Water Quality Report

South Platte River, Barr Lake, Milton Reservoir, and Groundwater

2022

Water Quality Division

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List of Acronyms

AY	annual year
BOD	biochemical oxygen demand
BMW	Barr Lake and Milton Reservoir Watershed Association
CBOD	carbonaceous biochemical oxygen demand
CDPHE	Colorado Department of Public Health and Environment
Chl-*a*	chlorophyll *a*
cfu/100 ml	colony forming units per one hundred milliliters (references concentrations of *E. coli*)
cfs	cubic feet per second
COS	soluble organic carbon
CPW	Colorado Division of Parks and Wildlife
DO	dissolved oxygen
E. coli	*Escherichia coli*
ELSP	early life stages present (for assessment of ammonia)
ELSA	early life stages absent (for assessment of ammonia)
EPA	Environmental Protection Agency
EPT	Ephemeroptera, Plecoptera, Trichoptera (macroinvertebrates) Index
FRICO	Farmers Reservoir and Irrigation Company
m	meters
MDL	method detection limit
mg/L	milligrams per liter
MMI	Multi-metric index
NO_5	Analysis for nitrate (NO_3) and nitrite (NO_2)
NTP	Northern Treatment Plant
PAR	Project Action Request
RWHTF	Robert W. Hite Treatment Facility of Metro Water Recovery, Denver, Colorado

QA/QC	quality assurance / quality control
SDI	Shannon Diversity Index
SPCURE	South Platte Coalition for Urban River Evaluation
SRP	soluble reactive phosphorus
SM	Standard Methods for the Examination of Water and Wastewater
TDP	total dissolved phosphorus
TDS	total dissolved solids
TKN	total Kjeldahl nitrogen (organic N and ammonia (NH3 and NH4)
TMDL	Total Maximum Daily Load
TN	total nitrogen
TOC	total organic carbon
TP	total phosphorus
TSI	trophic state index score
µg/L	micrograms per liter
WWTP	Wastewater Treatment Plant
WY	water year
USGS	United States Geological Survey

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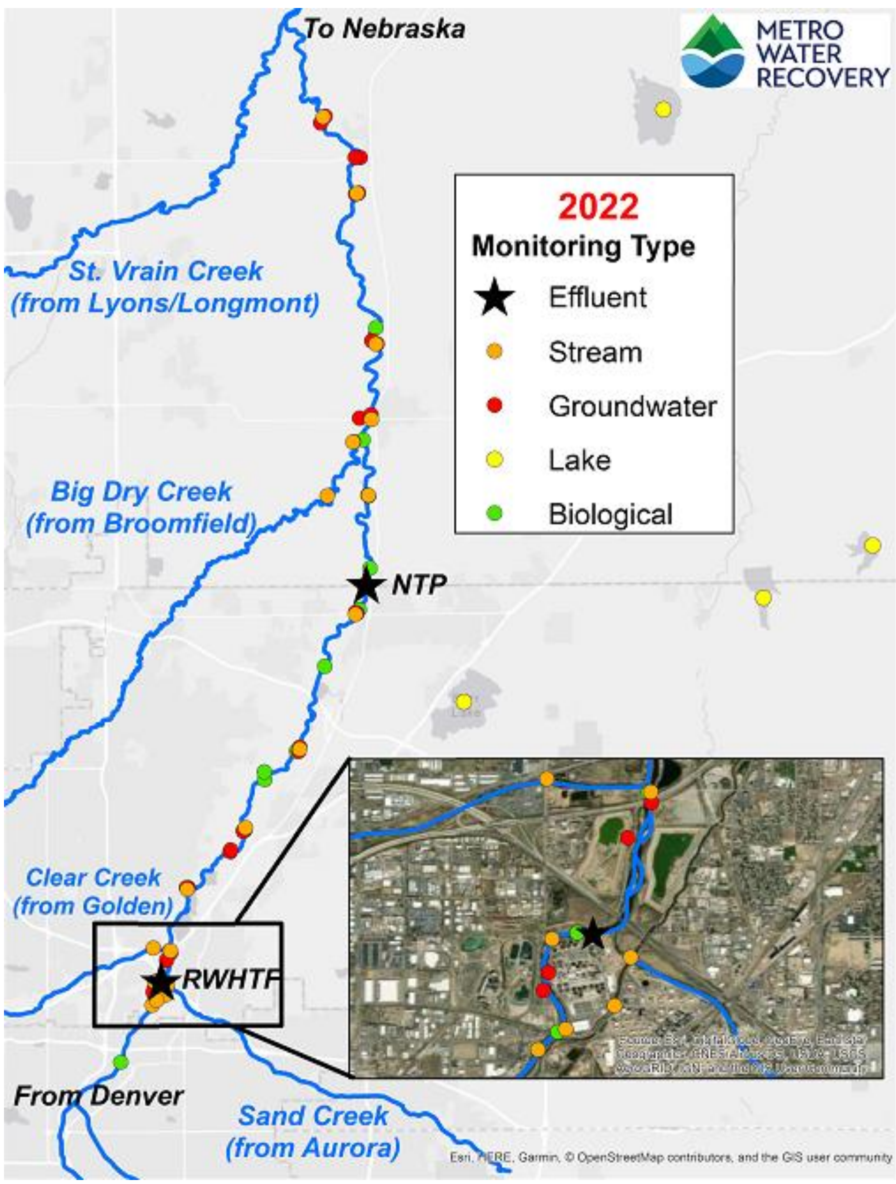
Executive Summary – 2022 Water Quality Report

Metro's Monitoring

Metro Water Recovery (Metro) has been monitoring the South Platte River from Denver to Platteville for over 50 years. This monitoring has included river habitat, fish, macroinvertebrates, reservoirs, pre & post restoration improvements, stormwater, groundwater, and special studies. Metro is a respected leader in water recovery and data collection. We provide reliable data to support regulatory policies and plant upgrades to protect the region's health and environment. Not only does Metro "*get your water*", but we also follow it down the river.



South Platte River

The South Platte River through Denver is the most monitored river in the state. Segment 15 is 26 miles long from the Burlington Ditch diversion to Big Dry Creek. Segment 1a continues another 17 miles to the confluence with the St. Vrain River. The South Platte River is a changing river that is heavily used for recreation, fishing, drinking water, and agricultural irrigation. Major influences on the river include stormwater, point sources of reclaimed water, changing flow regimes, urban and agricultural pressures, and a changing riparian habitat. In 2022, water quality monitoring occurred at 22 permanent sampling locations from upstream of the Robert W. Hite Treatment Facility (RWHTF) to the town of Platteville. Over 50 water quality parameters are tested twice per month all year long. Biological monitoring of fish and macroinvertebrate populations occurred at 11 locations in 2022.

Nutrients – In-stream total phosphorus (TP) and total nitrogen (TN) concentrations downstream of the RWHTF outfalls continue to decrease showing that treatment plant upgrades are working. Metro's enhanced biological nutrient removal is having a noticeable impact on the waterways and reservoirs downstream. For example, the average annual TN in Segment 15 of the South Platte River below the RWHTF outfalls was 4.5 mg/L in 2022, compared to 8.8 mg/L in 2013 prior to treatment upgrades. The average annual TP in Segment 15 was 0.44 mg/L in 2021, a 71% decrease from 1.5 mg/L in 2013.

Fish & Bugs – Of the 18 fish species documented, 10 were native to the South Platte River. Five of the six most common fish species observed in 2022 are native to the South Platte River (fathead minnow, longnose dace, sand shiner, white sucker and Iowa darter). Before and after habitat improvement construction surveys continue to show major improvements in fish diversity and abundance at the four completed phases downstream of the RWHTF outfalls. The 2022 benthic macroinvertebrate surveys demonstrated an increase in pollution sensitive taxa (mayflies and caddisflies) compared to 2018 surveys, in which there was an unexpected increase in pollution tolerant taxa (midge larvae, flatworms, leeches). In general, over the past seven years, Metro staff have identified encouraging aquatic life improvements, attributed to drastic reductions of in-stream ammonia concentrations, especially in the survey sites immediately downstream of the RWHTF outfalls.

Barr Lake & Milton Reservoir

Barr Lake (Barr) and Milton Reservoir (Milton) are influenced by Metro's effluent. These two downstream, off channel reservoirs have historically received large annual nutrient loads from Metro (37% of Barr's annual phosphorus load and 73% for Milton). Hypereutrophication conditions in both reservoirs include high pH, low DO, and high Chl-a levels. Metro participates in the Barr Lake and Milton Reservoir Watershed (BMW) Association to assist with implementing a phased pH/DO TMDL. Metro monitors both reservoirs 20 times a year and participates in special studies as part of this watershed effort.

Nutrients – Both Barr and Milton continue to see reductions in nitrogen and phosphorus concentrations for two reasons – treatment upgrades and no effluent pumping to Barr since 2012. When compared to 2003 – 2009 averages, the 2022 TP summer average for Barr was 52% less and 60% less for Milton. For the water year, Barr received 63,400 acre-feet of water which brought in 34,100 kg of phosphorus. The annual load goal is 5,779 kg/yr. Internal loading did occur between May and early July for both reservoirs, caused by low oxygen during thermal stratification. Both reservoirs did not exceed the ammonia standard.

Reservoir Management – Volume and timing of inflows can have a major impact on water quality. The 2022 water year (November 1st, 2021 to October 31st, 2022) brought both a wet spring and dry summer/fall. Milton received 37,600 acre-feet of water while Barr received 63,400 acre-feet. Full pool at Barr occurred for 30 days causing thermal stratification. With a large biomass of dead diatoms settling to the lake bottom and this isolation of bottom water, anoxic conditions allowed for internal loading of phosphorus for 54 days. Water depth, inflows, and outflows can have a direct impact on water quality.

Special Studies – The TMDL implementation plan includes projects that focus on all sources of phosphorus in both reservoirs. For point sources, Metro began full-scale biological phosphorus removal at the RWHTF facility in January 2021. South Platte Renew will begin their phosphorus treatment starting the summer of 2023. City and County of Denver received their new MS4 permit in 2021 that now requires more phosphorus monitoring. BMW collected eight storm water samples in 2021 to better understand phosphorus loads to Barr. Weekly composite samples were also collected to calculate loads. It is estimated that 34,600 kg of phosphorus entered Barr for the 2021 water year. The average weekly phosphorus load to Barr was 656 kg/week. Biomanipulation in Barr (i.e., removal of carp) has occurred since 2014. In 2021 469 carp were removed with the use of a box net. The overall total of carp removed is 8,700 which is close to 72,000 pounds. This equates to 207 pounds of organic phosphorus and 1,400 to 3,000 pounds of phosphorus prevented from excretion.

Looking Ahead to 2023

Water quality staff will continue to conduct field surveys to determine the effects of Metro's discharge on the South Platte River, Barr Lake, and Milton Reservoir. In particular, the group hopes to address the following goals and projects in 2023:

- Document potential aquatic life responses to TP concentrations related to start-up of full biological phosphorus controls at the Hite facility.
- Conduct fish surveys at newly constructed Phase IV Habitat Improvement Site at 88th Avenue to document potential improvements in native fish communities.
- Continue to document temperature profile of South Platte River downstream of RWHTF and NTP outfalls and assess how proposed temperature reduction strategies will impact attainment or exceedance of standards.
- Continue in-stream periphyton sampling program to assess algal abundance and chlorophyll-a concentrations in the South Platte River.
- Operate the stormwater monitoring station on the South Platte River to catch the first flush of water during a storm event and assess the nutrient load in that stormwater.
- Continue to monitor nutrients in Milton as it becomes a more recreational reservoir due to the opening of Haven Sporting Club, which will offer watersports, hunting, fishing, and camping on the site.
- Install autosamplers near Milton Reservoir to help better capture NPS pollutants.
- Determine a short list of best locations for Phase V Habitat Improvement Site.
- Calculate in more detail internal loading in both reservoirs.
- Develop a Dept. of Agriculture approved training course on phosphorus free lawn fertilizers for landscaping companies.

Introduction

Historical Perspective

The Water Quality Division at Metro is charged with monitoring and evaluating the water quality conditions of waters influenced by Metro's discharges. Water quality sampling has taken place since the opening of the Metro's Robert W. Hite Treatment Facility (RWHTF) in 1966. In a U.S. Environmental Protection Agency (EPA) study conducted in 1971, the river was found to be polluted with sludge beds, low dissolved oxygen (DO), and heavy metals contamination (CDM) but improved in comparison to previous conditions of the river. In 1978, the EPA concluded that even if the RWHTF discharged pure water, in-stream water quality would not be adequate to support the State of Colorado designated uses of secondary contact and warm water fisheries. By the mid-1980s, water quality had substantially improved, but still exceeded standards for fecal coliform bacteria, un-ionized ammonia, cadmium, copper, and zinc (CDM).

In 1992, Upper South Platte Segment 15, the receiving water for the discharge from the RWHTF, was included on the State's list of impaired waters (303(d) list) for DO and "other" constituents, which were clarified later to be cadmium and un-ionized ammonia (CDPHE 2010). Segment 15 remained on the 303(d) list for cadmium until 2006 when the cadmium Total Maximum Daily Load (TMDL) was completed. Water quality improved throughout the 1990s after Metro completed capital improvements that resulted in partial nitrification/denitrification in the North Complex and the construction of the dechlorination basin. Metro completed a number of studies in the 1990s and early 2000's which revealed that habitat quality was more limiting to fish populations than water quality (CDM 2006). In 1997, Metro entered into a Memorandum of Understanding with the Colorado Department of Public Health and Environment (CDPHE), Colorado Division of Parks and Wildlife (CPW), and the EPA that allowed for site-specific DO standards coupled with in-river improvements to improve dissolved oxygen and habitat conditions (CDM 2006). Metro added several re-aeration structures and is currently constructing additional habitat improvements at multiple locations throughout Segment 15.

Monitoring of the South Platte River has evolved over time, yet many of the same constituents have been continuously monitored for the past 45 years. Current monitoring efforts are guided by the South Platte Coalition for Urban River Evaluation (SPCURE), which is a collaborative organization designed to create a coordinated monitoring program that saves time and resources by eliminating duplication within the greater Denver metropolitan area. Many partners in SPCURE conduct similar water quality monitoring on the same days of the month to provide a comprehensive longitudinal dataset which can include grab samples, continuous temperature monitoring, and macroinvertebrate sampling. Currently, Metro is the only SPCURE member with resources on an annual basis to conduct fisheries and macroinvertebrate surveys because of the strength of its water quality program.

In July 2002, Metro began monitoring and evaluating the conditions at Barr Lake and Milton Reservoir in conjunction with BMW. The watershed association was established to address high pH issues due to nutrient loading in Middle South Platte Segment 4, which includes both reservoirs. A phased pH and DO TMDL was approved in 2013, and BMW continues to move forward with implementation.

Starting in 2003, Metro began quarterly monitoring of water quality at 20 well sites located adjacent to the South Platte River. This groundwater data is collected to help calibrate the South Platte Water Quality Model and to determine any possible water quality effects on the South Platte River.

General Description of the Study Area

The South Platte River begins high in the Rocky Mountains and flows through the Front Range out onto the eastern plains of Colorado. The watershed covers over 850 square miles and encompasses six Colorado counties: Adams, Arapahoe, Denver, Douglas, Jefferson, and Weld. The watershed generally flows south to north, paralleling the foothills of the Front Range of the Rocky Mountains. Over 500 miles of streams and 550 miles of man-made canals, ditches, and pipelines flow through the watershed, which have direct impacts on water quality.

The watershed is highly influenced by human activity including residential, industrial, agricultural, and recreational activities. The South Platte River changes dramatically as it flows from its headwaters out onto the eastern plains of Colorado, both naturally and because of human-induced influences.

Segment 15 – Upper South Platte River

Segment 15 of the South Platte River begins at a point immediately below the Burlington Ditch diversion structure, which is located just below 50th Avenue and Franklin Street in Denver. The segment ends immediately below the South Platte River confluence with Big Dry Creek near Fort Lupton (Figure 1). The segment is approximately 26 miles long and receives major stream tributary inflows from Sand Creek and Clear Creek. Several municipal dischargers are present on this segment, including the RWHTF, NTP, South Adams County Water and Sanitation District, and the City of Brighton's Wastewater Treatment Plant. Industrial dischargers are also present on the segment, including the Xcel Energy Cherokee Generating Station, Suncor oil refinery on Sand Creek, and numerous sand and gravel mining operations.

The segment is highly regulated for water rights, with several ditch companies withdrawing water at various times during the year. At the head of the segment, the Burlington diversion draws water to fill a series of reservoirs, including Barr Lake. The Fulton Ditch, Brantner Ditch, Brighton Ditch, and Lupton Bottoms all divert water out of Segment 15 below the RWHTF discharge. These diversions have the capacity and appropriation rights to divert the entire flow of the South Platte River during dry to average years. During low flow periods (late summer, autumn, and winter), the natural flows upstream of Metro's discharge are minimal.

Land use around Segment 15 was historically agriculture but is becoming increasingly urbanized. Urban land use close to the river is only predicted to increase in coming years, which can affect the river through increased stormwater and nonpoint source pollution.

Segment 1a – Middle South Platte River

Segment 1a of the South Platte River extends from a point immediately below Big Dry Creek to a point immediately below the confluence with the St. Vrain near Platteville, Colorado (Figure 1). The segment is approximately 17 miles long and is influenced by no major tributaries other than Big Dry Creek and Little Dry Creek. Only minor discharges are present on the segment, including the Fort Lupton Wastewater Treatment Plant and the Platteville Treatment Plant.

Like Segment 15, Segment 1a flow is highly managed by water rights with six major ditch diversions along the segment: Platteville Ditch, Platte Valley Canal (a.k.a. Evans Ditch), Meadow Island Ditches 1 and 2, Farmers Independent Ditch, and Western Mutual Ditch. The river is a gaining stream in Segments 15 and 1a, meaning that groundwater flows into the river, often keeping it from drying up completely. Sampling by Metro continues through Segment 1a to document water quality.

Land use around Segment 1a remains largely agricultural with a few small urban centers along the river, including Ft. Lupton and Platteville. Livestock and agriculture occur very close to the river, potentially contributing to nonpoint source pollution.

Segment 4 – Middle South Platte – Barr and Milton Reservoir

Located northeast of the Denver metropolitan area, Barr Lake (Barr) and Milton Reservoir (Milton) are warm water plains reservoirs principally filled through surface water diversions from the South Platte River at the Burlington Ditch and Platte Valley Canal headgates, respectively. Each reservoir holds a maximum storage capacity of approximately 30,000 acre-feet. In the early 1900s, the Farmer’s Reservoir and Irrigation Company (FRICO) purchased and enhanced the two reservoirs to regulate and store water for agricultural use.

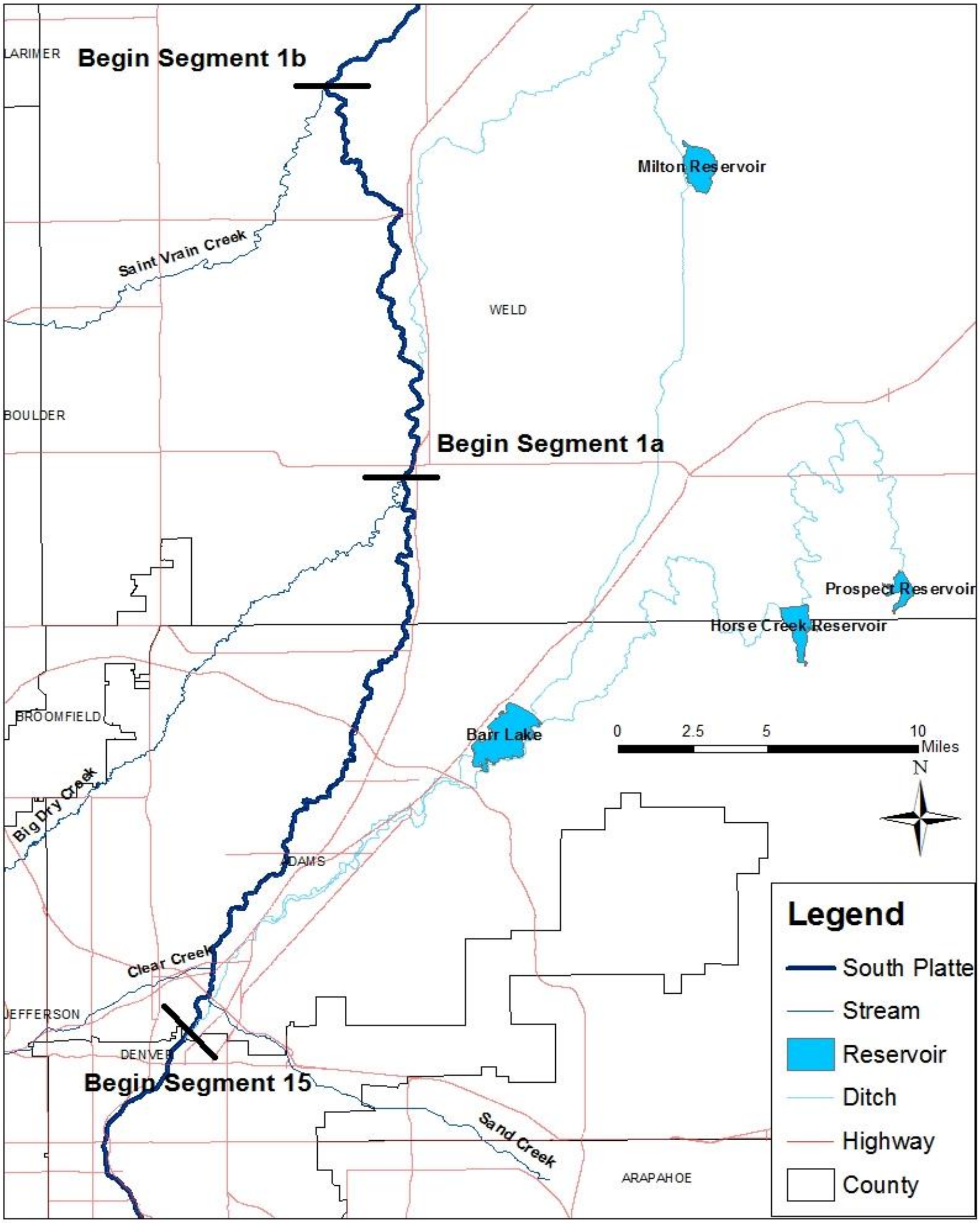


Figure 1. Map of Segments 15 and 1a of the South Platte River.

Monitoring Programs

Monitoring the condition of the aquatic environment requires sampling of physical habitat, water chemistry, biological condition, and flow. As conditions change, sampling techniques may be added or modified to gain additional insight or provide statistical rigor. Sampling may also be modified in response to changes in regulatory requirements or scientific advancement. The data collected during sampling events are not only used by Metro staff but are also submitted to state and national data collection centers. Data collected by Metro are used in a variety of settings from classrooms to state and national resource management agencies. Therefore, it is imperative that all data are collected and managed according to all standardized protocols. Maintaining high standards of data integrity over time requires that Metro personnel are adequately trained in acceptable field methods, sample handling, and data acquisition. The "Water Quality Division Procedural Manual" details all the relevant field sampling protocols for Metro's various monitoring programs. This procedural manual is reviewed and updated annually and provides more detail than presented in this general water quality report.

The Water Quality Division's monitoring programs consist of bi-weekly sampling of the South Platte River (in accordance with SPCURE monitoring agreements), bi-weekly sampling of Barr and Milton (monthly during the winter), quarterly monitoring of 20 groundwater wells co-located with the stream sampling sites, annual biological (fish and macroinvertebrates) sampling, and annual physical habitat evaluations. In addition to these regular monitoring programs, the Water Quality Division also conducts special studies, including sampling the South Platte River monthly to the Nebraska border and occasional sampling of ditches to determine the water quality of inflows to the reservoirs. Metro also conducts 30-hour studies to document diurnal variations in water quality to support the South Platte River Water Quality Model.

As part of these regular and special water quality studies, in situ field data (DO, temperature, turbidity, pH, specific conductance) are collected. Since 2007, the Water Quality Division has used In-Situ Multi-parameter AT600 probes to collect these field data. Before and after each use, the probes are calibrated and end-calibrated to ensure that measurements taken will be within an acceptable range (In-Situ Technical Note: *Aqua TROLL 500 and Aqua TROLL 600 Sensor Summary,* 2017). Depending on the objectives of the monitoring program, water samples are also collected and delivered to Metro's laboratory for further analysis. The following section briefly outlines the sampling protocols and associated water quality data for the regular monitoring programs.

Streams Program

Bi-Weekly Streams Sampling

The South Platte River, RWHTF and NTP Final Effluents, Sand Creek, Clear Creek, and Big Dry Creek are monitored regularly for several water quality parameters as part of the streams monitoring program. A total of 22 sites are sampled (Table 1).

Site	Description	Latitude	Longitude
SP-58	South Platte River at 58th Avenue	39.801	-104.960
HUMBLE	Humble Creek at RWHTF South Bridge	39.803	-104.957
SP-62	South Platte River at 62nd Avenue	39.807	-104.958
SP-64	South Platte River at 64th Avenue	39.812	-104.959
NFE	Robert W. Hite Treatment Facility North Final Effluent (PC)	39.813	-104.954
SFE	Robert W. Hite Treatment Facility South Final Effluent (PC)	39.813	-104.954
SC	Sand Creek on Burlington Ditch Flume	39.810	-104.951
BD-64	Burlington Ditch at 64th Avenue	39.805	-104.952
SP-CC	South Platte River 100 yards upstream confluence with Clear Creek	39.827	-104.949
CC	Clear Creek at York Street	39.828	-104.959
SP-88	South Platte River at 88th Avenue	39.856	-104.938
SP-104	South Platte River at 104th Avenue	39.885	-104.902
SP-124	South Platte River at 124th Avenue	39.923	-104.867
SP-160	South Platte River at 160th Avenue	39.987	-104.832
NTP-SPR	Northern Treatment Plant Effluent leaving Pond #3	40.001	-104.825
SP-RD8	South Platte River at County Road 8	40.044	-104.824
BDC	Big Dry Creek at mouth USGS Gage Station 067720990	40.069	-104.833
BDC-8	Big Dry Creek at Road 8	40.044	-104.849
SP-FTL	South Platte River at Colorado Highway 52 in Fort Lupton	40.080	-104.821
SP-RD18	South Platte River At Weld County Road 18	40.116	-104.818
SP-RD28	South Platte River at Weld County Road 28	40.188	-104.829
SP-RD32.5	South Platte River at Weld County Road 32.5	40.225	-104.850

Table 1. Sampling locations for bi-weekly streams sampling.

Sampling occurs on every 1st and 3rd Wednesday of the month throughout the year in accordance with the SPCURE monitoring program. In addition to the field data recorded from the In-Situ multi-parameter probe, samples are analyzed for metals and nutrients (Table 2).

Field Parameters	Metals	Nutrients and Other Parameters
Temperature, Dissolved Oxygen, Conductivity, pH, Turbidity	*Total Fraction*: Ag, As, Be, Ca, Cd, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, Pb, Se, Sb, Zn *Dissolved Fraction:* Ag, Ca, Cd, Cr, Cu, Fe, K, Na, Mg, Mn, Ni, Pb, Se, Zn	Total Phosphorus, Orthophosphate, Ammonia, Nitrite, Nitrate and Nitrite (NO_5), TKN, Total Dissolved and Suspended Solids, Alkalinity, Hardness, Chloride, Sulfate, *E. coli*, BOD, CBOD, TOC, COS

Table 2. Parameters for bi-weekly streams sampling.

Longitudinal Nutrient Study

The Water Quality Division also conducts nutrient water quality sampling monthly downstream of the regular stream monitoring segments 15 and 1a of the South Platte River. This special study area begins at Weld County Road 8 and continues downstream along the Lower South Platte River, terminating near the Nebraska border at Julesburg (Figure 2). There are a total of nine sampling locations (Table 3).

Site	Description	Latitude	Longitude
SP-RD8	South Platte River at County Road 8	40.044	-104.824
Milliken	South Platte River at Hwy 60 near Milliken	40.320	-104.811
Kersey	South Platte River at Hwy 37 at Kersey	40.412	-104.563
Goodrich	South Platte River at Hwy 39 at Goodrich	40.342	-104.060
Fort Morgan	South Platte River at Hwy 52 at Fort Morgan	40.268	-103.801
Hillrose	South Platte River at County Road 33 at Hillrose	40.359	-103.503
Iliff	South Platte River at County Road 55 at Iliff	40.748	-103.056
Crook	South Platte River at Highway 55 at Crook	40.842	-102.805
Julesburg	South Platte River at Hwy 385 at Julesburg	40.973	-102.251

Table 3. Sampling locations for the longitudinal nutrient study.

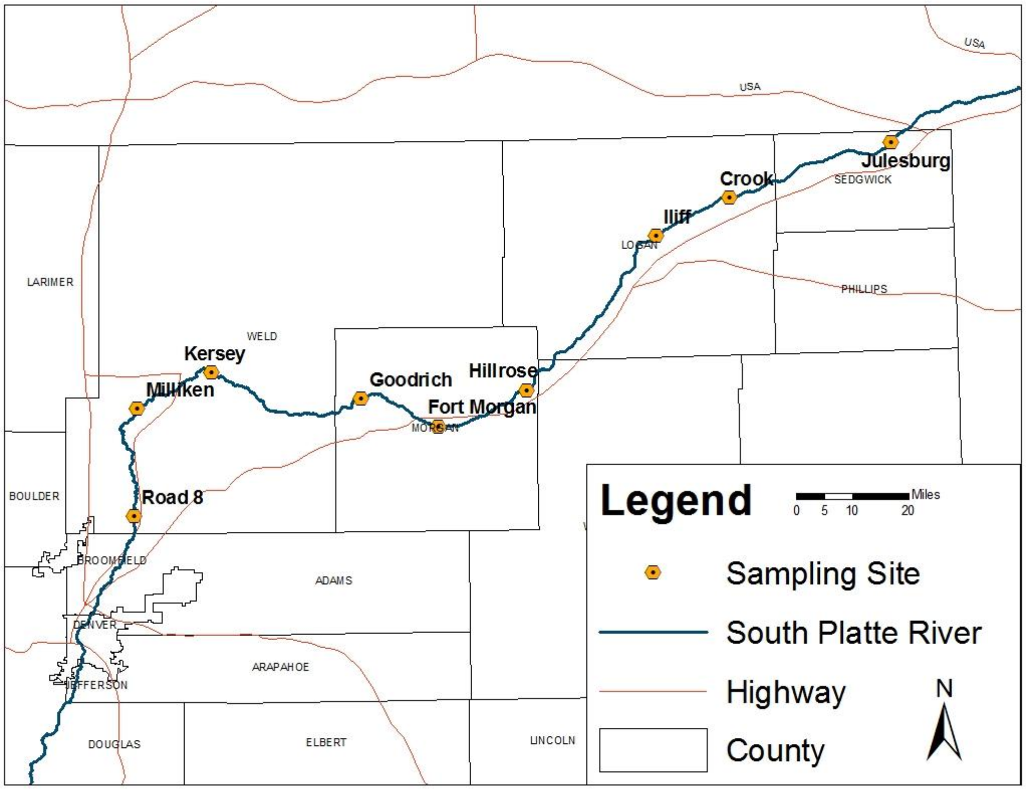


Figure 2. Map of longitudinal nutrient study locations.

In addition to the field data recorded from the In-Situ multi-parameter probe, samples are analyzed for nutrients and alkalinity (Table 4).

Field Parameters	Metals	Nutrients and Other Parameters
Temperature, Dissolved Oxygen, Conductivity, pH, Turbidity	None	Total Phosphorus, Ammonia, Nitrate (NO_5), TKN, Alkalinity, Total Nitrogen

Table 4. Parameters for the longitudinal nutrient study.

Biological Sampling

Fish Sampling

Fish diversity and abundance estimates are common ways to evaluate in-stream aquatic life. Electrofishing is currently one of the most reliable methods for sampling fish species and populations in streams. Unfortunately, low capture efficiencies are still inherent in the method, especially when working with small plains native species. Unlike game fish samples, sampling efficiently enough to create population estimates of plains species is challenging. Instead, sampling is targeted at obtaining a representative species composition at each site, different life stages of those species, and the relationships between life stages. Although the sampling procedures described here are not quantitative in a population sense, consistent sampling techniques are vital to obtaining valuable, relevant, and comparable information. Water Quality Division fisheries data are used by Metro staff, as well as the CPW to evaluate freshwater fish populations. Fish sampling is completed along a 100-meter stream reach at 14 different sites (Table 5). The locations are typically close in proximity to the bi-weekly stream sampling locations. After one thorough pass covering the entire 100-meter stream reach, the species, length, and weight of the individual fish are recorded. Length and weight data are only recorded for the first 100 individuals for each species; counts are made for the remaining individuals of the specific species.

Site	Description	Latitude	Longitude
SPR-1	South Platte River at 31st Ave	39.769	-104.982
SPR-1.8	South Platte River at 58th Ave at Metro South Bridge	39.800	-104.961
SPR-2	South Platte River at 64th, Denver, Adams County	39.812	-104.956
SPR-3.5	South Platte River upstream of Confluence with Clear Creek	39.827	-104.948
SPR-3.8	South Platte River at Phase IV Habitat Improvements (88th Ave.)	39.859	-104.927
SPR-4	South Platte River 1/2 mile downstream of 88th Ave	39.863	-104.928
SPR-5	South Platte River 1 mile upstream of 120th Ave	39.908	-104.889
SPR-5.5	South Platte River at Habitat Site Phase 2	39.912	-104.890
SPR-6	South Platte River 1/2 mile upstream of 124th Ave	39.919	-104.871
SPR-6.5	South Platte River at 144th (Phase 2)	39.962	-104.852
SPR-7	South Platte River at 160th Ave, Brighton	39.989	-104.830
SPR-8	South Platte River at 168th (Upstream of the NTP)	40.002	-104.825
SPR-8.5	South Platte River at Cty Rd 4 (Downstream of NTP)	40.012	-104.822
SPR-9	South Platte River 1 mile upstream of Big Dry Creek	40.060	-104.826
SPR-10	South Platte River 1/4 mile downstream of County Road 18	40.107	-104.823

Table 5. Sampling locations for biological assessment.

Benthic Macroinvertebrate Sampling

The objectives of benthic macroinvertebrate sampling are to assess invertebrate diversity within the river channel and overall aquatic life health. Kick net samples are taken in riffles using methods described in Appendix B of Water Quality Control Commission (Commission) Policy 10-1 (CDPHE 2010). Dip net samples are also taken to evaluate invertebrate populations on targeted habitat such as snags and vegetation. Benthic invertebrate sampling is completed in locations within the same 100-meter stream reaches sampled during electrofishing. If suitable locations for sampling are not available because of stream conditions, benthic invertebrates may be sampled in locations immediately adjacent to the 100-meter fish sampling reach.

For both the kick and dip net samples, the contents of the nets (benthic macroinvertebrates) are picked out with tweezers and placed into collection jars filled with a 90% solution of ethanol for preservation. The macroinvertebrates are counted and identified by a consultant, and the results are sent back to Metro for data analysis.

Habitat Sampling

The objective of stream habitat assessment is to qualitatively assess physical conditions that indicate the quantity and quality of aquatic habitat within the stream reach. This assessment, in addition to being important to determining site characteristics that may be important to aquatic species population dynamics (e.g., distribution, diversity, and population), enables comparison of stream reaches across years, between sites, and can be used to choose sites with similar habitats for a “before-after/control-impact” analysis of the habitat improvements constructed by Metro.

The Water Quality Division also completes a Rapid Bio-Assessment form for the stream bed, channel, banks, and adjacent land areas for the sample stream reach. Each of ten assessment items (including epifaunal substrate, pool substrate characterization, pool variability, sediment deposition, and channel flow status) are ranked numerically along a scale that defines conditions as “optimal,” “suboptimal,” “marginal,” or “poor.”

Currently, no analysis is performed on the habitat data; they are collected to assist in the interpretation of fisheries and macroinvertebrate data. Understanding habitat conditions can assist in determining the cause(s) for species distribution patterns.

Reservoir Program

Metro conducts regular reservoir monitoring to provide reliable information to stakeholder groups to assist with making management decisions for each reservoir. The goal is to define and identify water quality problems, understand the causes, use the collected data to build a model to help predict water quality changes, and to begin addressing the problems with rehabilitation that fits both the reservoir’s capabilities and the needs of the users.

