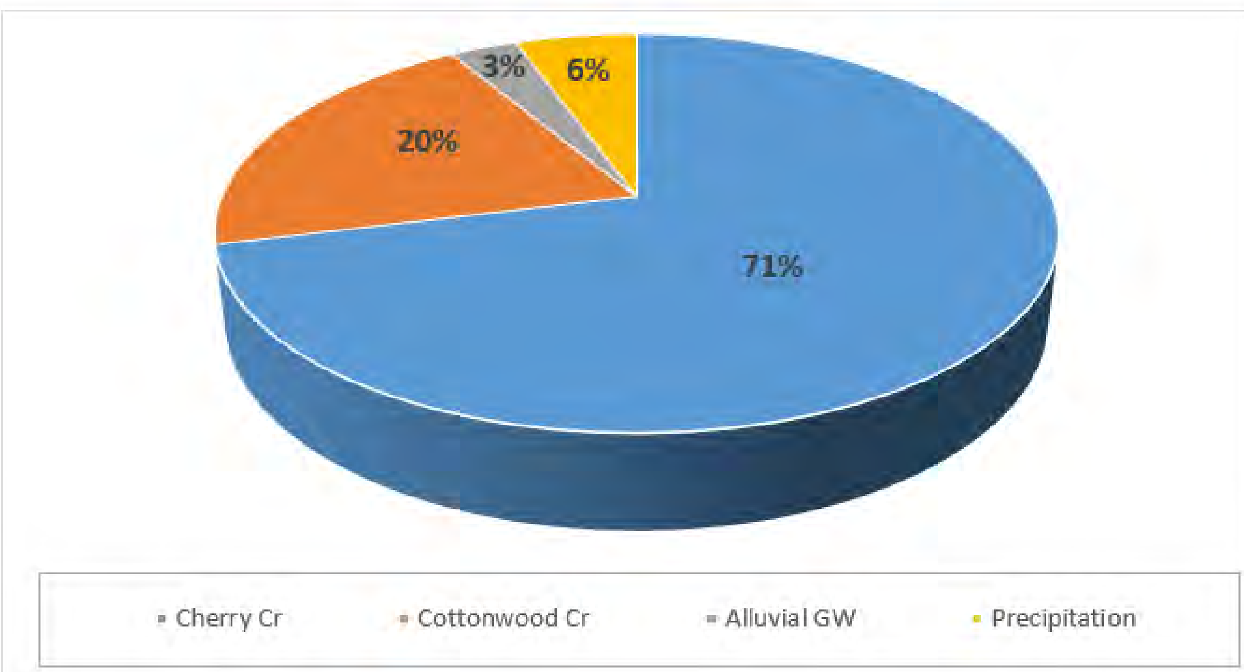



**Figure 51. Relative Contribution of Cherry Creek Inflows to Reservoir Nitrogen Balance in WY2017**

The WY2017 total nitrogen loading data are compared to prior year's loads in Table 16.

**Table 16. Comparison of Cherry Creek Reservoir WY2017 Total Nitrogen Loading to Historic Loads**

| Period | Inflows (pounds) | | | | Outflow (pounds) | Δ Storage (pounds) |
|---|---|---|---|---|---|---|
| | Surface Water | Alluvial Groundwater | Precipitation | Total | | |
| Median (1999 – 2015) | 59,573 | 2,337 | 6,578 | 68,592 | -35,727 | 32,865 |
| Median (2011 – 2015) | 54,126 | 2,337 | 5,720 | 62,234 | -32,120 | 21,434 |
| WY 2015 | 68,630 | 2,339 | 8,546 | 79,515 | -58,186 | 21,329 |
| WY2016 | 73,148 | 2,573 | 5,898 | 81,619 | -60,627 | 20,992 |
| **WY2017** | **76,365** | **2,573** | **4,650** | **83,588** | **-42,900** | **40,688** |

Note: Historic data modified from GEI (2016) Table 4-8.

The WY2017 total nitrogen inflow loads are similar to those in WY2015 and 2016 and larger than those exhibited in the long-term dataset. However, the mass of nitrogen retained in the Reservoir in WY2017 is above both recent and long-term retention rates.

## 4.3 FLOW-WEIGHTED NUTRIENT CONCENTRATIONS

As summarized in Table 14, the phosphorus loading to the Reservoir from external sources in WY2017 totaled 12,795 pounds (6.4 tons) and was derived from these sources:

- Surface water: 11,379 pounds.
- Groundwater: 1,136 pounds.
- Precipitation: 280 pounds.

With respect to nitrogen, external sources resulted in 83,588 pounds (41.8 tons) of this nutrient being delivered to the Reservoir in WY2017 from these sources (Table 16):

- Surface water: 76,365 pounds.
- Groundwater: 2,573 pounds.
- Precipitation: 4,650 pounds.

The “surface water” loads of phosphorus and nitrogen include those from Cherry Creek and Cottonwood Creek and have been adjusted for ungaged runoff (Section 4.1).

The flow adjusted-weighted concentrations of total phosphorus and total nitrogen in WY2017 are summarized in Table 17.

**Table 17. WY2017 Flow-Weighted TP, SRP, and TN Concentrations**

| Nutrient | Inflows (µg/L) | | | | |
|---|---|---|---|---|---|
| | Cherry Creek | Cottonwood Creek | Alluvial Groundwater | Precipitation | Total |
| Total Nitrogen | 1,260 | 1,809 | 430 | 1,977 | **1,284** |
| Total Phosphorus | 229 | 62 | 190 | 119 | **197** |
| Soluble Reactive Phosphorus | 163 | 16 | 185 | 19 | **155** |

The overall WY2017 flow-weighted TP inflow concentration of 197 µg/L is lower than the WY2016 value (213 µg/L), but very close to the 2011-2015 median of 200 µg/L. A majority of the phosphorus (155 µg/L) is SRP and in a dissolved form, readily available for plant uptake. In contrast, the overall WY2017 flow-weighted TN concentration of 1,284 µg/L is higher than the WY2016 value of 1,175 µg/L, but still below the 2011-2015 median of 1,344 µg/L.

# 5.0 CONCLUSION

The Reservoir is getting more productive as time goes on due to the natural progression of man-made lakes, elevated nutrient concentrations observed within the watershed (particularly from Cherry Creek) and recycled nutrients in the Reservoir sediments that are 2-100 times that of the flushing rate under current conditions in the Reservoir. The continued dominance of Cyanobacteria which produce chl-*a* values in excess of regulatory limits, is an indicator that phosphorus availability within the Reservoir is too high.

# 6.0 CREDITS

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# APPENDICES

Appendices A through G are provided under separate cover.