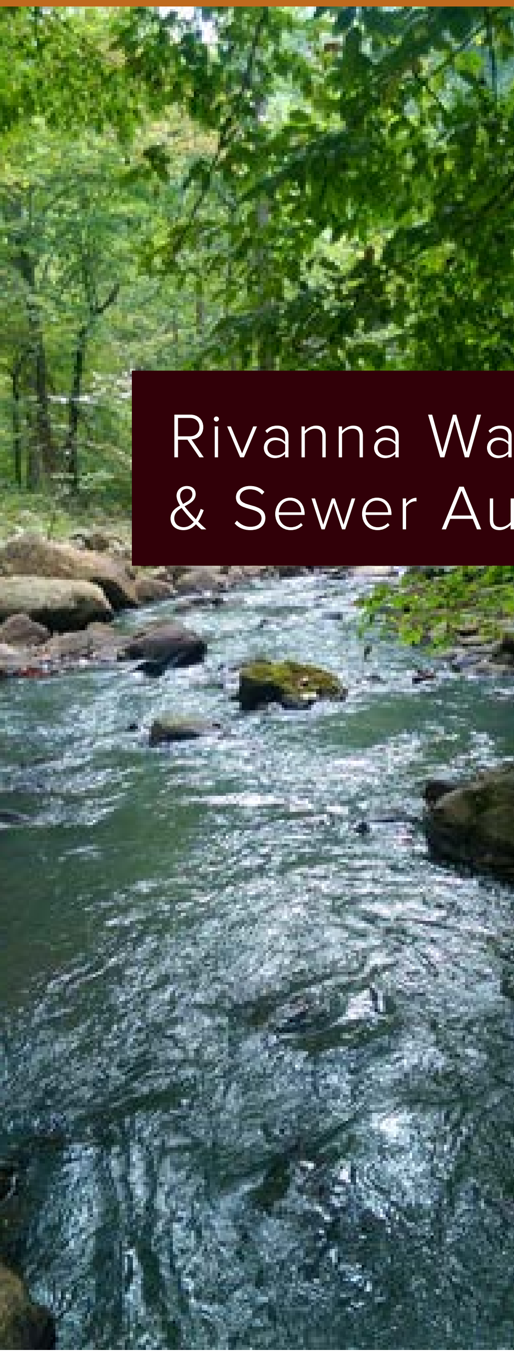
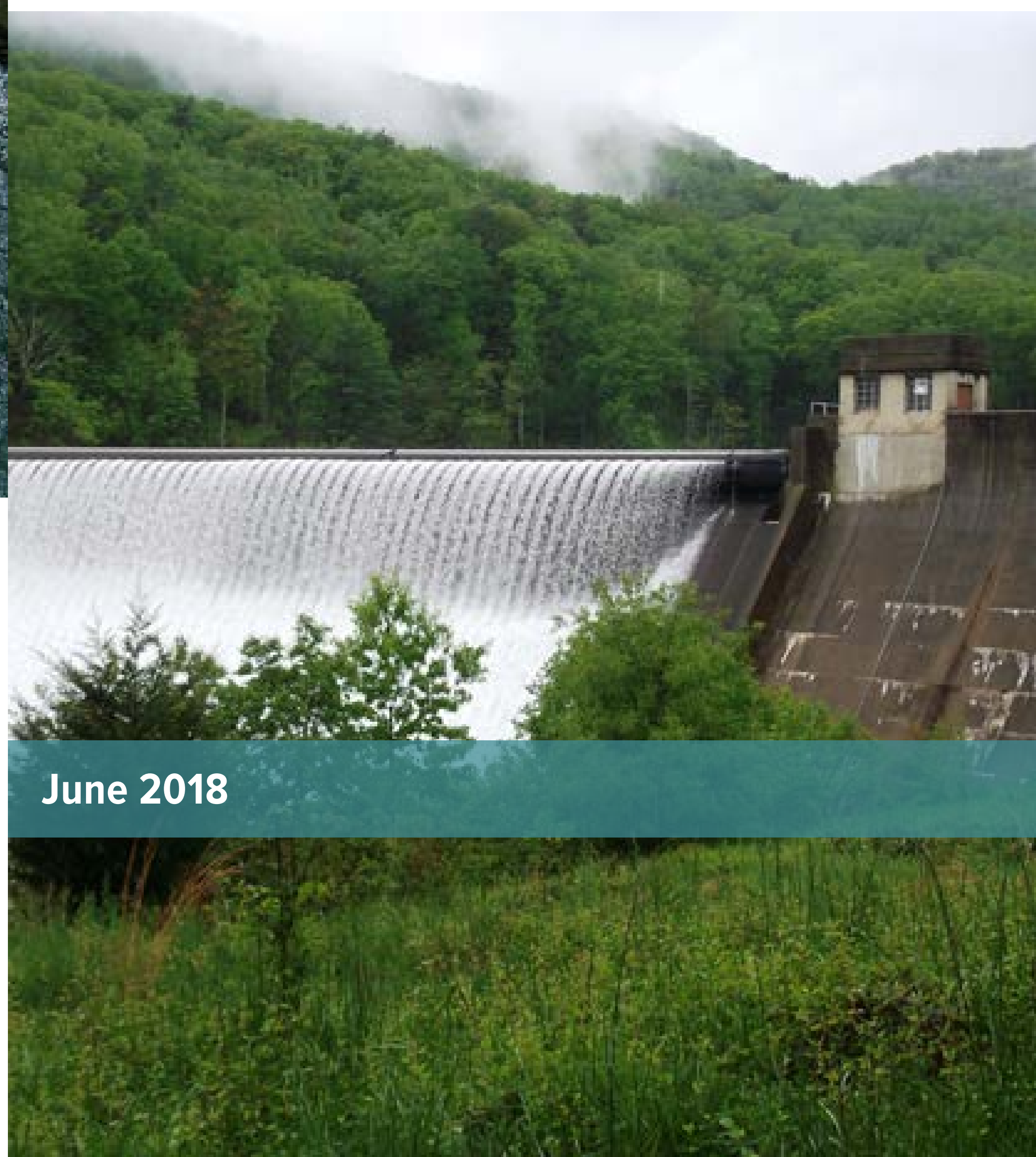


Rivanna Water
& Sewer Authority

RESERVOIR WATER QUALITY *and* MANAGEMENT ASSESSMENT



June 2018

RIVANNA WATER & SEWER AUTHORITY

DiNatale WATER CONSULTANTS

AHA

Acknowledgements

In November 2014, DiNatale Water Consultants and Alex Horne Associates were retained by the Rivanna Water and Sewer Authority to develop a comprehensive reservoir water quality monitoring program. This proactive approach is a revision from historic water quality management by the Authority that tended to be more reactive in nature.

The Authority embraced the use of sound science in order to develop an approach focused on reservoir management. Baseline data were needed for this scientific approach requiring a labor-intensive, monthly sampling program at all five system reservoirs. Using existing staff resources, the project kicked-off with training sessions on proper sampling techniques and use of sampling equipment.

The results and recommendations contained within this report would not have been possible without the capable work of the Rivanna Water and Sewer Authority staff:

- Andrea Terry, Water Resources Manager, Reservoir Water Quality and Management Assessment Project Manager
- Bethany Houchens, Water Quality Specialist
- Bill Mawyer, Executive Director
- Lonnie Wood, Director of Finance and Administration
- Jennifer Whitaker, Director of Engineering and Maintenance
- David Tungate, Director of Operations
- Dr. Bill Morris, Laboratory Director
- Matt Bussell, Water Manager
- Konrad Zeller, Water Treatment Plant Supervisor
- Patricia Defibaugh, Lab Chemist
- Debra Hoyt, Lab Chemist
- Peter Jasiurkowski, Water Operator
- Brian Estes, Water Operator
- Ken Holley, Water Operator
- Guy Maupin, Relief Operator
- Michael Webb, Relief Operator

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Abbreviations

ACSA	Albemarle County Service Authority
AF	Acre-feet
Ammonia	for purposes of this report includes both NH_3 and NH_4+
Authority	Rivanna Water and Sewer Authority
BCR	Beaver Creek Reservoir
BGA	Blue-green algae
cfs	Cubic feet per second
Chl *a*	Chlorophyll *a*, also referenced as "chlorophyll"
Contributing Basin	Watershed
DO	Dissolved oxygen
GAC	Granular activated carbon
HOS	Hypolimnetic oxygenation system
LOX	Liquid oxygen
m	meters
MG	Million gallons
mgd	Million gallons of water per day
µg/L	Micrograms per liter
mg/L	Milligrams per liter
N	Nitrogen
NH_3	ammonia
NH_4	ammonium
Nitrate	NO_3, NO_3-N, or nitrate-N. Nitrate measured as nitrogen. For purposes of this report, it also includes NO_2 or nitrite
P	Phosphorus
PAC	Powdered activated carbon
PO_4	Orthophosphate, soluble phosphate
RMR	Ragged Mountain Reservoir
SFRR	South Fork Rivanna Reservoir
SHR	Sugar Hollow Reservoir
T&O	Taste and odor
TCR	Totier Creek Reservoir
TIN	Total inorganic nitrogen (Nitrate + Ammonia)
TP	Total phosphorus
TSS	Total suspended solids
USGS	United States Geological Survey
VEM	Vigorous epilimnetic mixing
WTP	Water Treatment Plant

Glossary

Aeration any method of adding compressed air. Normally, the air is added as coarse bubbles in the deeper areas since that gives the best stirring effect. Unlike the fine-bubble aeration in wastewater treatment plants, little oxygen is added directly to the water in lake aeration. The oxygen mixed down from the surface waters is the primary source.

Algae microscopic cells with few specialized parts. The general term "algae" is very useful but is not a strict taxonomic classification and covers several different kinds of cells with different origins. Algae are almost always energized by photosynthesis so need sunlight. Algae are usually autotrophic so (most) grow using only inorganic nutrients like phosphate (PO_4) and nitrate (NO_3) which is why these chemicals are so important in water quality in reservoirs.

Anoxic The absence of dissolved oxygen in water. Anaerobic is often used as a synonym for anoxic but is technically incorrect since it implies the absence of air which is 79% N_2-gas. In reservoirs there is always plenty of dissolved N_2-gas but sometimes no dissolved O_2-gas.

Blue-green algae (also called Cyanobacteria) A major group of alga which are descended from bacteria but have ecology and metabolism like other algae. Despite their name(s) they look pretty green like most algae since chlorophyll dominates their pigments and obscures the blue-green colored accessory pigment cyanophycin. Their prime distinction in reservoir management is that blue-greens can regulate their buoyance with little energy expenditure. They can thus find the best light and nutrient conditions when these vary over 24 hours. If things go wrong, the buoyancy regulation fails and colonies float to the top to form scums, which can be fatal for them. The large colonial blue-greens like *Anabaena* in Sugar Hollow Reservoir float and sink rapidly since large objects have relatively less drag. These large colonial species favor less-well mixed water with strong thermal stratification found in 3 of the 5 Rivanna reservoirs. Small colonies like the filaments of *Planktothrix* (formerly *Oscillatoria*) found in South Fork Rivanna Reservoir rise and fall so rarely form scums and prefer the more mixed water found in this reservoir. However, *Planktothrix* did form a scum in SFRR in 2015. Some blue-greens can fix atmospheric nitrogen to form proteins (like beans or alder trees) and so can grow at low nitrate levels in water (it turns out that the Rivanna streams and reservoirs are now so saturated with nitrate that N_2-fixation is not an advantage). Finally, when some (still unknown) conditions occur, blue-green algae produce various nasty tastes and odors (geosmin MIB) as well as three classes of toxins which harm humans. Microcystin, which damages the liver and is quite persistent, is the worst from a drinking water viewpoint. Anatoxin which is a nerve poison like snake venom, can kill dogs and stock so is a problem for recreation and farming but does not persist long in water (EPA 2015). Also produced is a compound that causes skin irritation.

Chlorophyll *a* the measurement of how much green pigment is in the water. Algae, like trees or grasses, produce Chl-a through photosynthesis causing the plant to be green. Chl a is very important in the plant's process of transforming sunlight into biomass. By measuring how green the water is, one can get a relative understanding about how much algae is in the lake. Chl-a concentrations are expressed in units of micrograms per liter (µg/L) or parts per billion (ppb). Chl-a is not an exact measurement of biomass, but it is close. Some algae (e.g. diatoms) don't produce as much chl-a as others (e.g. blue-green algae) and can change their rate of chl-a production throughout the day. Chl-a is also not the same as the rate of productivity or how fast the algae are growing.

Δ (delta) the magnitude of difference in temperature (and thus density) between the upper epilimnion and deeper hypolimnion layers. When Δ is large thermal stratification occurs. In the Rivanna reservoirs where the minimum winter temperature is about 7°C, and initial Δ of 10°C is sufficient to begin thermal stratification. However, at higher temperatures that are found in summer, a Δ of only 1–3°C may be effective in producing sufficient resistance to wind mixing so anoxia can persist. The difference occurs because the density difference per centigrade degree increases at higher absolute temperatures. Effective thermal stratification in eutrophic lakes at high temperatures (> 23°C) can determine the kind of management methods used (for example, aeration-mixing vs. layer oxygenation).

DO dissolved oxygen is the measurement of how much oxygen gas is dissolved in the water. The two mechanisms that control oxygen dissolution are photosynthesis and diffusion from the atmosphere. DO concentrations are typically expressed in units of milligrams per liter (mg/L) or parts per million (ppm). Ranges from 0 mg/L (anoxia) to functional anoxia (0–2 mg/L in deepest water) to 10–14 mg/L (near saturation) to > 20 mg/L (super-saturation).