Barr Lake and Milton Reservoir are sampled bi-weekly from March–November and once a month from December–February. In addition, Horse Creek Reservoir and Prospect Reservoir are monitored once a month from May to September. For each reservoir, sampling is conducted from a boat near the dam, in the deepest area of the reservoir (Table 6). At each site, epilimnetic samples are collected at a depth of 1 meter, and hypolimnetic samples are collected 1 meter above the sediment. The hypolimnetic sample is eliminated when water depth is less than three meters deep. Profile data are collected from the surface to the bottom at half meter intervals.

Biological data includes monthly collection of zooplankton and phytoplankton samples. Water clarity, another indirect measurement of algae growth, is measured using an 8-inch, black and white Secchi disk.

Site	Description	Latitude	Longitude
BL03B	Barr Lake Dam, Hypolimnion	39.961	-104.751
BL03P	Barr Lake Dam, Epilimnion	39.961	-104.751
HCR02B	Horse Creek Reservoir, Dam, Hypolimnion	40.007	-104.583
HCR02P	Horse Creek Reservoir, DAM, Epilimnion	40.007	-104.583
MR03B	Milton Reservoir, Dam Location, Hypolimnion	40.238	-104.638
MR03P	Milton Reservoir, Dam Location, Epilimnion	40.238	-104.638
PR01B	Prospect Reservoir, Dam, Hypolimnion	40.018	-104.510
PR01P	Prospect Reservoir, Dam, Epilimnion	40.018	-104.510

Table 6. Sampling locations for reservoirs.

At each site, a multiparameter sonde is used to collect field parameters (turbidity, pH, DO percent and concentration, conductivity, and temperature) at each 0.5-meter interval along the water column, starting at the surface and progressing to the bottom sediment. In addition to this field data, the epilimnetic and hypolimnetic samples are lab-analyzed for a variety of parameters (Table 7).

Field Parameters	Metals	Nutrients and Other Parameters
Temperature, Dissolved Oxygen Percent Saturation and concentration, Conductivity, pH, Turbidity, Secchi Depth	*Total Fraction*: Ag, As, Be, Ca, Cd, Cr, Cu, Fe, K, Mo, Mg, Mn, Na, Ni, Pb, Se, Sb, S, Zn *Dissolved Fraction:* Ag, Ca, Cd, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, S, Se, Pb, Zn	Total Phosphorus, Orthophosphate, Ammonia, Nitrite, Nitrate (NO_5), TKN, Total Suspended Solids, Alkalinity, TOC, COS, Phytoplankton, Zooplankton, Chlorophyll *a*

Table 7. Parameters for reservoirs.

Groundwater Program

To better understand how shallow groundwater affects and interacts with the South Platte River in Segments 15 and 1a, the Water Quality Division initiated a groundwater monitoring program in 2002. The groundwater data are used to help recalibrate the South Platte River Water Quality Model which occurs approximately every five years. Monitoring is conducted four times a year in February, May, August, and November. The 20 groundwater wells are co-located with the bi-weekly stream sites (Table 8). Some of the sampling wells belong to the U.S. Geological Survey (USGS) and are part of its long-term groundwater monitoring program. The other wells were constructed by Metro on private property with landowner permission.

Site	Description	Latitude	Longitude
GW-104W	104th Avenue, Southwest Corner	39.8839	-104.9029
GW-124W	124th Avenue, Northwest Corner	39.9236	-104.8675
GW-160E	160th Avenue, Northeast Corner	39.9875	-104.8313
GW-160W	160th Avenue, Northwest Corner	39.9879	-104.8322
GW-CR32.5E	County Road 32.5, Northeast Corner	40.2252	-104.8489
GW-CR32.5W	County Road 32.5, Northwest Corner	40.222	-104.8517
GW-52E	Highway 52, Northeast Corner	40.0808	-104.8288
GW-64W	64th Avenue, West	39.807	-104.9594
GW-66E	Highway 66, Southeast Corner	40.2053	-104.8272
GW-66W	Highway 66, Southwest Corner	40.2053	-104.8304
GW-76E	Highway 76, East Side Platte	39.8259	-104.9485
GW-88E	88th Avenue, Northeast Corner	39.857	-104.9373
GW-88W	88th Avenue, Northwest Corner	39.857	-104.9383
GW-BDCW	Big Dry Creek, West	40.0695	-104.8327
GW-CR18E	County Road 18, Southeast Corner	40.1162	-104.8176
GW-CR18W	County Road 18, Northwest Corner	40.1177	-104.8207
GW-CR28E	County Road 28, Southeast Corner	40.1883	-104.8284
GW-CR28W	County Road 28, Southwest Corner	40.1879	-104.8302
GW-MRE	McKay Road, East Side	39.874	-104.9112
GW-MRW	McKay Road, West Side	39.8748	-104.9106

Table 8. Sampling locations for groundwater.

After recording the depth to groundwater, the wells are purged for 10 minutes at 4 liters/minute. After recording field parameters with the multi-parameter probe, a peristaltic pump is used to collect the water samples for analysis (Table 9).

Field Parameters	Metals	Nutrients and Other Parameters

Temperature, Dissolved Oxygen concentration, Conductivity, pH, Turbidity	*Total Fraction*: Ag, As, Be, Ca, Cd, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, Pb, Sb, Se, Zn	Total Phosphorus, Total Dissolved Phosphorus, Orthophosphate, Ammonia, Nitrite, Nitrate and Nitrate (NO_5), TKN, Alkalinity, TOC

Table 9. Parameters for groundwater.

A summary of the aggregated groundwater is provided in this report as Appendix 3. If you would like to see more specific groundwater data, the information is available upon request.

All Sampling Sites

The Water Quality Division does a thorough evaluation and monitoring of downstream water quality conditions. This comprehensive monitoring of the South Platte River, tributaries, groundwater, ditch diversions, and major reservoirs allows for a complete understanding of downstream conditions. Because of Metro's proactive efforts to understand the biological and chemical conditions, the South Platte River and BMW are the most monitored watersheds in Colorado (Figure 3).

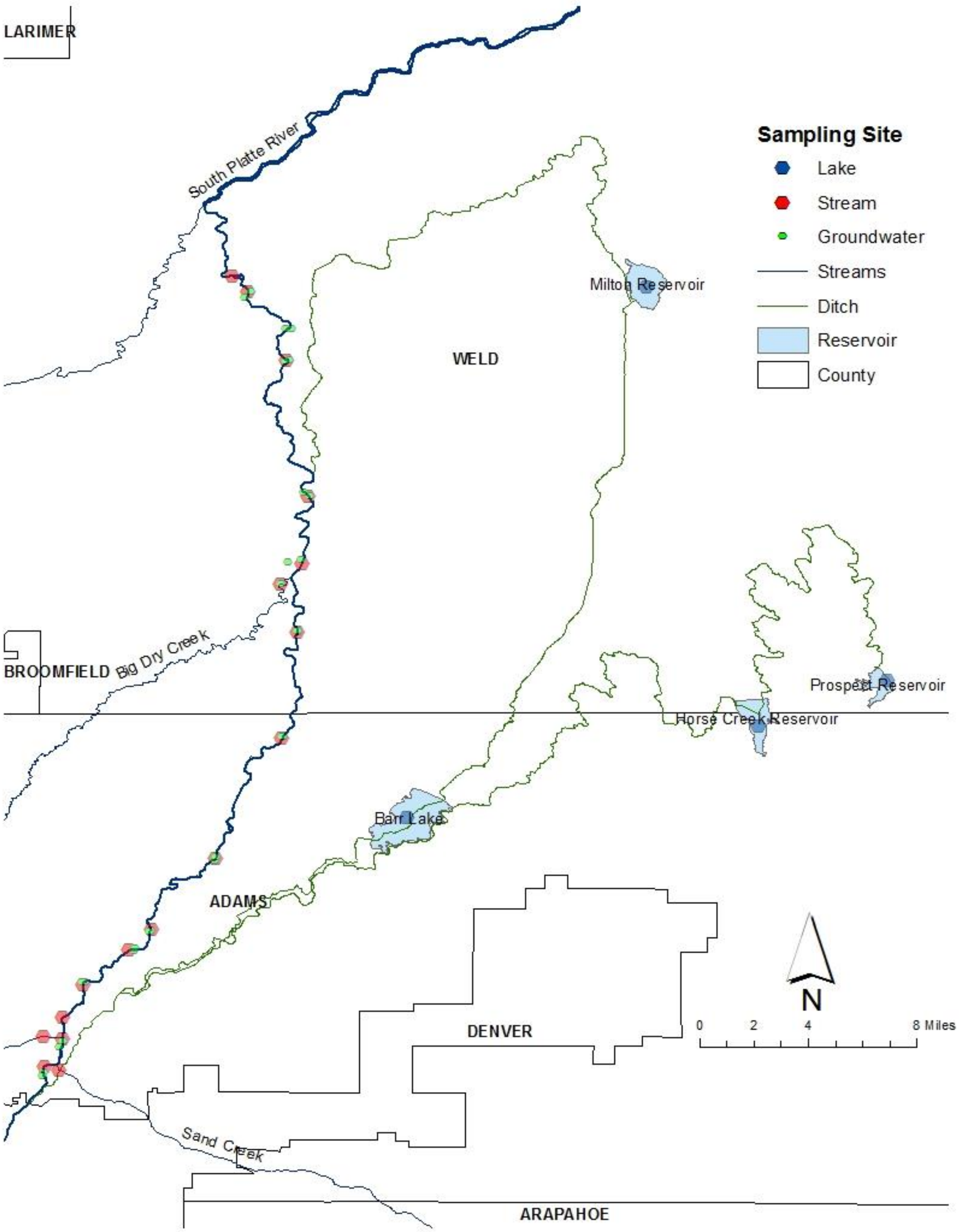


Figure 3. Location map of all Metro water quality sampling sites.

Data Analysis Methods

Method Detection Limits (MDL)

The method detection limit (MDL) is defined as the lowest concentration of a parameter of interest that can be reported with a 99% confidence that reliably measures the presence of the given constituent in the water sample. The MDL is based on the specific method and instrumentation used in the analysis. Therefore, as instrumentation changes over time, the MDL is likely to change as well. Current and historic MDLs for Metro analyses can be found in Appendix 2.

Concentrations lower than the MDL are reported as 0 as part of Metro's QA/QC protocols. There are various ways to handle data when the results are lower than the MDL, including labeling them as "Non-Detects" or less-thans (ex. <0.10 μg/L). A few of the analysis parameters were commonly at or below the MDL concentration including:

- Total and Dissolved Metals – most notably antimony, arsenic, beryllium, chromium, lead, and silver
- CBOD – especially in the downstream sampling sites in Segment 1a

The values are retained as part of Metro QA/QC protocols in part because the MDL will likely decline over time due to improvements in laboratory instrumentation and analytical methods.

Analysis

Time Series Plots

Time series plots of water quality parameters vs. time provide some of the most basic, but important relationships in water quality data analysis. These graphs can be used to demonstrate seasonal patterns, long-term trends, evidence of outliers, and random variability within the dataset. They also provide a visual representation of collection frequency and data gaps. In some of these time series graphs, connecting lines are used to highlight trends or seasonal patterns. It is important to note that these lines are only used as a visual aid for interpretation. They do not suggest that data points can necessarily be interpolated or extrapolated between and after recorded observations. Also, unless otherwise noted with statistical tests of significance, these lines do not imply a significant relationship.

Box and Whisker Plots

Box-and-whisker plots are included in this report because they provide a great deal of information about the distribution of the data in a simple visual representation. These plots can be used as a simple visual test of significance of change between groups by looking to see if the two groups generally overlap or not. The box in the box-and-whisker plot represents the middle 50% of the data (bottom = 25th percentile, horizontal line inside box = 50th percentile, top = 75th percentile) and the whiskers extend to above the box to the 90th percentile and below to the 10th percentile. The circles outside of these whiskers indicate the extreme values in the group.

Basic Summary Statistics

These simple statistics provide important quantitative measure of central tendency and data variability. In this report, the following summary statistics may be included:

- Number of Values
- Minimum and Maximum values
- 85^{th} Percentile
- Median and Mean Values
- Standard Deviation

Quality Assurance/Quality Control

Duplicate and blank samples are necessary for QA/QC of samples that are collected. Duplicates and blanks are completed once for each sampling effort. For example, a single field blank is prepared for all groundwater samples (single sampling effort), in contrast to one field blank for each *day* of groundwater sampling. Duplicates and blanks are preserved following the procedures outlined for normal sample collection. Additionally, a trip blank is used to test washing procedures and subsequent water quality analyses.

Data Analysis

Streams Program

Water Quality

Metro has been actively engaged in assessing the South Platte River for decades. Sampling of the river has varied over the years, adapting to serve the needs of Metro using a large scientifically-derived dataset. Metro staff currently sample 12 sites along the river, along with multiple tributaries. Not only are the data evaluated by Metro staff, but they also provide the foundation for the South Platte River Water Quality Model. The model provides unique site-specific information that supports water quality assessment and discharge permit evaluation activities. Few rivers in the United States have similar water management challenges, e.g., a natural system that fluctuates dramatically and a gaining stream with extremely high levels of nutrient metabolism. Having substantial volumes of site-specific data allows the development of an accurate understanding of the water quality and biotic integrity of the South Platte River.

In terms of water quantity, 2022 was an average year. The flows from January to April were low, typical of late-winter conditions along the South Platte River (Figure 4). There was not a prolonged period of high flows related to snowmelt in 2022, although there were multiple storms from May and June which contribute to scouring flows. The highest daily average flow at the Henderson stream gage (SP-124) was only 2580 cfs, which occurred June 1st. The flows declined to baseflow conditions in the early fall, with only minor storms that led to brief, but small increases in daily average flow. Figure 5 demonstrates the typical streamflow patterns in Segment 15 and 1a. During the low-flow period between September and April, flows upstream of the RWHTF are very low and the river downstream is effluent-dominated. The river gains flow between 124th Avenue and Weld County Road 18 due to groundwater seepage, tributary flow (Big Dry Creek) and permitted discharges (Brighton WWTP, NTP, Fort Lupton WWTP). Measurable precipitation events, as measured at the Hite facility weather station, are noted by the black triangles. As expected, these storms correspond to brief increases in flow in the form of stormwater runoff. For the five-year flow record between 2017 and 2021, 50% of the time the river immediately downstream of the RWHTF outfalls is comprised of over 95% treated effluent. The river was slightly less effluent dominated when looking at 2022 data only. For the majority of the year, the river was over 91% effluent (Figure 6).

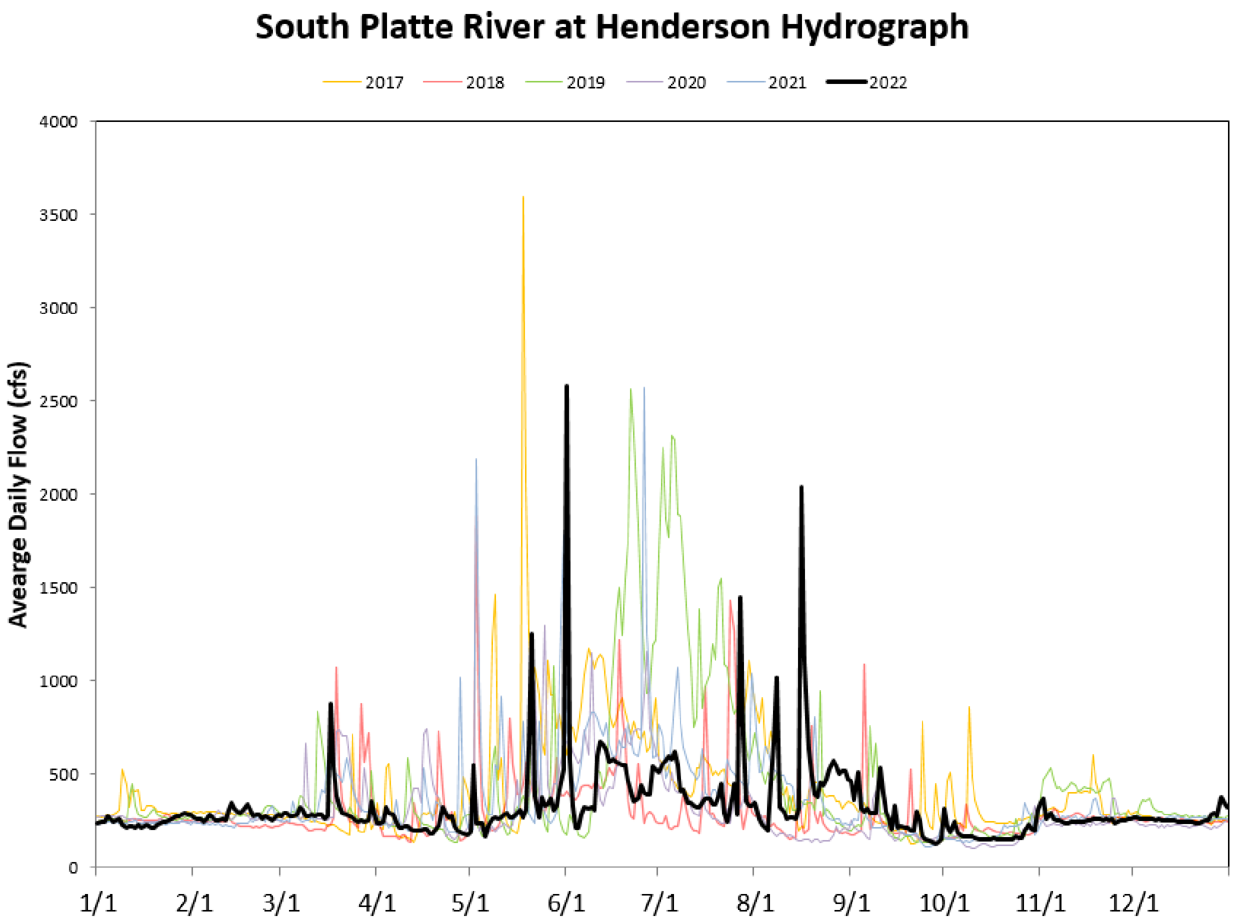


Figure 4. 2022 hydrograph at Henderson gage (SP-124).

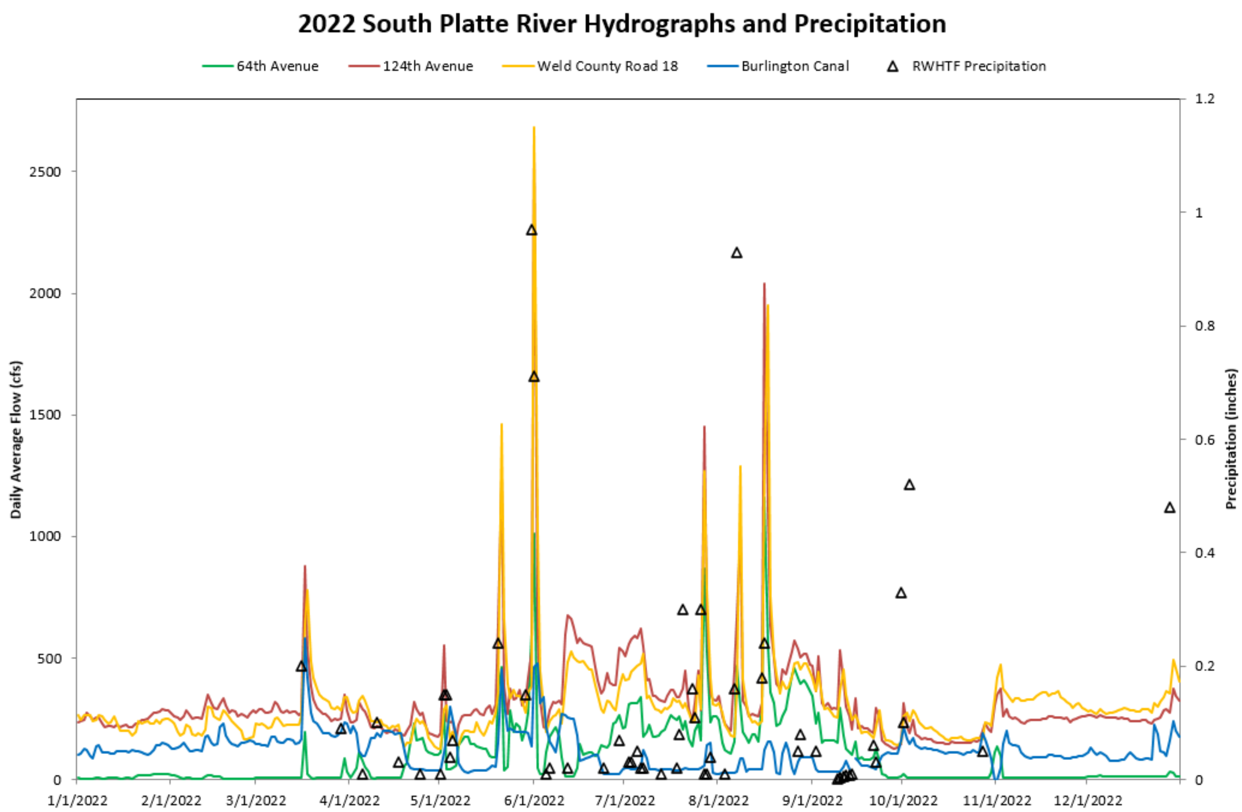


Figure 5. 2022 hydrographs at three locations along Segment 15 and 1a.

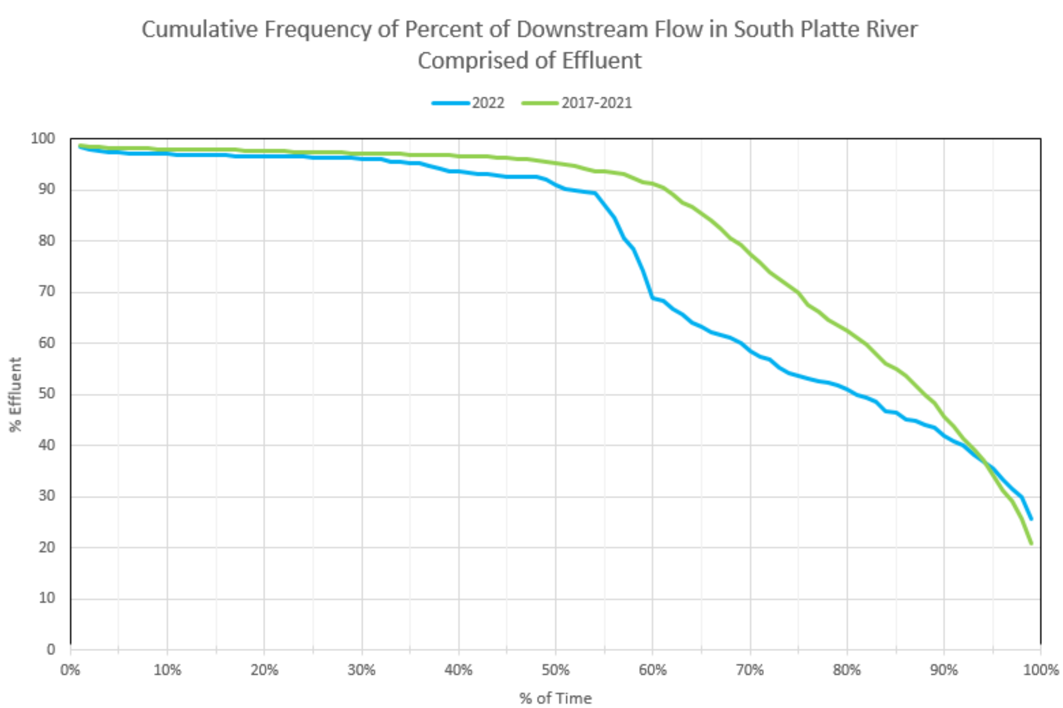


Figure 6. Cumulative frequency plot of percent effluent downstream of RWHTF outfalls.

General Chemistry

Stream sampling occurs twice a month in accordance with the sampling procedures of SPCURE. Each sampling event includes sample analysis for approximately 50 constituents at 22 locations along the river and its tributaries. The results in Table 10 and Table 11 summarize the conditions in Segments 15 and 1a respectively. All 2022 data from all the sites in a given Segment are presented together to produce a comprehensive picture of conditions. The summary results give minimum, average, medians , 85^{th} percentiles, and maximum of the data collected. The 85^{th} percentile is commonly used to assess the attainment of water quality standards, such as metals. It is not commonly used for other constituents but can provide insight on the distribution of the data. Further analysis of key constituents is included below.

Tributary data are not presented for this report. Data on the tributaries are typically only used to increase knowledge about water quality in the South Platte River.

Parameter	Fraction	Unit	Count	Minimum	Average	Median	85th Percentile	Maximum
Alkalinity	Total	mg/L	176	63	133	137	153	209
Ammonia-nitrogen	Total	mg/L	168	0.01	0.47	0.35	0.89	2.16
Antimony	Total	ug/L	178	0	0.45	0.4	0.6	0.9
Arsenic	Total	ug/L	178	0.6	1.17	1.1	1.5	2.5
Beryllium	Total	ug/L	178	0	0.02	0	0.02	0.31
BOD		mg/L	175	1	4.83	4	9	14
Bromide	Total	mg/L	178	0	0.14	0.15	0.19	0.26
Cadmium	Dissolved	ug/L	178	0.03	0.87	0.23	0.53	13.1
Cadmium	Total	ug/L	178	0	1.00	0.3	0.7	13.2
Calcium	Dissolved	mg/L	178	27.5	69.8	68.5	85.9	128
Calcium	Total	mg/L	179	27.4	71.2	68.9	83.4	213
CBOD		mg/L	165	0	1.97	2	3	5
Chloride	Total	mg/L	178	0.1	152	143	213	325
Chromium	Dissolved	ug/L	178	0	0.60	0.5	0.9	2.6
Chromium	Total	ug/L	178	0	1.42	0.8	1.99	42.2
Conductivity	Total	umho/cm	178	147	1235	1240	1637	2500
Copper	Dissolved	ug/L	178	1.1	2.20	2.1	2.65	8.2
Copper	Total	ug/L	178	1.8	4.95	4.1	6.85	22.8
Dissolved oxygen		mg/L	178	5.13	8.08	7.85	9.5	11.9
Escherichia coli		EC/100mL	178	27	651	261	1847	2420
Fluoride	Total	mg/L	178	0	0.74	0.75	0.88	1.32
Hardness, carbonate		mg/L	178	96	248	245	289	484
TIN (ammonia, nitrate and nitrite)	Total	mg/L	65	0.92	3.65	3.49	5.02	8.7

Nitrate (as NO_5)	Total	mg/L	111	0.63	2.88	2.71	4.24	6.95
Iron	Dissolved	mg/L	178	0.03	0.12	0.11	0.17	0.46
Iron	Total	mg/L	178	0.16	0.79	0.41	1.03	5.41
Kjeldahl nitrogen	Total	mg/L	169	0.02	1.56	1.5	2.48	3.9
Lead	Dissolved	ug/L	178	0	0.21	0.2	0.4	0.6
Lead	Total	ug/L	178	0.3	1.93	1.1	2.95	15.1
Magnesium	Dissolved	mg/L	178	6.47	17.5	18.0	20.7	33.3
Magnesium	Total	ug/L	179	6.57	17.8	17.4	21.1	66.7
Manganese	Dissolved	ug/L	178	8.1	135	133.5	209	366
Manganese	Total	ug/L	178	69.5	198	188	262	378
Molybdenum	Total	ug/L	178	3.34	6.85	6	9.74	13.5
Nickel	Dissolved	ug/L	178	0.8	2.30	2.2	2.8	7.1
Nickel	Total	ug/L	178	1.6	2.78	2.55	3.25	16.3
Nitrite	Total	mg/L	178	0	0.30	0.21	0.54	1.19
Nitrogen	Total	mg/L	169	0.97	4.50	4.2	6.26	10.4
Organic Carbon	Dissolved	mg/L	178	0	7.19	7	9	12
Orthophosphate	Dissolved	mg/L	178	0.07	0.30	0.28	0.42	0.97
pH		None	178	6.97	7.83	7.8	8.12	8.7
Phosphorus	Dissolved	mg/L	178	0	0.34	0.32	0.48	0.99
Phosphorus	Total	mg/L	174	0.12	0.44	0.42	0.55	1.19
Potassium	Dissolved	mg/L	178	3.1	11.4	11.8	15.2	24.1
Potassium	Total	mg/L	178	3.7	11.5	11.8	15	24.5
Selenium	Dissolved	ug/L	178	0	1.46	1.4	1.9	2.7
Selenium	Total	ug/L	178	0.5	1.43	1.4	1.85	2.5
Silver	Dissolved	ug/L	178	0	0.01	0	0	0.39
Silver	Total	ug/L	178	0	0.02	0	0.06	0.23
Sodium	Dissolved	mg/L	178	39.9	118	118	165	235
Sodium	Total	mg/L	179	34.7	117	116	156	235
Sulfate	Total	mg/L	178	0.1	137	140	158	373
Temperature, water		deg C	178	1.1	14.6	14.0	21.1	28.3
Total Dissolved Solids		mg/L	170	194	643	643	803	1290
Total suspended solids		mg/L	178	3	30.0	14	39	392
Turbidity		NTU	161	0	14.0	5.03	16.5	134
Zinc	Dissolved	ug/L	178	0	23.3	22.4	34.5	89.9
Zinc	Total	ug/L	170	11	33.8	29.8	42.4	327

Table 10. 2022 summary statistics for Segment 15 of the South Platte River (all sites are combined in this analysis).

Parameter	Fraction	Unit	Count	Minimum	Average	Median	85th Percentile	Maximum
Alkalinity	Total	mg/L	91	74	142	148	161	187
Ammonia-nitrogen	Total	mg/L	89	0.01	0.11	0.07	0.21	0.41
Antimony	Total	ug/L	91	0	0.45	0.4	0.5	1.1
Arsenic	Total	ug/L	91	0.5	1.63	1.4	1.85	11.4
Beryllium	Total	ug/L	91	0	0.05	0	0.10	0.55
BOD		mg/L	90	1	4.24	4	8	14
Bromide	Total	mg/L	90	0.05	0.17	0.17	0.21	0.81
Cadmium	Dissolved	ug/L	91	0	0.19	0.17	0.30	0.39
Cadmium	Total	ug/L	91	0	0.34	0.3	0.4	1.7
Calcium	Dissolved	mg/L	91	35.6	72.3	75.1	82	101
Calcium	Total	mg/L	91	39.5	72.8	74.8	84.8	99.9
CBOD		mg/L	80	0	1.49	1	2	4
Chloride	Total	mg/L	90	51.2	156	153	214	272
Chromium	Dissolved	ug/L	91	0	0.28	0.3	0.5	1.3
Chromium	Total	ug/L	91	0	1.48	0.8	2	10.6
Conductivity	Total	umho/cm	91	263	1288	1343	1602	1912
Copper	Dissolved	ug/L	91	1.9	2.76	2.7	3.2	4.2
Copper	Total	ug/L	91	2.8	7.35	5.1	8.25	39.1
Dissolved oxygen		mg/L	91	6.22	8.76	8.45	10.4	11.9
Escherichia coli		EC/100mL	91	1	490	152	1033	2420
Fluoride	Total	mg/L	90	0.33	0.80	0.8	0.94	1.14
Hardness, carbonate		mg/L	91	138	264	273	307	398
TIN (ammonia, nitrate and nitrite)	Total	mg/L	24	1.21	2.40	2.27	3.37	3.97
Nitrate (as NO_5)	Total	mg/L	69	0.92	2.73	2.6	3.61	5.29
Iron	Dissolved	mg/L	91	0	0.08	0.07	0.1	0.75
Iron	Total	mg/L	91	0.11	1.36	0.58	1.9	10.6
Kjeldahl nitrogen	Total	mg/L	89	0.05	1.20	1.1	1.7	3.7
Lead	Dissolved	ug/L	91	0	0.29	0.2	0.3	8.4
Lead	Total	ug/L	91	0.2	3.95	1.8	5.35	34.4
Magnesium	Dissolved	mg/L	91	7.85	19.7	20.5	22.8	34
Magnesium	Total	ug/L	91	9.24	19.9	20.6	23.6	37.1
Manganese	Dissolved	ug/L	91	3.4	67.7	45.8	122	402
Manganese	Total	ug/L	91	6.1	232	177	336	1240
Molybdenum	Total	ug/L	91	3.9	6.35	5.85	8.26	9.9
Nickel	Dissolved	ug/L	91	1.3	2.66	2.7	3.1	3.7
Nickel	Total	ug/L	91	2.3	3.46	3.2	3.65	8.4

Nitrite	Total	mg/L	91	0	0.07	0.05	0.12	0.31
Nitrogen	Total	mg/L	89	1.6	3.81	3.76	4.8	7.3
Organic Carbon	Dissolved	mg/L	91	3	6.05	6	7	9
Orthophosphate	Dissolved	mg/L	90	0.12	0.26	0.26	0.31	0.54
pH		None	91	6.7	8.00	8.05	8.27	8.71
Phosphorus	Dissolved	mg/L	91	0.14	0.29	0.28	0.34	0.59
Phosphorus	Total	mg/L	91	0.17	0.41	0.38	0.56	1.1
Potassium	Dissolved	mg/L	91	5.4	11.3	11.3	14.4	20.8
Potassium	Total	mg/L	91	6.8	11.5	11.6	14.4	21.8
Selenium	Dissolved	ug/L	91	0.6	1.51	1.5	1.8	3.1
Selenium	Total	ug/L	91	0.7	1.50	1.5	1.75	2.9
Silver	Dissolved	ug/L	91	0	0.00	0	0	0.15
Silver	Total	ug/L	91	0	0.06	0	0.11	2.04
Sodium	Dissolved	mg/L	91	44.9	129	133	168	214
Sodium	Total	mg/L	91	47.3	127	131	165	190
Sulfate	Total	mg/L	90	67.8	161	169	184	314
Temperature, water		deg C	91	1.6	13.5	14.5	21.1	23.3
Total Dissolved Solids		mg/L	87	306	687	706	818	934
Total suspended solids		mg/L	91	3	59.4	25	67	736
Turbidity		NTU	79	0	28.1	9.8	24.7	253
Zinc	Dissolved	ug/L	91	7.3	21.0	18.2	30.8	83.3
Zinc	Total	ug/L	87	8.8	37.6	30.9	47.1	168

Table 11. 2022 summary statistics for Segment 1a of the South Platte River (all sites are combined in this analysis).

Nutrients

Nutrient loading has been identified as one of America's most widespread, costly, and challenging environmental problems. Both nitrogen and phosphorus have natural cycles in which they support the growth of plants and animals and neither component is toxic to aquatic life, except for nitrogen as ammonia. Excess nitrogen and phosphorus can cause algal growth, which can have important impacts on DO, pH, and discourage recreational users. Nutrients have become a primary focus for the water quality community in recent years and are regulated in a number of ways. Because total nitrogen (TN) and total phosphorus (TP) are not toxic, typical endpoints for environmental assessment are not available.

In 2012, the Colorado Water Quality Commission (Commission) adopted interim numeric values for TP, TN, and chlorophyll-*a* (Chl-*a*) to be implemented in streams and rivers over the next ten years. In addition, the Commission adopted a control regulation, Regulation 85, to provide a path forward for nutrient reductions at regulated point sources around the state. Metro is striving to provide the most timely and useful data possible to ensure that nutrient regulations are appropriate over time.

Total Phosphorus

Average TP concentrations ranged from 0.38 mg/L at SP-RD32.5 to 0.47 mg/L at SP-124. Prior to 2021, there was a clear longitudinal pattern as the effect of the Metro's RWHTF outfalls could be seen in higher TP concentrations at SP-CC and SP-88. However, since January 2021, the closest site downstream of the RWHTF outfalls (SP-CC), now has similar average TP concentrations compared to upstream of the outfalls.