Epilimnion warmer, less dense layer of water that floats and forms the upper of the three water layers during the spring-fall thermal stratification period.

Eutrophication the process of enrichment in lakes usually due to increases in nutrients. It is characterized by low DO in deep water, excess algae (especially blue-green algae scums), more fish biomass, and cloudy water. All waters can undergo eutrophication but the main distinctions for the Rivanna system is the trophic state. Eutrophic waters are turbid (< 2 m Secchi depth, higher chlorophyll and nutrients) while the more desirable mesotrophic state has a Secchi depth > 2 m and lower algae and nutrients.

Flood storage pool The amount of water capacity (lower water elevation) deliberately left in a reservoir to hold much of a storm or flood flow and prevent flooding downstream.

Granular activated carbon (GAC) GAC is a widely-used preparation derived from heating coal or waste wood products with little or no oxygen that results in a very porous powder or granules which are often excellent at removing organic matter such as algal toxins or taste and odor compounds.

Growth-limiting nutrients This can be a controversial topic. It is based on the useful simplification that at any time the growth of anything is limited by only one factor. For terrestrial plants sunlight or water are common limiting factors and fertilizers counteract shortages of iron, potassium, nitrogen and phosphorus. In aquatic ecosystems light, P, N, Fe, Si and CO_2 can limit chemically while light, mixing of the water and sometimes temperature can also affect growth rates of algae. In the real world different algae may be limited by different factors so the growth-limiting factor concept should not be used alone to give the best way to manage nuisance algae.

HOS -Hypolimnetic Oxygen Systems A general term to cover any method of adding pure oxygen to the deep cool waters of a lake or reservoir.

Hypolimnion the cooler, denser layer of water that lies below the epilimnion during thermal stratification.

Lake turnover Turnover is another name for lake destratification that occurs in the fall.

Mesotrophic The reservoir is intermediate in productivity in between eutrophic (lots of algae, fish & nutrients) and oligotrophic (little algae, fish or nutrients). Mesotrophy is a desired state for water quality since oligotrophic reservoirs are hard to construct due to their large drainage basins.

Metalimnion the layer of intermediate density water between the epilimnion and hypolimnion.

Nitrogen: Phosphorus (N:P) ratios of nutrient concentrations in water The ratio is widely used to determine nutrient limitation. Most aquatic organisms have a ratio of 16:1 (N:P) so water with similar ratio is judged as nutrient balanced; ratios > 16 are limited by P and ratio < 16 are N-limited. Historically the ratio was developed in temperate climate lakes using Total N (TN) and Total-P (TP) and most waters were found to be P-limited. However, experimental additions of nutrients showed that these same waters were as often as stimulated by nitrate or even by iron as by phosphate. The problem with the interpretation of the simple TN:TP ratio is that most TP is bioavailable to algae while most TN is not. A better index ratio is Total Inorganic Nitrogen TIN: TP, where TIN = nitrate + ammonia. A longer discussion of the N:P ratio is presented as Appendix A.

Nutrients Algae use many nutrients for growth but most are always present in adequate quantities. The main nutrients that algae use but are used up during the growth season are phosphorus (TP or Total Phosphorus), nitrogen as nitrate or ammonia, soluble iron and silica (diatoms only). Ortho-phosphate (PO_4) is the only species of phosphorus that algae can use and is often present at low concentrations in surface waters but can be concentrated in deep water in summer and in some streams receiving polluted runoff. However, TP includes a number of inorganic and organic species most of which are assumed to readily convertible to PO_4. So TP is used to indicate the amount of P available for algae but Total Inorganic Nitrogen (TIN = NH_3+NH_4+NO_3) is used to indicate bioavailable-N rather than TN.

Nutrient loading The amount of nutrients like nitrogen and phosphorus that are added to the lake either from inflowing creeks (external loading) or from the sediments (usually in summer internal loading). Nutrient loading can be expressed as amount/surface acre or volume or as an increase in concentration at any specified time.

Periphyton attached algae, which form dense colonies that often break away from rocks or the sediments, When abundant periphyton can become a nuisance in terms of clogging filters or valves, but are rarely associated with taste and odor or toxicity.

Phosphate immobilization Phosphorous can be removed from water using various di- and tri-valent metals the most commonly used in lakes and reservoirs including Ca++, Fe+++, Al+++, La+++. In the U.S. alum (aluminum sulfate) is most common for lakes and Phosloc (lanthanum salt) is more common in Europe and Australia. In natural situations calcium and iron are important but iron availability is partially dependent on its binding with sulfur.

Phytoplankton consists of many forms including diatoms, blue-green algae, dinoflagellates and green algae. Algae are free-floating individual cells and are very small but large colonies, just visible by the eye. Scums of algae formed during blooms of blue-green algae are a very visible nuisance on the water surface. Most of the problems in the Rivanna Reservoirs are caused by blue-green algae.

Polymictic Irregular mixing of the water column top-to-bottom in summer. Thermal stratification into the epilimnion and hypolimnion layers has two variations. The first is a long seasonal stratification that lasts, uninterrupted, from spring to fall (monomictic = one mixing with no winter ice and dimictic = two mixings if ice forms in winter and prevents wind mixing). The second is an irregular stratification (polymictic) that may form, be destroyed, and reform at intervals.

Standards for trophic states There are several ways to measure trophic state but the following are good guides and are partially based on work by various experts. Although algae can only use soluble phosphate (PO_4) to grow, this species is difficult to measure at low concentrations. So TP is used instead even though most TP in reservoirs is actually inside algal cells. The flow of PO_4 from TP is fast so the approximation that TP measures PO_4 and P-bioavailability is usually valid. In contrast, the equilibrium TN to NO_3 (or NH_4) is slow so TIN (NO_3 + NH_4) is best used to estimate bioavailable-N.

Parameter	Eutrophic to Mesotrophic boundary measured in the epilimnion (surface waters)		
	Cooke & Welch (2007)	Horne (1995)	Average
Chlorophyll *a* (µg/L)	9	8	8.5
Secchi depth (m/ft)	2.0 (6.6 ft)	2.0 m (6.6 ft)	2.0 m (6.6 ft)
TP (µg/L)	29	32	30
Soluble ortho-PO_4	None given	10*	10
TN (µg/L)	Not considered limiting	Not appropriate for a standard	
TIN (µg/L)	Not considered limiting	110	110

* Some fractions of TP and PO_4 cycle very rapidly via enzyme action so this value is tentative since at low TP concentrations PO_4 is usually a small percentage but at higher TP levels, as in eutrophic lake, most of the TP can be in the directly bioavailable PO_4 fraction.

Thermocline the region of greatest change in density with depth. It lies within the metalimnion and is sometimes used as an alternative for the metalimnion with no great loss of meaning.

Total Suspended Solids (TSS) The weight of insoluble particles like algae, silt or sand that are carried along with water. Because stream water moves rapidly it can hold more TSS than reservoir water. TSS can clog water treatment filters and high values indicate erosion in streams after a storm or land disturbance by heavy machinery or livestock.

VEM (Vigorous Epilimnetic Mixing) VEM is a form of aeration-mixing that uses aeration over most of the lake, not just the deeper waters as is typical of aeration which focus on elimination of the hypolimnion. The idea is that continually mixed epilimnion results in a hostile environment for most blue-green algae that thrive on stable stratified waters. Blue-green algae can regulate their position in the water column for optimal light and nutrients. If the water is stirred, this advantage is neutralized. All blue-green algae control their buoyancy but large colonial forms are much better at controlling buoyancy than single filament forms.

Water supply pool The amount of water capacity in a reservoir able to be released and put to beneficial use.

Ragged Mountain Reservoir intake tower July 14, 2015

1 : Introduction

The Rivanna Water and Sewer Authority (Authority) is a wholesale water and wastewater utility that provides potable drinking water to the City of Charlottesville, Virginia and portions of Albemarle County. The Authority's system includes five raw water reservoirs and five water treatment plants (WTPs) that serve three service areas. The Authority sells water wholesale to City of Charlottesville and the Albermarle County Service Authority (ACSA). In addition, the Authority also provides wastewater treatment in some areas.

The Authority is now implementing a proactive "multiple-barrier approach" to their drinking water supply, including barriers that remove contaminants within the watersheds, reservoirs or treatment works, as well as managing the reservoirs to minimize the formation of harmful algae blooms and other compounds that lead to objectionable taste and odor (T&O). Additionally, these compounds contribute to water plant operational concerns.

DiNatale Water Consultants and Alex Horne Associates conducted this study in close cooperation with Authority staff to develop a comprehensive reservoir water quality monitoring program, training Authority staff in sampling techniques, and evaluation of water quality data. The goal was to identify potential methods of management for the reservoirs so that water withdrawn could be treated to finished water quality at the WTPs without excessive treatment, capital or operations and maintenance costs. While the application of algaecides can serve the Authority's short-term reservoir management goals, and may sometimes be necessary, the Authority requested investigation of alternative management tools.

This report includes the following:

- A review of watershed, reservoir inflow, and reservoir physical data.
- Identification and description of the existing or potential water quality concerns at each reservoir, that may result in objectionable T&Os in the finished water, interfere with the treatment of raw water at the Authority's water treatment plants, or present other negative impacts on recreation or other uses.
- A review of reservoir monitoring program data for 2015-2017.

- Recommendations on a strategic, scientifically based monitoring plan that focuses on data and trends essential to benchmarking reservoir performance against the Authority's objectives and minimizes sampling or water quality analyses that are not required to characterize such conditions and trends.

- Recommendations on strategies based on sound science for management of water quality in the Authority's five drinking water reservoirs.

- Recommendations on and review of additional sampling and studies to allow identification of key factors or parameters that are regularly or seasonally carried by streams from the watershed to the reservoirs and contribute to water quality problems.

- Recommendations on and review of additional watershed studies based on a general understanding of the specific watershed areas, that would identify sources of nutrient and other inputs into the reservoirs.

- A review of monitoring programs and management methods of several other utilities with reservoirs similar to those of the Authority.

Boat on South Fork Rivanna Reservoir

2 : Raw Water System Overview

Figure 1 is a schematic of the Authority's water system, showing the source of raw water supply for each WTP. Figure 2 is a map showing the location of each reservoir and its contributing watershed. Each reservoir is unique in watershed size and characteristics. Beaver Creek and Totier Creek watersheds are the sole sources of supply for the Crozet and Scottsville water systems, respectively. There is a critical need to minimize any potential contamination or major T&O events at both Beaver Creek Reservoir and the Totier Creek diversion and Totier Creek Reservoir that may create problems for the associated Crozet and Scottsville WTPs in treating these water sources. There are three reservoirs (Sugar Hollow, South Fork Rivanna, and Ragged Mountain) and a river intake (North Fork Rivanna) that supply three WTPs as input to the urban water system. The protection of the water supplies to these three WTPs supplying the urban water system are also a top priority to ensure adequate high quality water supply during times of high demand or drought.

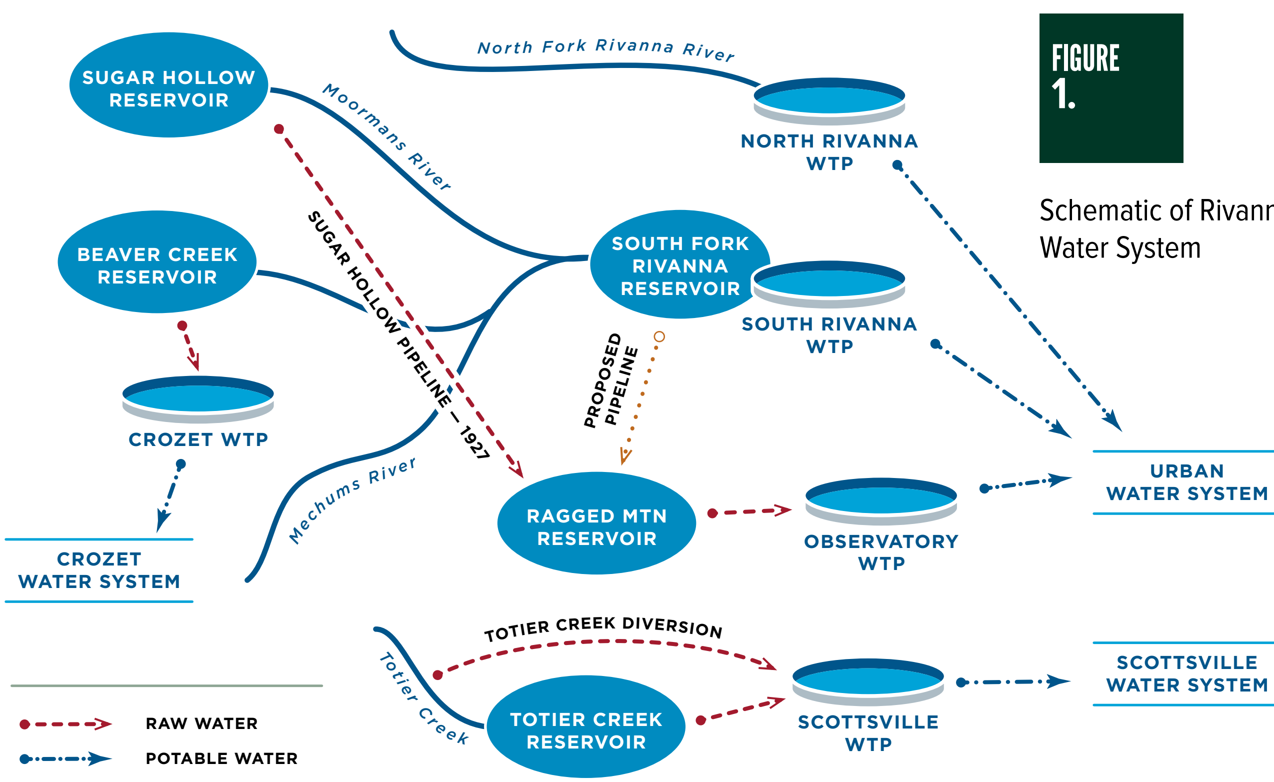
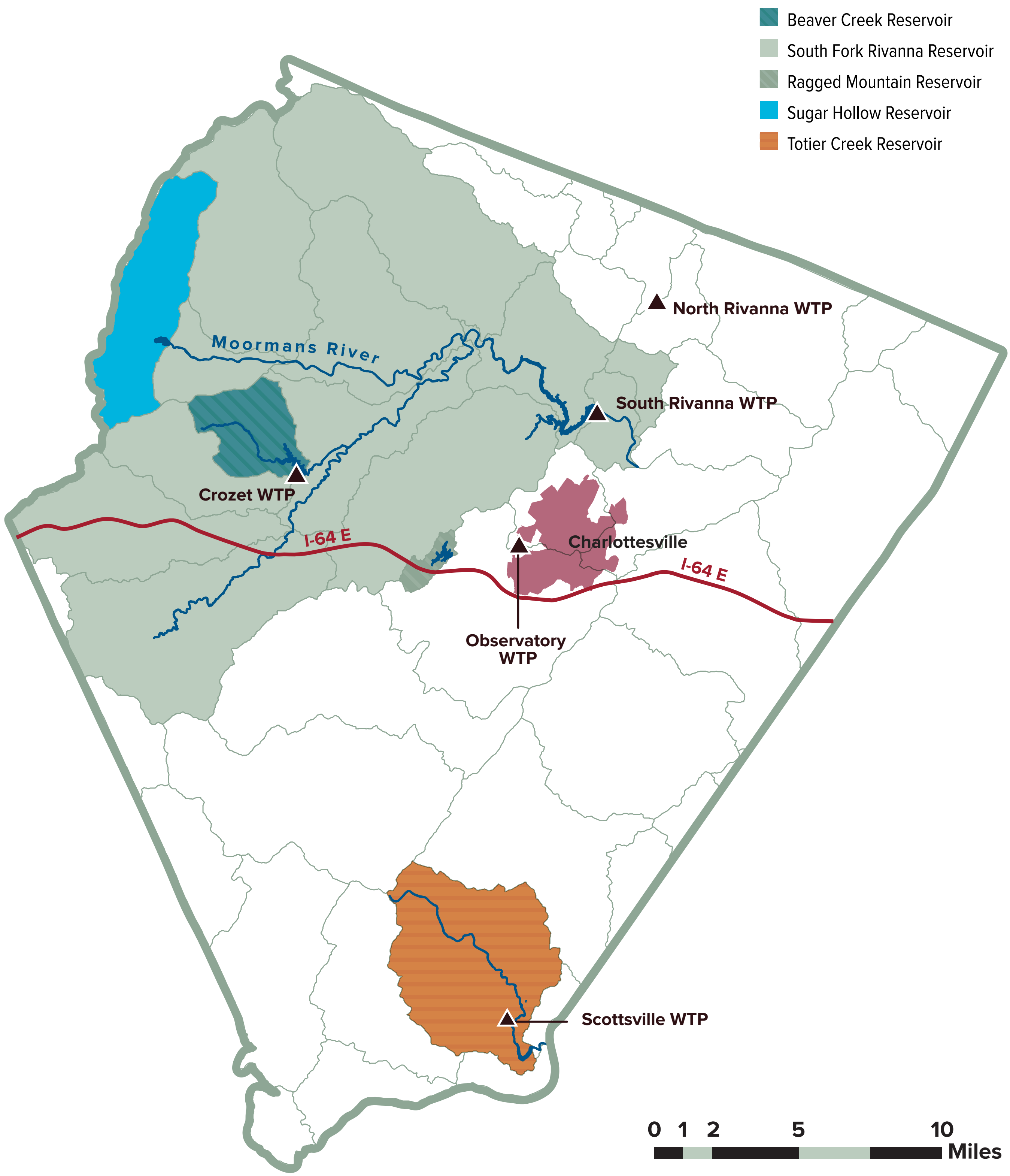


FIGURE 1.

Schematic of Rivanna Water System

FIGURE 2. Location of Rivanna Water and Sewer Authority Reservoirs and Watersheds, and Water Treatment Plants



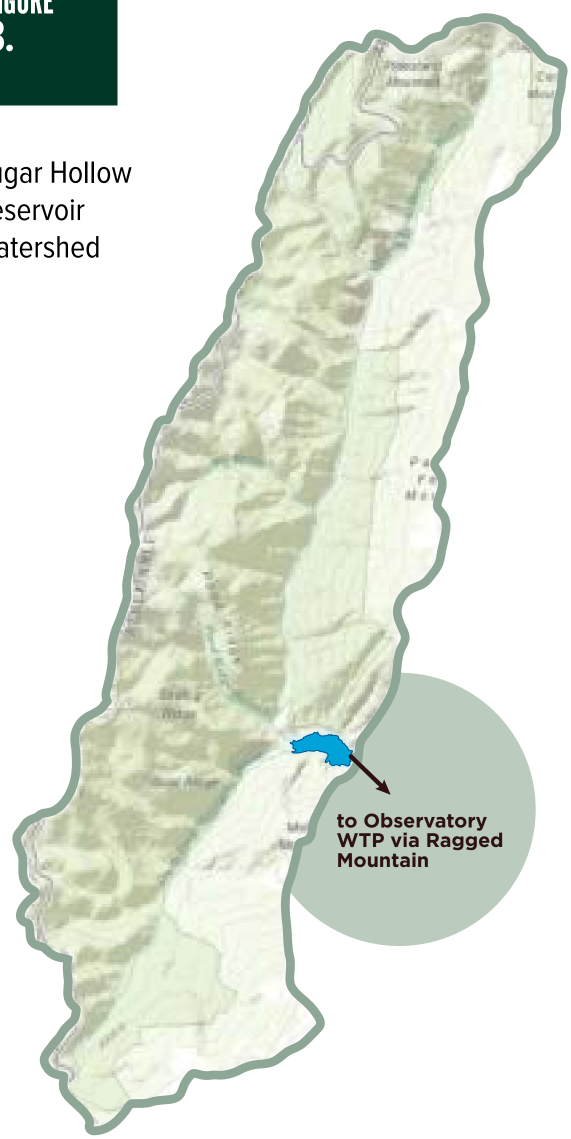
2.1 : Watersheds

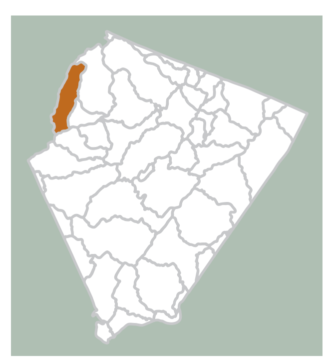
2.1.1 : Sugar Hollow Reservoir

Sugar Hollow Reservoir (Sugar Hollow) is located at the headwaters of the Moormans River. The Sugar Hollow watershed has an area of approximately 11,200 acres (17.5 square miles). Water from Sugar Hollow is currently pumped via pipeline to Ragged Mountain Reservoir and then to the Observatory Water Treatment Plant. Figure 3 shows the watershed and Sugar Hollow Reservoir. Sugar Hollow can also release water directly to the Moormans River and subsequently divert this water at South Fork Rivanna Reservoir. During the drier summer months, the flow in the Moormans river below Sugar Hollow can be very low. In the long term, the authority will abandon use of the pipeline from Sugar Hollow to Ragged Mountain to fill Ragged Mountain. Instead, water will be released from Sugar Hollow to the Moormans River and subsequently diverted at South Fork Rivanna Reservoir to be conveyed to Ragged Mountain Reservoir in a future pipeline. This will increase flow in Moormans River between Sugar Hollow and South Fork Rivanna Reservoirs, bolstering the downstream ecology.

FIGURE 3.

Sugar Hollow Reservoir Watershed



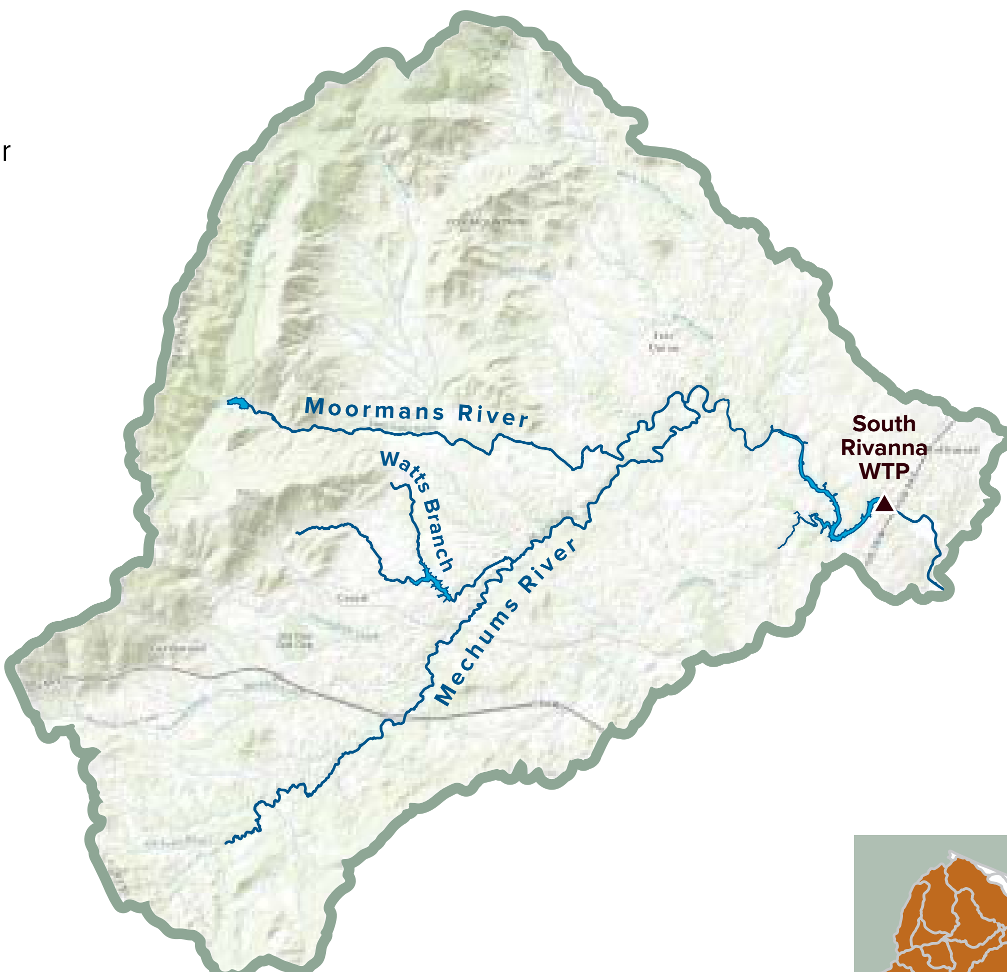


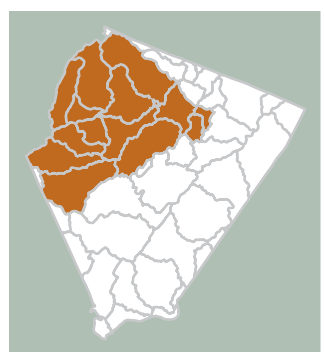
2.1.2 : South Fork Rivanna Reservoir

South Fork Rivanna Reservoir (South Fork Rivanna) is located on South Fork Rivanna River. South Fork Rivanna has a contributing basin area of approximately 165,830 acres (259.1 square miles). The Authority delivers water from the reservoir via pipeline to the South Rivanna WTP. Figure 4 shows the watershed, the reservoir, and South Fork WTP. The South Fork WTP serves the same treated water pressure zone as the Observatory WTP, but each WTP enters the service area at different locations.

FIGURE 4.