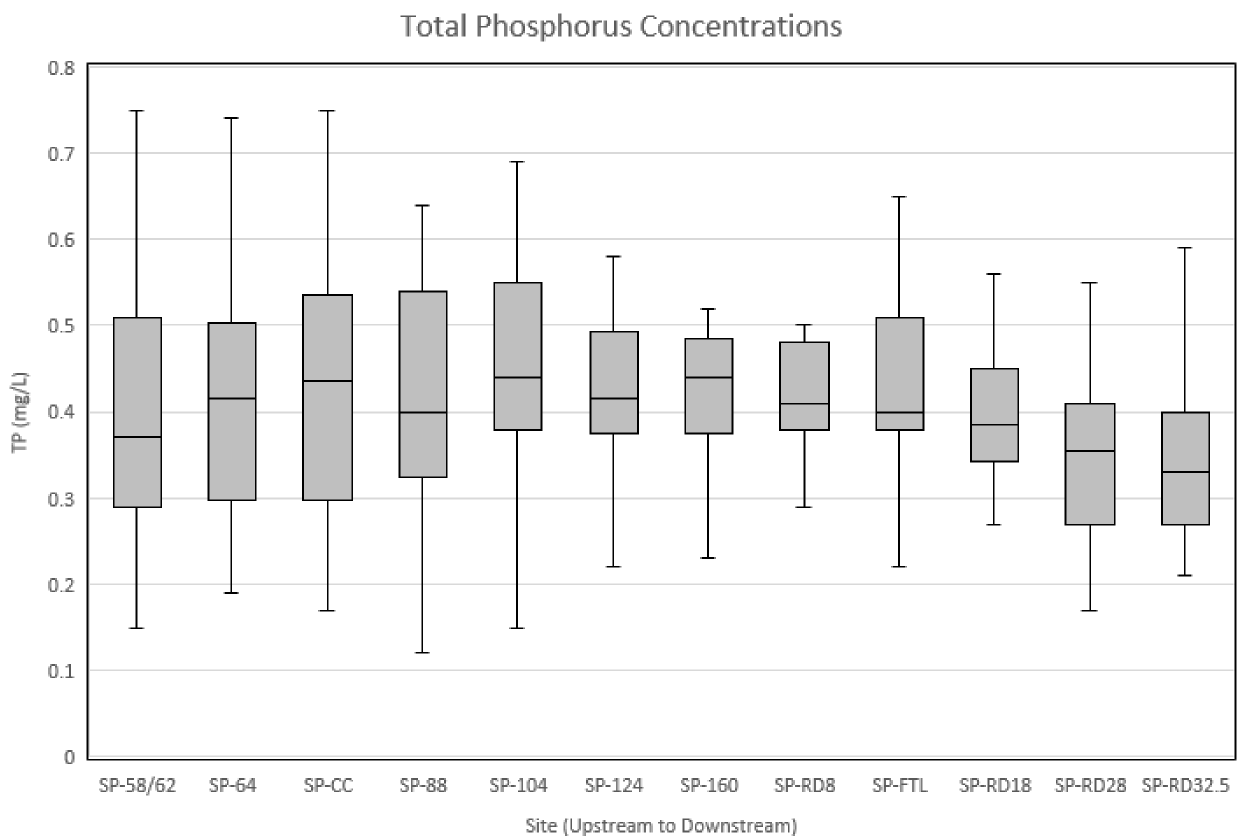


Figure 7. Concentrations of TP from 58th Avenue to Weld County Road 32.5.

Metro began full-scale biological phosphorus removal at the RWHTF facility in January 2021. Past pilot testing in 2015 has shown that there are significant corresponding reductions in in-stream TP concentrations downstream when effluent concentrations of phosphorus are lowered. In the RWHTF South Final Effluent, the average TP concentrations was 0.4 mg/L in 2022 (Figure 8), much lower than the 2017-2020 average TP concentrations of 2.1 mg/L. The total phosphorus concentrations in the RWHTF North Final Effluent and NTP Effluent leaving Pond #3 remained low in 2022, generally below 0.5 mg/L. The bar graphs of average annual TP concentrations at downstream river sites reflect the overall reductions of in-stream TP concentrations since 2015

(Figure 9). The Water Quality Division staff will continue to document changes in river conditions as biological nutrient removal is implemented throughout the RWHTF in coming years.

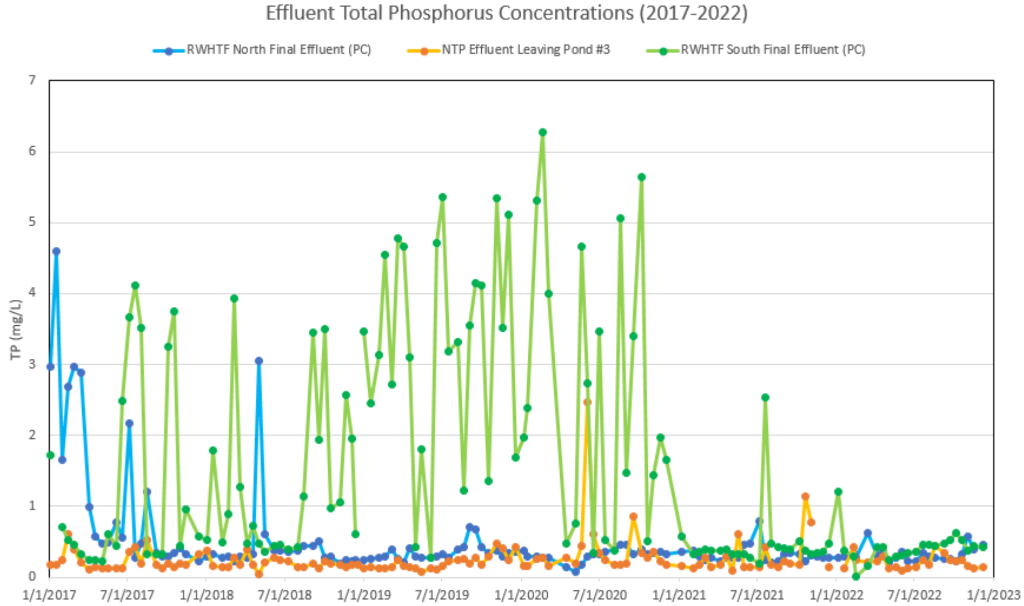


Figure 8. 2017-2022 time series of total phosphorus (TP) concentrations in the final effluent.

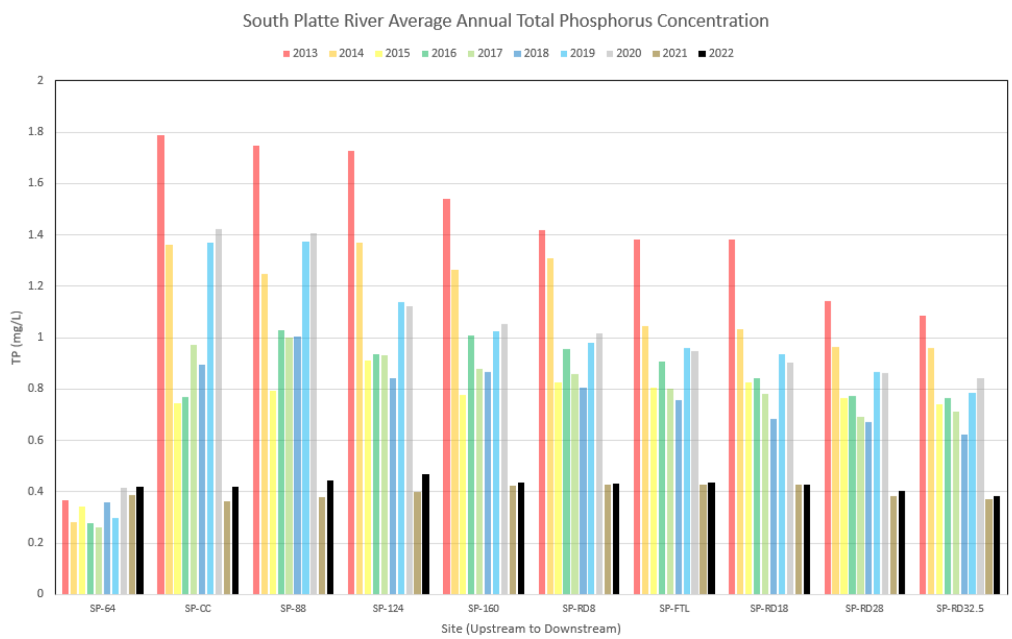


Figure 9. Bar graph of annual average total phosphorus concentrations from 2013-2022.

Total Nitrogen

The highest total nitrogen values were seen during the winter months, with the highest value of 10.4 mg/L occurring at SP-124 (Figure 10). The lowest values were seen during the May, June, and July sampling events, when flows were high with spring runoff. 2022 was the eighth complete year in which the South Complex secondary improvements were fully operational, resulting in drastically lower ammonia concentrations in the South Final Effluent. This resulted in a corresponding decrease in TN concentrations in all the stream sites. Figure 11 shows annual average TN concentrations for 2013 (no improvements yet), 2014 (improvements initiated middle of year) and 2015, 2016, 2017, 2018, 2019, 2020, 2021 and 2022 (south secondary improvements fully operational). There are significant TN reductions at all sites in 2015-2022 as compared to previous years. However, as seen in the box plot in Figure 10, the high variability in TN concentrations remains, indicating a variety of TN sources.

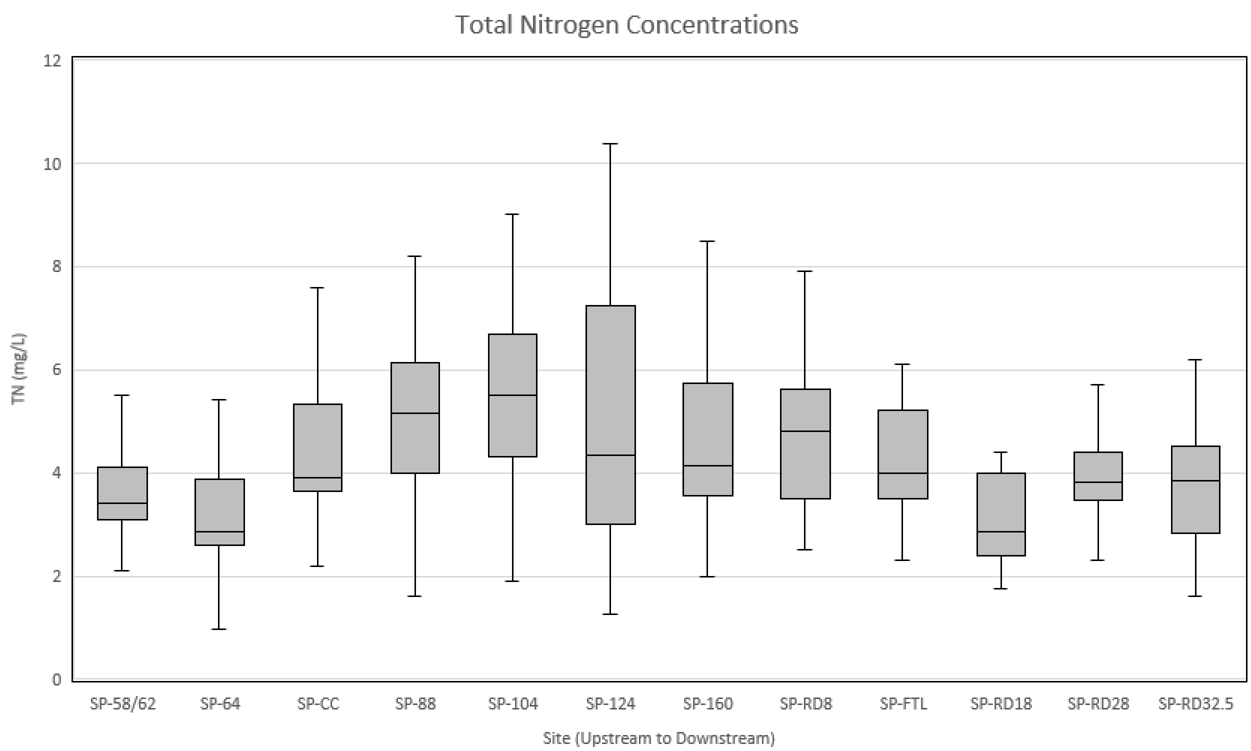


Figure 10. 2022 concentrations of TN from 58th Avenue to Weld County Road 32.5.

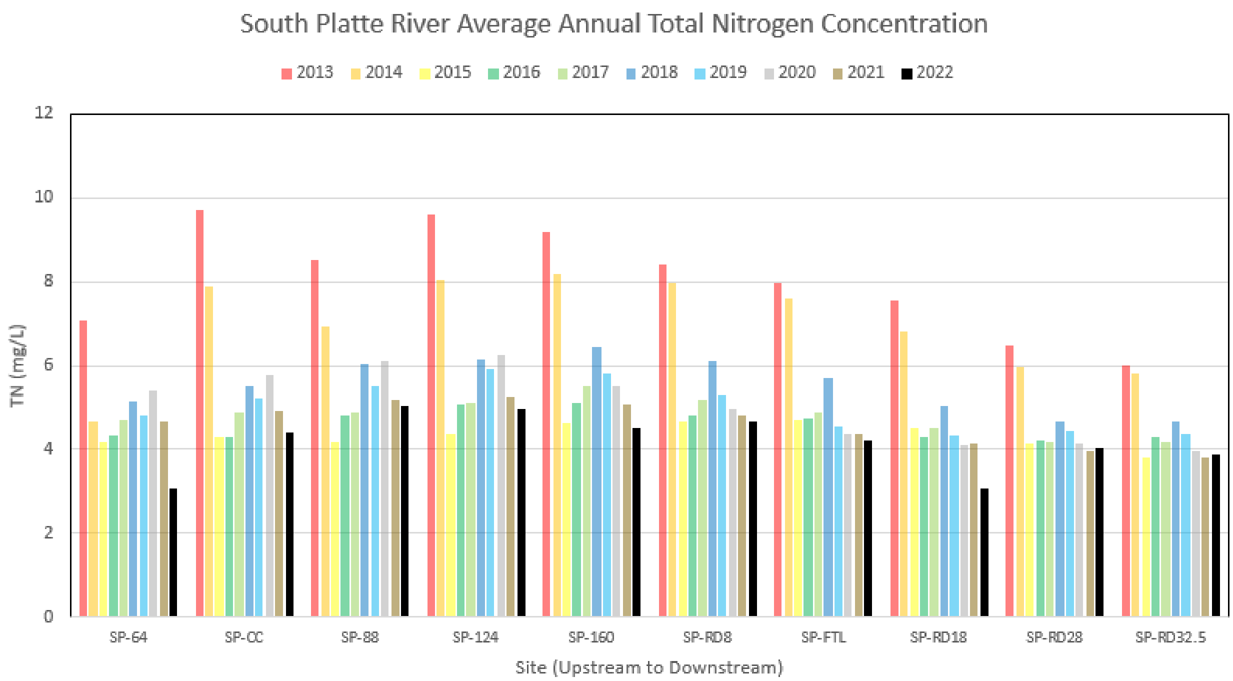


Figure 11. Bar graph of annual average TN concentrations from 2013-2022.

Ammonia

Ammonia is the only component of TN that can be toxic to fish, but the level of toxicity is dependent on both temperature and pH. Ammonia concentrations ranged from below detection limits at all monitored sites except SP-CC, SP-88, SP-104 and SP-124 to 2.2 mg/L at SP-104 (Figure 12). Ammonia concentrations in 2022 remained reduced due to the start-up of the South Complex secondary improvements in the fall of 2014, constructed to meet the 1999 Ammonia criteria established by the EPA. The improvements can be seen in in-stream ammonia concentrations (Figure 13). For example, the 2013 average ammonia concentration at SP-CC (~1 mile downstream of RWHTF outfalls) was 4.91 mg/L, compared to the 2022 average ammonia concentration of 0.54 mg/L. There are similar drastic reductions at all the downstream monitoring sites. These results are encouraging in terms of regulatory compliance of instream ammonia standards, as well as expected benefits to aquatic life.

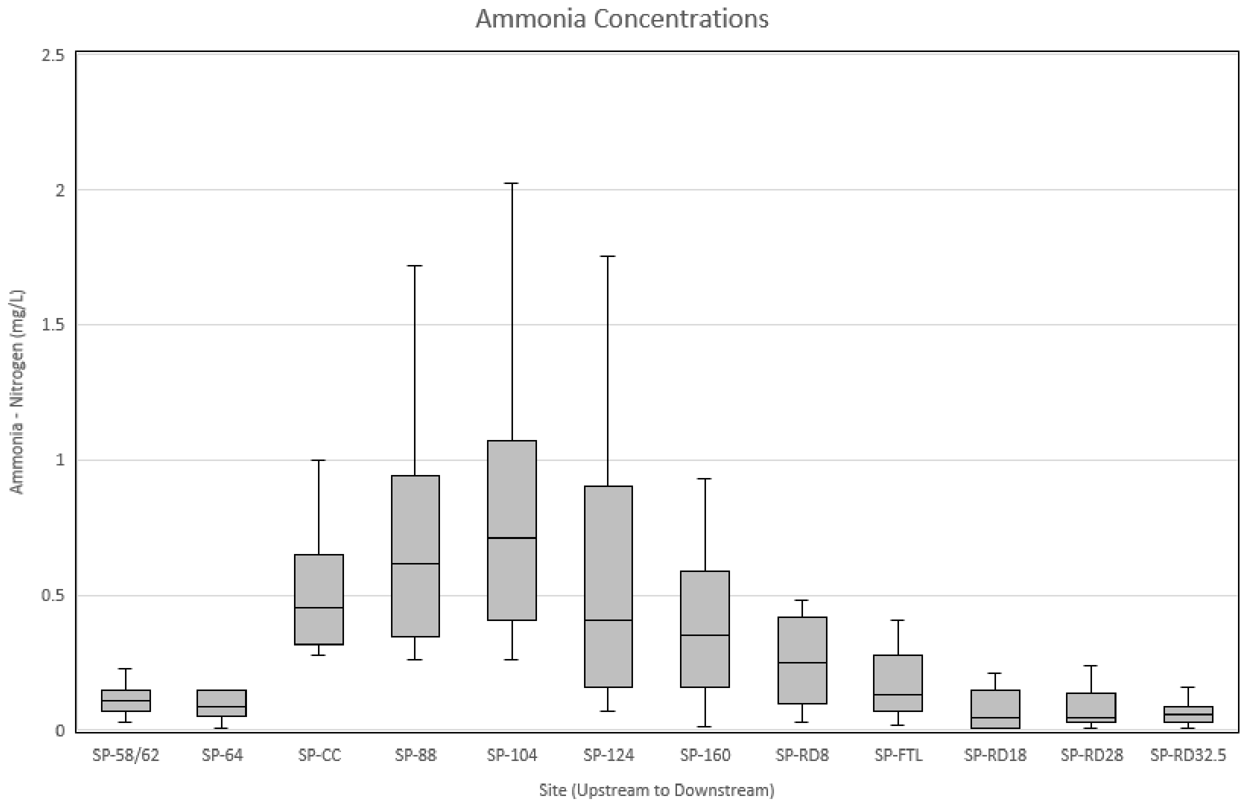


Figure 12. 2022 concentrations of ammonia from 58th Avenue to Weld County Road 32.5.

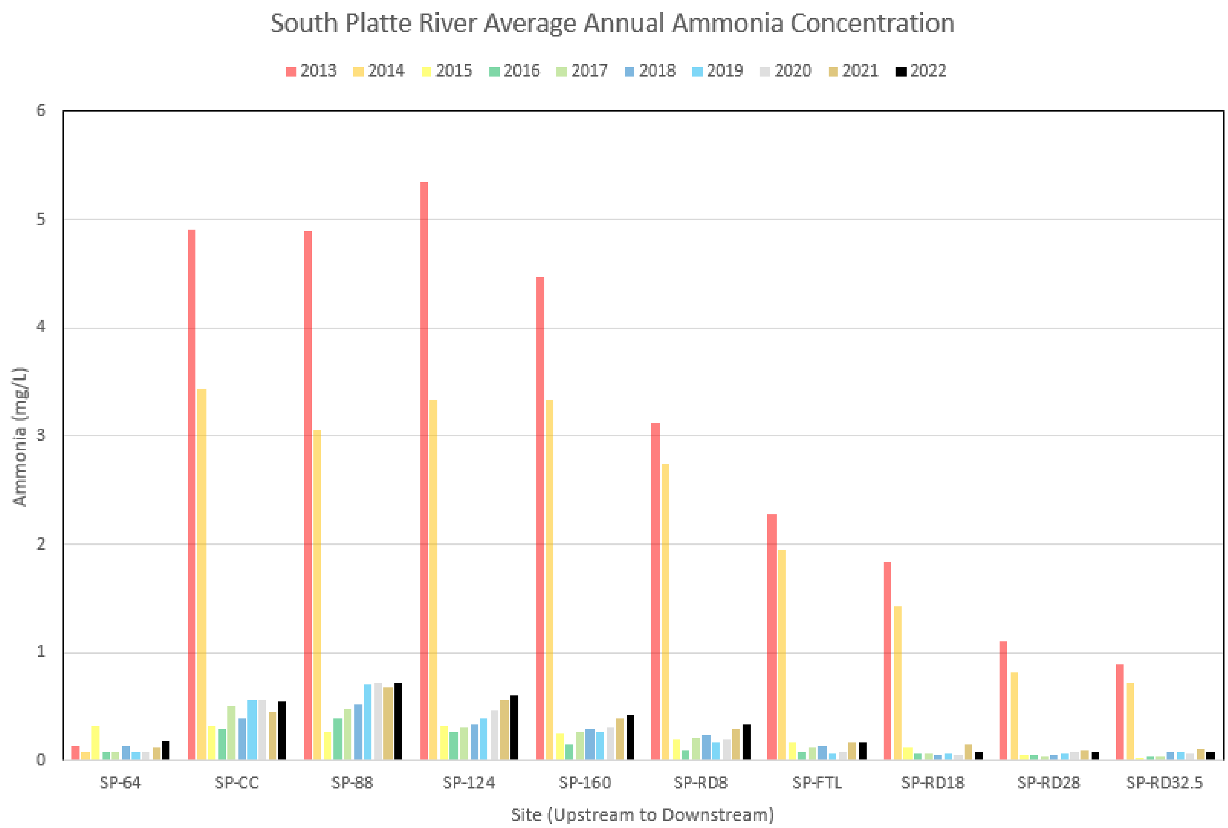


Figure 13. Bar graph of annual average ammonia-N concentration from 2013-2022.

Dissolved Oxygen

Along with temperature, nutrient concentrations can affect dissolved oxygen concentrations. On average, 2022 monthly DO concentrations in Segment 15 remain between 6.2 and 9.3 mg/L. There is a pronounced seasonal pattern, with summertime and early-fall values tending to be lower as compared to the higher DO concentrations in the winter months. During the extreme low flow and warm period between August and October, the DO concentrations at SP-88 dipped below 6 mg/L, but never below the aquatic life standard of 5.0 mg/L. This seasonal pattern is expected because the solubility of oxygen decreases as temperature increases; therefore, cold water holds more DO than warm water. The pattern is similar in Segment 1a, with average monthly DO concentrations ranging from 7.2 to 10.6 mg/L (Figures 14 and 15). Summer concentrations also show less variability in the lower segment. The 2022 results suggest that the South Complex secondary improvements may have indirectly benefited DO levels, as the lower ammonia concentrations in the river result in less nitrification and consumption of dissolved oxygen. In 2023, Metro will monitor continuous DO concentrations between the RWHTF outfalls and 160th Avenue to better characterize the diel patterns and help put the low values observed during biweekly sampling into context.

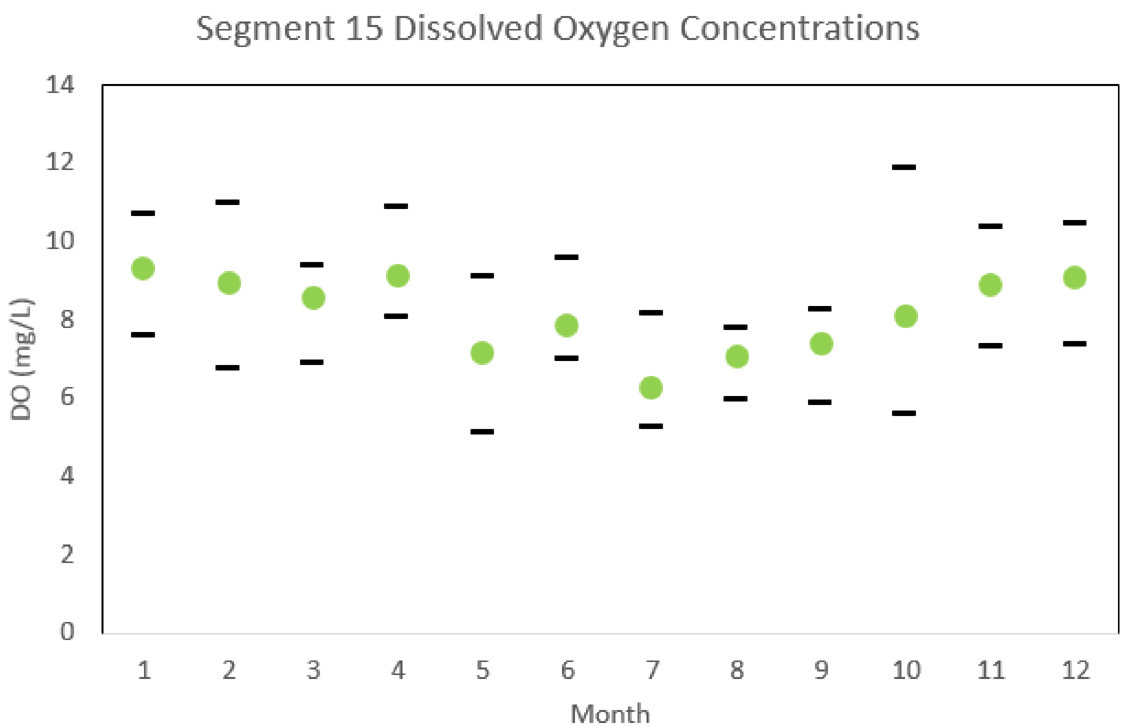


Figure 14. Concentrations of DO in Segment 15 by month (green circles indicate average values and black lines indicate high and low values).

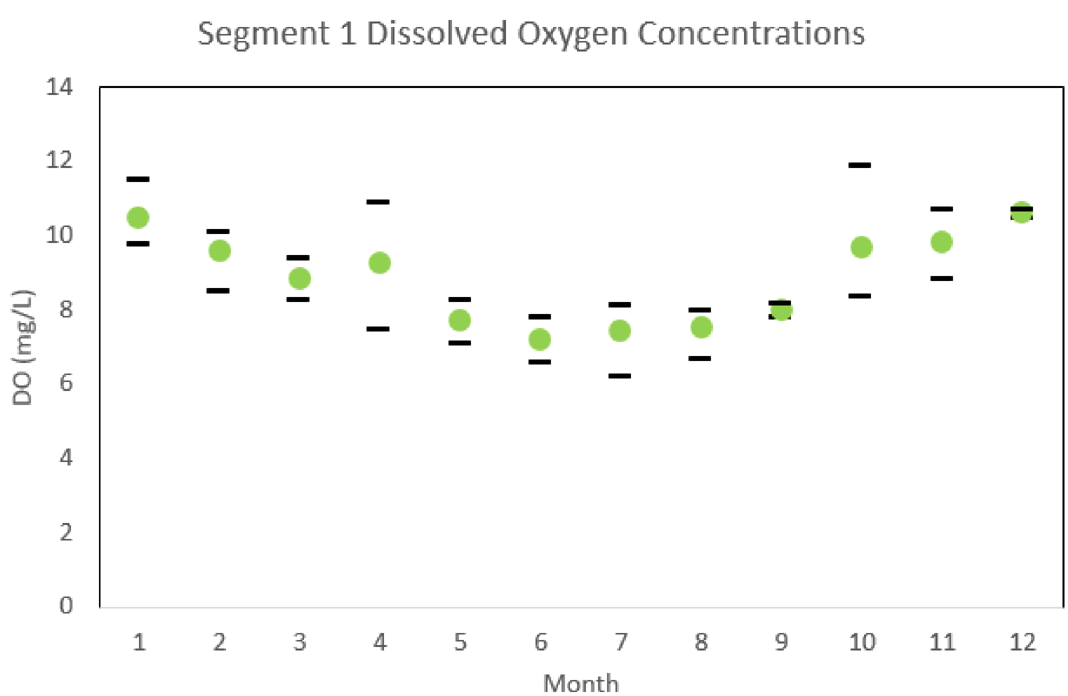


Figure 15. Concentrations of DO in Segment 1a by month (green circles indicate average values and black lines indicate high and low values).

pH

pH concentrations can also be affected by nutrient cycling. The average values in Segments 15 and 1a for 2022 were 7.8 and 8.0 respectively. Sites close to Metro's outfalls can show lower pH values (minimums as low as 7.2), which are a closer reflection of the conditions in the effluent.

Total Dissolved Solids

Total dissolved solids (TDS) are solids in water that can pass through a filter and can include carbonate, bicarbonate, chloride, sulfate, phosphate, nitrate, calcium, magnesium, sodium, organic ions and other ions. Sometimes, TDS is also referred to as salinity. TDS can enter the stream from irrigation return flows and storm events, washing in pollutants such as fertilizers and deicing compounds. The effluent from wastewater treatment plants also adds dissolved solids to streams, although most of the suspended solids are removed as part of the treatment process. There is also a natural component of salinity, as some rocks naturally release ions easily when water flows over or around them. The EPA has set a secondary drinking water standard of 500 mg/L for TDS. Aquatic organisms are not adversely affected until TDS gets over 1000 mg/L. Between 1000 – 5000 mg/L, there may be reductions in crop yield. The highest values in Segment 15 occur at 64th Avenue, where the average TDS was 770 mg/L in 2022 (Figure 16). The concentrations generally range between 500 – 800 mg/L at the other sites throughout Segments 15 and 1a, with slight increases in salinity moving downstream into Segment 1a.

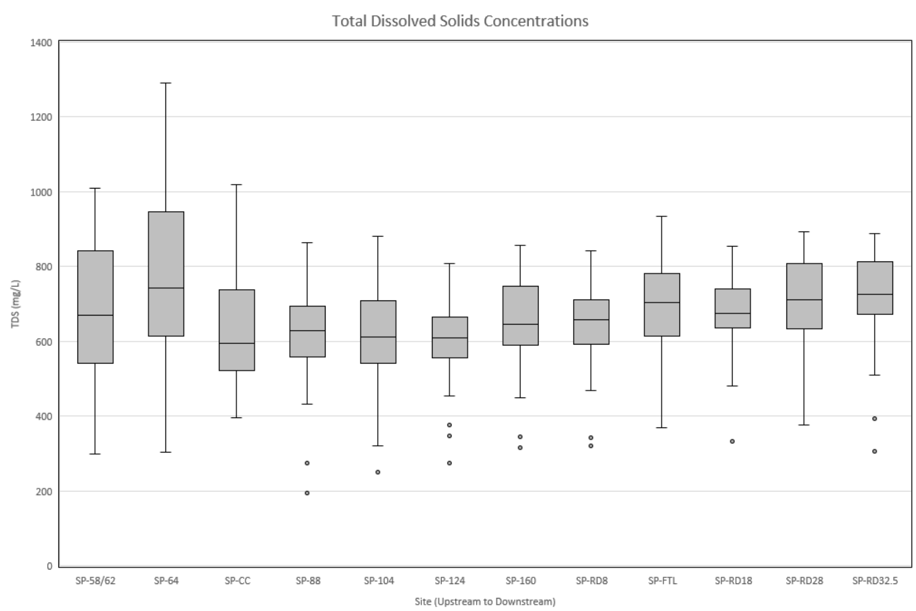


Figure 16. 2022 TDS concentrations from 58th Avenue to Weld County Road 32.5.

E. coli

Segment 15 was placed on the State's 303(d) list of water-quality impaired water bodies for non-attainment of the *Escherichia coli* (*E. coli*) water quality standard in 2002. This impairment affects the beneficial use of existing recreation (Recreation E) and was therefore a priority for the completion of a TMDL due to the non-attainment of a human health-based standard. Metro staff, in conjunction with partners in SPCURE, submitted a final draft TMDL to CDPHE to address *E. coli* in Segment 15. The TMDL was open to public comment during November 2015 and approved by the EPA in February 2016. The evaluation of *E. coli* levels uses two-month geometric mean calculations. Data from 2022 shows similar patterns to data from previous years, with more exceedances occurring during summer months when flows are very low. In 2022, all sites sampled along the South Platte River in Segments 15 and 1a show geometric mean calculations higher than the standard of 126 cfu/100 ml (Table 12). The discharges from the Metro's RWHTF are consistently well below the standard and increasing point source treatment is not considered an effective solution to address high *E. coli* values in natural systems. Sources in Segments 15 and 1a include runoff from storm events, agricultural facilities, and wildlife contributions.

	Segment 15	Segment 1a
Jan/Feb	**245**	108
Mar/Apr	80	50
May/Jun	**433**	**340**
Jul/Aug	**953**	**699**
Sep/Oct	**316**	**131**
Nov/Dec	**263**	101

Table 12. Geometric means of all *E. coli* data by Segment (bolded red text indicates values exceeding the river standard of 126 cfu/100 mL).

Metals

Arsenic

Arsenic is a naturally occurring element that can be toxic. It is commonly used to strengthen metals and used to help produce pesticides but is also naturally occurring in soils. Total arsenic in the South Platte River ranged from 0.5 to 2.5 μg/L during 2022 (Figure 17). Arsenic was lowest at SP-CC, SP-88 and SP-104, which are the closest downstream sites to the RWHTF discharge. The values typically increase as the river moves downstream, which may be driven by groundwater inflows (groundwater data indicates that groundwater is naturally high in arsenic). The arsenic standard is a hybrid standard based on the water supply use designation. All sites show concentrations higher than the first human-health risk-based number in the hybrid standard (0.02 μg/L), but all are well below the maximum contaminant level goal standard (10 μg/L).

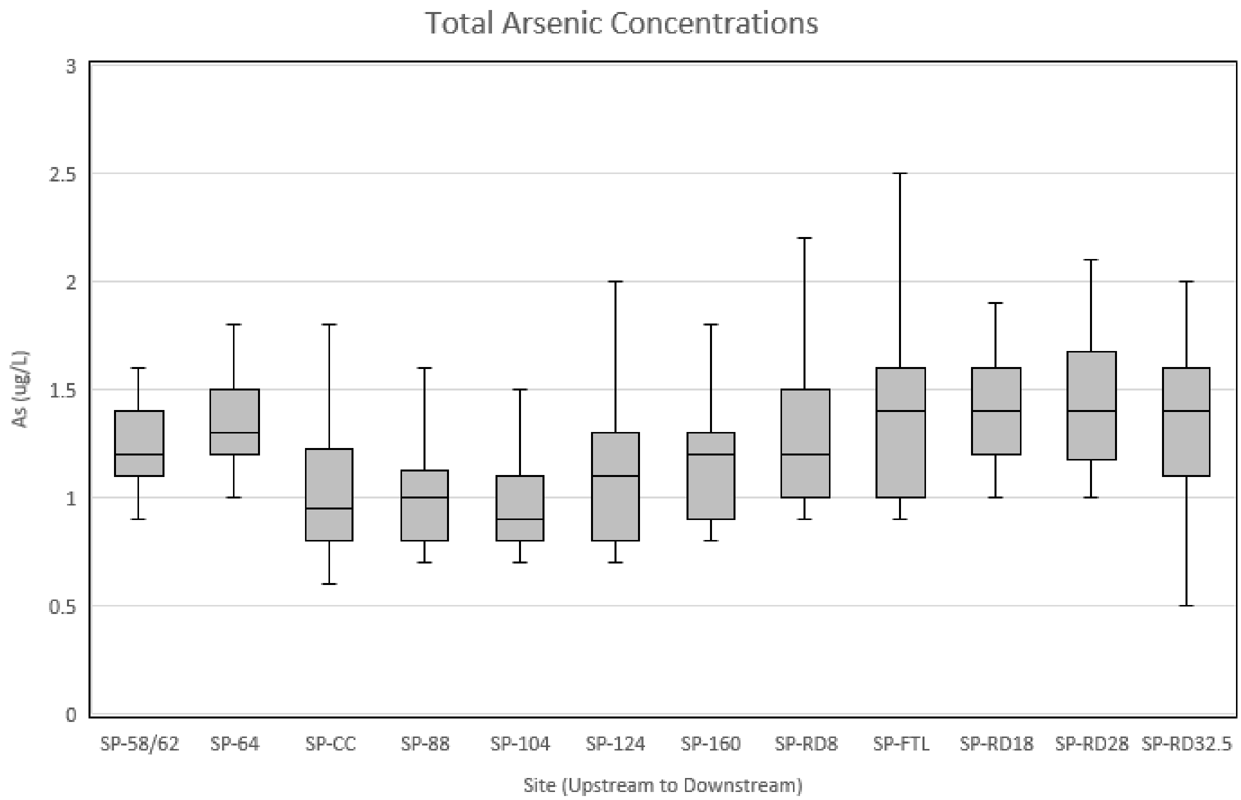


Figure 17. 2022 concentrations of total arsenic from 58th Avenue to Weld County Road 32.5.

Cadmium

Cadmium is a metal of concern in Segment 15, as aquatic life use-based water quality standards for this constituent are not attained in the portion of the South Platte River between the Burlington Ditch headgate and Clear Creek. Currently, water quality goals exist for dissolved cadmium from SP-64 to SP-88 based on a TMDL implemented in 2011 (CDPHE 2011). According to the TMDL, surface water and groundwater data in the area indicate that contaminated groundwater plumes originating under or near the former Globeville ASARCO Facility (https://cdphe.colorado.gov/asarco-globe) are the primary sources of cadmium loading. The upstream (SP-64) dissolved cadmium concentrations remain elevated (2022 average = 5.2 ug/L). The RWHTF effluent dilutes the upstream water and all downstream sites met the chronic aquatic life criteria (85th percentile = 1.45 ug/L) (Figure 18). 2022 data from the river monitoring sites at 58th Avenue and 62nd Avenue indicate that the elevated cadmium concentrations are isolated at 64th Avenue. The 2022 average 58th/62nd Avenue dissolved cadmium concentrations were 0.06

ug/L, indicating clearly that the groundwater plume enters the South Platte River somewhere in the 0.4-mile reach between 62nd Avenue and 64th Avenue.

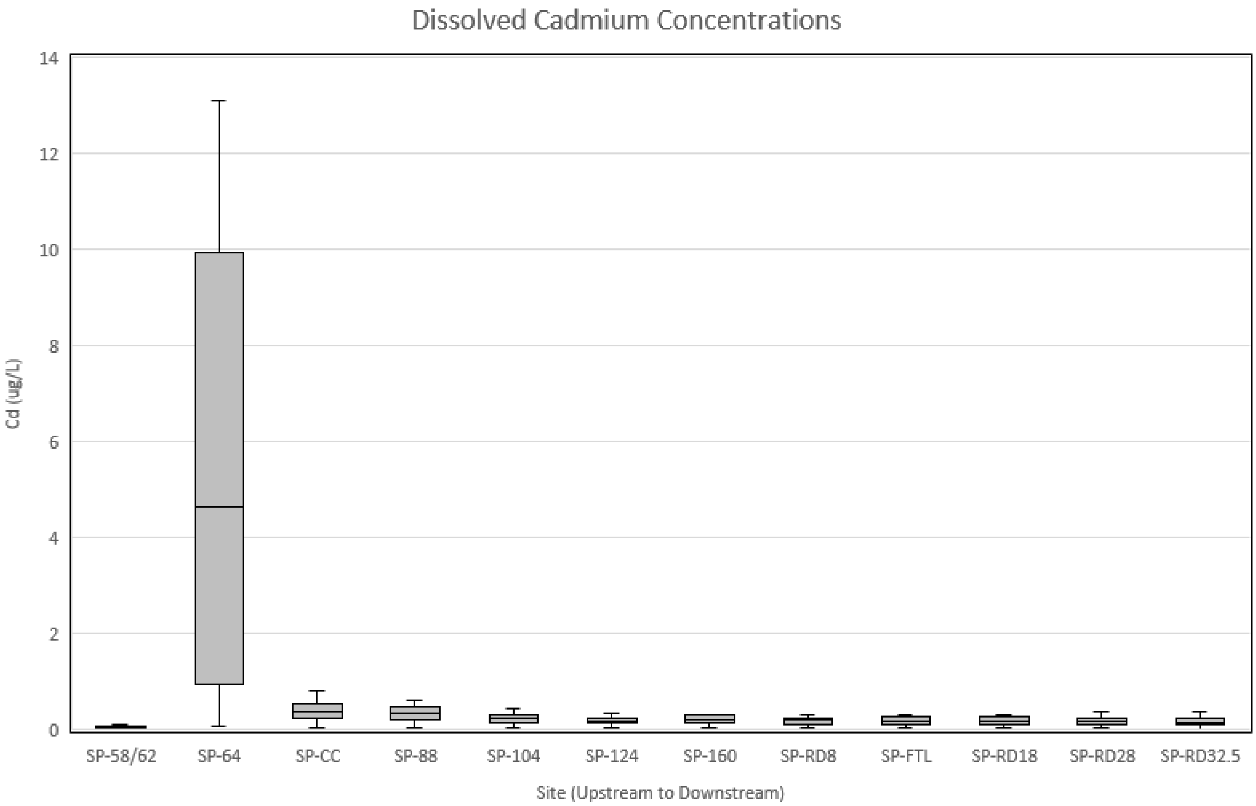


Figure 18. 2022 concentrations of dissolved cadmium from 58th Avenue to Weld County Road 32.5.

Iron

Iron is a common element often used to make steel and other common products, and is also naturally occurring in soils. Iron is not toxic to humans and is a vital contributor to respiration. Iron is regulated in the South Platte River to protect fish populations and water supplies. Past years' data indicated that total recoverable iron concentrations were approaching the chronic aquatic life standard of 1 mg/L (50th percentile). In 2022, the total recoverable iron concentrations were lower than in previous years, with the highest median concentration at SP-RD18 (0.63 mg/L). Total recoverable iron concentrations become higher and slightly more variable in Segment 1a. Median values are relatively higher from SP-FTL to SP-32.5 at the downstream end of Segment 1a. While not presented here, these high total iron values in Segment 1a can also be attributed to high concentrations in Big Dry Creek which enters the South Platte River between SP-RD8 and SP-FTL.

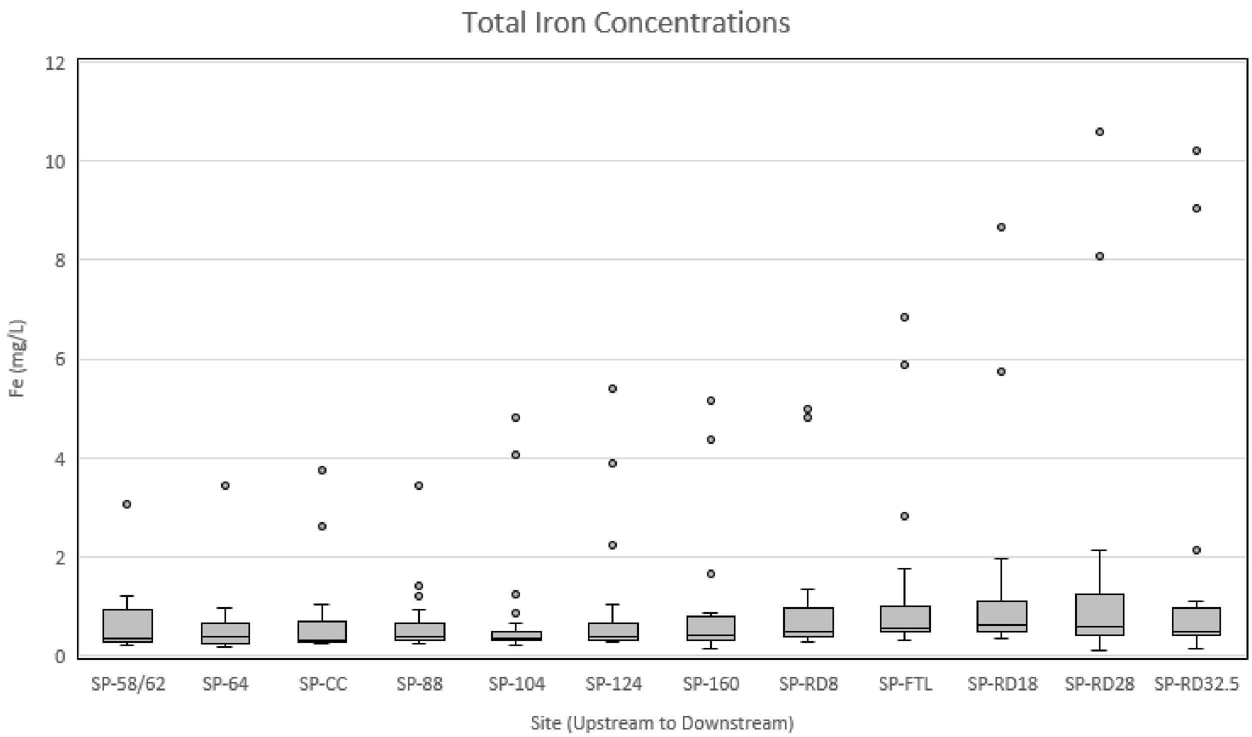


Figure 19. 2022 concentrations of total iron from 58th Avenue to Weld County Road 32.5.

Manganese

Manganese is a mineral that naturally occurs in rocks and soil. In low concentrations, it produces objectionable stains on surfaces with which it comes in contact. Deposits also collect in pipelines and tap water may contain sediment and turbidity due to precipitated manganese. The EPA Secondary Drinking Water Regulations recommend a limit of 50 ug/L dissolved manganese due to potential staining, as well as taste and odor issues. However, human health is not a concern until concentrations are an order of magnitude higher. The Segment 15 water supply standard for dissolved manganese is 400 ug/L, while the Segment 1a standard is based on the secondary drinking water standard of 50 ug/L. The mean dissolved manganese concentrations in the Segment 1a sites were 67.7 ug/L in 2022 (Figure 20). Elevated manganese in both segments is likely the result of groundwater inputs, as dissolved manganese concentrations in monitoring wells are typically well above 400 ug/L. The range of dissolved manganese concentrations upstream of the RWHTF outfalls at SP-58 and SP-64 is greater than the downstream range, indicating that the effluent concentrations are more consistent than the upstream ambient concentrations.

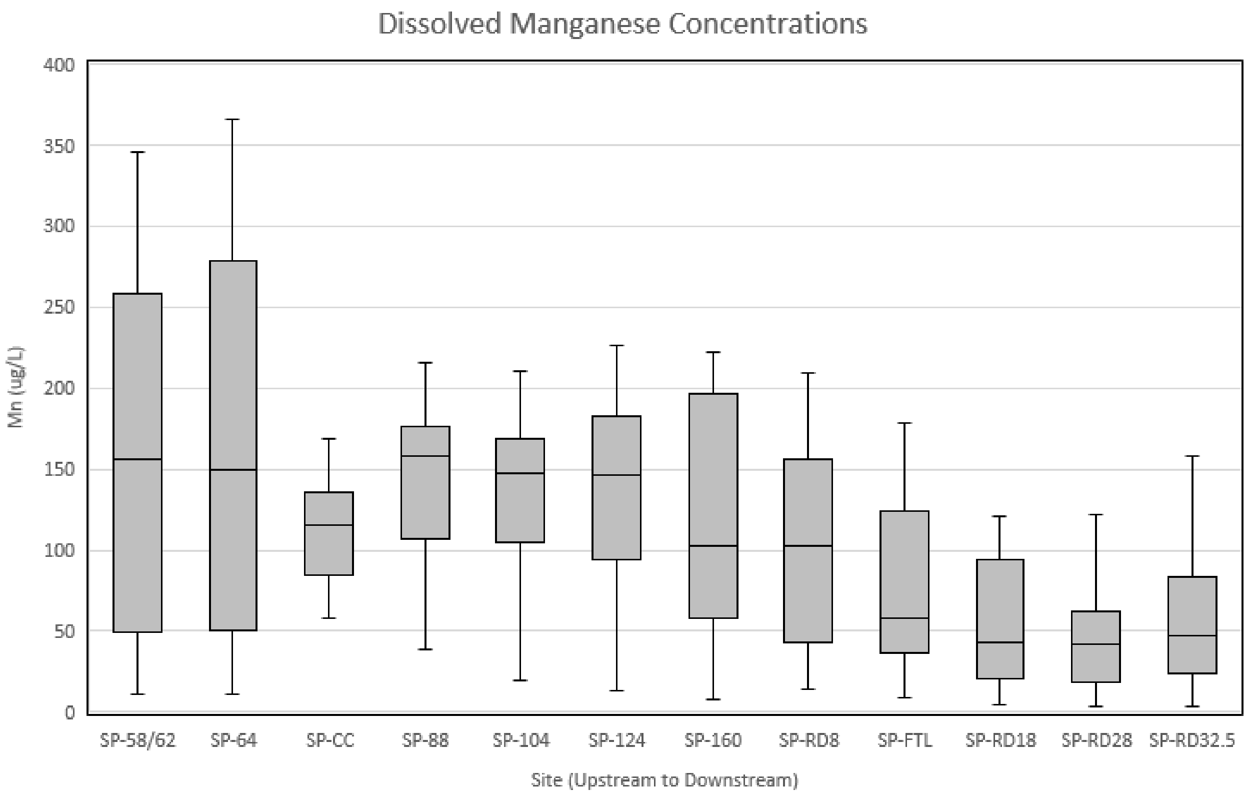


Figure 20. 2022 concentrations of dissolved manganese from 58th Avenue to Weld County Road 32.5.

Selenium

Selenium is a naturally occurring element that is nutritionally essential but can be toxic to aquatic life where concentrations are elevated. It is toxic to cormorants and other birds that consume aquatic organisms containing excessive levels of selenium. Toxic levels of selenium in water bodies have mostly been related to irrigation of western soils that are naturally high in selenium. Risks stem from aquatic life eating food that is contaminated with selenium rather than from direct exposure to selenium in the water. Although selenium bioaccumulates, i.e., accumulates in tissues of aquatic organisms, it is not significantly biomagnified, unlike mercury or PCBs. The chronic aquatic life standard for Segments 15 and 1a is 4.6 ug/L. There was a temporary modification for the chronic standard in Segment 1a (6.9 ug/L) that expired at the end of 2015. Data from 2022 sampling indicate that all sites are below the 4.6 ug/L standard (Figure 21).

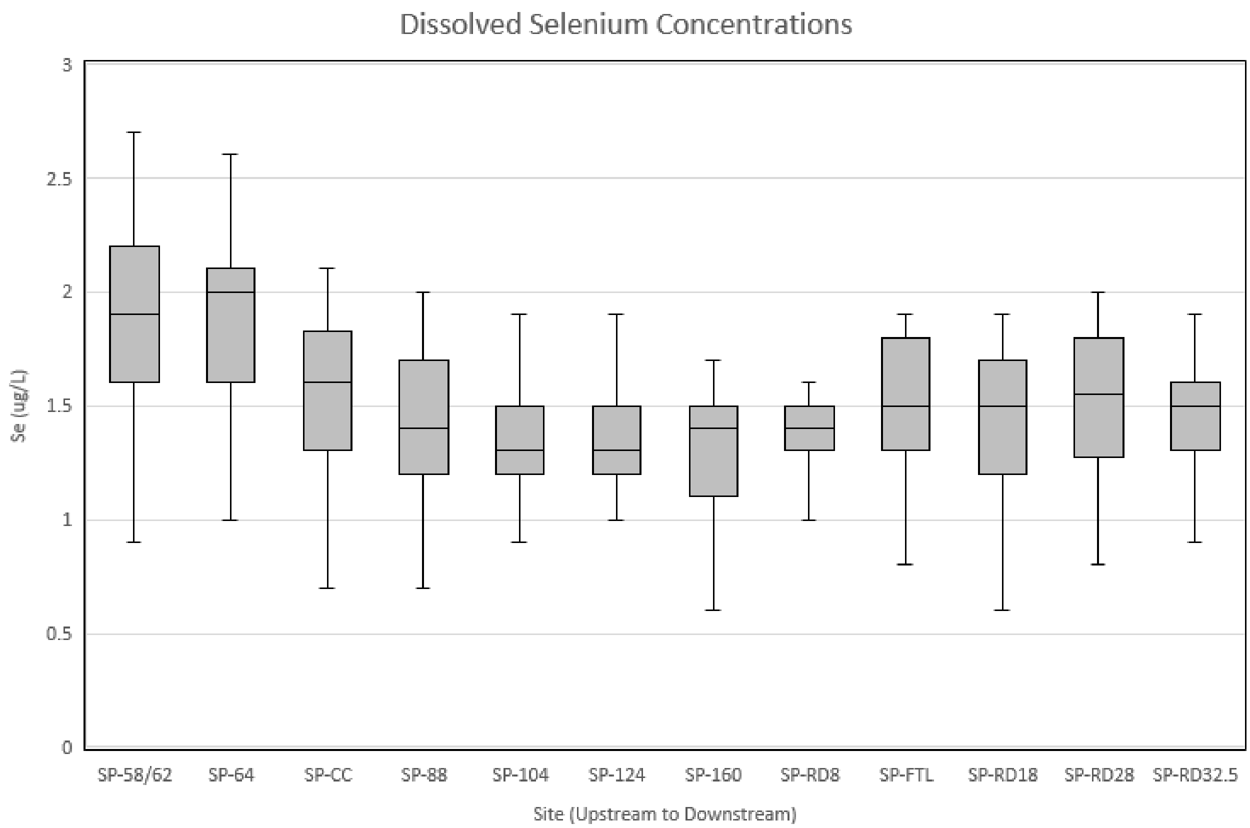


Figure 21. 2022 concentrations of dissolved selenium from 58th Avenue to Weld County Road 32.5.

Biology

Fish

Metro has been collecting fish data since 1986, using traditional electroshocking techniques. The collection of fisheries data provides the backbone of aquatic life assessment along the South Platte River. Since 1986, 34 species of fish have been found in Segments 15 and 1a. On average, 17 fish species are collected per year primarily because catch efficiencies on large river systems are low and some species are more likely to be missed than others. In 2022, 18 fish species were found during ten sampling events (Table 13). As mentioned earlier, flows remained low throughout the entire late-summer and fall, creating ideal conditions for fish. Of the 18 species, ten were native to the South Platte Basin, and eight were introduced species. Most of the species not documented in 2022 are either rare, non-native species, or are typically residents of tributaries. According to historical records, 23 species are native to the South Platte basin, indicating that resident populations were in place before settlers arrived in the West. A few of these species, such as plains topminnow and plains killifish are commonly found in warmer environments and periodically found in Segment 1a. Others have become rare in the basin and are unlikely to be found again in Segment 15 or 1a, such as the suckermouth minnow and northern redbelly dace.

Most of the fish species native to the South Platte basin are considered to be tolerant because of the geomorphology of the river itself. As the South Platte River flows out onto the eastern plains, the river gradually subdivides into a braided series of parallel, sandy channels. The channels are often shallow and warm because of a lack of canopy and riparian vegetation. Many species needed to adapt to drought, flooding, high turbidity, and changing habitat conditions (Woodling 1985). Species considered to be tolerant include the fathead minnow, green sunfish, creek chub, and black bullhead (Pflieger 1997).

Two of the eight introduced species are considered invasive, the common carp and western mosquitofish. The invasive nature of these fish species indicates that they have a negative impact on native fish populations and habitat in the river. Western mosquitofish are prolific, reproducing three to four times in a single summer and can compete with native populations for food resources (Pflieger 1997). Common carp were introduced in the 1800s as a source of food and have since become one of the most widespread species across the United States. Carp are voracious eaters, consuming both plant and animal material and often cause habitat deterioration, increase turbidity, and destroy aquatic vegetation in the process (Pflieger 1997). Carp are also one of the largest fish species in the South Platte River, often reaching lengths of 25 inches (Pflieger 1997). The remaining six introduced species are game fish that wash out of reservoirs stocked for fishing.

Scientific Name	**Common Name**	**Distribution**	**Total #**
Pimephales promelas	Fathead Minnow	Native	3077
Gambusia affinis	Western Mosquitofish	Introduced	1306
Rhinichthys cataractae	Longnose Dace	Native	1173
Notropis stramineus	Sand Shiner	Native	1168
Catostomus commersoni	White Sucker	Native	871
Etheostoma exile	Iowa Darter	Native	100
Cyprinus carpio	Common Carp	Introduced	72
Lepomis cyanellus	Green Sunfish	Native	67
Micropterus salmoides	Largemouth Bass	Introduced	35
Etheostoma nigrum	Johnny Darter	Native	33
Semotilus atromaculatus	Creek Chub	Native	19
Catostomus catostomus	Longnose Sucker	Native	17
Perca flavescens	Yellow Perch	Introduced	9
Culaea inconstans	Brook Stickleback	Native	8
Micropterus dolomieui	Smallmouth Bass	Introduced	7
Lepomis macrochirus	Bluegill	Introduced	5
Pomoxis nigromaculatus	Black Crappie	Introduced	3
Pomoxis annularis	White Crappie	Introduced	1

Table 13. Fish species found in 2022.

Like previous years, fathead minnows, longnose dace, sand shiners and white suckers were the dominant native species found in the South Platte River in 2022. Fathead minnows were found in large numbers at all survey sites. As a relatively tolerant species, they are not commonly limited by habitat. The second most common native fish species in 2022 was the longnose dace. These native minnows preferred microhabitats are narrow riffles and they have been observed in high numbers in constructed riffles designed as part of Metro's instream habitat improvement projects. In 2022, the highest numbers of longnose dace were observed at SPR-8.5 (691 individuals), immediately downstream of the NTP outfalls. The third most common native fish species found in 2022 was the sand shiner. This species is commonly found in shallow, slow-moving water along sandy margins, especially downstream of the constructed riffle at Habitat Improvement Phase I (236 individuals) and downstream of the NTP outfalls (495 individuals). The fourth most common native species, the white sucker, prefers pools and runs, low to moderate flows and sandy substrate. The highest numbers of white suckers were found at the Fort Lupton site (196), Weld County Road 18 site (151) and at the Phase III Habitat Improvement site at 144th Avenue (143). As in previous years, the invasive western mosquitofish was observed in relatively high number at farthest downstream site (Weld County Road 18). This species is concerning, as their presence has been linked to the decline of native warm water fish species including the plains topminnow and plains killifish.

In 2006, Metro and CDM conducted a comprehensive study to assess alternatives and develop recommendations on methods to protect and improve aquatic life and habitat throughout Segment 15 (CDM 2006). After comprehensive fish, habitat, and flow surveys, the report detailed recommendations for habitat improvements along different sections of river adding either backwater habitat, riffle and pool habitats, or increasing protective cover. Phases I and II of the habitat improvement were constructed upstream of 120th Avenue. The Phase III habitat improvement projects was completed in 2013 and is located at 144th Avenue. 2022 sampling included the ninth year of post-construction sampling for Phase III of the habitat improvements. The main features of the Phase III improvements include two constructed riffles, bio-engineered banks, snags, a vortex weir and a secondary channel. After some modifications to repair structures in 2015, the flow of the river through this habitat improvement reach is split almost evenly between the main river channel and secondary channel. The resulting configuration provides significantly more important streambank habitat for native fishes. Fish surveys from the past nine years show a significant increase in both the number of fish species and the abundance of native fish species. In 2013 prior to construction of these habitat improvements, only 22 individual fish of five different species were collected. In 2022, 825 individual fish of eleven different species were collected, a notable improvement (Figure 24). Other phases of habitat improvement projects have been similarly successful in creating sorely needed microhabitat for the native fish of the South Platte River. Metro staff will continue to survey all of these habitat sites in future years to document further evidence of improvements.

Overall, there are no significant longitudinal patterns in the total number of fish (Figure 22), indicating that site-specific habitat availability is likely still a limiting factor. In fact, in *The South Platte River Segment 15 Aquatic Life/Habitat Assessment* (PAR 991) conducted by CDM, a Limiting Factors Analysis was conducted which determined that of all chemical, biological, and physical impacts on fish species within the Segment, habitat limitation was the most critical issue. There is also year-to-year variability in terms of fish caught. Analyzing the full length of Metro's fish count dataset (1986-2022) there continue to be no long-term trends in the species richness (number of species observed) for either native or non-native species (Figure 23). However, in terms of fish abundance, Metro staff observed the highest total number of individual fish in 2020 (25,108) since beginning the fish survey program in 1986.

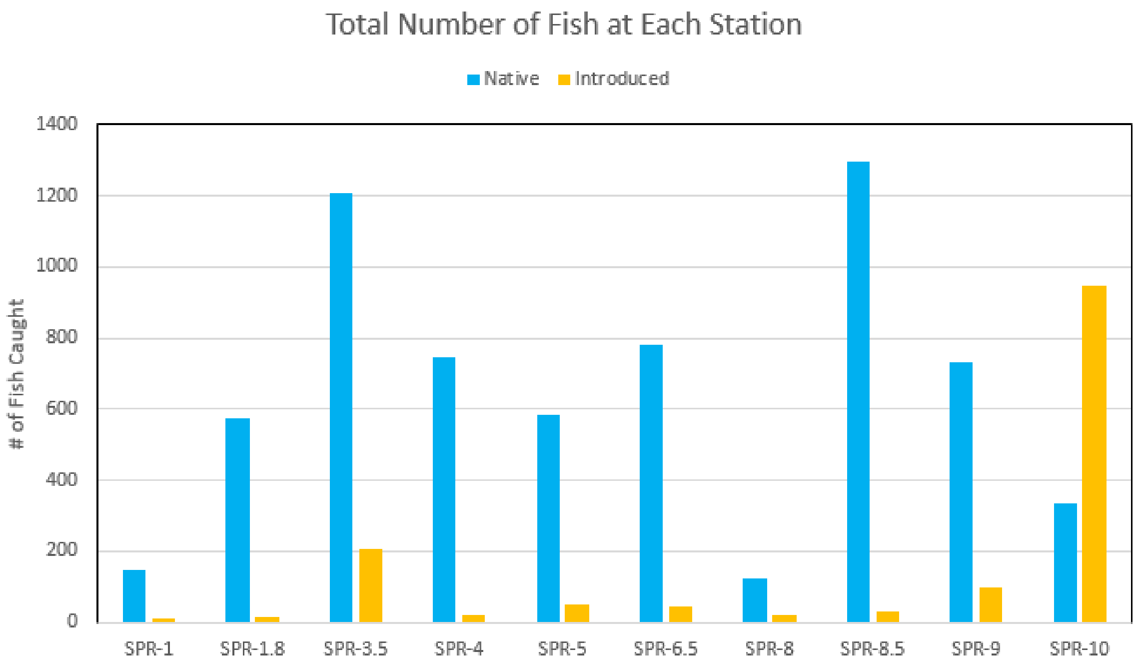


Figure 22. Total number of fish found at each sampling location in 2022 (includes all species).

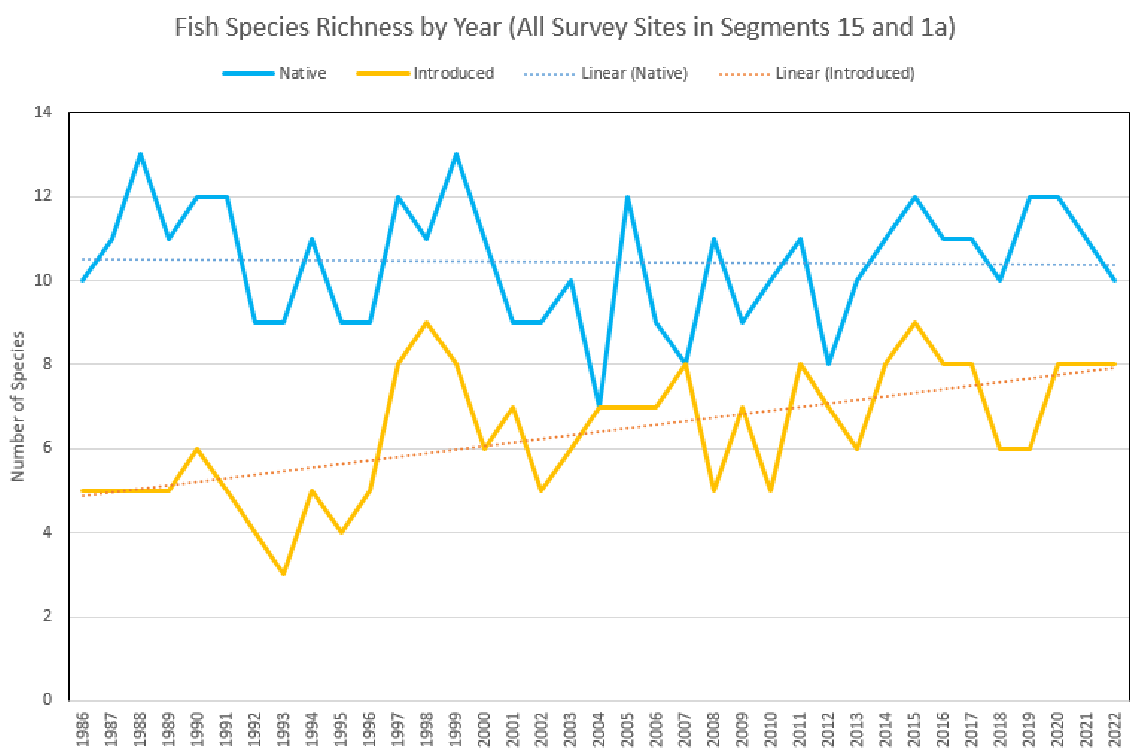


Figure 23. Species richness by year for all MWRD survey sites (1986-2022).

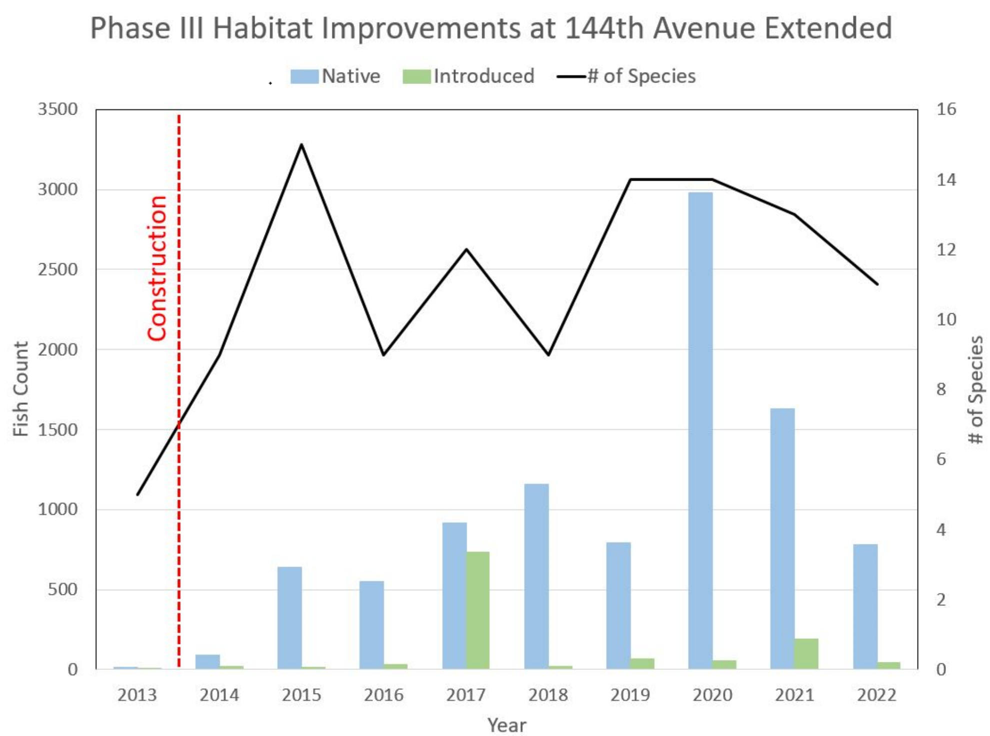


Figure 24. Summary of fish count data at Phase I Habitat site before and after construction.

Macroinvertebrates

In 2022, eight macroinvertebrate samples were collected along the South Platte River. Most samples were collected at Metro's fish sampling locations, but a few additional samples were taken at bi-weekly stream sampling sites. For all eight samples, both a kick net (benthic organisms in a riffle) and dip net (multi-habitat) sample were taken.

Macroinvertebrate data are used in Colorado as the primary indicator of aquatic life health in streams and rivers. The Colorado Water Quality Control Division uses a Multi-Metric Index (MMI) to evaluate a given stream using data collected with a kick net. For plains streams, the index is based on the percent EPT (Ephemeroptera, Plecoptera, Trichoptera) excluding *Baetidae* of all individuals in the sample (caddisflies, mayflies and stoneflies), the total number of taxa in the sample, the total number of intolerant taxa (like mayflies and dragonflies), the number of facultative predator taxa, the percent facultative scrapers, non-insect taxa as a percentage of total taxa and the number of sprawler taxa in the sample (a classification based on habit). Each of these categories is associated with species characteristics that are defined by current biological research and categorization. Any score above 42 indicates attainment and any score below 29 indicates impairment.

Currently, the MMI is not applied to large rivers including the South Platte River because, according to the CDPHE "Aquatic Life Use Attainment" policy document, large rivers have different populations and different habitat conditions (CDPHE, 2017). Calculating the scores for the South Platte River can provide insight into current aquatic condition in the river. In 2022, scores in Segment 15 have ranged from 22.3 to 35.4, with an average of 29.1 (Figure 25). The two highest MMI scores of all the 2022 samples were observed at 160th Avenue (35.1) and at Fort Lupton (35.4). The lowest MMI score (22.3) was from the biological monitoring site upstream of 120th Avenue in Segment 14. There were no significant longitudinal patterns in the MMI scores in 2022.

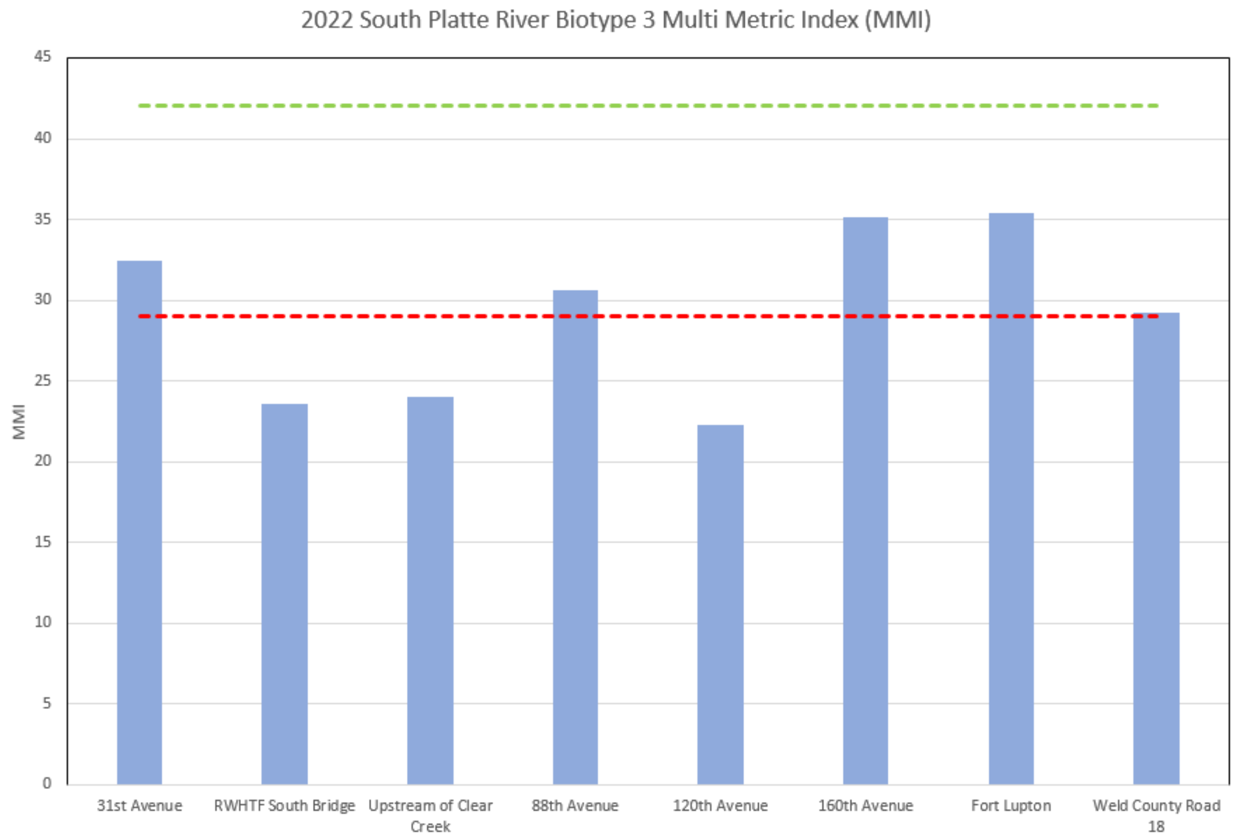


Figure 25. 2022 Multi Metric Index scores at eight monitoring sites.