South Fork Rivanna Reservoir Watershed



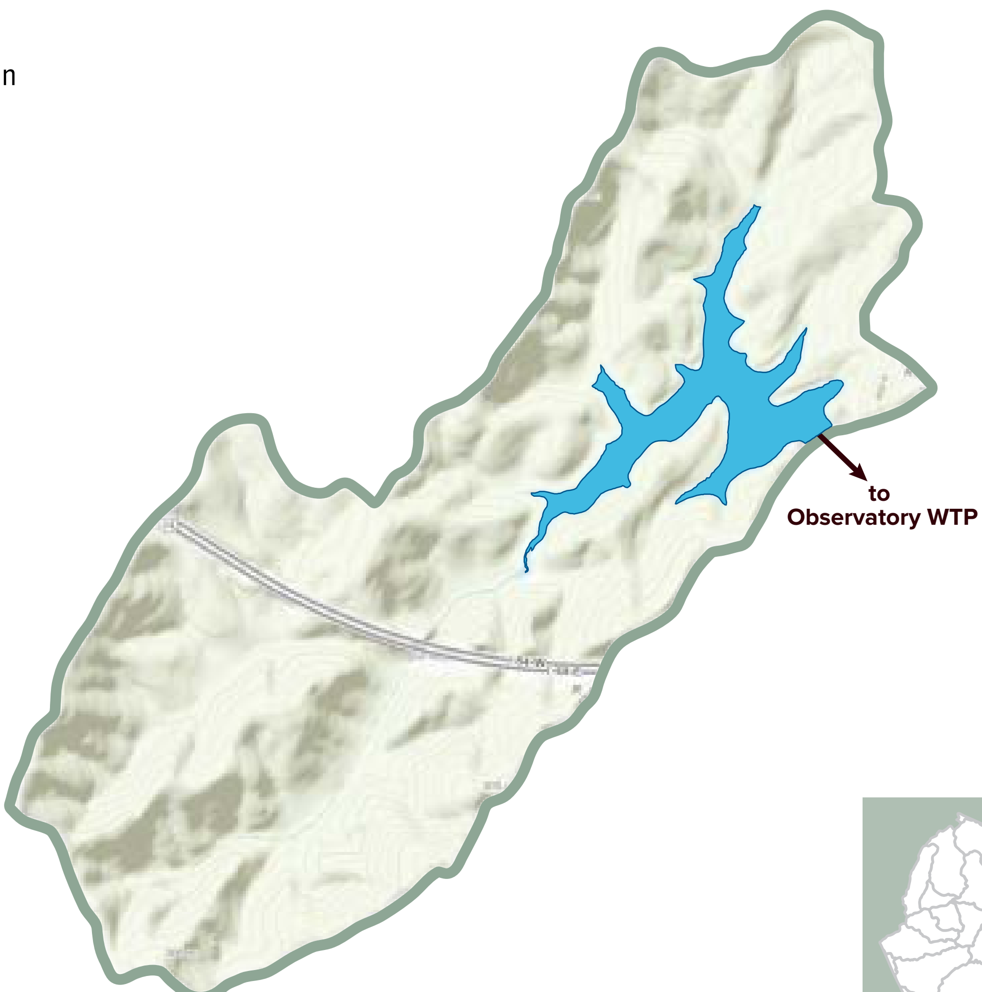


2.1.3 : Ragged Mountain Reservoir

Ragged Mountain Reservoir (Ragged Mountain) is located on Moores Creek. Ragged Mountain has a small direct watershed area of approximately 1,180 acres (1.8 square miles). The primary source of supply is water delivered to Ragged Mountain Reservoir via pipeline from Sugar Hollow Reservoir. In the future, the Authority will divert water via a pipeline from South Fork Rivanna Reservoir. Water from Ragged Mountain is delivered via pipeline to the Observatory Water Treatment Plant. Figure 5 shows the direct Ragged Mountain watershed, the reservoir, and Observatory Water Treatment plant.

FIGURE 5.

Ragged Mountain Reservoir Watershed

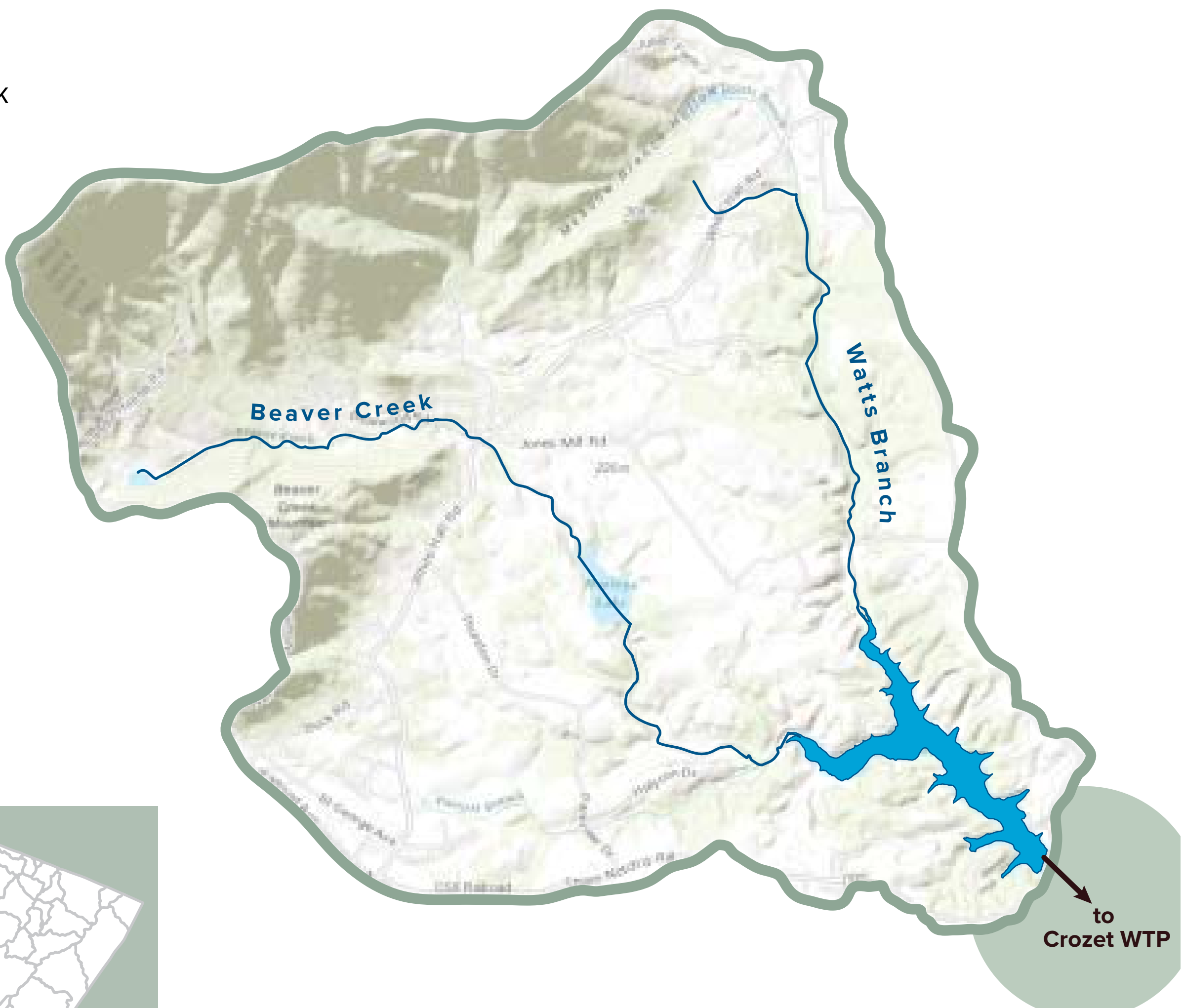


2.1.4 : Beaver Creek Reservoir

Beaver Creek Reservoir is located on Beaver Creek, a tributary of the Mechums River. The Reservoir has a contributing basin area of approximately 6,080 acres (9.5 square miles). Water from the reservoir is pumped via pipeline to the Crozet WTP. The Crozet WTP serves the Crozet Water System, which is completely separate from the urban water system. Beaver Creek Reservoir is the only source of supply for the Crozet WTP and associated water system. Figure 6 shows the watershed, Beaver Creek Reservoir, and Crozet WTP.

FIGURE 6.

Beaver Creek Reservoir Watershed



2.1.5 : Totier Creek Reservoir

Totier Creek Reservoir is located on Totier Creek. The Reservoir has a contributing basin area of approximately 18,240 acres or 28.5 square miles. Water from the reservoir is pumped via pipeline to the Scottsville WTP on the occasions when the creek water is unavailable. Due to high turbidity and resulting poor water quality in the reservoir, the preferred water supply diversion to the Scottville WTP is a diversion from Totier Creek upstream of the reservoir. Figure 7 shows the watershed, Totier Creek Reservoir, and Scottsville WTP. The Scottsville WTP serves the Scottsville Water System, which is completely separate from the urban water system. Totier Creek and the Totier Creek Reservoir are the only sources of supply for the Scottville WTP and associated water system.

FIGURE 7.

Totier Creek Reservoir Watershed

2.2 : Physical Data

2.2.1 : Physical Characteristics of Reservoirs

The Authority's five reservoirs vary in contributing watershed size, with drainage areas ranging from 1,180 acres for Ragged Mountain Reservoir to over 165,000 acres for South Fork Rivanna Reservoir. Similarly, the reservoirs vary in storage volume, with Totier Creek having the smallest volume of 182 million gallons (559 AF) and Ragged Mountain the largest at 1,721 million gallons (5,281 AF.) A summary of the watershed area, surface area, ratio of watershed to surface area, estimated current maximum depth and storage volume are shown in Table 1. There were multiple data sources for watershed area, current depth and storage volume. The values in Table 1 represent estimated values based on the various data sources. Additional details on each reservoir are provided below.

TABLE 1. Reservoir Physical Characteristics

Reservoir Name	Watershed Area, Acres	Surface Area, Acres	Ratio of Watershed to Surface Area	Estimated Current Maximum Depth, Feet	Total Storage Volume, Million Gallons, (AF)	Useable Storage Volume, Million Gallons, (AF)
Sugar Hollow	11,200	47	238	58	360 (1,105)	324 (994)
South Fork Rivanna	165,830	366	453	35	1,282 (3,934)	883 (2,710)
Ragged Mountain	1,180	170	7	80	1,721 (5,282)	1,549 (4,754)
Beaver Creek	6,080	104	58	40	585 (1,795)	521 (1,599)
Totier Creek	18,240	66	276	25	182 (559)	155 (476)

Each reservoir has an outlet structure with multiple outlet gates that allow water to be withdrawn from varying depths. Some of the outlet gates have capacity limitations and the WTP operators are limited to the rate of flow that they can selectively withdraw from certain gates. Selectively choosing the depth of withdrawal for water quality purposes at those times when water quality may vary can potentially improve the quality of water delivered to the respective WTPs.

Sugar Hollow Reservoir can withdraw water at depths of 7 and 32 feet below full reservoir level. South Fork Rivanna Reservoir can withdraw water at 5, 10 and 15 foot depths. The new Ragged Mountain outlet structure can withdraw water at 11, 26 and 50 foot depths. Beaver Creek Reservoir can withdraw water from the surface and at 5, 10, 15 and 20 foot depths, although the 5, 10, 15 and 20 foot depth gates have limited capacity. Totier Creek Reservoir can withdraw at 3, 6 and 11 foot depths.

Figure 8 shows the relationship of the depths of the outlets at each reservoir in relation to the total reservoir depth. As noted, there are multiple data sources for maximum reservoir depth. Any storage below the lowest outlet for each reservoir is dead storage and could only be accessed in an emergency using temporary pumps, to the extent the dead storage is not filled with sediment.

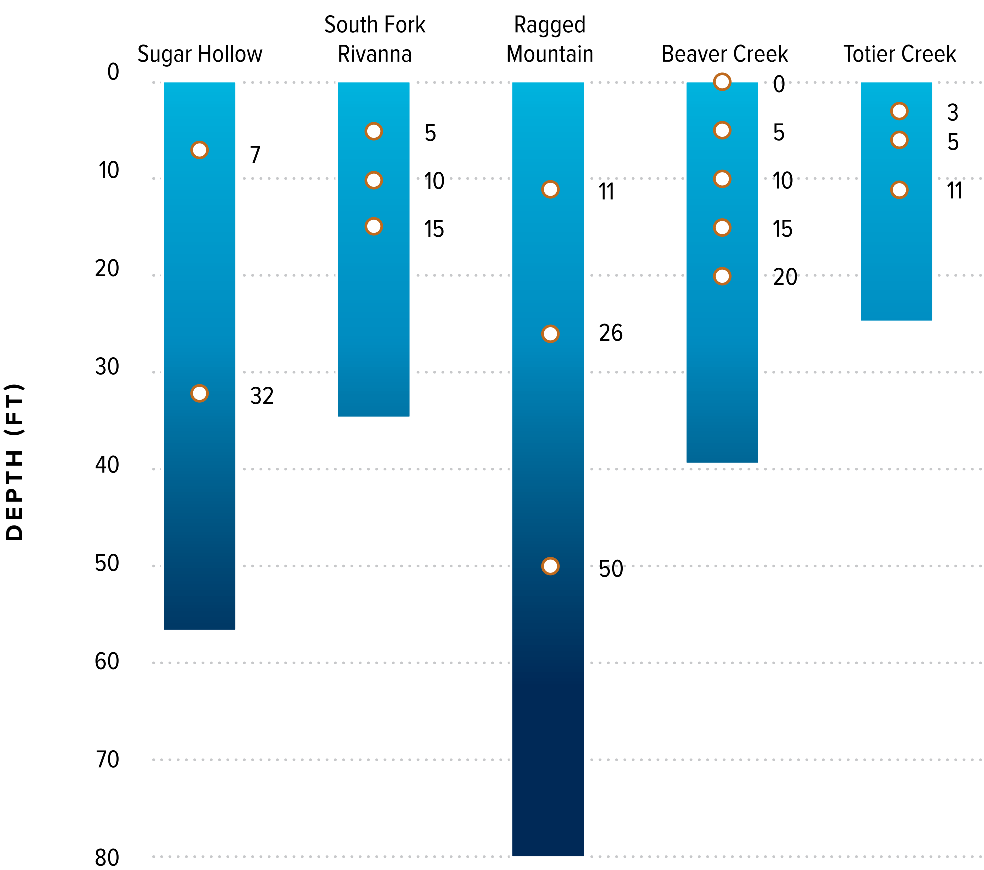


FIGURE 8.

Estimated Reservoir Depth at Outlet Tower is shown by Bars with Outlet Depths Indicated

2.2.2 : Sugar Hollow Reservoir

Sugar Hollow Reservoir was constructed in 1947. To increase spillway capacity while maintaining storage capacity, an inflatable bladder was added to the spillway crest in 1999. The reservoir dead storage is the bottom 32 feet located below the lowest outlet gate. The reservoir is 47 surface acres with 360 MG (1,105 AF) of storage when full.