Two auxiliary metrics in Policy 10-1 are relevant to macroinvertebrate assessment: the Hilsenhoff Biotic Index (HBI) and the Shannon Diversity Index (SDI). The HBI is a widely used indicator of organic pollution. Higher values of the index indicate a predominance of tolerant organisms (i.e., the sensitive species may not be present). In 2022, all macroinvertebrate samples had an HBI of less than 7.6 (average = 5.2), the auxiliary metric threshold for attainment. In general, following completion of the South Secondary Complex Improvements at the RWHTF in 2014 that led to drastically lower instream ammonia concentrations, the HBI scores have been lower downstream of the outfalls (Figure 26). The SDI characterizes species richness (number of species) and evenness (relative abundance) of the species present, with a higher value indicating better richness and evenness. In 2022, the average SDI score for all samples was 2.6, above the attainment threshold of 2.4. Three sites had SDI scores below the 2.4 attainment threshold, the location upstream of the RWHTF outfalls (SDI = 1.9), upstream of the confluence with Clear Creek (SDI = 2.2) and at Weld County Road 19 (SDI = 2.2). As with the HBI, the SDI scores have improved at the macroinvertebrate monitoring locations downstream of the RWHTF outfalls since 2014 (Figure 27). Metro staff will continue to monitor these biological communities in 2023 and hopes to learn more about the complicated stressor-biological health relationship.

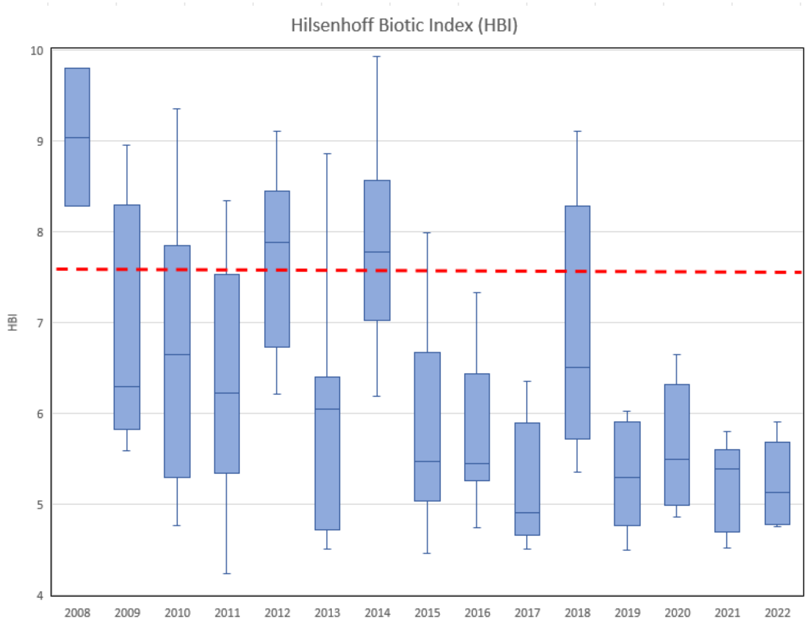


Figure 26. Box plot of HBI scores at all macroinvertebrate sites by year.

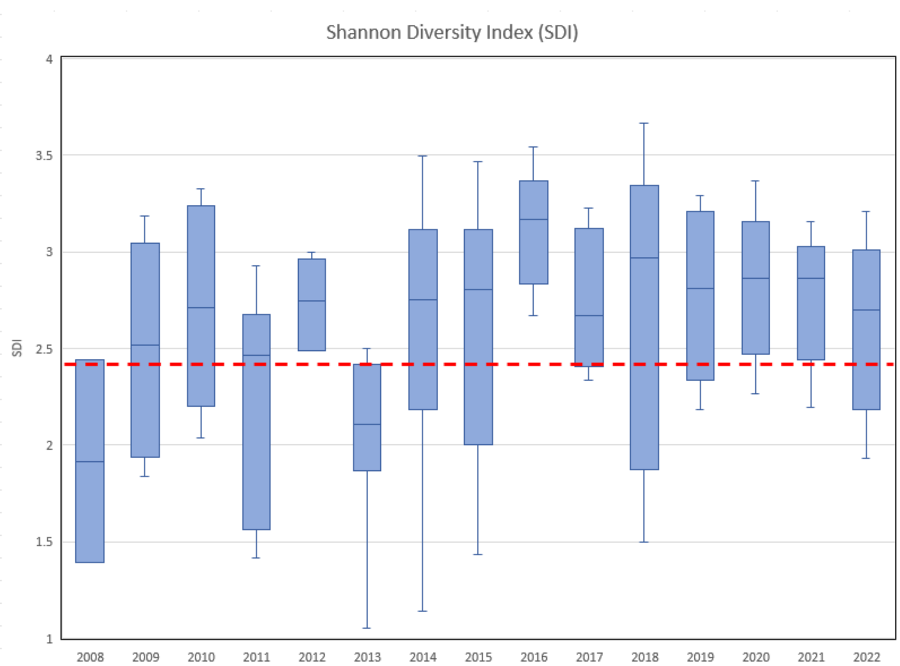


Figure 27. Box plot of SDI scores at all macroinvertebrate sites by year.

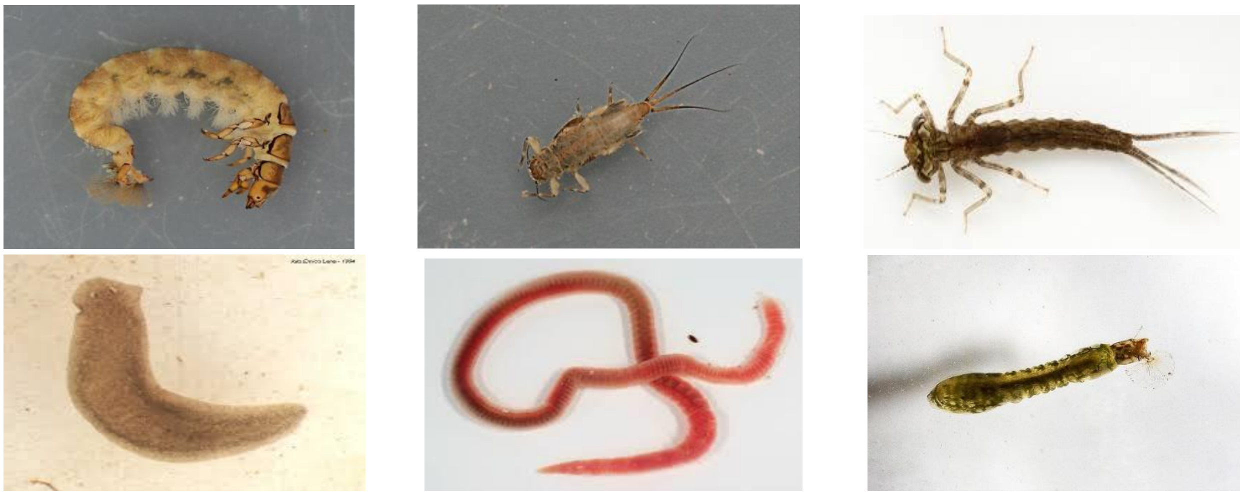


Figure 28. Examples of macroinvertebrates found in South Platte River. Upper left to right: Hydropsyche sp. (EPT taxon), Tricorythodes explicatus (EPT and sprawler taxon) and Coenagrionidae (predator taxon) Lower left to right: Dugesia sp. (tolerant taxon), Tubificidae sp. (tolerant taxon) and Similium sp. (tolerant taxon).

Special Studies

Temperature

Long-term temperature series data are routinely collected by Water Quality Division staff for the South Platte River at 12 mainstem locations, 3 tributaries, the North and South Final Effluents of the RWHTF and the NTP effluent as it leaves Pond #3. Wherever possible, the data logging thermistors are co-located with the bi-weekly stream sampling sites. This temperature information has several uses. Seasonal trends in temperature of the South Platte River below the effluent discharge, as well as the daily cycling of temperature, are important to the calculation of ammonia limits. In 2009, the Water Quality Control Commission adopted temperature regulations for cold and warm streams throughout the state. Long-term series data will allow Metro staff to evaluate seasonal and spatial variability of temperature in the South Platte River to evaluate the compliance status of the South Platte River below Metro's point of discharge as judged by the applicable aquatic life temperature standards. In the past, temperature compliance for the South Platte River below the outfalls has been assessed by use of the bi-weekly monitoring data for temperature.

The 2022 temperature data demonstrate that both the North and South Final Effluents are consistently above the wintertime stream chronic standard. While the upstream river site (64th Avenue) was in attainment throughout the winter, the monitoring sites immediately downstream of the RWHTF exceeded the stream standard (Figures 29). For the chronic standard, there were wintertime exceedances downstream to 104th Avenue, approximately seven river miles downstream of the RWHTF outfalls. In many cases, these exceedances occurred during the abrupt change to the winter standard (December through February). While the river exhibits a gradual warming and cooling, the standard itself does not reflect this seasonal pattern. The Colorado Water Quality Control Division is in the process of revising how they assess temperature exceedances, and these proposals may provide some regulatory relief during the shoulder seasons. However, even with these proposed changes, the South Platte River will likely still exceed the chronic wintertime standard between the RWHTF outfalls and 88th Avenue (3.6 miles downstream). The river was in full attainment at the 124th Avenue monitoring site during the winter months. In 2022, there were summer month exceedances of the chronic temperature standard at all mainstem South Platte River sites except the upstream of Clear Creek confluence site in late-July and early-August. These exceedances were due to high air temperatures and low flow conditions.

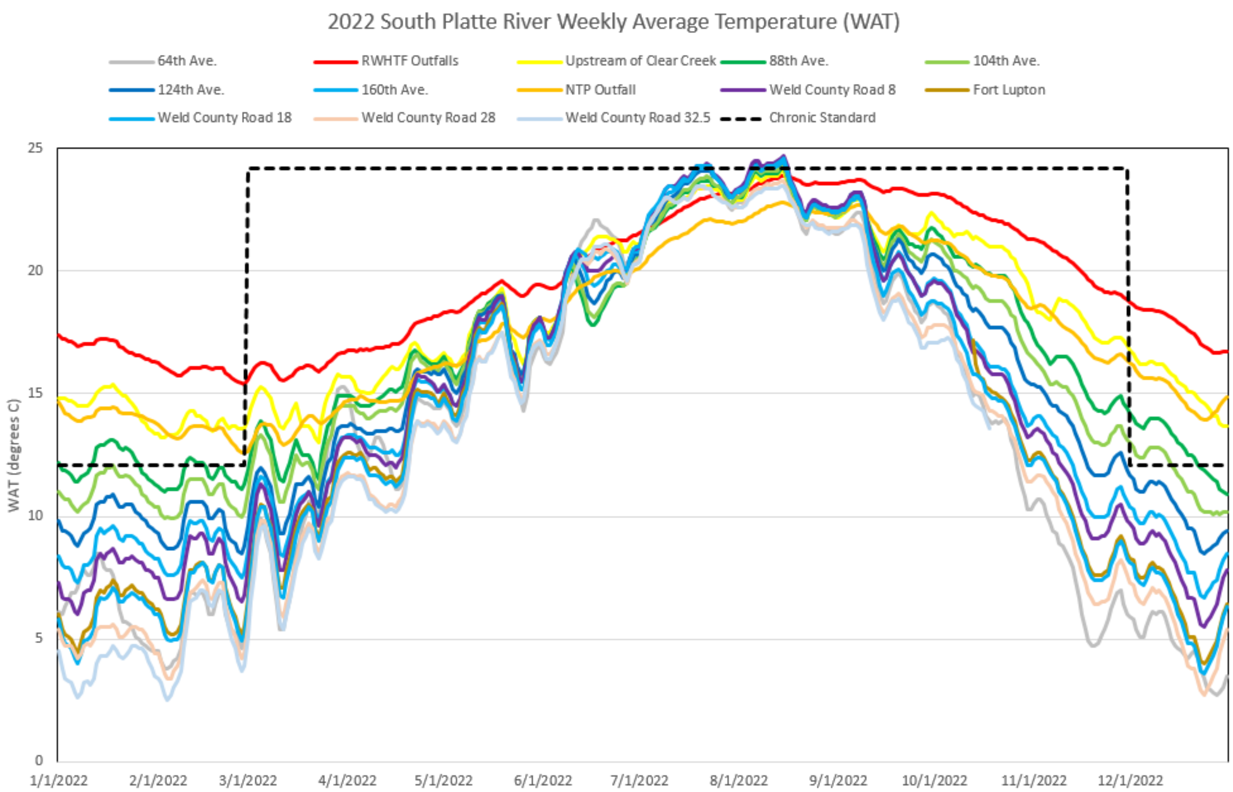


Figure 29. Rolling weekly average temperature calculations for RWHTF effluents and South Platte River mainstem temperature monitoring locations.

30-Hour Studies

Periodically, Water Quality staff is asked to sample the river repeatedly over a 30-hour time frame to provide data for calibration of Metro's South Platte Water Quality Model. This data is used to assess diurnal changes in water quality, especially in relation to biological processes including photosynthesis and respiration. Metro staff conducted seven of these 30-hour studies in 2022. Data from 2022 is particularly important for the modeling efforts as it provides information of current conditions since full-scale biological phosphorus removal has been implemented. The model relies on monthly calibration and staff hopes to collect data for the remaining uncharacterized months in 2023.

Longitudinal Nutrient Study

In 2022, nine sites were sampled monthly to determine nutrient concentrations from Segment 1a to the Colorado-Nebraska border. In past years, concentrations of both TN and TP declined as the river approached the border, with the sharpest decrease occurring between County Road 8 and Milliken. However, this pattern has changed since 2015 and the sharp decrease in TN at the lower portion of Segment 1a was not observed in 2022 (Figures 31 and 32). Both the TN and TP concentrations were lower at all sites in 2015-2022 compared to previous years, likely due to the nutrient reductions in the RWHTF effluent. This is an encouraging finding, demonstrating that the treatment upgrades are resulting in lower nutrient concentrations further downstream on the river than previously seen.

Concentrations of TN were highest at the Kersey sampling site (mean = 6.3 mg/L; Figure 30). For reference purposes, the interim numeric value for TN that would apply to the South Platte River in 2027 is 2.01 mg/L. Preliminary analysis indicates that all locations currently sampled could be impaired.

Prior to full scale biological phosphorus removal at the RWHTF in January 2021, TP concentrations were elevated at Weld County Road 8 and declined consistently as the river flowed to the Colorado-Nebraska border. However, the 2022 border nutrient data reflects the significant reduction of phosphorus concentrations in Segment 15 and 1a. In fact, the highest annual average TP concentration in 2022 was at Kersey. The averages ranged from 0.72 mg/L at Kersey to 0.07 mg/L at Julesburg (Figure 31). For reference purposes, the interim numeric value for TP that would apply to the South Platte River in 2027 is 0.17 mg/L. As with TN, preliminary analysis indicates that all locations currently sampled along the South Platte River could be impaired for TP.

Sampling of nutrient concentrations to the Colorado-Nebraska border is planned to continue until nutrient regulations are fully implemented to help establish baseline conditions and to document any improvement in river conditions due to treatment upgrades at the RWHTF.

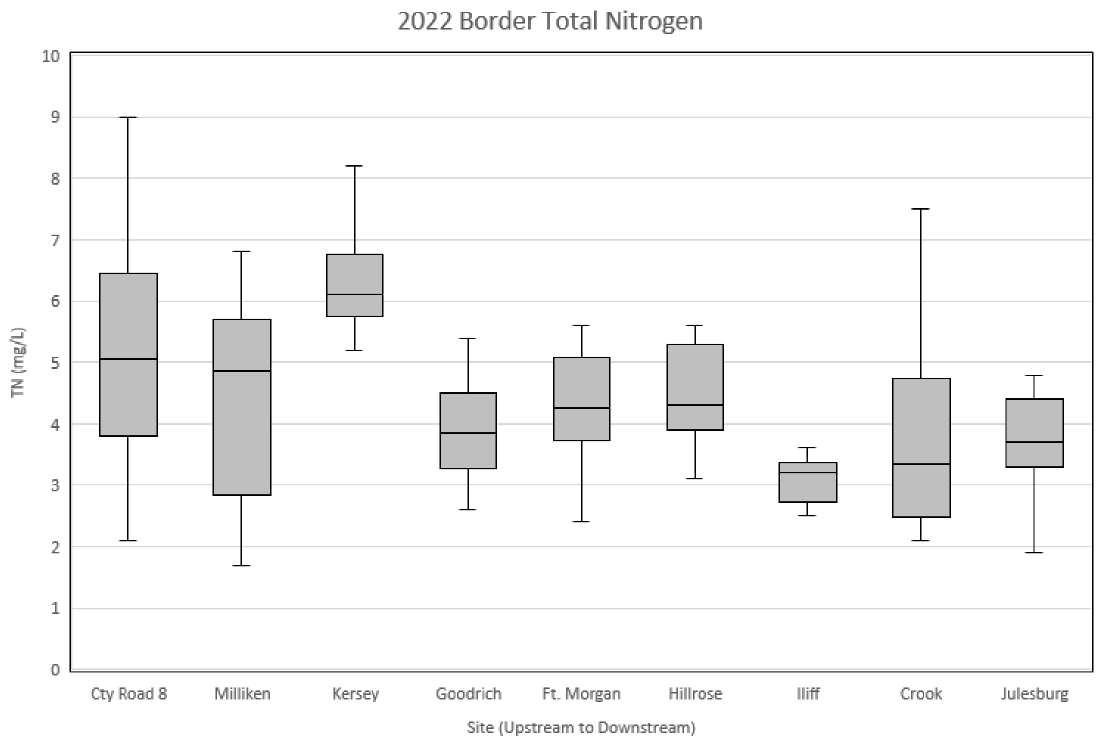


Figure 30. Box plot of TN concentrations from Weld County to the State Line.

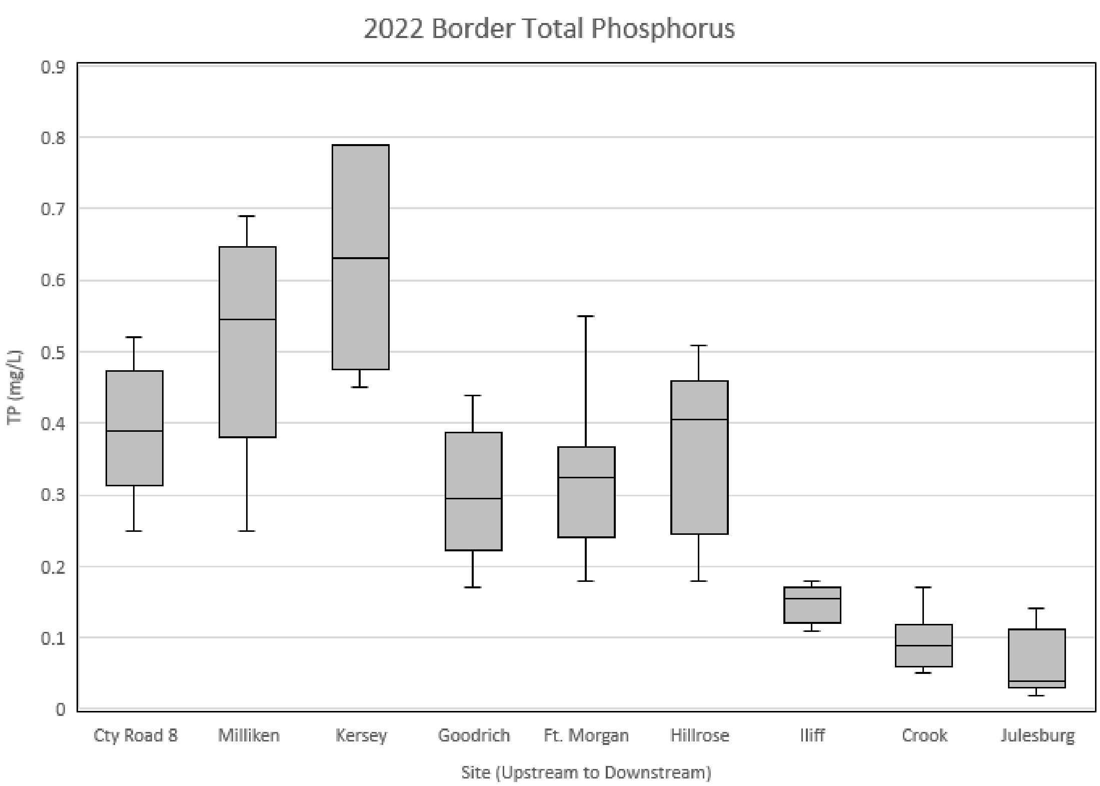


Figure 31. Box plot of TP concentrations from Weld County to the State Line.

Reservoirs Program

Barr (Barr) and Milton Reservoir (Milton) have been routinely monitored by Metro since June of 2002. The five-year period (2003 – 2007) was before any TMDL implementation occurred, and reservoir management relied on pumping of effluent to Barr. The 2022 water quality data will be compared to this 5-yr period to show how water quality has changed over the past 20 years. Barr and Milton's water quality is impacted by nutrient loading from point and non-point sources in the watershed and requires a 92% annual phosphorus load reduction to satisfy the 2013 pH/DO Phased TMDL.

Water Quantity

Reservoir management, weather conditions, and spring snowpack determine water depth by controlling the inflow and outflow rates and the timing of these flows. Monthly and annual management decisions by FRICO based on quantities can have a major impact on the water quality in both reservoirs.

The water year (WY) for both reservoirs is from November 1st to October 31st. The annual year (AY) is from January 1st to December 31st. Base flows from the South Platte River during the months of November through February typically refill both reservoirs. Barr fills first followed by Milton. Spring rains and snow runoff keep the reservoirs at full pool until the irrigation season begins in June. Both reservoirs filled earlier and were above normal in late March and then gradually released water and were below average in water depth for the remainder of 2022. Milton initiated a major wet dredging project and delayed the refill in the fall (Figure 32).

Burlington Pumps, owned and operated by Denver Water and in management agreement with FRICO and City of Thornton, have not been activated since February 10, 2012. No pumping occurred in 2022. The September 2013 floods caused major erosion on the west bank of Sand Creek and washed out the pipeline that delivered treated effluent to the Burlington Ditch.

Metro effluent can still reach Barr via the Beebe Pipeline, a 36-inch pipeline (rated at 50 cfs) that diverts from the South Platte River just downstream of the 124th Avenue crossing. This pipe, owned and operated by United Water, delivers river water necessary to meet water rights in Barr. Approximately 7,437 acre-feet of water was diverted in 2022 AY. This was 620 less acre-feet than in 2021.

Barr has reached full pool for the past ten years. The lack of effluent pumping to the Burlington Ditch has not prevented the reservoir from being filled. In 2022 AY, a total of 43,100 acre-feet of water went into Barr, and of that, 35,600 acre-feet came from the South Platte River via the Burlington Head Gate. The Burlington Head Gate swept the South Platte River 36% of the year (131 days) and diverted some water 99.7% of the year (364 days). Of the 148,700 acre-feet of water that was in the South Platte River at the Burlington Head Gate in 2022 AY, 57% was diverted to the Burlington Ditch past the BURCANCO flow gauge. Not all of the BURCANCO flows go to Barr, 42% of the flows were delivered to Barr and the other 58% went to the Little Burlington Ditch or past Barr to fill up Horse Creek Reservoir and Prospect Reservoir.

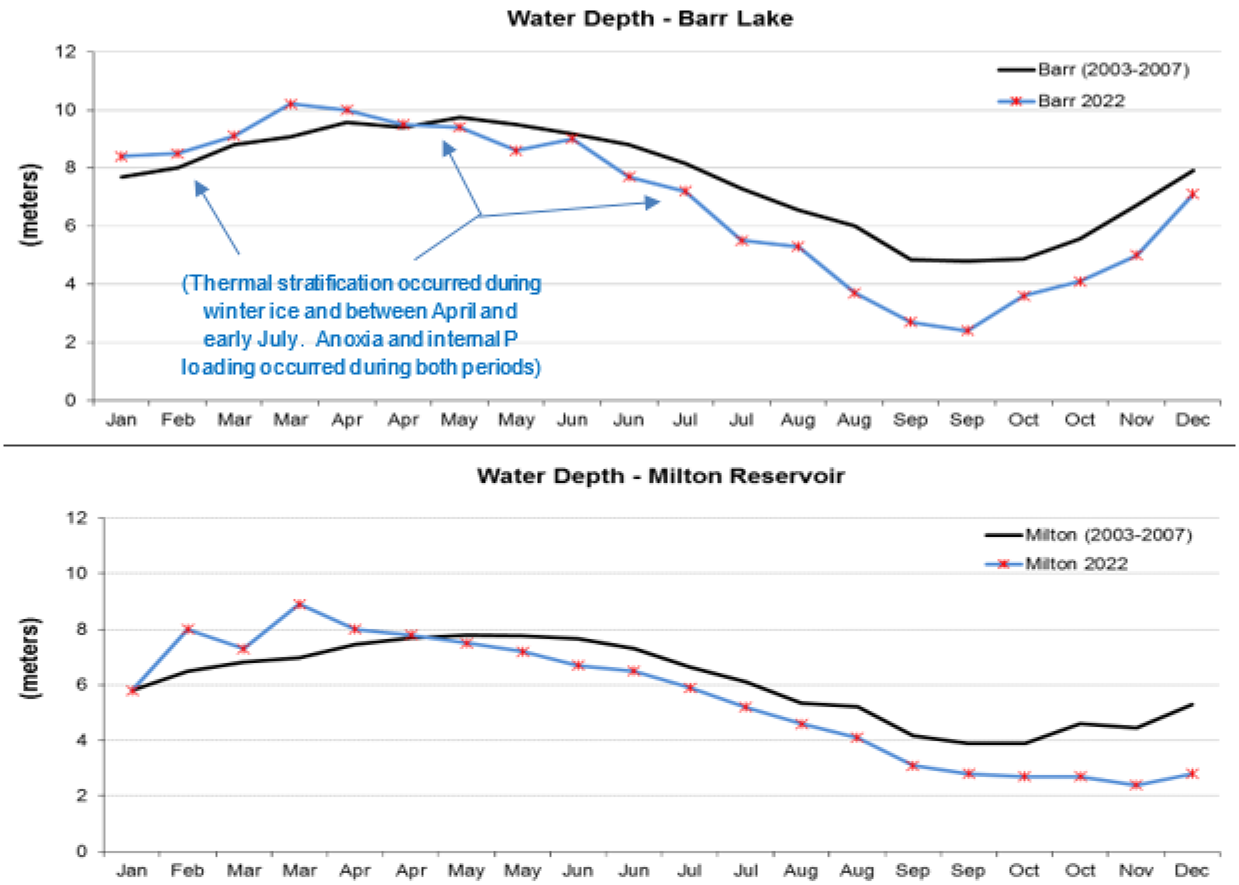


Figure 32. Seasonal variability of water depth in 2022.

Water Quality

Nutrients (nitrogen and phosphorus), pH, chlorophyll-a (chl-a), water clarity, alkalinity, temperature, and dissolved oxygen (DO) are key parameters for the reservoir monitoring program. Lake or reservoir eutrophication occurs when nutrients accumulate, triggering algal growth and a series of water quality symptoms. Both reservoirs have experienced cultural eutrophication (human caused) for the past 135+ years and have been listed on the 303(d) list since 2002 as being impaired for pH, DO, and ammonia (Barr was removed from the list for ammonia in 2015).

Phosphorus (TP and SRP)

Total phosphorus (TP) is the summation of all phosphorus: particulate and soluble, organic and inorganic, reactive and non-reactive, and biologically available and non-available. TP is used as an endpoint for the phased pH/DO TMDL. Soluble reactive phosphorus (SRP) is the phosphorus that is readily available in dissolved inorganic form, mainly as orthophosphate. SRP determines how much phosphorus in the water is readily available for primary productivity. When TP is mostly SRP, this can help with source identification. Wastewater and internal loading are two typical sources of SRP. Storm water phosphorus is typically in particulate and insoluble form.

In 2022, 20 phosphorus epilimnetic (top mixing layer) samples were collected for each reservoir along with 15 hypolimnetic (bottom 3 meters) samples from Barr and 13 hypolimnetic samples from Milton. The annual average TP_{epi} for Barr was 296 µg/L, down from 316 µg/L in 2021 and 296 µg/L, up from 264 µg/L in 2021 for Milton. Both annual averages are above the proposed interim numeric values of 83 µg/L for warm-water lakes and reservoirs. The annual average SRP_{epi} for Barr was 171 µg/L and 82 µg/L for Milton. The summer season (July 1 – September 30) TP_{epi} average for Barr was 350 µg/L and 238 µg/L for Milton. The summer season SRP_{epi} average was 260 µg/L for Barr and 38 µg/L for Milton. The summer season is typically the most important because of length of day, warmest water temperatures, and highest recreational uses.

Despite being below the 2003-2007 average, both reservoirs still had relatively high levels of phosphorus. Barr and Milton have seen a major decrease in TP over the past 20 years, but the 2022 values are still multiple times higher than the proposed standard. Two important highlights with phosphorus are: 1) SRP_{epi} is noticeably less than TP_{epi}, indicating a change in TP sources. There were 18 values below 100 µg/L. 2) TP_{hypo} values that are greater than the TP_{epi} values coincide when there are anoxic conditions or winter filling. As soon as DO goes below 1.0 mg/L, internal loading occurs (Table 14). Lower phosphorus levels were observed for the ninth year in a row when compared to the 2003-2007 timeframe.

Table 14. 2022 Barr and Milton epilimnion phosphorus data (µg/L). Note: red bold values indicate exceedances of the interim standard. Blue bold italic values indicate internal phosphorus loading caused by low oxygen levels or plunging of inflows

Month	Barr Lake			Milton Reservoir		
	TP_{epi}	TP_{hypo}	SRP_{epi}	TP_{epi}	TP_{hypo}	SRP_{epi}
Jan	380	***800***	160	880	490	480
Feb	290	***1,080***	100	600	370	270
Mar	330	***700***	180	330	300	200
Mar	350	320	150	280	***760***	120
Apr	190	***200***	10	230	230	20
Apr	140	160	80	240	160	<10
May	160	160	180*	120	100	10
May	190	190	140	160	***230***	110
Jun	180	***630***	140	130	***140***	60
Jun	320	***360***	300	190	***300***	130
Jul	**380**	***570***	340	**240**	***250***	150
Jul	**360**	340	290	**190**	***200***	70
Aug	**380**	370	340	**150**	***190***	<10
Aug	**390**	NA	310	**270**	NA	10
Sep	**370**	NA	240	**280**	NA	<10
Sep	**220**	NA	40	**300**	NA	<10
Oct	400	NA	20	330	NA	<10
Oct	210	NA	50	370	NA	<10

Nov	270	270	150	340	NA	<10
Dec	400	***500***	200	280	NA	<10
*unreliable SRP values that are higher than TP values						

The seasonal variability of TP is consistent year-to-year due to the annual flow regime. The increase in TP between November and February is based on the South Platte River TP concentrations and the quantity of water that is diverted to refill each reservoir. The winter recharge of phosphorus supports a community of diatoms, greens, and blue-green algae in the spring that help consume some of the phosphorus. The baseline TP_{epi} concentration going into the summer season is 200 – 300 µg/L. There is a noticeable increase in phosphorus between June and August. This increase is driven by inflows during “free water” events on the South Platte River and internal loading during periods of no inflows (Figure 33).

Barr had a noticeably lower TP concentration between January and May. This is because of improvements in South Platte River water quality and the elimination of effluent pumping to the Burlington Ditch. TP in Barr remained below 400 µg/L for the entire year.

Internal loading in Barr occurred during two periods of extended anoxia, 02/08/22 – 03/08/22 and 06/14/22 – 07/11/22). During these periods, TP_{hypo} increased above TP_{epi} levels, and SRP_{epi} increased. The volume of reservoir that was anoxic on 02/08/22 was 10,960 acre-feet or 52% of the water volume. Internal loading of P was 303 pounds from the sediment. Inlet water did come in during this period, about 12,000 acre-feet with an average TP of 440 µg/L. The external loading was 135 pounds. The second period of anoxia was shallower but for a longer period, approximately 28 days. TP_{epi} change from 180 µg/L to 380 µg/L during this 28-day period (Table 14). External flows also entered Barr from 06/01/22 to 06/15/22. Approximately 4,200 acre-feet came from the South Platte River. This is an example of both internal loading and external loading occurring just before the peak of the cyanobacteria season.

Milton maintained a steady concentration of TP_{epi} for 2022 except for January and February. The refill from the South Platte River elevated the phosphorus in January. Some of that phosphorus can come from non-point sources along the Platte Valley Canal. By May, the TP_{epi} concentration decreased by 86% (880 µg/L to 120 µg/L). The higher TP_{epi} values occurred both in the winter and fall. Between January and March, higher values were because of inflows. The increase in TP in August was during a period of no inflows and anoxic conditions for 28% of the reservoir volume. Milton experienced some of the highest chl-a values in 2022.

SRP is the critical portion of TP that is readily available for algal growth. SRP historically was very similar to the TP concentrations. In 2022, there was a noticeable difference between TP and SRP for both reservoirs. It seems that in 2022, SRP was being consumed by algae faster than it was getting replaced and then internal loading during the summer replenished the available P.

Phosphorus cycling in both reservoirs is controlled both by external and internal influences. Both are then determined by reservoir management decisions. As point sources are reduced in the watershed, it will become more important that lake management decisions are made with water quality in mind.