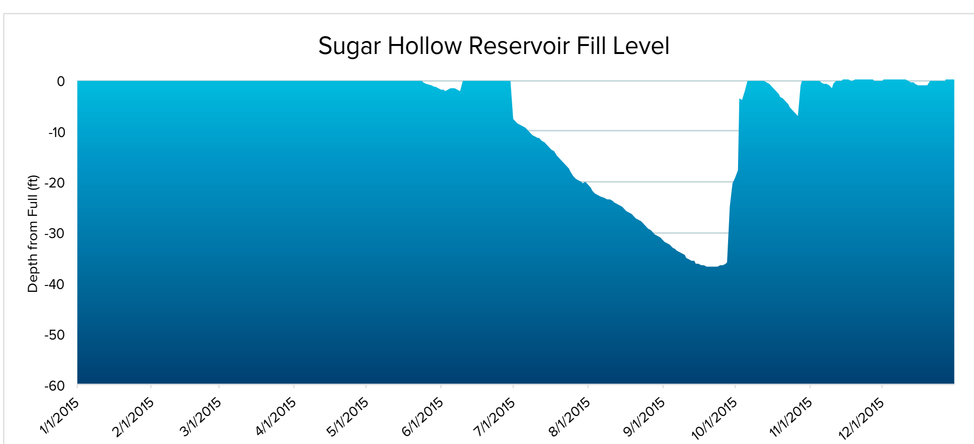
The Reservoir has a multi-level outlet tower. Plans provided by the Authority, indicate this tower has two operable outlets at depths of 7 and 32 feet, as shown in Figure 8, and one deeper gate that is inoperable due to blockage from trees and sediment. According to operations staff, changing the outlet gates to a different elevation or releases is relatively easy, although it requires a staff member to drive approximately 45 minutes to reach the reservoir.

The Reservoir is operated generally under the following parameters:

The Sugar Hollow intake tower can discharge into a 13-mile-long, 18-inch diameter pipeline that conveys water directly to Ragged Mountain Reservoir and then to the Observatory WTP. The pipeline capacity is approximately 4 mgd. Currently, there is a transfer of water from Sugar Hollow to Ragged Mountain through this pipeline. Water from the pipeline discharges into the Ragged Mountain watershed and flows overland into Ragged Mountain Reservoir. During 2015, Sugar Hollow Reservoir reached a minimum surface depth of 36.9 ft. below full in late September. A significant storm in late September increased flows into the reservoir and it refilled on October 6. A chart of reservoir level for the year 2015 is show in Figure 9. Sugar Hollow Reservoir can also discharge directly to Moormans River, which flows into the South Fork of the Rivanna River and South Fork Rivanna Reservoir.

FIGURE 9.

Sugar Hollow Reservoir Fill Level, 2015.



Top left: Inflow to Sugar Hollow Reservoir, April 15, 2015

Above & Top right: Moormans River immediately downstream of Sugar Hollow Reservoir, April 15, 2015

Right: Sugar Hollow spillway April 15, 2015

Below: Sugar Hollow Reservoir at low level, 31.8 ft below full, September 2, 2015

2.2.3 : South Fork Rivanna Reservoir

South Fork Rivanna Reservoir was constructed in 1966. The reservoir has dead storage of 15 feet located below the lowest outlet gate and various bathymetric surveys indicate significant sedimentation in the reservoir , resulting in the loss of approximately 22 percent of the water supply volume since construction to 2009 (HDR, 2010). The reservoir is 366 surface acres with an estimated 1,282 MG (3,934 AF) of total storage and 883 MG (2,710 AF) of usable storage. The reservoir does not have an operating flood storage pool and the water supply pool extends to the spillway. Releases to the South Fork Rivanna River generally occur as spillway overflow when the reservoir is full.

The Reservoir has a multi-level outlet tower. This tower has three outlets at depths of 5, 10, and 15 feet as shown in Figure 8. According to Authority WTP staff, they have used the 10 foot depth intake almost exclusively for approximately the last 15 years. The Reservoir is normally full except for very dry periods. In 2015, the reservoir was below full from August 22 through September 28. Changing the outlet gates to withdraw water from a different level takes a WTP operator approximately 30 minutes to an hour.

South Fork Rivanna Reservoir conveys water via pipeline directly to the adjacent South Fork WTP. Sugar Hollow Reservoir can discharge to Moormans Creek, which ends up in South Fork Rivanna Reservoir. The South Fork Rivanna to Ragged Mountain Reservoir pipeline will be constructed in the future and replace the Sugar Hollow to Ragged Mountain pipeline as the primary means to fill Ragged Mountain.

South Fork Rivanna Reservoir and spillway overflow after a storm in May 2015. Note the turbid water.

Left: View of old Ragged Mountain Dam from left abutment of new dam August 5, 2014
Right: New Ragged Mountain Dam and old dam to the right August 5, 2014

2.2.4 : Ragged Mountain Reservoir

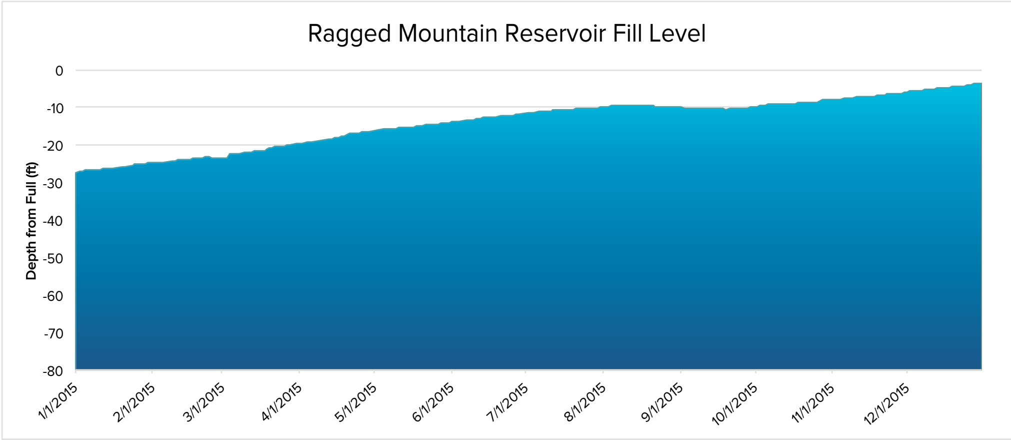
Ragged Mountain Reservoir was constructed in 1885. A recent enlargement of the reservoir was completed and the reservoir began filling in 2014.

The reservoir has dead storage of 30 feet located below the lowest outlet gate. The reservoir is 170 surface acres and has 1,549 MG (4,754 AF) of usable storage when full. The reservoir does not have an operating flood storage pool. Since the reservoir has a small watershed, it only has an emergency spillway.

Ragged Mountain Reservoir has a multi-level outlet tower with three outlets, which are located at 11, 26, and 50 foot depths as shown in Figure 8. At the end of 2015, the enlarged reservoir the reservoir was 3.6 feet below full. The reservoir filled in early 2016. A chart of the 2015 fill levels for Ragged Mountain Reservoir is shown in Figure 10. The Reservoir conveys water via an 18-inch diameter pipeline directly to the Observatory WTP. There are two pipelines for redundancy. The long-term operations plan for the reservoir calls for a pipeline from South Fork to Ragged Mountain. There is a new minimum release plan for the enlarged Ragged Mountain Reservoir that is undergoing implementation. The release schedule could potentially change after the pipeline connecting South Fork and Ragged Mountain is constructed and operational. Currently, a 20 gpm release from Ragged Mountain is required as part of the reservoir enlargement permit.

FIGURE
10.

Ragged Mountain Reservoir Fill Level, 2015



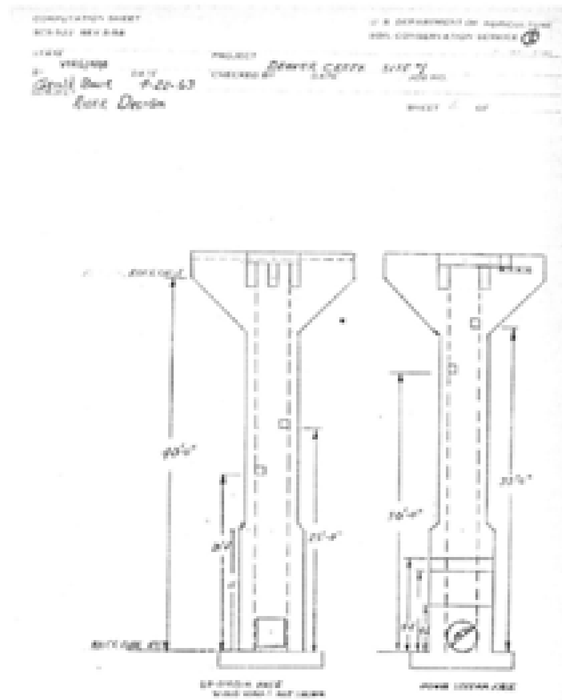
Ragged Mountain Reservoir, October 2015

2.2.5 : Beaver Creek Reservoir

Beaver Creek Reservoir was constructed in 1963. The reservoir has dead storage of 20 feet located below the lowest outlet gate. The reservoir is approximately 104 surface acres with 521 MG (1,599 AF) of usable storage when full. The water supply pool extends to the top of the intake tower, which is open to the reservoir as shown in Figure 11. Water from the intake tower is transferred to a pump station and then via a 1.3 MG capacity pipeline to the Crozet WTP. The pump station has two 1 MGD pumps with only one in operation at a given time. The reservoir does not have an operating flood storage pool, although flows in excess of the capacity of the intake tower overflow will be temporarily detained in the reservoir and released as capacity is available in the overflow.

The Reservoir has a multi-level outlet tower. The majority of releases occur via the surface overflow structure. When the reservoir is below the surface overflow level, one or more of the four outlet gates at depths of 5, 10, 15, 20 feet must be used. Figure 11 is a schematic of the intake tower from the original reservoir design plans. These gates, shown above, have limited flow capacity. Authority staff reported that the overflow was not active in summer 2014 because water level dropped below the level of the overflow. There is a flow meter to measure flow released to the Creek downstream of the reservoir. Water from the reservoir is pumped via pipeline to nearby Crozet WTP.

FIGURE 11. Beaver Creek Reservoir Intake Tower



Beaver Creek outlet tower April 16, 2015

2.2.6 : Totier Creek Reservoir

Totier Creek Dam was completed in the fall of 1971 (History of the Development of Totier Creek, 1976). The reservoir has dead storage of 11 feet located below the lowest outlet gate. The reservoir is 66 surface acres with approximately 155 MG (476 AF) of usable storage when full. The reservoir does not have an operating flood storage pool.

The Reservoir has a multi-level outlet tower. This tower has three outlets at depths of 3, 6, and 11 feet as shown in Figure 8. The outlet tower is located to the left of the main channel in an area with little circulation. The Authority has considered adding an extension to the intake to allow water to be withdrawn from the main channel.

The Scottsville WTP normally withdraws water from Totier Creek upstream of Totier Reservoir, in lieu of diverting water from the reservoir intakes. The pump station on the creek is directly behind the WTP. Authority staff reports that water in the creek is generally better quality than the water in the reservoir. Water can be drawn from reservoir if necessary, and the pumps from the reservoir are exercised once per week.

Totier Creek upstream of reservoir, November 28, 2011

2.3 : Land Use

Land cover for the watershed for each reservoir was analyzed using the vfcm05_level2.rrd GIS layer downloaded from the Virginia Department of Forestry website at http://www.dof.virginia.gov/gis/. The project team evaluated the land use GIS layer developed by Albemarle County, but determined that the Department of Forestry land cover categories, although at a lesser resolution than the County layers, were more useful for the purpose of this study in order to better show major land use differences at the watershed scale.. Aerial images were obtained from the World Imagery base layer in ArcMap, Source: ESRI, i-cubed, USDA FSA, USGS, AEX, GeoEye, Getmapping, Aerogrid, IGP.

Beaver Creek Reservoir from the Air

2.3.1 : Sugar Hollow Reservoir

The Sugar Hollow Reservoir watershed is primarily forested, with wooded land cover comprising approximately 97% of the watershed area. Much of the watershed is located in the Shenandoah National Forest. Other land uses include small amounts of cropland, roads, residences, and forest harvest, which refers to land containing recent timber logging operations.

The land use cover within the watershed and a companion aerial photo are shown in Figure 12. A summary of the land uses by percent and acres is listed in Table 2.

TABLE 2.

Land Use within the Sugar Hollow Reservoir Watershed

Land Use	Sum of Acres	Percentage
Crop	111	1%
Forest Harvest	96	1%
Hardwood Forest	9,416	84%
Mixed Forest	545	5%
Pavement	71	1%
Pine Forest	950	8%
Residential/Industrial	8	<1%
Water	48	<1%
Grand Total	**11,245**	**100%**

FIGURE 12.

Land Use and Aerial Photo of the Sugar Hollow Reservoir Watershed

2.3.2 : South Fork Rivanna Reservoir

The land use cover within the South Fork Rivanna Reservoir watershed and an aerial photo are shown in Figure 13. This is a very large watershed and includes the Sugar Hollow and Beaver Creek reservoirs watersheds, as well as the Moormans and South Rivanna rivers, Beaver Creek, and numerous other tributaries to these waterways. Total watershed area is approximately 169,000 acres, with approximately 70% of the watershed classified as various types of wooded cover, as shown in Table 3. Cropland is the other dominant land use at 24% or 40,000 acres. The crop land cover is found adjacent to the rivers and creeks within the watershed. Residential and industrial land cover comprise only 3% of the land use cover, but residential land use is likely much greater as many residences are heavily wooded and may be listed under one of the forest land use covers.