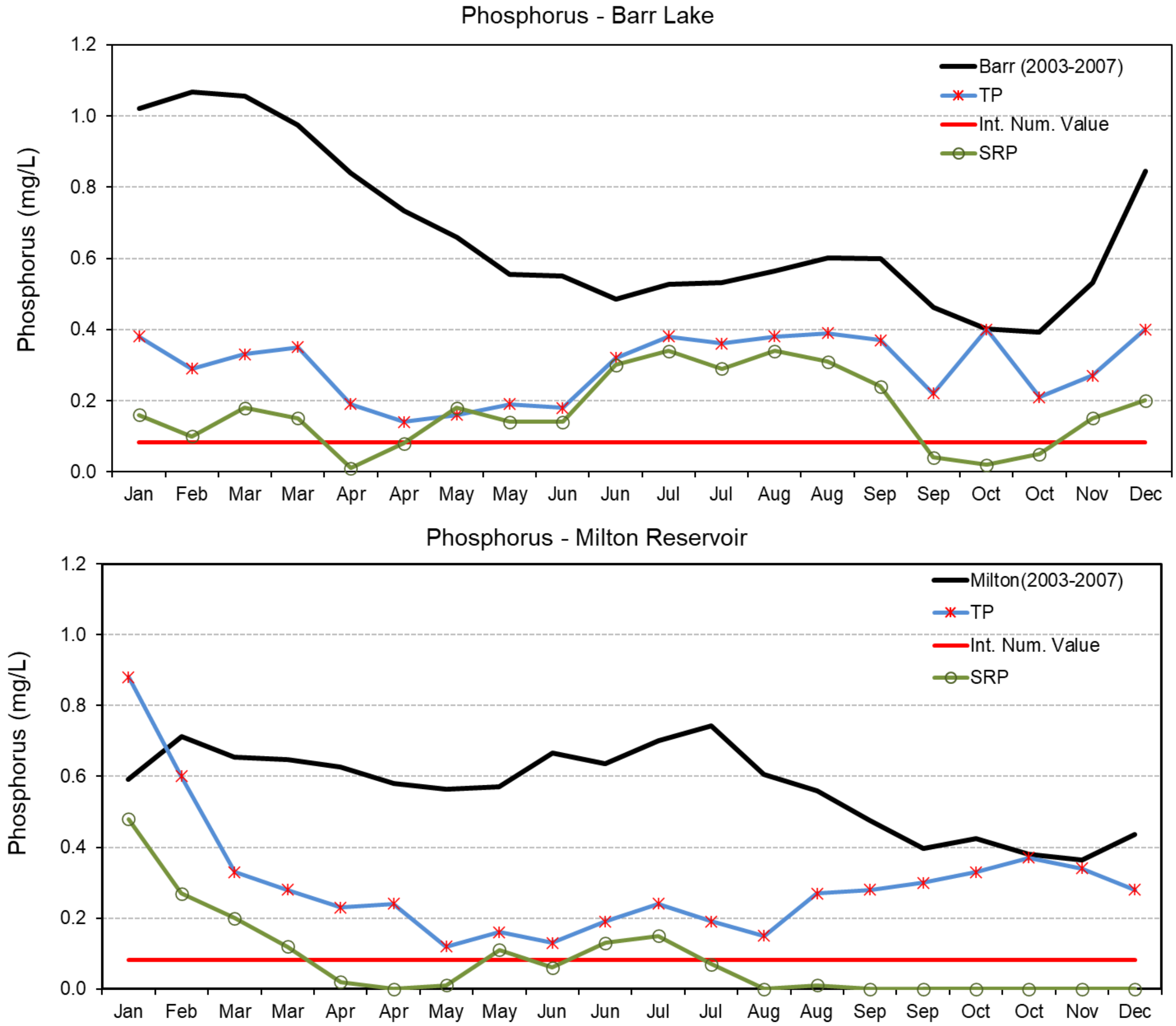


Figure 33. Seasonal variability of TP in 2022

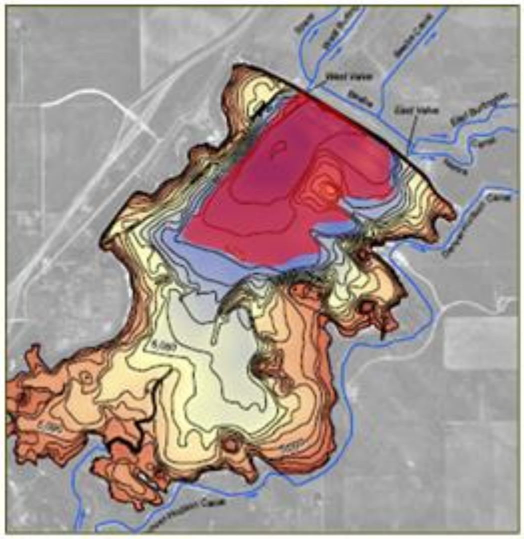


Figure 34. Bathymetric map of Barr showing surface area of water by late September (<450 acres or 5% lake volume shown in red)

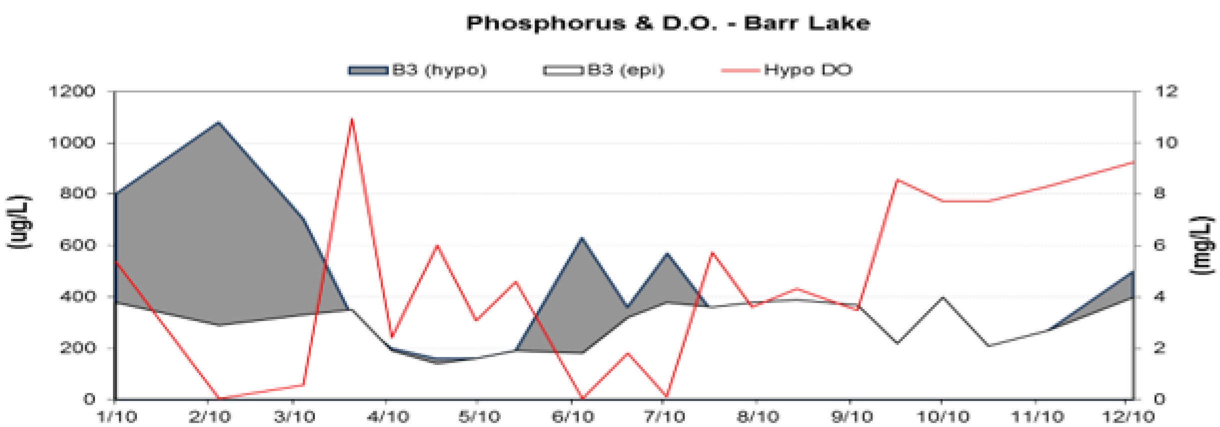


Figure 35. Comparison of 2022 epilimnion TP and hypolimnion TP with sediment DO levels

Nitrogen (NH3, NO2, NO3, TKH, TN)

Because of excessive phosphorus concentrations in both reservoirs, nitrogen is typically the limiting factor in respect to algal growth. When total nitrogen to total phosphorus (TN:TP) ratios are less than 15, nitrogen is limiting, and cyanobacteria can use aqueous nitrogen gas to outcompete other algal species. This is a main advantage of cyanobacteria and often the reason for algal blooms in both reservoirs.

Milton was placed on the 303(d) list for ammonia in 2010. Barr was delisted from the 2012 Monitoring/Evaluation list for ammonia because of attainment. Both Barr and Milton had no ammonia exceedances in 2022.

Total Kjeldahl Nitrogen (TKN) is the summation of organic nitrogen, ammonia, and ammonium. In both reservoirs, the TKN is dominated by organic nitrogen and is usually stable during the year. Nitrate and nitrite are quickly depleted by June or July due to assimilation.

In 2022, 20 nitrogen epilimnion samples were analyzed for each reservoir. For comparison, the TN interim value for warm water reservoirs greater than 25 acres during the summer season is currently 0.91 mg/L (Table 15).

Table 15. Barr and Milton 2022 epilimnion nitrogen data (mg/L). Note: red bold values indicate exceedances of the interim standard. Blue bold italic values indicate internal ammonia loading caused by low oxygen levels

	Barr Lake (mg/L)						Milton Reservoir (mg/L)					
Month	**NH_3**	**NO_3**	**NO_2**	**TKN**	**TN**	**TN:TP**	**NH_3**	**NO_3**	**NO_2**	**TKN**	**TN**	**TN:TP**
Jan	0.11	1.79	0.09	2.2	4.08	11	0.16	2.65	0.07	3.2	5.92	7
Feb	***0.33***	1.49	0.09	2.2	3.78	13	0.09	2.65	0.09	3.2	5.94	10
Mar	***0.35***	1.68	0.08	1.9	3.66	11	0.07	2.25	0.07	1.6	3.92	12
Mar	0.23	1.55	0.07	2.0	3.62	10	***0.13***	1.92	0.08	1.8	3.80	14
Apr	0.10	0.95	0.05	2.6	3.60	19	0.05	1.18	0.07	2.1	3.35	15
Apr	0.40	0.87	0.06	1.7	2.63	19	0.03	0.65	0.07	3.0	3.72	16
May	0.74	0.68	0.06	1.7	2.44	15	0.12	0.34	0.06	1.8	2.20	18
May	0.54	0.56	0.06	1.6	2.22	12	***0.76***	0.28	0.04	1.9	2.22	14
Jun	***0.42***	0.44	0.07	1.4	1.91	11	***0.38***	0.21	0.04	1.6	1.85	14
Jun	***0.70***	0.24	0.06	2.0	2.30	7	***0.29***	0.09	0.02	1.8	1.91	10
Jul	***0.49***	0.15	0.05	1.5	**1.70**	5	0.11	<0.02	<0.02	1.5	**1.50**	6
Jul	0.03	0.02	<0.02	1.7	**1.72**	5	0.03	0.03	<0.02	2.2	**2.23**	12
Aug	0.05	<0.02	<0.02	1.0	**1.00**	3	0.02	<0.02	<0.02	1.4	**1.40**	9
Aug	0.04	0.02	<0.02	1.9	**1.92**	5	0.13	<0.02	<0.02	2.7	**2.70**	10
Sep	0.39	0.02	<0.02	2.0	**2.02**	6	0.02	<0.02	<0.02	3.0	**3.00**	11
Sep	0.16	0.32	0.03	2.3	**2.65**	12	<0.01	<0.02	<0.02	3.0	**3.00**	10
Oct	0.02	0.45	0.08	4.1	4.63	12	0.01	<0.02	<0.02	3.3	3.30	10
Oct	0.20	0.73	0.09	2.1	2.92	14	0.04	0.16	<0.02	3.8	3.80	11
Nov	0.29	1.02	0.09	2.0	3.11	12	0.16	0.16	<0.02	3.9	3.90	12
Dec	0.04	1.02	0.07	2.0	3.09	8	0.61	0.19	<0.02	4.1	4.29	15

The average TN_{epi} for Barr in 2022 was 2.75 mg/L (2.77 mg/L in 2021) and 3.21 mg/L (2.88 mg/L in 2021) for Milton. These values are higher than each reservoir's respective summer season

TN_{epi} averages (Summer Barr = 1.84 mg/L, Summer Milton = 2.31 mg/L). Typically, the summer seasonal average is lower than the annual average due to the winter fill period as well as increased biologic activity in the summer.

The seasonal variability with TN is consistent year to year. Like TP, TN tends to increase during the fill period and then decline until early September. TN usually increases around September, likely caused by internal recycling resulting from cyanobacteria and other algae (Figure 36). In 2022, both reservoirs experienced a decline in TN concentrations from January to August. Barr did see an increase in TN in early October due to TKN which is a strong indication of algal growth.

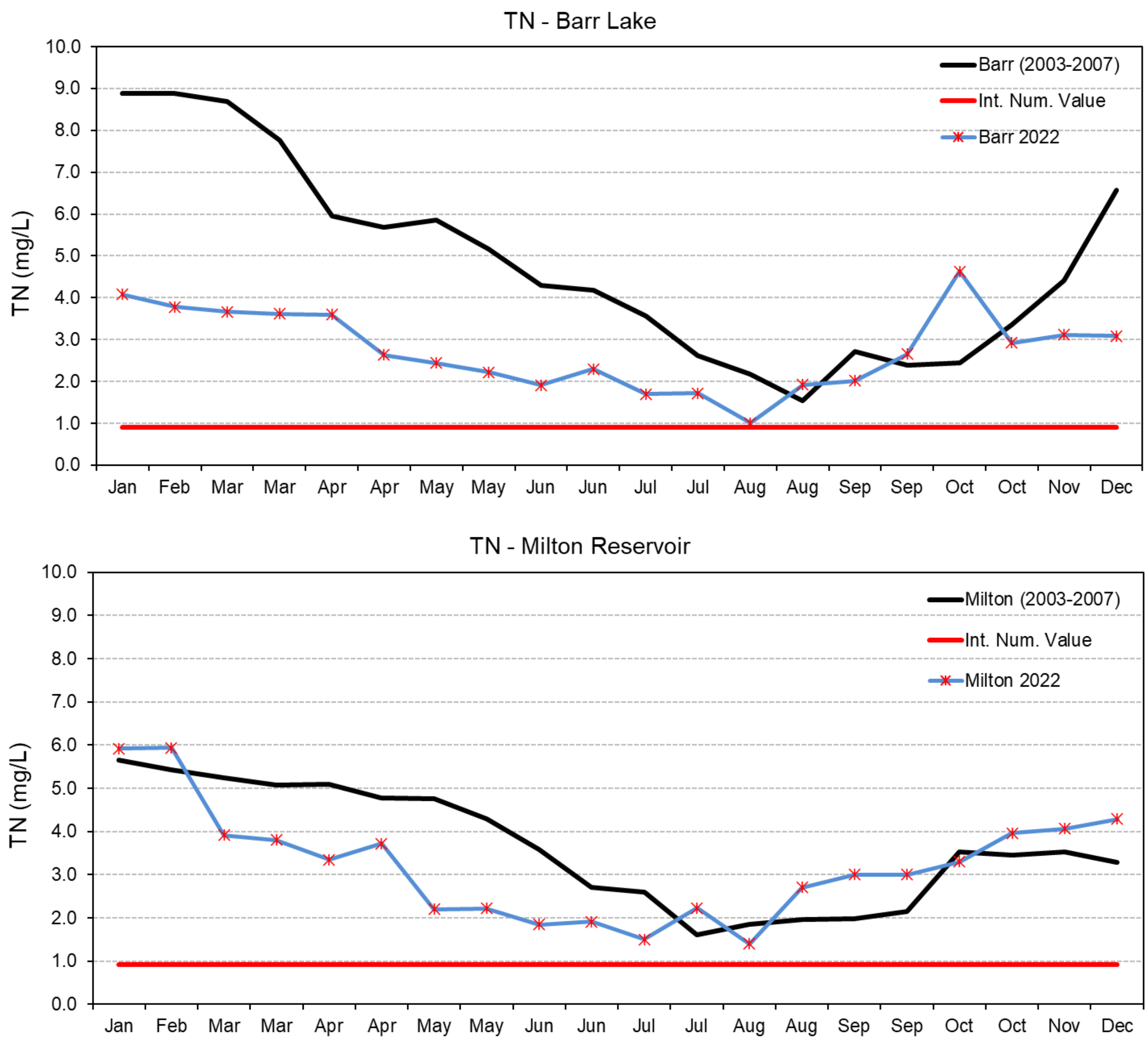


Figure 36. Seasonal variability of TN in 2022

Nitrate (NO_3) concentrations typically decrease below detection limits by mid-summer. Some of that nitrogen is converted to organic nitrogen. The nitrate standard of 10 mg/L was attained during all of 2022 in both reservoirs. NO_3 in both reservoirs was below average from most of the year. This continuing trend of below average NO_3 concentrations are the result of 2017 treatment improvements at the South Platte Renew facility.

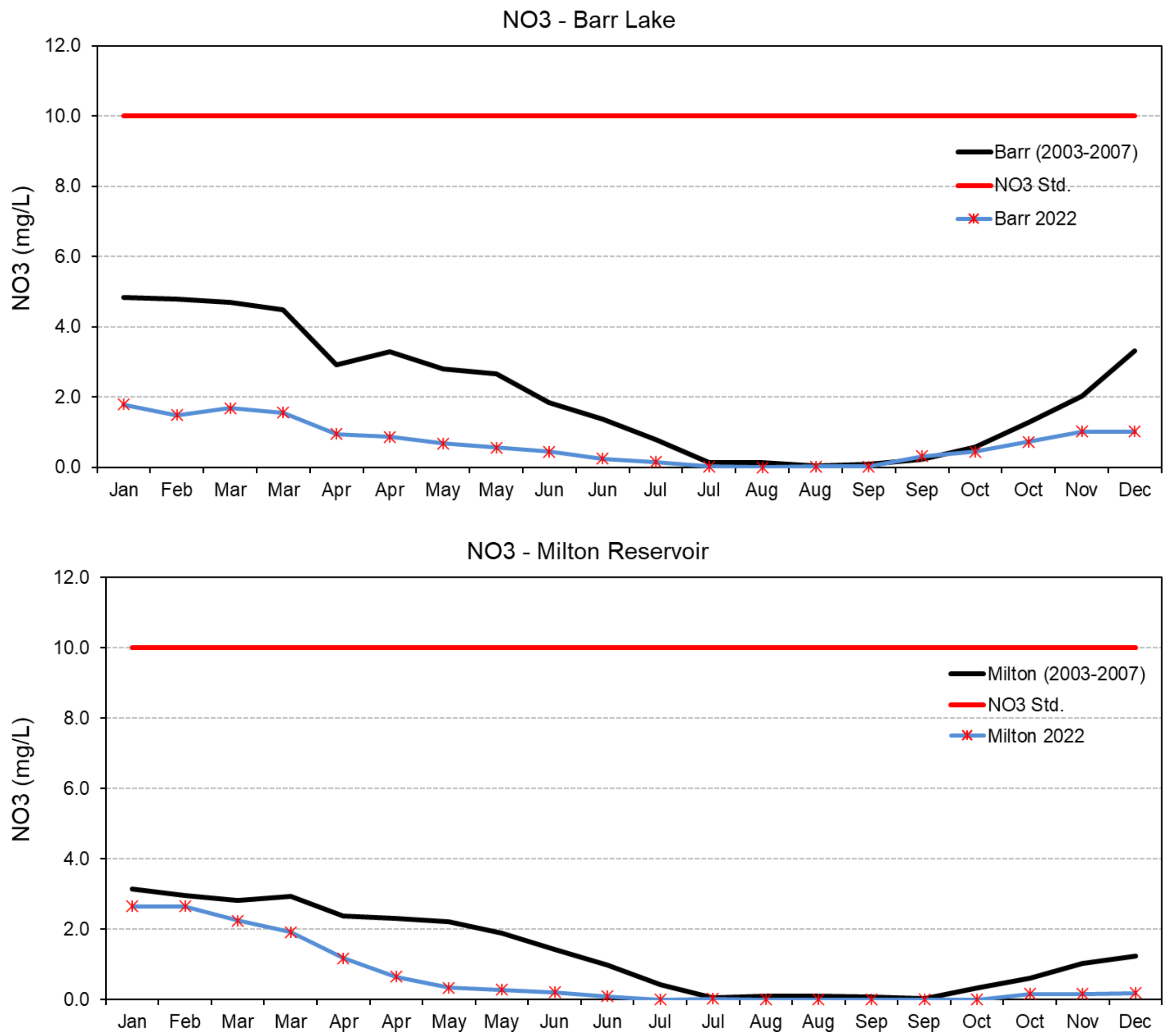
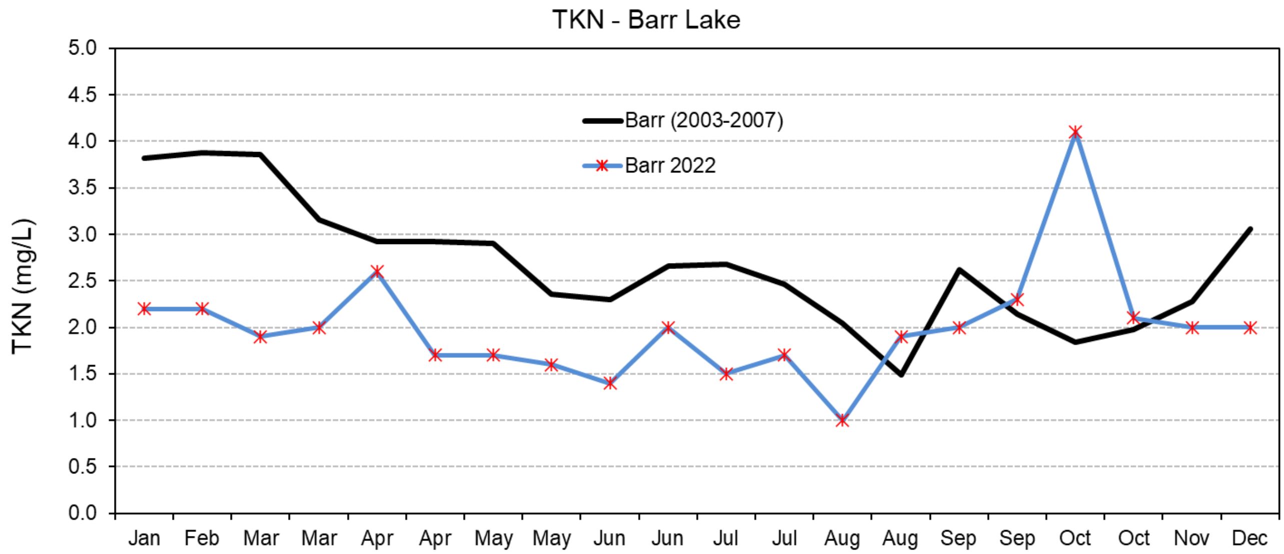


Figure 37. Seasonal variability of NO3 in 2022

When ammonia does not increase with increasing TKN, this indicates that a reservoir is experiencing an algal bloom. The TKN, or organic nitrogen patterns, closely track the algal growth. This was especially true during the short-lived cyanobacteria bloom in Barr in late July and then the continue algal growth during the fall drawdown (Figure 38). TKN, on average in both reservoirs, accounts for 70% to 80% of the TN. Nitrogen is being stored in the biomass within the water column. Milton's cycling of algae growth and decline is easily seen with the patterns of TKN during the late growing season. This is a good demonstration that TKN is driven by algal growth instead of external inputs.



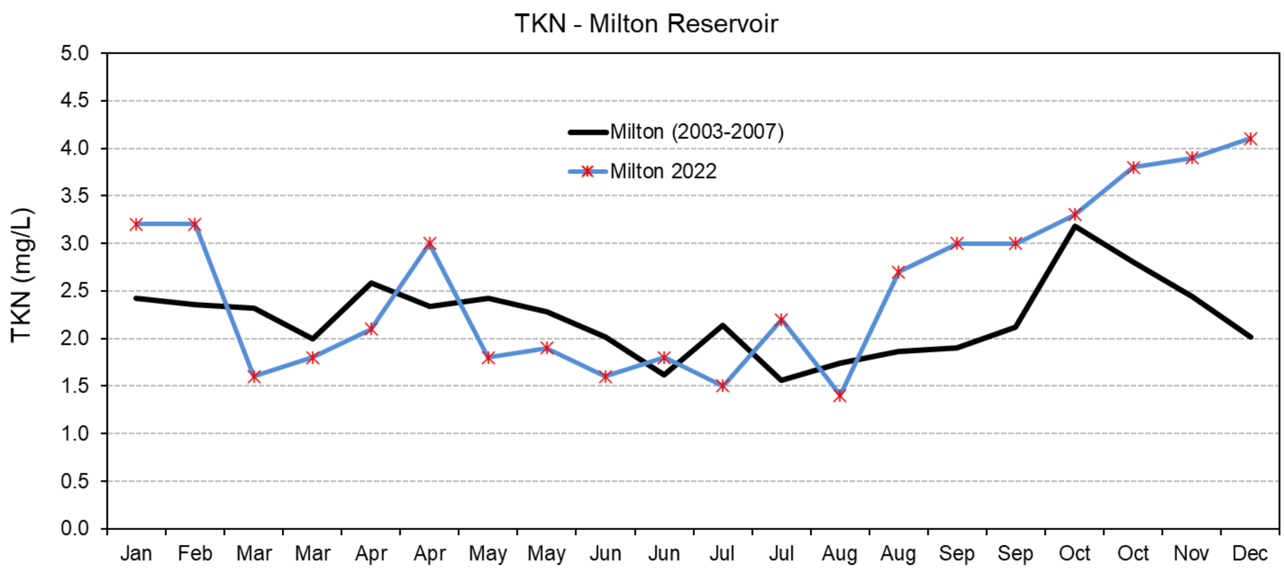


Figure 38. Seasonal variability of TKN in 2022

The ammonia (NH_3) standard is based on two chronic conditions: early life stages absent (ELSA) from August 1 to March 31 and early life stages present (ELSP) from April 1 to July 31. Acute conditions do not apply, as salmonids are not present. During the winter months of January and February, both reservoirs can experience a buildup of ammonia under the ice. When the reservoirs are iced-over, oxygen is depleted and ammonification increases.. Oxygen levels can also decrease during the month of April due to the decomposition of spring algal blooms.

The acute ammonia standard changes throughout the year, but is generally above 1.0 mg/L. Both reservoirs typically stay below 0.50 mg/L of ammonia. In 2022, both reservoirs did not exceed the ammonia standard (Figure 39). Water temperature and pH are two parameters used in the ammonia standard calculations. These parameters can be contributing factors in some cases.

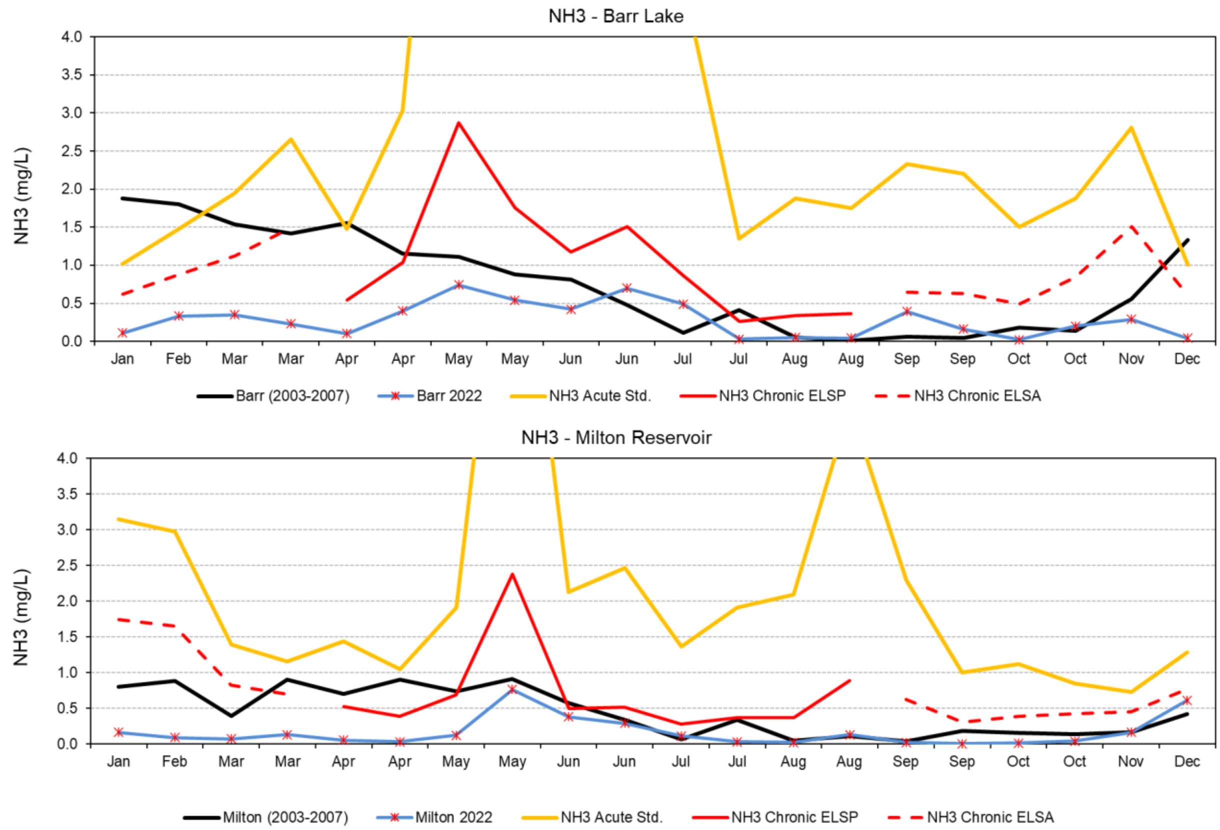


Figure 39. Seasonal variability of NH_3 in 2022

Chlorophyll-a

Chl-a is an indirect measurement of algal biomass and a response parameter to nutrients. As nutrients and water temperature increase, chl-a, pH, and surface DO can also increase. As primary productivity increases, water clarity and DO will decrease. Different species of algae produce different quantities of chl-a. Diatoms do not produce as much chl-a as cyanobacteria but can affect water clarity and DO. The cyanobacteria bloom at Barr in late August lasted about a week and was not reservoir wide. The chl-a interim numeric water quality standard during the summer season for warm-water reservoirs is 20 µg/L. Chl-a can change drastically in a short period of time, on an hourly time scale (Table 16). When summarizing chl-a data, medians are calculated instead of averages to avoid skewing the data with extreme low or high values.

Table 16. Barr and Milton 2022 chlorophyll-a data (µg/L)

Month	Chl-a (Barr)	Chl-a (Milton)
Jan	90.0	206.0
Feb	53.2	225.0
Mar	105.0	41.6
Mar	67.3	71.4

Apr	65.8	93.5
Apr	2.2	131.0
May	3.0	36.8
May	3.0	3.0
Jun	4.0	15.3
Jun	5.2	29.2
Jul	17.8	**32.7**
Jul	**40.5**	14.7
Aug	**25.5**	**75.2**
Aug	**84.1**	**89.4**
Sep	**43.1**	**174.0**
Sep	**94.2**	**135.0**
Oct	181.0	183.0
Oct	84.4	277.0
Nov	51.3	447.0
Dec	192.0	259.0

In 2022, the median chl-a for Barr was 52.3 µg/L (46.8 µg/L in 2021) and 91.5 µg/L (68.4 µg/L in 2021) for Milton. Although algal growth is of greatest concern during the summer, algae grow year-round. The summer season median for Barr was 41.8 µg/L (44.3 µg/L in 2021) and 82.3 µg/L (55.3 µg/L in 2021) for Milton. In contrast to previous years (2003-2015), the annual median in 2022 is larger than the summer median due to less algae during the summer and more growth during the fall and winter. Since 2019, the fall through spring diatom growth has become the leading cause of pH exceedances and overall water quality stresses.

Milton experienced some of the highest chl-a values and medians since 2003. The median chl-a concentration from September to December was 221.0 µg/L with a maximum value of 447.0 µg/L occurring on 12/20/22 (Figure 40). Like Barr, Milton appeared to have more algal activity during the spring and fall. Barr's largest bloom of algae, cyanobacteria, was in October (Figure 41).

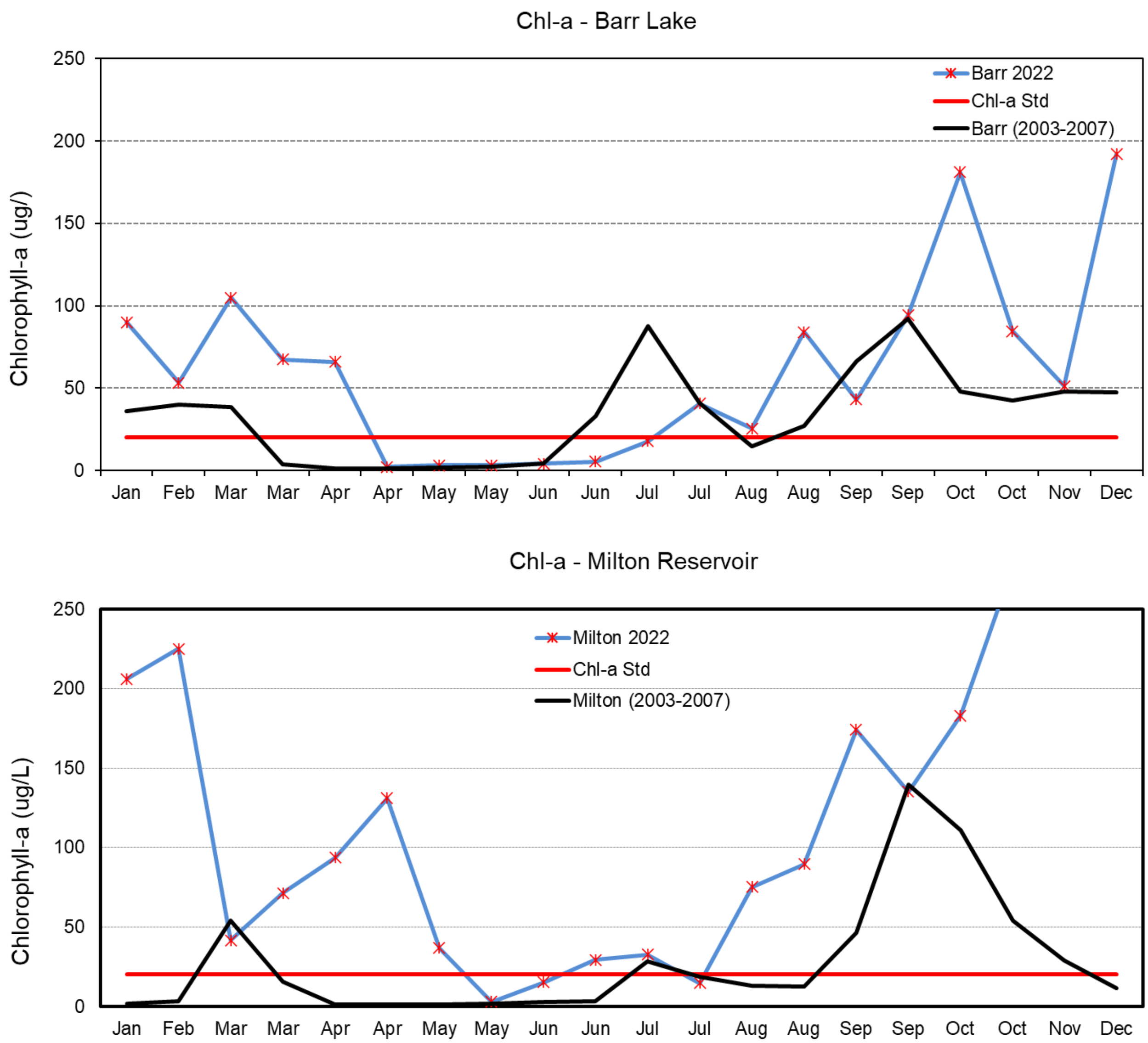
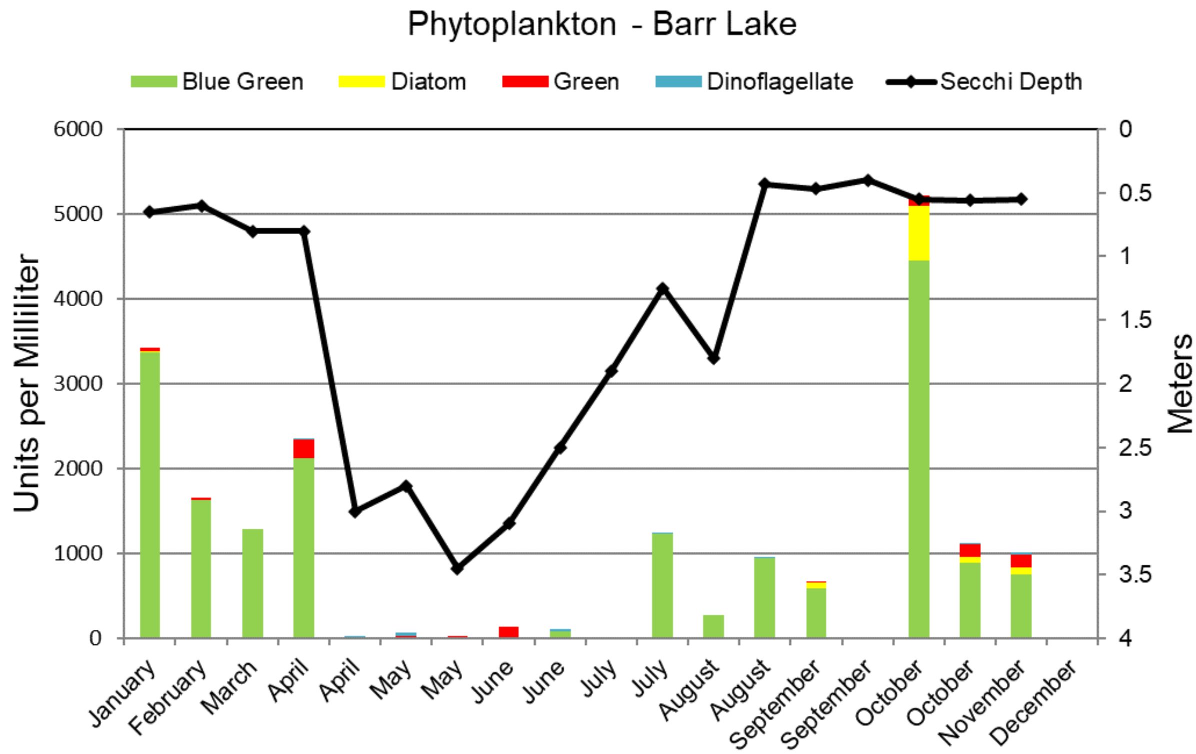


Figure 40. Seasonal variability of Chl-a in 2022



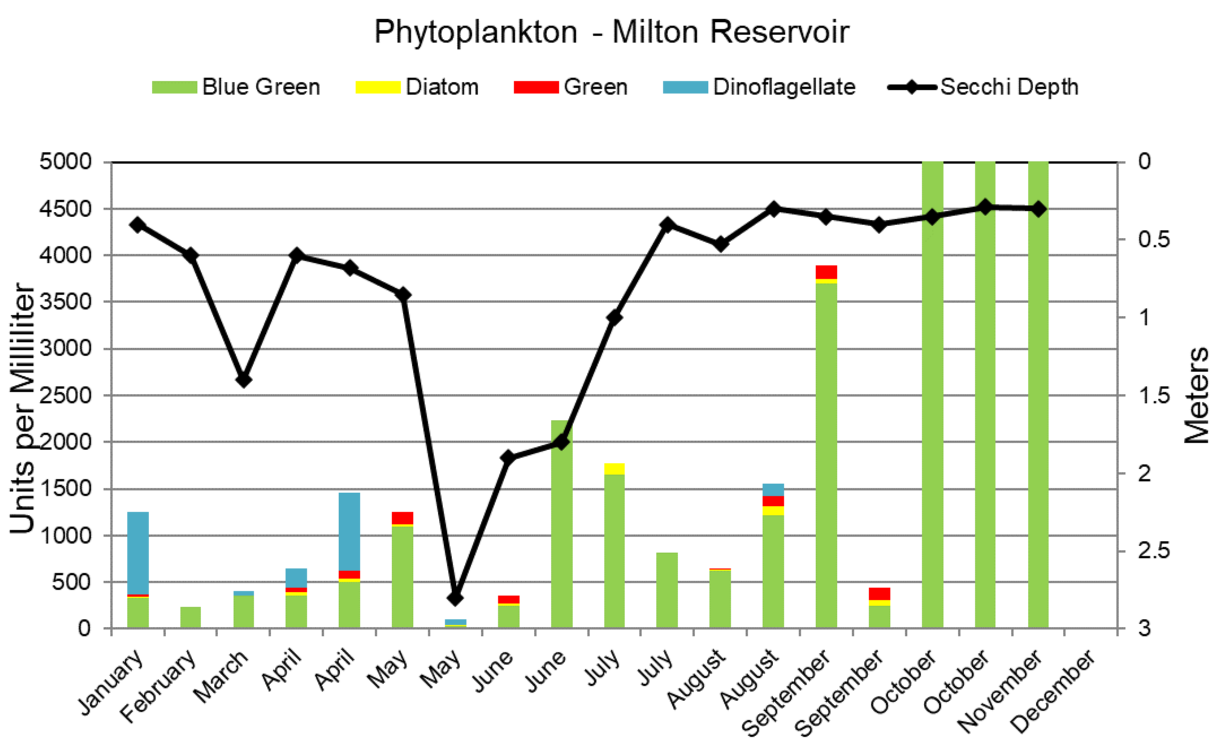


Figure 41. 2022 Phytoplankton units per milliliter

Water Clarity

Water clarity is measured with an 8-inch diameter, black and white, Secchi disk. In addition to measuring water clarity, the Secchi depth is also closely correlated with chl-a, TP, and a trophic state index score (TSI) developed by Bob Carlson (Carlson, 1977).