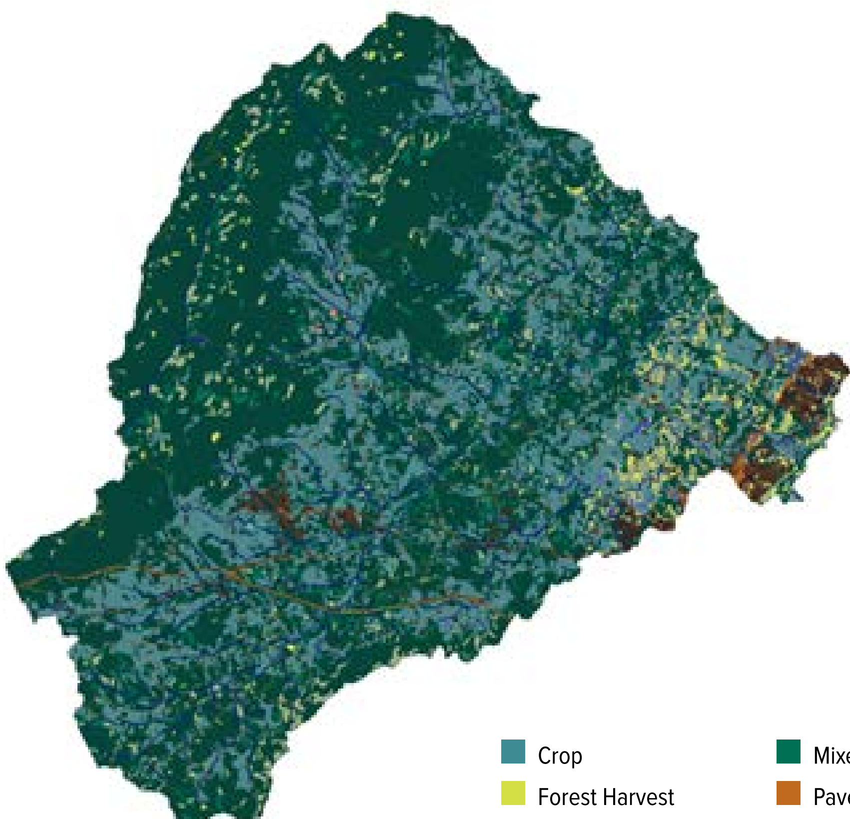
TABLE 3.

Land Use within the South Fork Rivanna Reservoir Watershed

Land Use	Sum of Acres	Percentage
Crop	39,843	24%
Forest Harvest	2,018	1%
Hardwood Forest	98,530	58%
Mixed Forest	10,395	6%
Pavement	3,832	2%
Pine Forest	9,171	5%
Residential/Industrial	4,500	3%
Rooftop	76	<1%
Water	1,006	1%
Grand Total	**169,372**	**100%**

FIGURE
13.

Land use and aerial photo of the South Fork Rivanna Reservoir watershed



2.3.3 : Ragged Mountain Reservoir

The land use cover and aerial photo of the Ragged Mountain watershed are shown in Figure 14. Land cover is predominately forest with significant portions of water and pavement. Ragged Mountain has a very small watershed of approximately 1,200 acres, with the current source of water diversions from the Sugar Hollow pipeline. Upon completion of the future South Fork Rivanna pipeline, the water source will be water withdrawn from South Fork Rivanna Reservoir. A land cover table for the immediate Ragged Mountain watershed is shown in Table 4.

TABLE 4.

Land Use within the Ragged Mountain Reservoir Watershed

Land Use	Sum of Acres	Percentage
Hardwood Forest	997	85%
Mixed Forest	16	1%
Pavement	26	2%
Pine Forest	57	5%
Residential/Industrial	5	<1%
Water	77	6%
Grand Total	**1,179**	**100%**

FIGURE 14.

Land use and aerial photo of the Ragged Mountain Reservoir watershed

2.3.4 : Beaver Creek Reservoir

The land use cover within the Beaver Creek Reservoir watershed and a companion aerial photo are shown in Figure 15. The watershed is primarily farmland and woods land use. Authority staff reports there is not much tillage as the farmland is primarily orchard farms. There are cattle grazing on the pastures, but it is unknown if the pastures are fertilized. There is one large horse training facility within the Watts Creek subwatershed, a tributary to the reservoir. Approximately 4% of the watershed is residential. Authority staff report that residential homes directly around the reservoir use septic systems for wastewater disposal, while the high density residential areas are sewered, collected in an interceptor and pumped to and treated at the Moores Creek Advanced Water Resources Recovery Facility.

The land use breakdown is shown in Table 5.

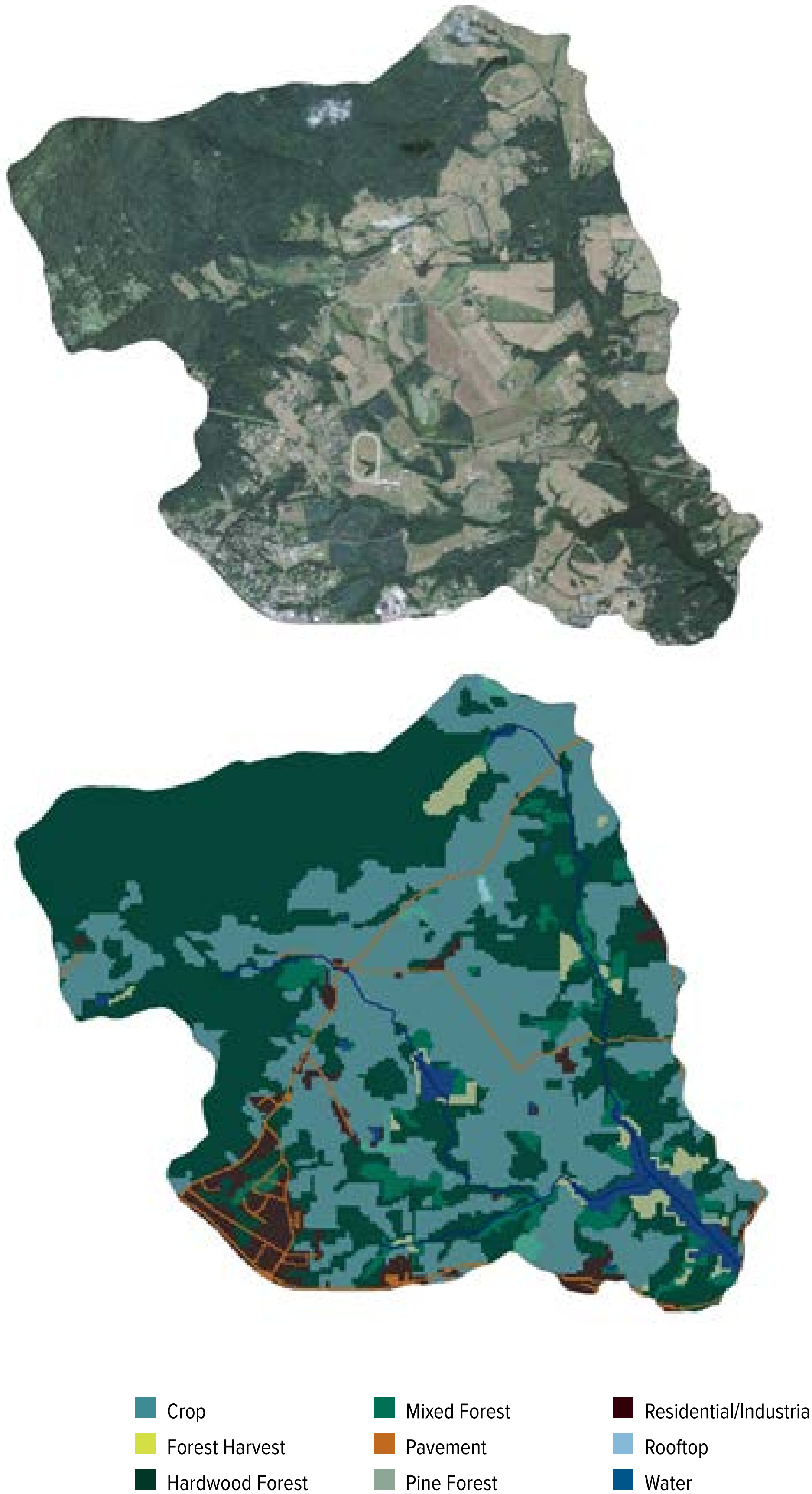
TABLE 5.

Land Use by Type within the Beaver Creek Reservoir watershed

Land Use	Sum of Acres	Percentage
Crop	2,330	38%
Hardwood Forest	2,790	46%
Mixed Forest	288	5%
Pavement	120	2%
Pine Forest	134	2%
Residential/Industrial	256	4%
Rooftop	4	<1%
Water	150	2%
Grand Total	**6,071**	**100%**

FIGURE 15.

Land use and aerial photo of the Beaver Creek Reservoir watershed



2.3.5 : Totier Creek Reservoir

The land use cover within the Totier Creek Reservoir watershed and a companion aerial photo are shown in Figure 16. The watershed is primarily composed of cropland (33%) and wooded cover.

The land use breakdown is shown in Table 6.

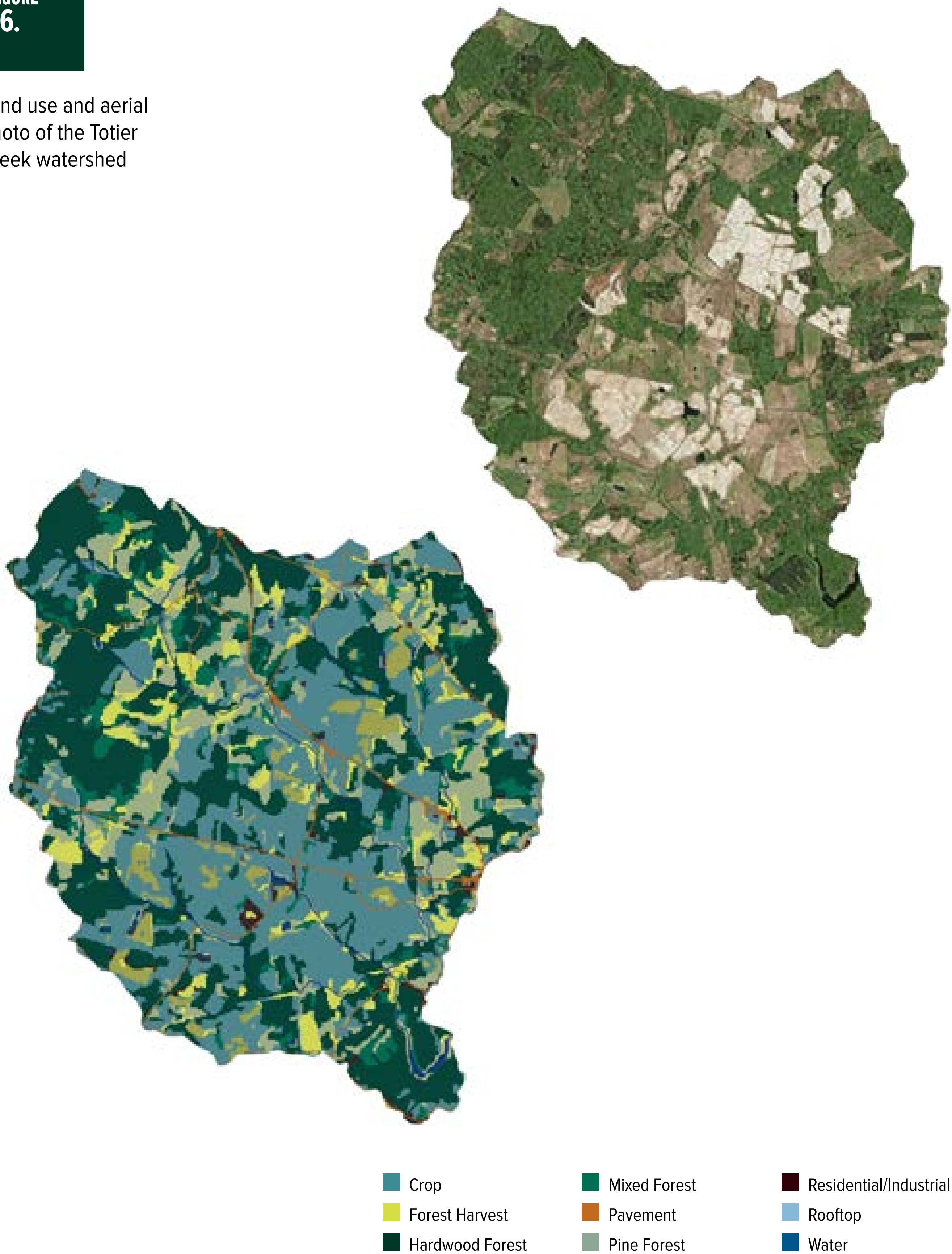
TABLE 6.

Land Use within the Totier Creek Reservoir Watershed

Land Use	Sum of Acres	Percentage
Crop	6,111	33%
Forest Harvest	1,308	7%
Hardwood Forest	6,640	36%
Mixed Forest	1,211	7%
Pavement	393	2%
Pine Forest	2,390	13%
Residential/Industrial	251	1%
Rooftop	2	<1%
Water	88	<1%
Grand Total	**18,394**	**100%**

FIGURE
16.