Table 17. Barr and Milton 2022 Secchi Depth data (meters)

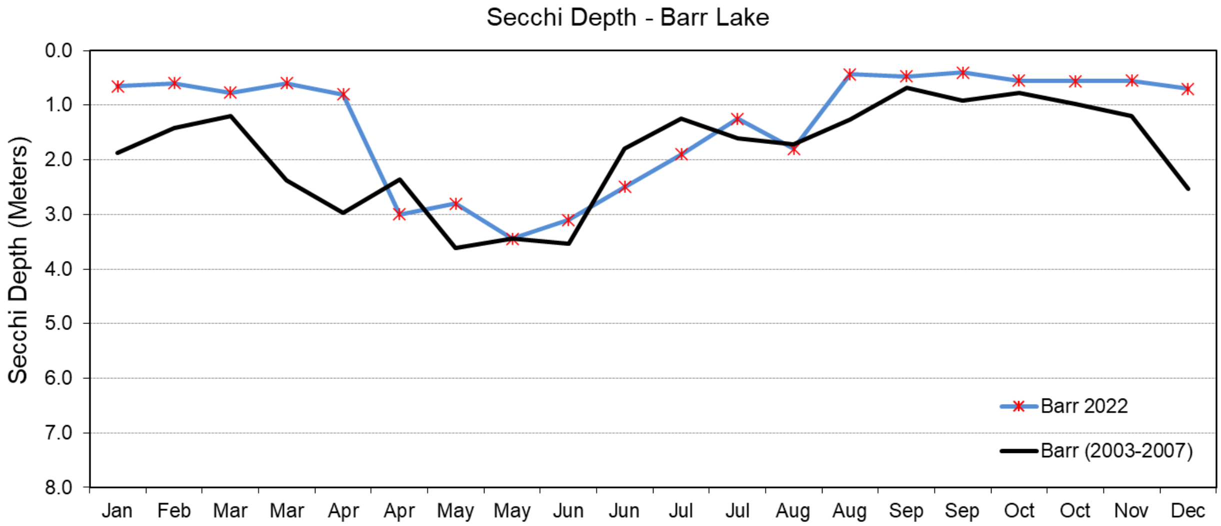
	Barr Lake		Milton Reservoir	
Month	**Secchi Depth (meters)**	**TSI Score**	**Secchi Depth (meters)**	**TSI Score**
Jan	0.65	77	0.40	86
Feb	0.60	74	0.58	83
Mar	0.77	76	1.40	70
Mar	0.60	76	0.90	73
Apr	0.80	72	0.60	75
Apr	3.00	53	0.68	76
May	2.80	55	0.85	67
May	3.45	54	2.80	55
Jun	3.10	56	1.90	61
Jun	2.50	60	1.80	65
Jul	1.90	66	1.00	69
Jul	1.25	71	0.40	70
Aug	1.80	68	0.53	73
Aug	0.43	79	0.30	79
Sep	0.47	76	0.35	81
Sep	0.40	77	0.40	79
Oct	0.55	80	0.35	82
Oct	0.56	75	0.29	84
Nov	0.55	74	0.30	85
Dec	0.70	79	0.30	83

The average Secchi depth for Barr in 2022 was 1.34 m (1.29 m in 2021) and 0.81 m (1.05 m in 2021) for Milton. Water clarity closely follows the algal growth throughout the year. Both reservoirs typically experienced a clearing phase between April and June (Table 17). Milton had a shallower and shorter clearing phase than Barr. Barr's clearing phase was close to average and slightly extended later into the summer. The TSI scores varied from eutrophic (>50) to hypereutrophic (>70) for both reservoirs.

The summer season average Secchi depth for Barr was 1.04 m (1.01 m in 2021) and 0.50 m (0.79 m for 2021) for Milton. Water clarity was less than average for most of the year. The summer TSI average for Barr was 73 (72 for 2021) and 75 (73 for 2021) for Milton. These scores are considered "hypereutrophic".

The seasonal variability in water clarity closely follows the chl-a pattern. Water clarity is at, or below, 1.0 meter during any major algal growth. In the spring after the diatoms have ceased blooming, the zooplankton graze on the available algae, clearing up the water for one to three months. You can see this pattern with the averages for both reservoirs (Figure 42).

Both reservoirs experienced enough algal growth to impact water clarity for most of the year. Barr did get to 3.45 meters in late May with a gradual decline in clarity by late July. Milton had a difficult year because of the algae. Clarity was less than average all year long. It is desirable to have water clarity greater than one meter for recreational uses. There is no water clarity standard for Colorado.



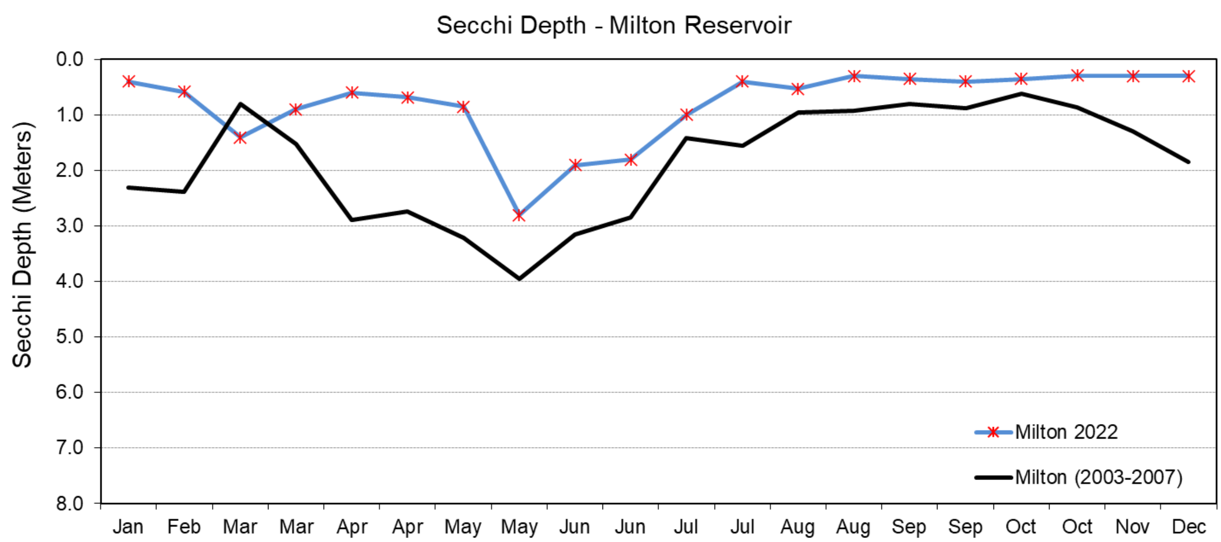


Figure 42. Seasonal variability of water clarity for 2022

Dissolved Oxygen

DO is an important response parameter when determining the health of a lake or reservoir. Oxygen can only enter the water two ways, from the atmosphere and from photosynthesis. When at 100% saturation, respiration equals photosynthesis. DO can decrease below 100% when respiration is greater than photosynthesis. The opposite can also occur. DO can exceed 100% when there is an excessive rate of primary productivity. Understanding DO throughout the water column assists in understanding the overall health of a waterbody.

The DO standard is applied as an average of the upper mixed layer (0.5 – 2.0 meters) of a reservoir and cannot go below 5 mg/L at any time when the water depth is greater than 5 meters. If less than 5 meters, then the top 40% of the water column is analyzed for compliance. This shallow water analysis occurred in Barr (August through October) and Milton (August through December). There is no upper limit or frequency of violations for DO.

In 2022, 20 DO averages were recorded for each reservoir (Table 18). Barr's lowest DO average was 5.7 mg/L (73%) in early September. Milton's lowest DO average was 4.4 mg/L (62%) in late August. Barr met the DO standard while Milton did not. Milton experienced a higher level of algal growth in 2022, and the lower DO in August reflects this.

Table 18. 2022 Barr and Milton epilimnion DO data (mg/L and %)

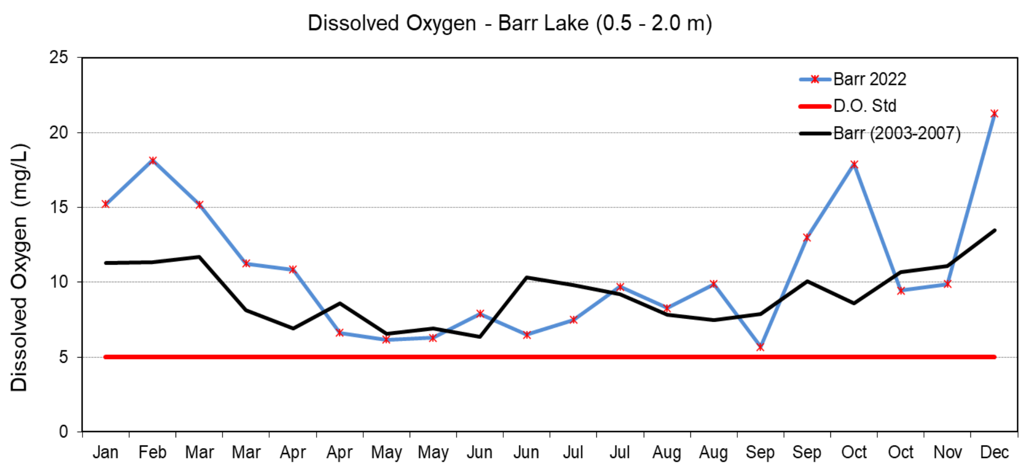
Month	Barr DO mg/L & %	Milton DO mg/L & %
Jan	15.2 (130.6%)	12.5 (105.1%)
Feb	18.1 (159.2%)	14.4 (126.8%)
Mar	15.2 (140.7%)	18.9 (170.4%)
Mar	11.3 (106.4%)	14.0 (129.4%)
Apr	10.8 (110.6%)	10.7 (107.5%)
Apr	6.6 (76.7%)	14.7 (165.3%)
May	6.2 (72.8%)	9.7 (112.3%)
May	6.3 (76.1%)	5.6 (66.3%)
Jun	7.9 (107.5%)	9.0 (121.7%)
Jun	6.5 (91.3%)	9.6 (131.2%)
Jul	7.5 (105.2%)	6.9 (96.3%)
Jul	9.7 (140.1%)	5.8 (82.2%)
Aug	8.3 (120.6%)	8.1 (118.3%)
Aug	9.9 (139.1%)	**4.4 (61.5 %)**
Sep	5.7 (72.7%)	11.5 (147.9%)
Sep	13.0 (164.3%)	15.0 (186.6%)
Oct	17.9 (220.8%)	12.9 (155.9%)
Oct	9.4 (103.7%)	12.7 (135.1%)
Nov	9.9 (100.2%)	14.4 (137.3%)

Dec	21.3 (183.4%)	18.0 (155.6%)

Two factors that create lower oxygen levels in the spring are microbial decomposition of diatoms and respiration by grazing zooplankton. With not as much grazing and more of a steady growth of algae, the percent DO for Barr were not that high. Percent DO can be as much as 250% saturation. Phytoplankton growth and concentration can change quickly, by the hour, so starting in 2021, phytoplankton and zooplankton counts occurred during each sampling event.

The summer season DO average for Barr was 9.00 mg/L (8.06 mg/L in 20212) and 8.39 mg/L (8.43 mg/L in 2021) for Milton.

Like water clarity, the seasonal variability of DO closely follows the chl-a pattern. The other two factors that control DO are water temperature and pressure. As water temperature cools and pressure increases (water depth increases), water can hold more dissolved oxygen.



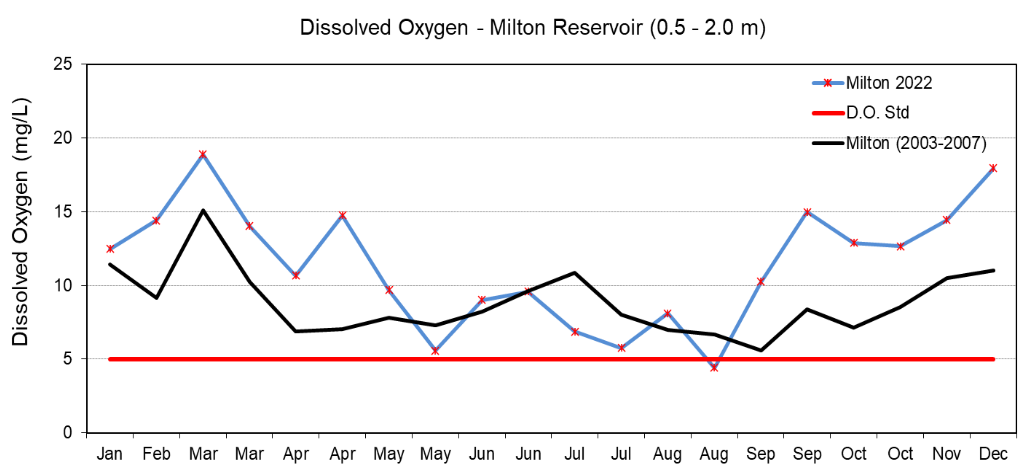


Figure 43. Seasonal variability of DO for 2022

pH

pH measurements are taken at half meter increments throughout the water column, and measurements in the top two meters are averaged. In 2022, 20 pH averages were recorded for each reservoir (Table 19). The 2022 85th percentile pH value was 8.94 (9.07 for 2021) for Barr and 9.16 (9.08 for 2021) for Milton. All the pH exceedances occurred outside of the growing season except for one.

The seasonal variability of pH follows the other parameters mentioned. pH increases when photosynthesis increases. Both reservoirs experienced decreases in pH when algal productivity declined (Figure 44). For a fourth year at Barr, the summer cyanobacteria bloom did not cause a pH violation. Milton's bloom from September to December caused pH to stay above 9.0. This has become the new norm for both reservoirs – when there is an increase in TP or TN because of internal or external sources, then that triggers the summer algal bloom.

Table 19. 2022 Barr and Milton epilimnion pH data

Month	pH (Barr)	pH (Milton)
Jan	**9.18**	8.51
Feb	8.93	8.54
Mar	8.77	8.97
Mar	8.60	**9.09**
Apr	8.93	8.95
Apr	8.53	**9.16**
May	7.88	8.78
May	8.18	7.99
Jun	8.21	8.72
Jun	7.96	8.64
Jul	8.30	8.98
Jul	8.99	8.78
Aug	8.79	8.73
Aug	8.83	8.30
Sep	8.67	8.68
Sep	8.70	**9.19**
Oct	8.92	**9.11**
Oct	8.79	**9.33**
Nov	8.57	**9.46**
Dec	**9.19**	**9.02**

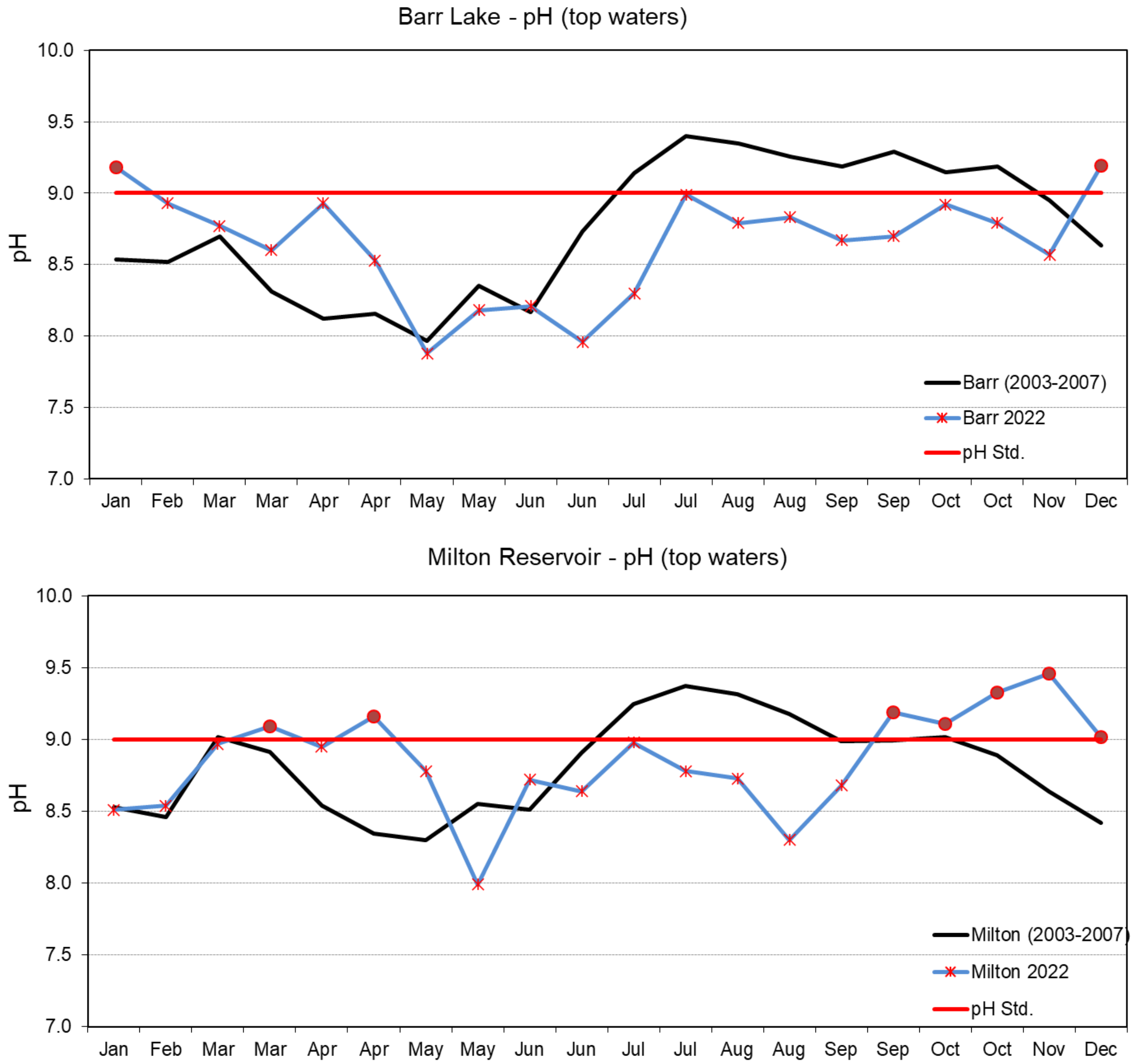


Figure 44. Seasonal variability of pH for 2022

Temperature

The temperature standard for warm water lakes (deeper than 5 meters) only applies to the epilimnion (0.5 – 2.0 meters). The values are 26.2°C (chronic) and 29.3°C (acute) between April and December, and 13.1°C (chronic) and 24.1°C (acute) between January and March. Acute temperature standards are calculated as a daily maximum average, and chronic standards are the maximum average during the summer season. A reservoir can exceed these temperatures if there is deeper water that meets both the temperature and DO standards.

Temperature data are collected throughout the water column in half-meter increments. The epilimnion data are averaged. In 2022, 20 temperature averages were recorded for each reservoir. The temperature standard was attained in both reservoirs. The summer average for Barr was 22.0°C (22.3°C for 2021) and 22.1°C (23.0°C for 2021) for Milton.

The seasonal variability of water temperature in both reservoirs is greatly influenced by air temperature and length of day. Because of this, gradual warming in the spring and cooling in the fall occurs on a nice bell curve (Figure 45). Ice cover can form as early as November and remain on until early March, depending on winter storms and cold fronts. A strong warming or cooling trend can alter the reservoir's temperature on a weekly scale. March and May were cooler than average followed by a slightly warmer than average summer. This large fluctuation in weather did have an impact on water temperatures. The peak water temperature of both reservoirs occurred in early August. Barr and Milton have similar temperature cycles, but there are subtle differences from day to day. Milton appears to have a wider range of temperatures with thicker ice during the winter and slightly warmer water during the summer.

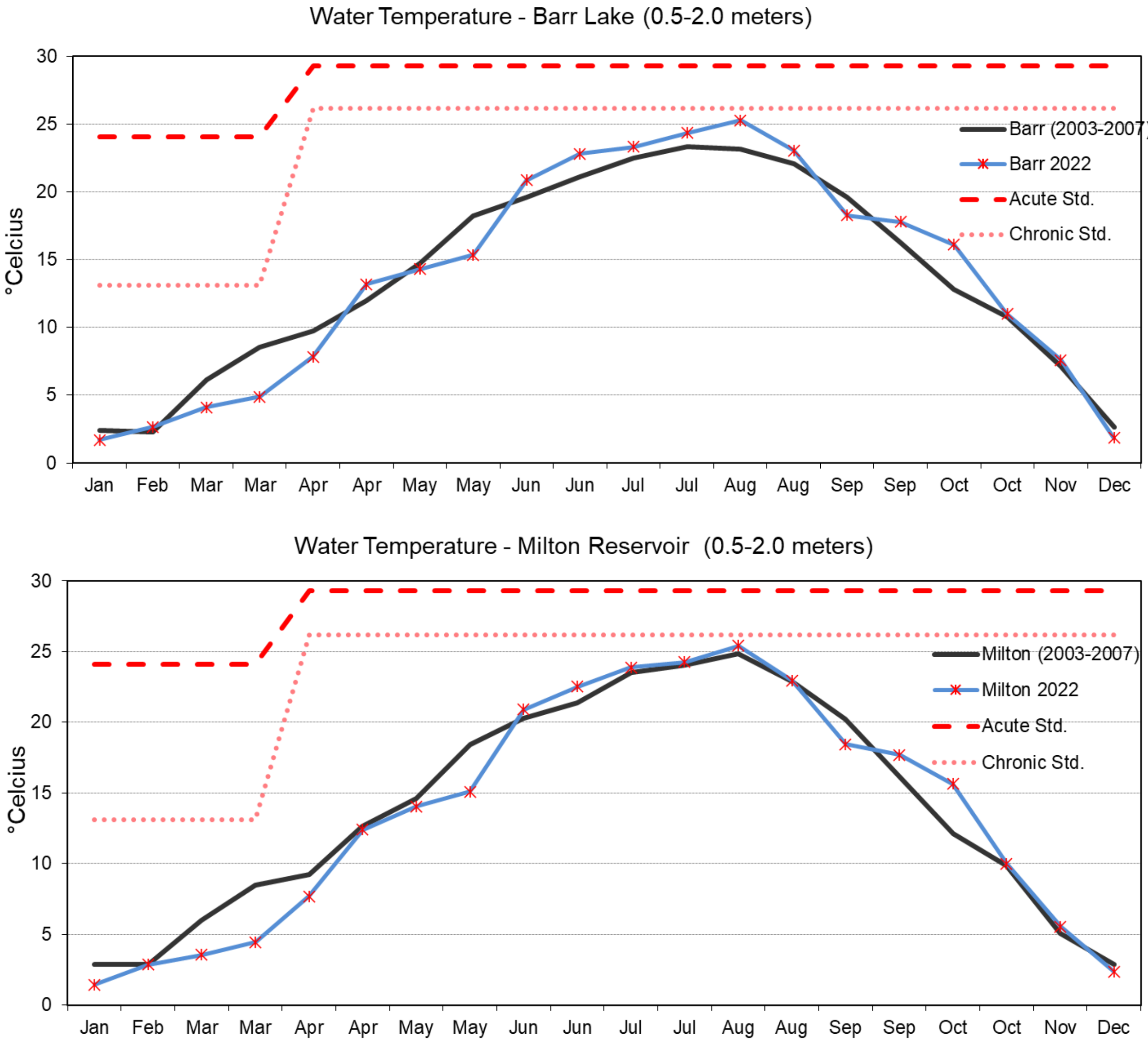


Figure 45. Seasonal variability of water temperature for 2022

Seasonal Variability

The annual water quality changes in Barr and Milton are driven by weather and flow dynamics. Water temperature (i.e., weather) and reservoir depth (i.e., water rights) determine how the water column mixes throughout the year. Barr and Milton are both dimictic (full, isothermal water column mixing in the fall and spring) when deeper than seven meters. The stratification period under ice cover and during the early summer are low gradient allowing for periodic mixing of the water column. Once the water depth is less than eight meters, wind can cause frequent periods of full or partial mixing (polymictic) of the water column. The temperature profiles for Barr throughout the spring and early summer showed how the bottom water temperatures increased as the water depth got shallower and as the thermal gradient degraded. Bottom water temperatures increased from 4.9°C on 03/24/22 to 16.1°C on 06/14/22. Entrainment and mixing occurred as well as periods of thermal stratification. As thermal energy was able to move deeper in the water column, nutrient rich water migrated up to the photic zone (Figure 46).

The hydrologic residence time for Barr is 7.5 months and 6.4 months for Milton (Boyer, 2008). Barr and Milton fill during the winter, remain at full elevation for 2-4 months in the spring, and then water is released during the irrigation season. This annual hydrological cycle greatly influences the water quality patterns. The nutrient peaks that occur during the winter affect the biological responses during the following summer season.

The past few years have brought a change in the hydrologic cycle of Barr Lake. In 2007, use of the Burlington Pumps began to decrease due to a water court case. The 2013 floods then removed all possibilities of pumping.

During the period of 2014 to 2022, the Burlington Head Gate swept the South Platte River, on average, 38.8% of the time. This equates to 142 days per year that the South Platte River is completely diverted down the Burlington Ditch. The Burlington Head Gate diverts some or all the South Platte River water on average, 98.3% of the time (259 days). In 2022, the Burlington Head Gate was open for 364 days and swept the South Platte River for 131 days.

Addition monitoring of the inflows to the Burlington Ditch between the head gate and the inlet to Barr started up in 2022. These inflows include First Creek, Second Creek, Third Creek, and Beebe Pipeline. The purpose is to understand the seasonality of these flows and to quantity the nutrient loads to the Burlington Ditch. Monitoring of these Burlington Ditch inputs will continue in 2023.

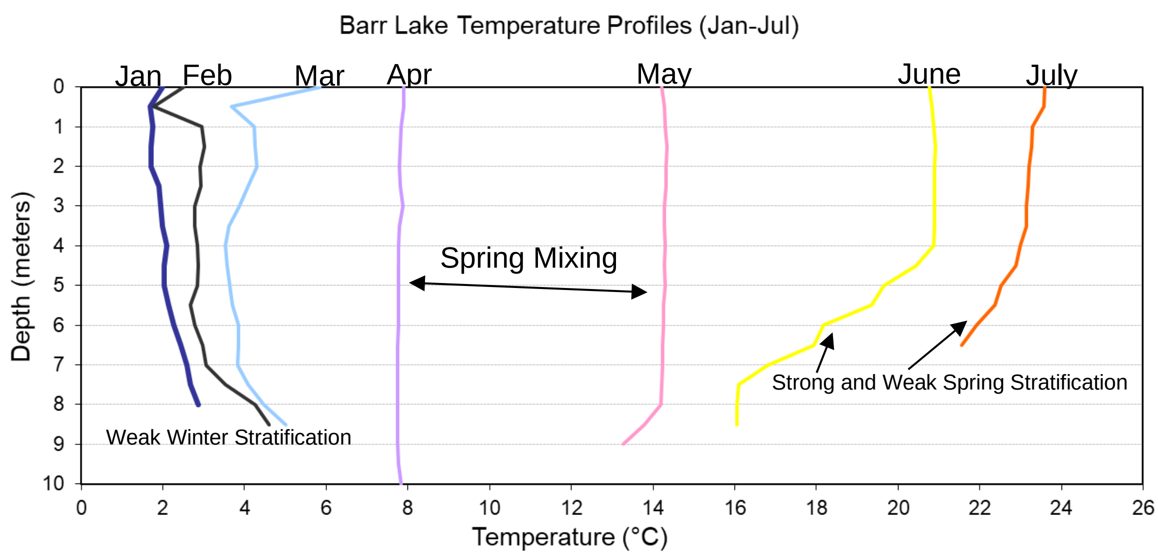


Figure 46. Barr Lake water temperature profiles for first half of 2022

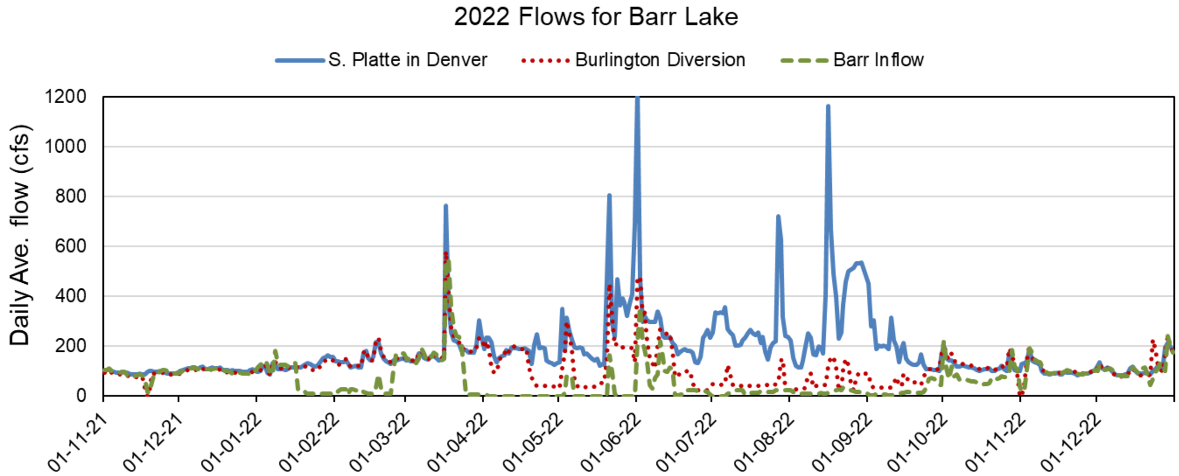
2022 Water Quality Summary

Barr had a slightly better than average year meeting both pH and DO standards while Milton had a productive year of algae that caused violations of both pH and DO. These conditions in water quality are likely due to the following: 1. No pumping of effluent to Barr, 2. Reduced loads to Milton, and 3. Timing of inflows and nutrient loads from the South Platte River.

1) No Effluent Pumping - Metro effluent has not pumped to Barr for the past 10 years. According to the pH/DO TMDL loading allocations, TP has decreased by 35,800 kg/yr. That is a 51% reduction in the annual TP load to Barr. 2022 TP concentrations decreased by 55% and 56% for Barr and Milton in comparison to TP concentrations from 2003 and 2007 (Figure 47).

2) Reduced Nutrient Loads to Milton - Milton continues to experience reductions in TP, despite Barr no longer receiving pumped effluent. These reductions are due to lower TP concentrations in the South Platte River as well as lower water volumes diverted to Milton in comparison to Barr. From the 2022 WY, Milton received 27,600 acre-feet of water (25,400 from the Platte Valley Canal inlet), while Barr received 41,800 acre-feet of water. Milton refilled between December 30, 2021 and February 6, 2022. A total of 14,500 acre-feet flowed in during this 39-day period (Figure 48). Volume and concentration both play an important role in the overall nutrient loading for Milton. The 2022 median TP was 54% lower than the 2003-2007 average.

3) South Platte River Inputs – Barr had three distinct periods of South Platte River inputs to impact water quality in 2022. This included a winter refill from November 1, 2021 to January 19, 2022 (15,600 acre-feet), late winter period from February 24, 2022 to March 24, 2022 (11,300 acre-feet), and a fall/winter period from September 24, 2022 to December 31, 2022 (18,300 acre-feet). Weather and drought conditions have a major impact on the overall inputs to both Barr and Milton. It seems that drier years bring less water into both reservoirs. For Barr in 2022 WY, the 41,800 acre-feet of water was less dry than drought years like the 2020 amount of 30,100 acre-feet. Milton had two distinct periods of South Platte River inputs in 2022. This included a fast winter refill from December 30, 2021 to February 6, 2022 (14,500 acre-feet) and then a spring fill from March 8, 2022 to April 20, 2022 (7,500 acre-feet).



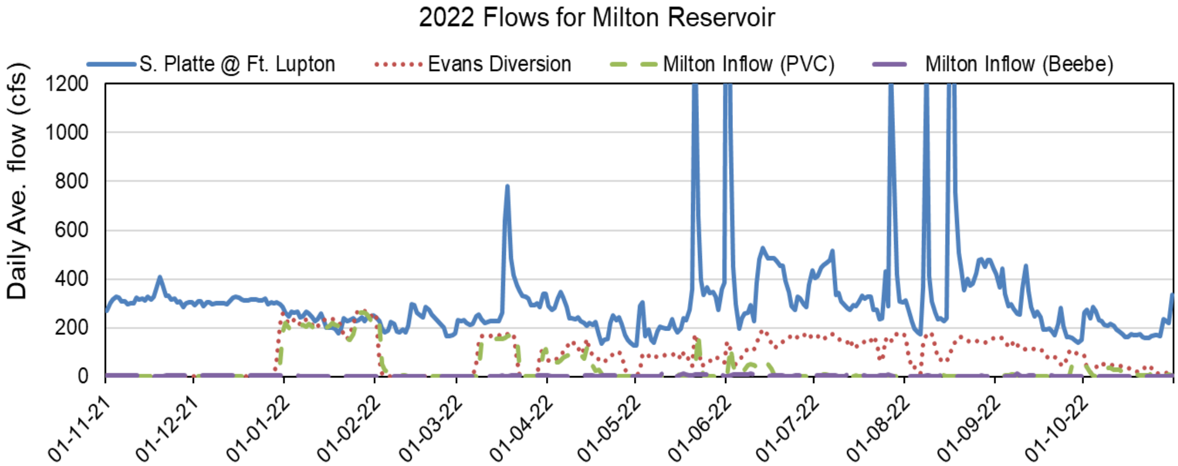
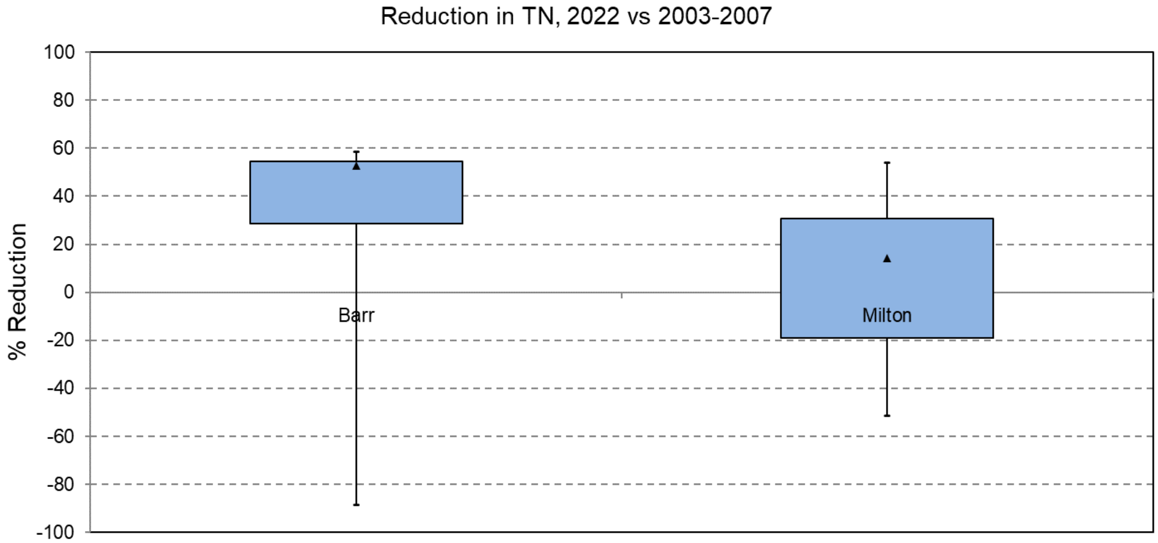
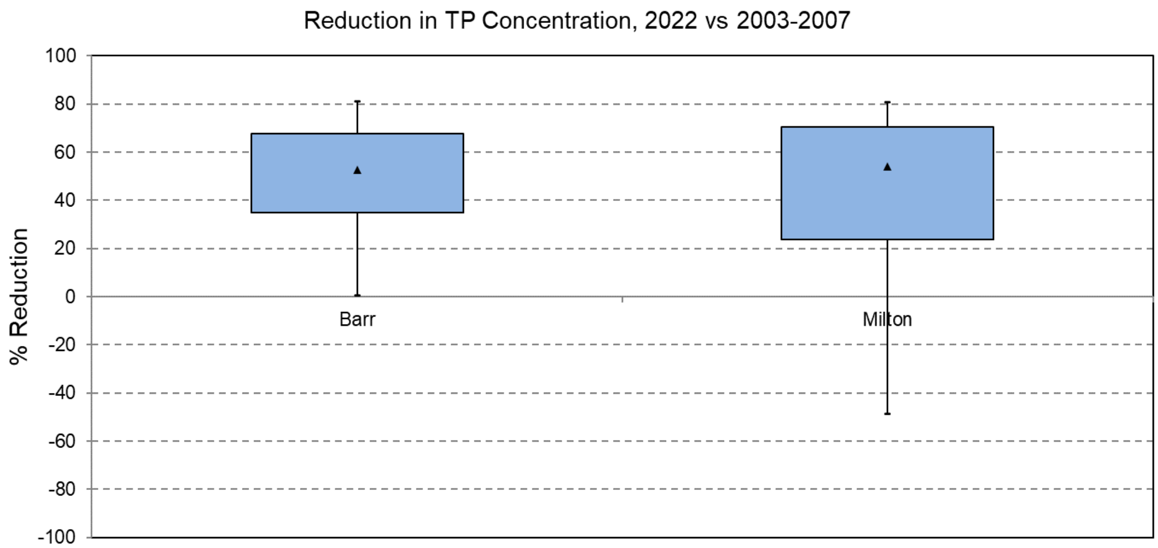


Figure 47. Percent changes in TP and TN in 2022 compared to 2003-2007 data





The management of flows to Barr and Milton have a major impact on water quality. Water quality management decisions and weather allowed both reservoirs to reflect the conditions from the South Platte River. The lower nutrient concentrations from the river were masked by the increase in amount of water diverted to each reservoir. The overall phosphorus concentrations are decreasing but loads increased because of the increase in inflows. Point source reductions will continue to help with water quality improvements. South Platte Renew started their tertiary phosphorus removal at the end of November, 2022. This will have a major impact for 2023.