Land use and aerial photo of the Totier Creek watershed

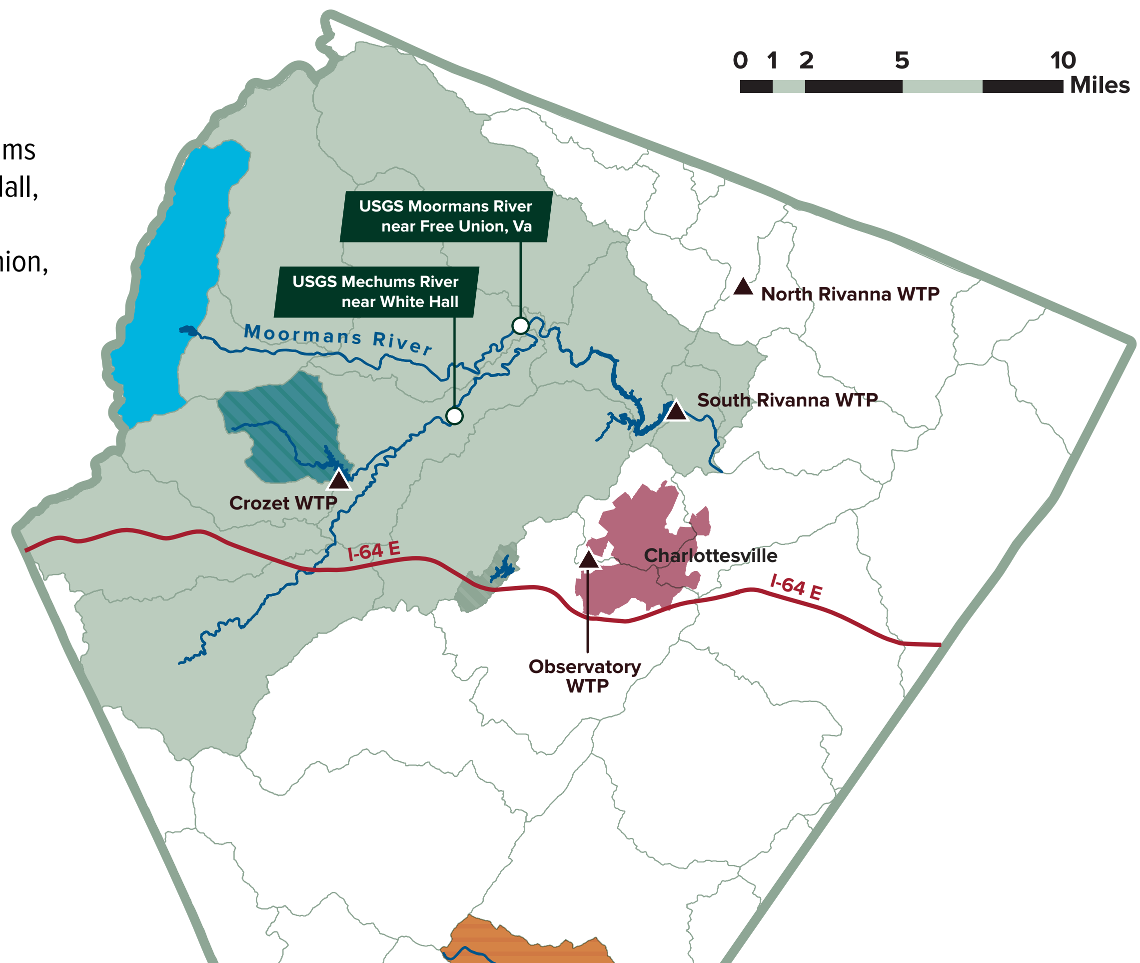


2.4 : Hydrology

Inflows to the individual reservoirs are not gaged. The USGS streamflow monitoring gage 02031000 Mechums River near White Hall, VA has historically been used by the Authority as a surrogate for reservoir inflows. There are consistent recorded gage data from 1980 through present. This gage has a drainage area of 95.3 square miles. The location of the Mechums River and Moormans River gages in relation to the Authority's reservoirs are shown in Figure 17. A combination of the Mechums River near Whitehall and the USGS streamflow monitoring gage 02032250 Moormans River near Free Union, VA gages is likely a better surrogate for flows into South Fork Rivanna Reservoir and the Moormans River gage alone is likely a better surrogate for flows into Sugar Hollow Reservoir.

FIGURE 17.

Location of Mechums River near White Hall, VA and Moormans River near Free Union, VA USGS gages



2.4.1 : Watershed Area Weighted Estimation of Reservoir Inflows

Table 7 shows the average annual (calendar year) daily cfs, average annual discharge in MG for the entire drainage area contributory to the Mechums River gage, and the cfs and MG values per square mile, based on the 95.3 square mile drainage area, for the years 1980–2013. The median flows are very close to the average (mean) flows, but annual variations in flow are significant, with minimum flow 15% of both the average and median. Maximum annual flow was approximately 170% of the average and median. The annual average cfs for the gage for the entire drainage area is shown in Figure 18.

	Average Daily flow, cfs	Total Annual Flow, MG	Average daily flow, cfs per square mile	Total Annual Flow, MG per square mile
Average	105	24,800	1.1	260
Minimum	25	5,945	0.3	62
Maximum	201	47,393	2.1	497
Median	106	25,041	1.1	262.8

TABLE 7.

USGS gage 02031000 Mechums River near White Hall, VA, 1980–2013

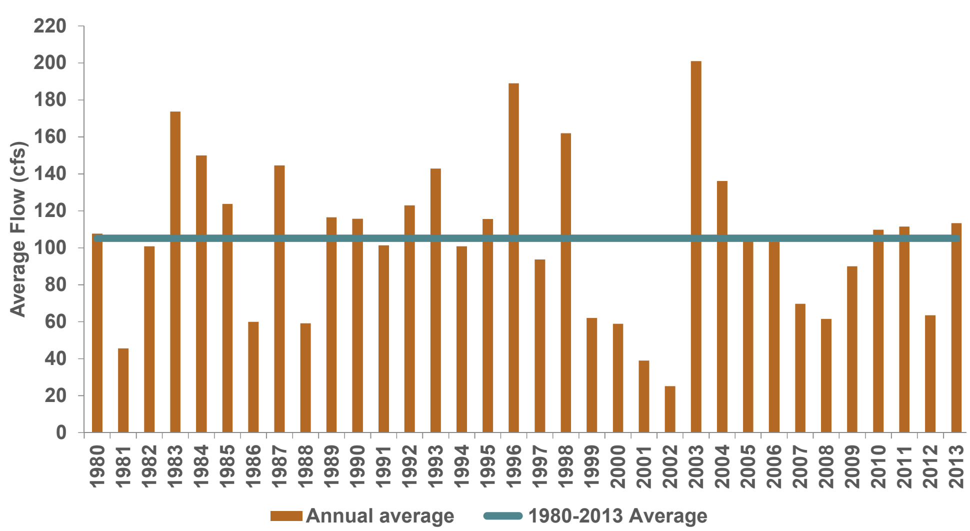


FIGURE 18.

Average Annual Flow Mechums River near Whitehall, VA

The average daily flow for the gage for 1980–2013 is 105.6 cfs. There is a significant variation in annual average daily flow, ranging from a minimum of 15.0 cfs in 2002 to a maximum of 178.4 cfs in 1996.

While the Moormans river gage was not in operation from 1998 to 2005, the surrounding data can inform estimates of inflows to South Fork Rivanna and Beaver Creek Reservoirs. Table 8 shows the average annual (calendar year) daily cfs, the average annual discharge in MG for the entire drainage area contributory to the Moormans River gage, and the values per square mile, based on the 77 square mile drainage area, for the years 1980–2013. Since the gage was not in operation from 1998 to 2005, the years are not used in the calculations. The median flows are very close to the average (mean) flows, but annual variations in flow are significant, with minimum flow approximately 30% of both the average and median. Maximum annual flow was approximately 175% of the average and median. The annual average cfs for the gage for the entire drainage area is shown in Figure 19.

TABLE 8.

USGS gage 02032250 Moormans River Near Free Union, VA, 1980–2013

	Average Daily flow, cfs	Total Annual Flow, MG	Average daily flow, cfs per square mile	Total Annual Flow, MG per square mile
Average	98	23,074	1.3	300
Minimum	28	6,629	0.4	86
Maximum	170	39,986	2.2	519
Median	95	22,364	1.2	290

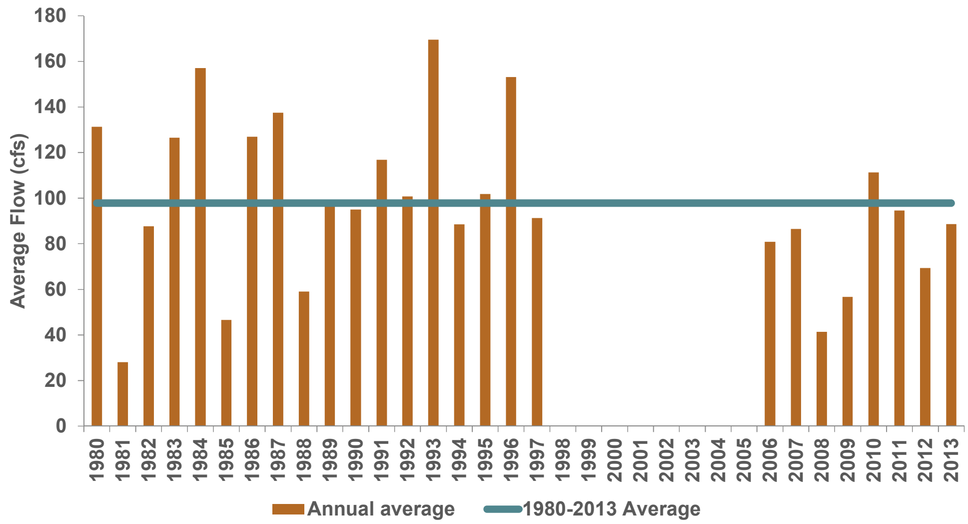


FIGURE 19.

Average Annual Flow Moormans River Near Free Union, VA. No Data From October 1997 to July 2005

As noted, there are no inflow data available for the individual reservoirs and the Mechums River gage is used by the Authority as a surrogate. This provides an indication of the volume and variation in flow, although neither gage is adjusted for withdrawals by the Authority from individual reservoirs to the respective WTPs, transfers from Sugar Hollow Reservoir to Ragged Mountain Reservoir, or variations in elevation, precipitation, and runoff within the watersheds of each reservoir. Based on the unit flow per square mile determined in Table 7 and 8, the calculated average, minimum and maximum annual cfs inflow to four of the Authority's reservoirs is shown in Table 9. The estimates for Beaver Creek and Totier Creek reservoirs are based on data from the Mechums River gage. Sugar Hollow Reservoir estimates are based on data from the Moormans River gage with dates during which the gage was not operational (October 1997 through July 2005) omitted from the calculations. Estimates for South Fork Rivanna Reservoir are based on data from both gages. For dates where the Moormans River gage was not operational, only data from the Mechums River gage is used in the calculation.

TABLE 9.

Estimated Annual Inflows to Reservoirs, Daily cfs, 1980–2013

	Sugar Hollow	South Fork Rivanna	Beaver Creek	Totier Creek
Watershed Area, square miles	17.5	259.1	9.5	28.5
Average	22.6	293.3	10.1	30.2
Minimum	6.4	65.8	2.4	7.2
Maximum	38.5	524.2	19.2	57.7

The total annual inflows to each reservoir was also calculated and shown in Table 10. Estimated average annual reservoir inflows range from a low of 2,472 MG (7,586 AF) for Beaver Creek Reservoir to a high of 70,840 MG (217,400 AF) for South Fork Rivanna. Minimum annual inflows range from a low of 593 MG (1,820 AF) for Beaver Creek to a high of 16,163MG (49,602 AF) for South Fork Rivanna and maximum annual inflows range from a low of 4,724 MG (14,497 AF) for Beaver Creek and a high of 128,852 MG (392,432 AF) for South Fork Rivanna.

TABLE 10.

Estimated Annual Inflows to Reservoirs, Million Gallons, 1980–2013

	Sugar Hollow	South Fork Rivanna	Beaver Creek	Totier Creek
Average	5,244	70,840	2,472	7,417
Minimum	1,507	16,163	593	1,778
Maximum	9,088	128,852	4,724	14,173

2.4.2 : Modeled Reservoir Inflows

The Authority had a reservoir yield model prepared for the reservoirs that supply the urban water system by HydroLogics, a consultant to the Authority. The model of the Authority's system is used to predict drought conditions. Steven Nebiker of HydroLogics provided modeled inflows to Sugar Hollow, Ragged Mountain, South Fork Rivanna, and Beaver Creek reservoirs. The project team compared the HydroLogics modeled inflows to the watershed weighted area method described above using the period of 1980–2010 and found that the results were similar with the exception of Sugar Hollow Reservoir.

HydroLogics used a similar weighting method to estimate inflows, taking streamflow data from USGS gage stations and making linear adjustments based on the contributing drainage area using methodology detailed in an Authority Safe Yield study by Gannett Fleming, 2004. This study notes that Sugar Hollow inflows were corrected by adjusting measurements at the Moormans River near White Hall gage with Authority withdrawals at an upstream intake, likely accounting for the difference in the two modeled inflows. Due to the adjustment, HydroLogics estimates are thought to better capture inflows into Sugar Hollow Reservoir. Estimates below for South Fork Rivanna Reservoir inflows from HydroLogics are the result of three separate estimates and represent the sum of modeled inflows for Sugar Hollow Reservoir, the Mechums River Pumping Station, and the portion of the South Fork watershed without these two.

2.4.3 : Sugar Hollow Reservoir

The average estimated annual inflows, based on record from 1980–2010, for Sugar Hollow Reservoir are show in Table 11. The watershed area weighting method shows average annual inflows of 5,339 MG (16,385 AF), while the HydroLogics estimate is 7,201 MG (22,013 AF). Maximum values are 9,088 and 16,742 MG (27,890 and 51,380 AF) for the watershed area weighting method and the HydroLogics model respectively. The relatively large discrepancy between these values is most likely explained by the fact that HydroLogics estimates for Sugar Hollow have been corrected by adjusting measurements at the Moormans River near White Hall gage with Authority withdrawals at an upstream intake. Minimum values obtained by the watershed area weighting method and HydroLogics agree more closely and are 1,507 and 1,207 MG (4,625 and 3,703 AF) respectively.