Figure 48. Flow regimes comparing the South Platte River, head gate, and inlet flows for 2022

Biology

Phytoplankton and zooplankton sampling occurred 20 times in 2022. Since the phosphorus levels have decline in recent years, the annual cycle and biodiversity has noticeably changed. In the past, each reservoir produced a massive monoculture of cyanobacteria from June to October. The reservoirs now support a more diverse community of phytoplankton species and have a more manageable cyanobacteria season.

Phytoplankton composite samples are collected from the photic zone and are based on water clarity values. When the Secchi depth is two meters or less, phytoplankton are collected from 1-meter deep. When water clarity is greater than three meters, a composite sample is made from 1-meter, the Secchi depth, and 1.5 times the Secchi depth to represent the entire photic zone.

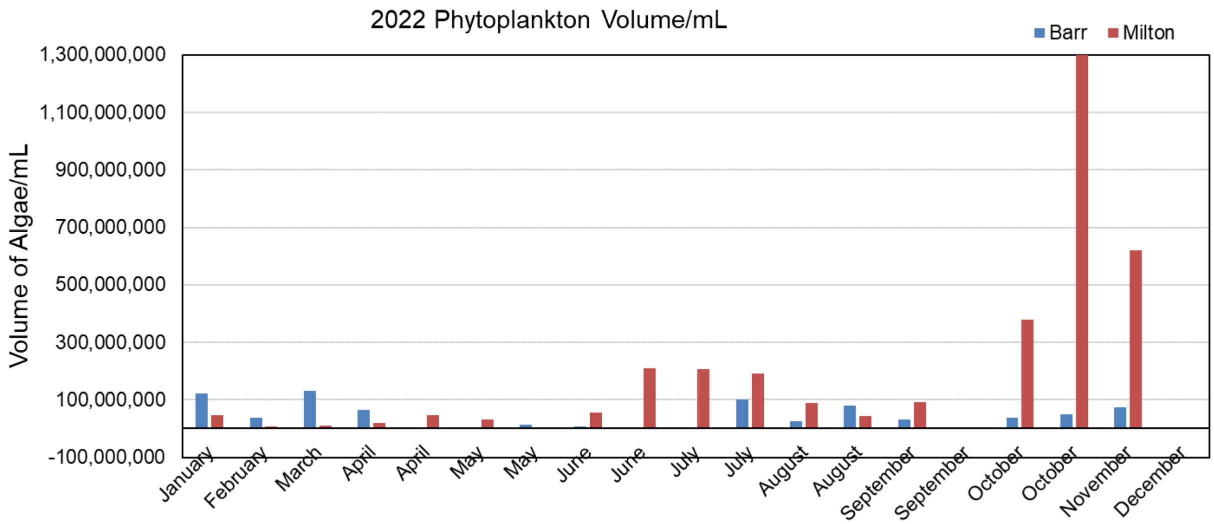
Bacilliariophyta (diatoms) and *Cyanophyta* (cyanobacteria) are the two dominant phylum of algae. Diatoms prefer cooler water and bloom in early spring, while cyanobacteria prefer the warmest water between July and September. Occasionally, *Chlolorphyta* (green algae) will grow in both reservoirs and we are seeing more dinoflagellates. Diatom, dinoflagellate, and green algae are favorable over the scum-forming cyanobacteria. One water quality goal is to reduce the length of time that cyanobacteria dominate. If cyanobacteria only appeared for a short period of time in late summer, and the percent volume was below 60%, certain parameter standards such as pH, chl-a, ammonia, and DO might be met.

In 2022, Barr had a different algal cycle than years past. Instead of diatoms in the winter/spring, Barr had cyanobacteria under the ice and then dinoflagellates dominated in late April and early May. Green algae then occurred in May and June (Figure 49). Cyanobacteria were present in all the months except for the end of April, May, and June. The highest percent abundance of cyanobacteria occurred in early March and late August at 100%. The major bloom in late July was *Aphanizomenon* (1,050 units/ml) and just a few *Microcystis* (181 units/ml).

The third phylum of algae in Barr, green algae, ranged in percent abundance from 82% in May to as low as 0% in the winter and summer months. The growth of green algae represents a major change in comparison to past conditions when only diatoms and cyanobacteria grew. A diverse algal community is a sign of improving water quality.

There were no dinoflagellates found before 2020, and in 2022 dinoflagellates seemed to really take hold. April and early May, dinoflagellates dominated (100 and 60%). (Note: A different Water Quality Scientist counted phytoplankton. Jillian Taylor counted phytoplankton before July of 2021 and Blanca Hinojosa counted after.)

In 2022, the phytoplankton community in Milton was similar to Barr; cyanobacteria (*Aphanizomenon, Anabaena, Planktothrix, and Microcystis*) dominated during every month in Milton except for late May. Filamentous cyanobacteria were mainly blooming after June all the way into September. The largest bloom occurred in October, *Aphanizomenon* of 18,000 units/ml.



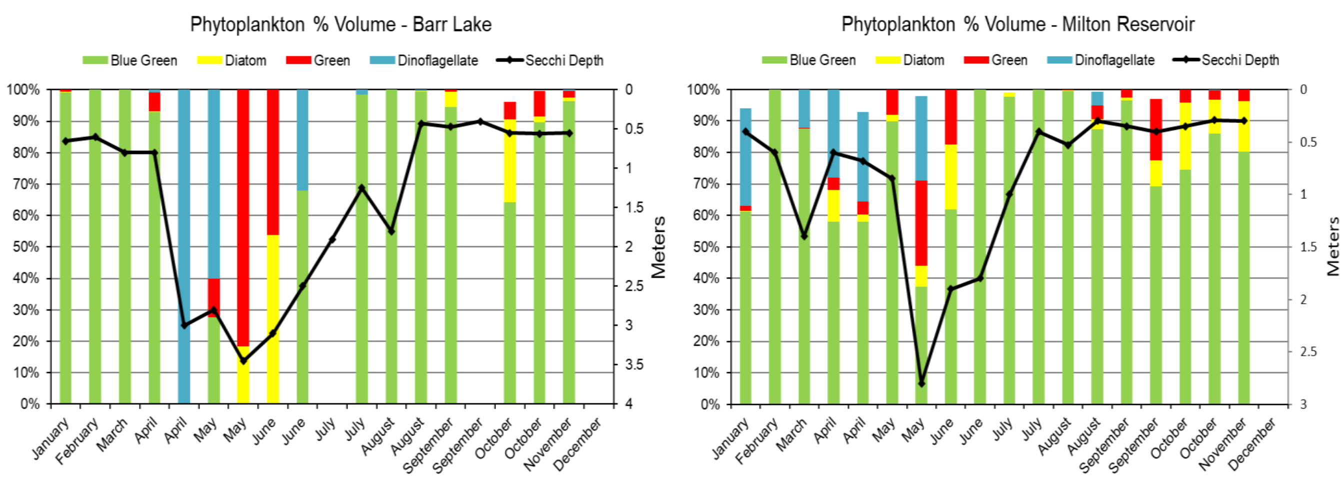
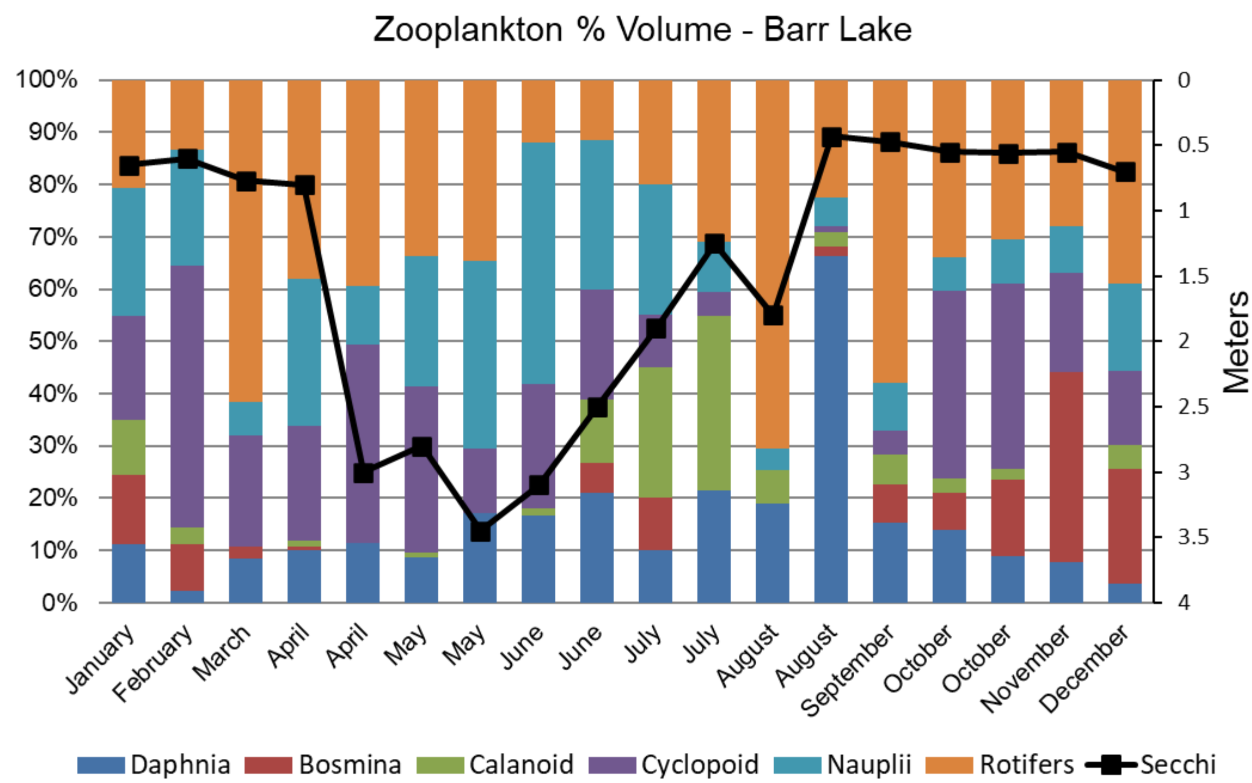


Figure 49. Summary 2022 phytoplankton data

Figure 50. 2022 Phytoplankton volume comparison

Zooplankton were collected during each sampling event by performing a complete water column vertical tow using a Wisconsin net. Zooplankton migrate to the darker, bottom water during the day to avoid predation and then migrate to the top waters at night to graze on algae. The large-bodied grazers, such as *Daphnia,* favor different species of algae typically grazing on diatoms over cyanobacteria. When diatoms dominate the algal community, the larger zooplankton tend to thrive. As cyanobacteria abundance increases, the smaller grazers, such as rotifers and smaller copepods, often increase. Both reservoirs can have great water clarity in the spring due to the heavy grazing on the diatom population.

In 2022, *Daphnia* populations were observed in Barr in every month with the highest concentrations in April and August (Figure 51). Milton did not have *Daphnia* in February, March, and throughout the fall/winter. For Milton, the highest numbers of *Daphnia* were in May which caused the increased water clarity in the spring. Of note is the *Bosmina* increase when *Daphnia* numbers go down. *Bosmina* have a different eating pattern, prefer different particle sizes, and are known to thrive in more eutrophic water quality conditions. Typically, cylcopoids occurred more often than calanoids. This is another indication of eutrophic conditions, as cyclopoids survive better in nutrient-rich waters. Rotifers occurred in greater abundance during the spring than in the fall in both reservoirs. Rotifers are generally tolerant of cyanobacteria blooms. *Nauplii* are the juvenile stages of various copepods. Both reservoirs maintained a steady population of juvenile zooplankton throughout the year. The concentration of zooplankton over 900 animals/mL seems to make a difference in algae and the water clarity. Barr's clearing phase occurred April to June when the zooplankton range was 946 – 251 animals/mL. Milton's clearing phase occurred May to June when the zooplankton range was 1,508 – 272 animals/mL.


Zooplankton % Volume - Barr Lake
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.5
1
1.5
2
2.5
3
3.5
4
Meters
January
February
March
April
April
May
May
June
June
July
July
August
August
September
October
October
November
December
Daphnia
Bosmina
Calanoid
Cyclopoid
Nauplii
Rotifers
Secchi

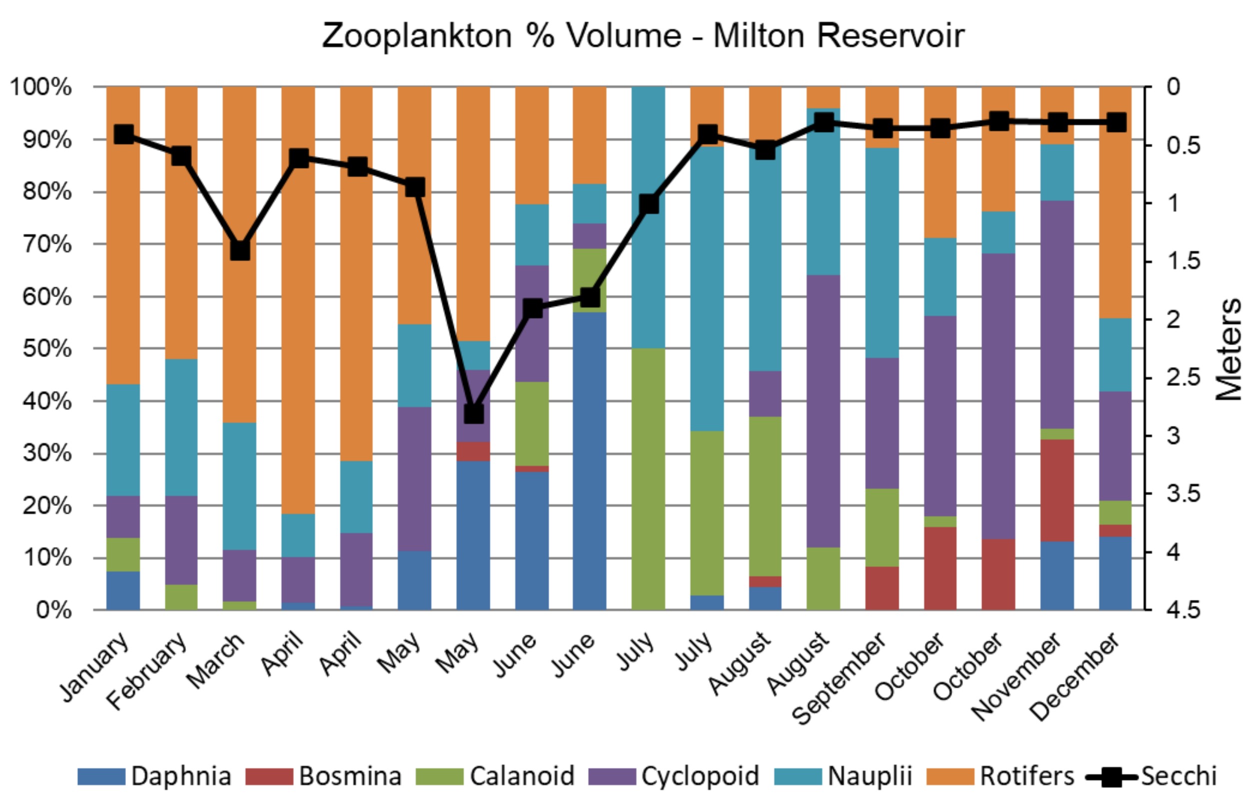

Zooplankton % Volume - Milton Reservoir
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
Meters
January
February
March
April
April
May
May
June
June
July
July
August
August
September
October
October
November
December
Daphnia
Bosmina
Calanoid
Cyclopoid
Nauplii
Rotifers
Secchi

Figure 51. 2022 summary of zooplankton data

Special Studies

BIOMANIPULATION – The TMDL implementation plan includes in-reservoir techniques to help reduce internal nutrient loading. Approximately 2,000 kg of phosphorus per year is loaded into Barr and Milton from internal sources. Not considered in these internal loading estimates is bioturbation and excretion by carp. Barr's adult carp population is in the thousands. Invasive, nuisance carp can be controlled, potentially improving water quality. Close to 8,885 carp (73,300 pounds) have been removed from Barr since 2014. Methods include electrofishing, seining, tournament, and bowfishing by locals. In 2022, a carp fishing tournament was organized. Cash prizes were handed out for the most carp caught from shore and from a boat. Just under 80 carp were removed during the one-day tournament.

At 2,880 mg of TP per kg of fish, the amount of organic phosphorus removed from Barr since 2014 is 211 pounds. Carp also provide mobility of phosphorus that is stored in the sediment due to their benthic feeding habits and by excreting the nutrients after digestion. Based on several carp excretion studies, the excretion rate ranges from 1.9 to 4.0 µg of phosphorus per gram of fish/hour. This rate depends on age of fish and water temperature. Assuming that carp in Barr are actively excreting for four months out of the year, the range of excreted phosphorus is 355 to 755 pounds/year. By removing carp each year since 2014, an estimated 1,800 to 3,800 pounds of phosphorus has been prevented from recycling within Barr. The box net will be used in 2023 and a carp fishing tournament will be conducted.

STORM WATER MONITORING – The City and County of Denver, City of Lakewood, City of Aurora, and Mile High Flood District (Joint Task Group) have been conducting wet weather monitoring since 1998. The current program has five monitoring stations (South Platte River at Union Blvd., South Platte River at Denver, South Platte River at Henderson, Toll Gate Creek in Aurora, and Sand Creek above Burlington Ditch). The Denver monitoring station is near the confluence with Cherry Creek. A large section of Denver between downtown and city/county limits near the Burlington Head Gate is not currently monitored.

The location of the auto-sampler monitoring station was adjacent to the Metro District's Delany Siphon, located about a quarter mile upstream of the Burlington Head Gate on the east bank of the South Platte River (SP-BD). SP-BD was permitted and built in 2018, and operation began in March 2019. The construction of the National Western Center and a new bridge crossing occurred in 2022 just upstream of the Burlington Head Gate and just downstream of the current auto-sampler location. SP-BD was temporarily relocated in early December of 2020 to the Burlington Ditch at Metro Water Recovery. A total of 49 24-hr composite samples were collected in 2022, one per week except during very cold conditions and when the ditch was not flowing. With flow data from various gauges and the FRICO flow dataset, a weekly phosphorus loading was calculated for the Burlington Ditch and for Barr (Figure 52). The in-reservoir Barr TP and Chl-a data is also shown to compare loading data and the timing of in-reservoir TP concentrations.

The average weekly phosphorus load to Barr was 388 kg/week (233 kg/week for 2020), with a minimum of 0 kg/week for 16 weeks (25 weeks with no inflow in 2020) and a maximum of 1,851 kg/week during the second week of March, which included a major runoff event. A total of 52,600 kg of phosphorus went down the Burlington Ditch in 2022 WY. Of that, 20,200 kg of phosphorus entered Barr for the TP load in 2022 WY (20,100 kg for 2022 AY).

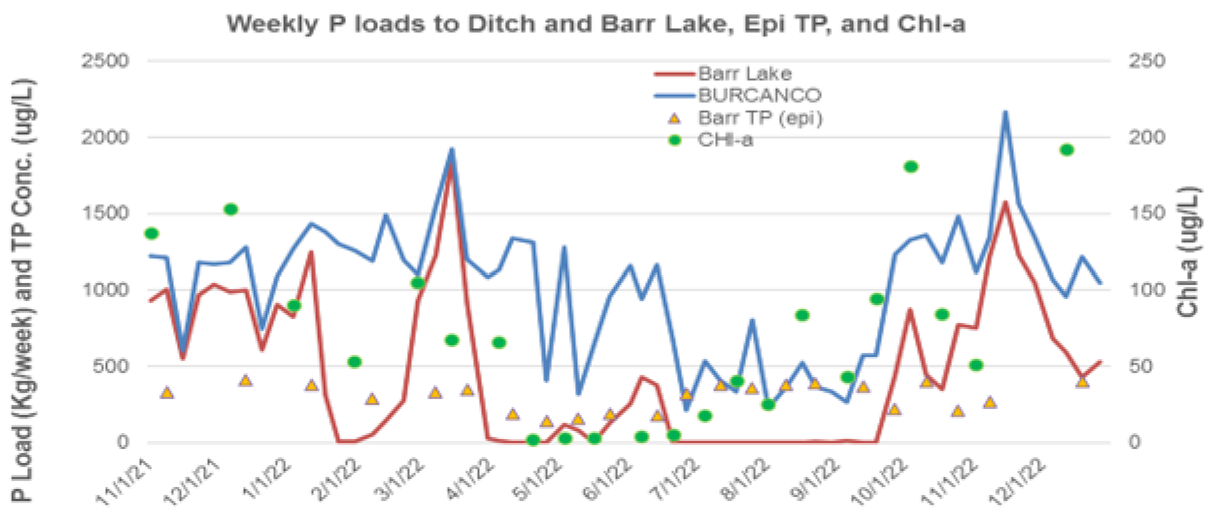


Figure 52. 2022 phosphorus loads to Burlington Ditch and Barr based on SP-BD monitoring

Conclusion

Metro's water quality monitoring program has documented significant improvements in water quality and the aquatic life assemblage in the South Platte River downstream of Metro's discharge since the 1970s. The South Platte River has gone from one that the EPA characterized as highly polluted and virtually devoid of aquatic life, to one that CPW characterizes as one of the few sustaining native fisheries in the State. One of the goals of this program in the future will be to document further incremental improvements as Metro implements treatment upgrades at the RWHTF.

Sampling and analysis conducted by the Water Quality Division has provided Metro with one of the most robust water quality and biological datasets available statewide. The data provide the foundation for the South Platte Water Quality Model, which has been an integral part of the development of effluent limitations for parameters such as dissolved oxygen and ammonia. As water quality issues become increasingly complex and challenging, this scientific knowledge will become more essential.

The Water Quality Division has focused sampling efforts on providing information to relevant topics in water quality regulation while also providing a robust long-term dataset, increasing efficiencies, and reducing costs. Future sampling efforts will continue to maintain these priorities while addressing additional needs. The results can then be used to inform future treatment decisions as regulations for constituents like nitrogen and phosphorus become more stringent. Monitoring decisions are also made in conjunction with outside groups like SPCURE and the Colorado Monitoring Framework to ensure our collection methods and schedules line up with other efforts. The coordination effort supplies Metro with a larger body of information both upstream and downstream of our collection efforts and is essential to continue in future years. Many water quality problems, such as *E. coli*, are not going to be solved by one organization alone, but by the collective actions of a variety of agencies.

As nitrogen, phosphorus, and Chl-a limits are implemented through Regulations 31 and 85, increased biological monitoring will be necessary. Metro is currently experimenting with sampling techniques for periphyton and Chl-a analysis because it is anticipated that Segment 15 will not attain the recreational standard associated with benthic algae. In future years, additional outside services funding may be necessary to maintain macroinvertebrate sampling and add periphyton identification tasks.

Several regulatory issues have yet to be addressed. For example, new EPA guidance has been published regarding ammonia standards to protect aquatic life based on new data regarding *Unionid* mussels and snails. Metro may need to support efforts to undertake a comprehensive survey of mussel presence within the watershed. New criteria also will be published in the next two to five years for selenium, arsenic, conductivity, and potentially many other water quality constituents. It will be imperative that the Water Quality monitoring program continues to evolve and change, collecting the data needed to support Metro in dealing with the ramifications of these new criteria.

Implementation of capital improvement projects at Metro will provide the foundation for water quality in this portion of the South Platte Basin. It is imperative that the ecological results of these efforts are documented through the maintenance of a robust water quality record. The data collected, in conjunction with scientifically based modeling efforts, will assist with future regulatory decision-making.

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Glossary

303(d) list – references the section of the Clean Water Act that directs the impairment of waterbodies

acute – a standard typically based on the value not to be exceeded by the concentration of a single sample or the calculation of samples collected in a one-day period, designed to address the toxic effects of a single exposure or multiple exposures in a short space of time

benthic macroinvertebrates - small animals living among the sediments and stones on the bottom of streams, rivers and lakes.

chlorophyll *a* – a specific form of chlorophyll used in oxygenic photosynthesis, typically used as a surrogate for algal presence

chronic – a standard typically based on the value not to be exceeded by the concentration of a single sample or the calculation of samples collected in a thirty-day period, designed to address toxic effects after continuous or repeated exposure

denitrification - a microbially facilitated process of nitrate reduction (performed by a large group of heterotrophic facultative anaerobic bacteria) that may ultimately produce molecular nitrogen through a series of intermediate gaseous nitrogen oxide products

dimictic – lakes that mix from the surface to bottom twice each year, during the summer they are thermally stratified and can be divided into an epilimnion and hypolimnion

epifaunal substrate – the variety of natural structures in the stream, such as cobble, large rocks, fallen trees, logs, branches and undercut banks.

epilimnion (epilimnetic) - the water layer overlying the thermocline of a lake (typically warmer)

eutrophic – a lake or stream that is rich in organic and mineral nutrients and supporting an abundant plant life, which in the process of decaying depletes the oxygen supply for animal life (a state in Carlson's trophic state index (TSI))

hypereutrophic – a lake or stream that is very nutrient rice, characterized by severe nuisance algal blooms and low transparency (a state in Carlson's trophic state index (TSI))

hypolimnion (hypolimnetic) - the part of a lake below the thermocline made up of water that is stagnant and of essentially uniform temperature except during the period of overturn (typically colder)

MDL – the minimum concentration of an analyte (substance) that can be measured and reported with a 99% confidence that the analyte concentration is greater than zero as determined by the procedure. The MDL is based on the specific method and instrumentation used in the analysis

nitrification - the biological oxidation of ammonia with oxygen, then into ammonium, then into nitrite followed by the oxidation of these nitrites into nitrates

oligotrophic – a lake or stream that is poor in nutrients and plant life and rich in oxygen (a state in Carlson's trophic state index (TSI))

phytoplankton – flora of freely floating, often minute organisms that drift with water currents

polymictic – lakes that are too shallow to develop thermal stratification

riverine – of, relating to, formed in, living in, or growing in rivers and streams

thermocline – a horizontal plane across a lake at the depth of the most rapid vertical change in temperature and density in a stratified lake

un-ionized ammonia – NH3, the form of ammonia that is toxic to aquatic life, toxicity depends on both temperature and pH of the water

zooplankton - small floating or weakly swimming animals that drift with water currents

Appendix 1: Metal Abbreviations

Ag	Silver
As	Arsenic
Be	Beryllium
Ca	Calcium
Cd	Cadmium
Cr	Chromium
Cu	Copper
Fe	Iron
K	Potassium
Mg	Magnesium
Mn	Manganese
Mo	Molybdenum
Na	Sodium
Ni	Nickel
Pb	Lead
S	Sulfur
Sb	Antimony
Se	Selenium
Zn	Zinc

Appendix 2: Metro Laboratory Method Detection Limits (MDL)

Constituent	Unit	Lab Method	2017
Alkalinity, Tot., Man.	mg/L	SM2320B-97 21ed	20
Ammonia Nitrogen, AA	mg/L	EPA 350.1 rev2	0.05
Antimony, Tot.	ug/L	EPA 200.8 rev5.4	0.2
Arsenic, Tot.	ug/L	EPA 200.8 rev5.4	0.2
Beryllium, Tot.	ug/L	EPA 200.8 rev5.4	0.05
BOD, 5-Day	mg/L	SM5210B-01 21ed	0
Cadmium, Diss.	ug/L	EPA 200.8 rev5.4	0.05
Cadmium, Tot.	ug/L	EPA 200.8 rev5.4	0.1
Calcium, Diss.	mg/L	EPA 200.7 rev4.4	0.5
Calcium, Tot.	mg/L	EPA 200.7 rev4.4	0.5
Carbon, Sol., Organic	mg/L	ASTM D7573-09	1
CBOD, 5-Day	mg/L	SM5210B-01 21ed	0
Chloride, AA	mg/L	SM4500CL E 20ed	5
Chromium, Diss.	ug/L	EPA 200.8 rev5.4	0.1
Chromium, Tot.	ug/L	EPA 200.8 rev5.4	1
Conductivity, Field Measure	umho/cm	EPA 120.1	0.5
Copper, Diss.	ug/L	EPA 200.8 rev5.4	0.5
Copper, Tot.	ug/L	EPA 200.8 rev5.4	0.5
DO, Field Measure	mg/L	EPA 360.1	0.1
E-Coli, MPN Idexx Colilert	EC/100ml	SM9223B 20ed	1
Hardness, as CaCO3 (calc)	mg/L	SM 2340B 18ed	5
Iron, Diss.	mg/L	EPA 200.7 rev4.4	0.007
Iron, Tot.	mg/L	EPA 200.7 rev4.4	0.1
Lead, Diss.	ug/L	EPA 200.8 rev5.4	0.2
Lead, Tot.	ug/L	EPA 200.8 rev5.4	0.8
Magnesium, Diss.	mg/L	EPA 200.7 rev4.4	0.1
Magnesium, Tot.	mg/L	EPA 200.7 rev4.4	0.1
Manganese, Diss.	ug/L	EPA 200.8 rev5.4	1
Manganese, Tot.	ug/L	EPA 200.8 rev5.4	0.5
Molybdenum, Tot.	ug/L	EPA 200.8 rev5.4	1
Nickel, Diss.	ug/L	EPA 200.8 rev5.4	1
Nickel, Tot.	ug/L	EPA 200.8 rev5.4	0.5
Nitrite Nitrogen, AA	mg/L	EPA 353.2	0.02
NO3+NO2 as N - Cd Red.	mg/L	EPA 353.2 rev2	0.02
Orthophosphate as P, AA	mg/L	EPA 365.1 mod	0.03
pH, Field Measure	STD	EPA 150.1	0.1
Phosphorus, Tot., AA	mg/L	SM 4500-P-H 21ed	0.01

Potassium, Diss.	mg/L	EPA 200.7 rev4.4	1
Potassium, Tot.	mg/L	EPA 200.7 rev4.4	1
Selenium, Diss.	ug/L	EPA 200.8 rev5.4	1
Selenium, Tot.	ug/L	EPA 200.8 rev5.4	0.5
Silver, Diss.	ug/L	EPA 200.8 rev5.4	0.2
Silver, Tot.	ug/L	EPA 200.8 rev5.4	0.2
Sodium, Diss.	mg/L	EPA 200.7 rev4.4	1
Sodium, Tot.	mg/L	EPA 200.7 rev4.4	5
Solids, Tot. Dissolved	mg/L	SM2540C 20ed mod	50
Sulfate, AA	mg/L	SM4500-SO4	10
Temperature, Field Measure	Deg C	EPA 170.1	0.5
TKN, High Level, AA	mg/L	EPA 350.1	0.3
Total Suspended Solids	mg/L	USGS I-3765-85 m	1
Turbidity, Field Measure	NTU	EPA 180.1	0.1
Zinc, Diss.	ug/L	EPA 200.8 rev5.4	5
Zinc, Tot.	ug/L	EPA 200.8 rev5.4	10

Appendix 3: 2022 Groundwater Summary Statistics

Parameter	Sample Fraction	Unit	Count	Minimum	Maximum	Mean
Alkalinity total	Total	mg/L	68	134	322	198.2
Ammonia-nitrogen	Total	mg/L	68	0	1.37	0.2
Antimony	Total	ug/L	68	0	6.3	0.6
Arsenic	Total	ug/L	68	0.4	109	4.6
Beryllium	Total	ug/L	68	0	4.76	0.2
Cadmium	Dissolved	ug/L	68	0	4	0.5
Cadmium	Total	ug/L	68	0	20.1	1.9
Calcium	Dissolved	mg/L	68	54.4	250	105.2
Calcium	Total	mg/L	68	54.2	260	107.9
Chromium	Dissolved	ug/L	68	0	1.9	0.1
Chromium	Total	ug/L	68	0	71	2.4
Conductivity	Total	umho/cm	68	957	3047	1583.6
Copper	Dissolved	ug/L	68	0	62.1	4.3
Copper	Total	ug/L	68	0	211	12.7
Dissolved oxygen (DO)		mg/L	68	0.15	7.32	2.6
Inorganic nitrogen (NO_5)		mg/L	68	0	7.35	1.6
Inorganic nitrogen (TIN)	Total	mg/L	68	0.15	7.38	1.8
Iron	Dissolved	mg/L	68	0	4.6	0.4
Iron	Total	mg/L	68	0	90.6	5.0
Kjeldahl nitrogen		mg/L	68	0.2	4.2	0.6
Lead	Dissolved	ug/L	68	0	1	0.0
Lead	Total	ug/L	68	0	83.3	3.6
Magnesium	Dissolved	mg/L	68	12	40.3	23.6
Magnesium	Total	mg/L	68	12.4	40.3	24.5
Manganese	Dissolved	ug/L	68	0	6600	1055.2
Manganese	Total	ug/L	68	4.4	7220	1421.5
Molybdenum	Total	ug/L	68	2.86	24.4	7.7
Nickel	Dissolved	ug/L	68	1	11.9	4.0
Nickel	Total	ug/L	68	1.1	60.1	6.2
Nitrite		mg/L	68	0	0.43	0.1
Nitrogen	Total	mg/L	68	0.4	7.8	2.2
Organic Carbon	Total	mg/L	68	2	26	4.0
pH			68	5.23	7.53	7.1
Phosphorus	Dissolved	mg/L	68	0.04	1.45	0.4
Phosphorus	Total	mg/L	68	0.03	11.8	0.8
Potassium	Dissolved	mg/L	68	4.1	16.7	9.7

Potassium	Total	mg/L	68	5.2	17.8	10.2
Selenium	Dissolved	ug/L	68	0	24.8	3.2
Selenium	Total	ug/L	68	0	23.9	3.5
Silver	Dissolved	ug/L	68	0	0.89	0.0
Silver	Total	ug/L	68	0	0.67	0.0
Sodium	Dissolved	mg/L	68	87.5	323	157.4
Sodium	Total	mg/L	68	97.7	313	162.6
Temperature, water		deg C	68	4.8	20.7	13.7
Total suspended solids		mg/L	68	0	7380	162.3
Turbidity		NTU	68	0	3897	85.5
Zinc	Dissolved	ug/L	68	0	103	8.5
Zinc	Total	ug/L	68	0	513	32.3