Figure 20 shows the estimated historical inflows to Sugar Hollow Reservoir based on HydroLogics estimates. Daily precipitation measured at the reservoir and estimated daily inflows for Sugar Hollow Reservoir based on the watershed area weighted method applied to daily flow data for 2015 from the Moormans River gage are shown in Figure 21. Tables of daily gage data, watershed weighted inflows, and precipitation at the nearest WTP for 2015 are available in Appendix B for each Reservoir.

TABLE 11.

Estimated Annual Inflows to Sugar Hollow Reservoir 1980–2010

	Sugar Hollow	
	Watershed Area Weighted, MG per year	HydroLogics, MG per year
Average	5,339	7,173
Minimum	1,507	1,207
Maximum	9,088	16,742

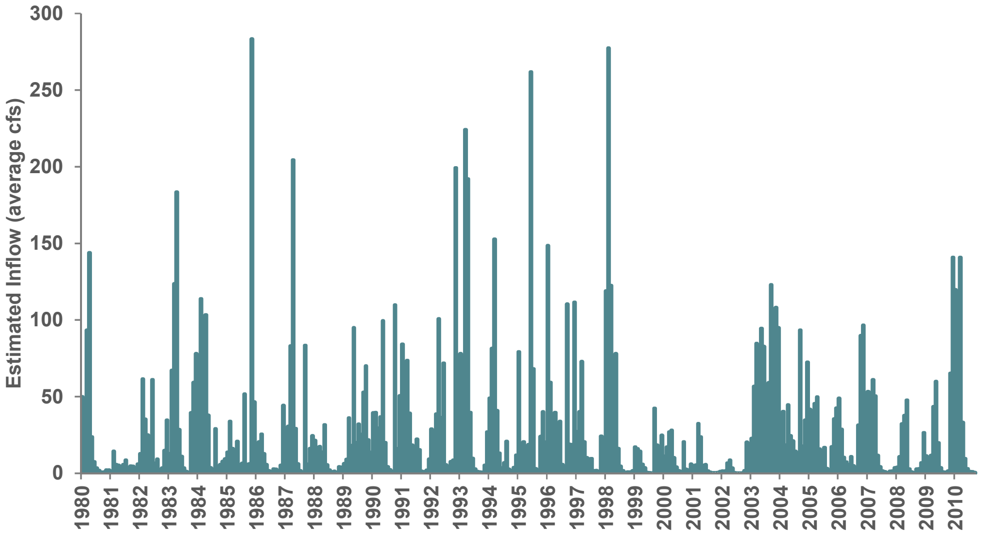


FIGURE
20.

Sugar Hollow Reservoir Estimated Monthly Inflows

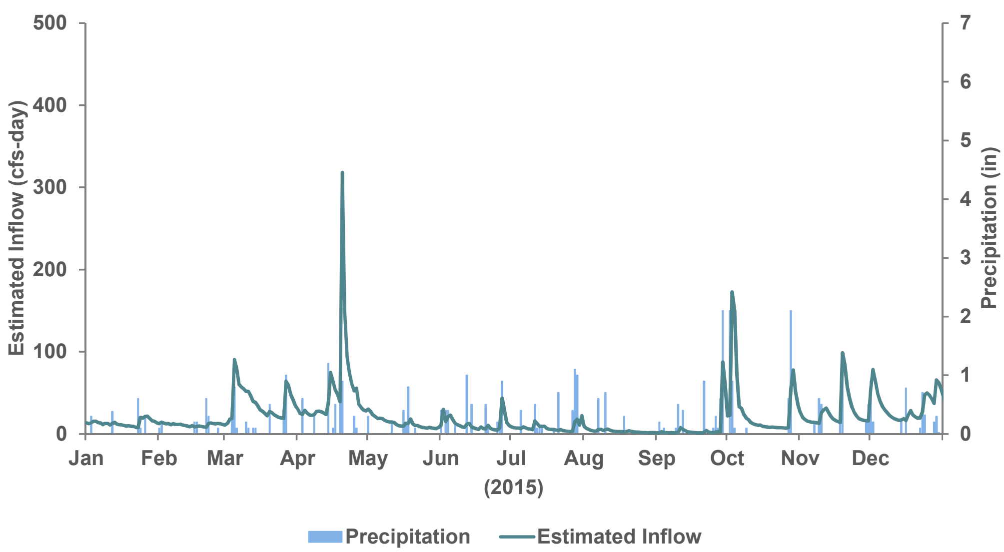


FIGURE
21.

2015 Estimated Daily Inflows and Recorded Precipitation for Sugar Hollow Reservoir, 2015

2.4.4 : South Fork Rivanna Reservoir

Estimated annual inflows for the South Fork Rivanna Reservoir, from 1980–2010, are shown Table 13. Average values obtained from the watershed area weighting method and HydroLogics model are 71,480 and 71,246 MG (219,364 and 218,647 AF) respectively, with minimums of 16,163 and 16,203 MG (49,602 and 49,726 AF) respectively. Maximum values from the two estimates yield similar results as well, with the watershed area weighting method producing an estimate of 128,852 MG (395,432 AF) and HydroLogics producing an estimate of 136,710 MG (419,247 AF).

Figure 22 shows the estimated historical inflows to South Fork Reservoir based on the watershed area weighting method. Daily precipitation measured at the South Fork Rivanna WTP and estimated daily inflows for South Fork Rivanna Reservoir based on the watershed area weighted method were applied to daily flow data for 2015 from both the Moormans River and Mechums River gages are shown in Figure 23. Note that not all of the high precipitation events recorded at the South Fork WTP are reflected in the estimated inflows to the reservoir. This is likely the result of a more localized precipitation event at the WTP that did not also occur in the watersheds above Mechums and Moorman's gages.

TABLE 12.

Average Annual Inflows to South Fork Rivanna Reservoir, Million Gallons, 1980–2010

	South Fork Rivanna Reservoir	
	Watershed Area Weighted	HydroLogics
Average	71,480	71,246
Minimum	16,163	16,203
Maximum	128,852	136,710

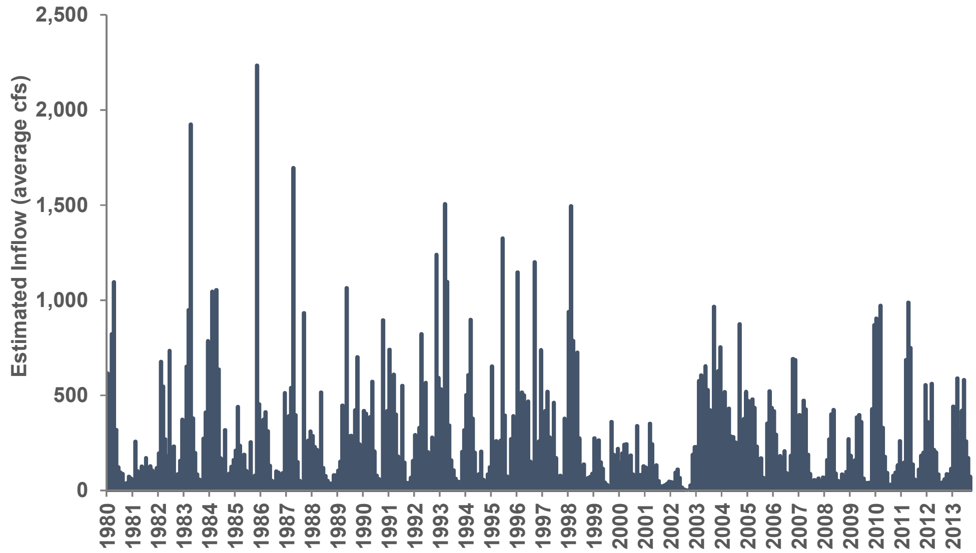


FIGURE 22.

South Fork Rivanna Reservoir Estimated Monthly Inflows

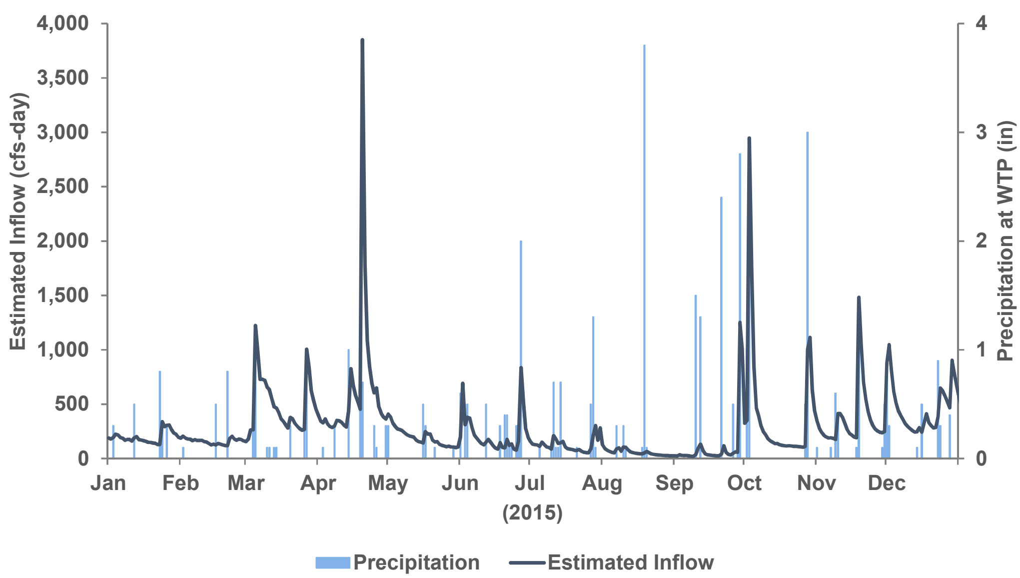


FIGURE 23.

2015 Estimated Daily Inflows and Recorded Precipitation for South Fork Rivanna Reservoir, 2015

2.4.5 : Ragged Mountain Reservoir

The project team did not analyze the hydrology for Ragged Mountain for this report due to its small natural watershed, the recent reservoir enlargement and the filling of the reservoir from the Sugar Hollow pipeline.

2.4.6 : Beaver Creek Reservoir

The estimated annual inflows to Beaver Creek Reservoir for 1980–2010, are shown in Table 13. Average values obtained from the watershed area weighting method and HydroLogics model are 2,493 and 2,491 MG (7,651 and 7,664 AF) respectively, with minimums of 593 and 585 MG (1,819 and 1,795 AF) respectively. Maximum values for each method are 4,724 MG (14,497 AF) for watershed area weighting and 4,678 MG (14,357 AF) for HydroLogics. Inflows estimated by both methods closely agree in average, minimum, and maximum.

Figure 24 shows the estimated historical inflows to Beaver Creek Reservoir based on the watershed area weighting method using discharge data from the Mechums River gage. Daily precipitation measured at the Crozet WTP and estimated daily inflows for Beaver Creek Reservoir based on the watershed area weighted method applied to daily flow data for 2015 from the Mechums River gage are shown in Figure 25. Note that not all of the high precipitation events recorded at the Crozet WTP are reflected in the estimated inflows to the reservoir. This is likely the result of a more localized precipitation event at the WTP that did not also occur in the watersheds above the Mechums gage.

TABLE 13.

Estimated Annual Inflows to Beaver Creek Reservoir, Acre-feet, 1980–2010

	Beaver Creek	
	Watershed Area Weighted	HydroLogics
Average	2,493	2,491
Minimum	593	585
Maximum	4,724	4,678

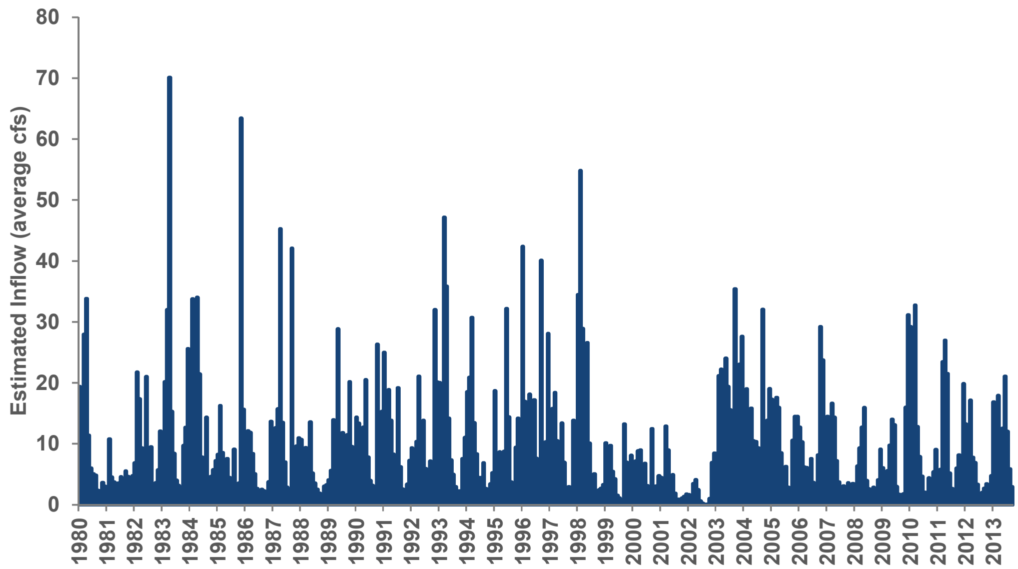


FIGURE 24.

Beaver Creek Reservoir Estimated Monthly Inflows

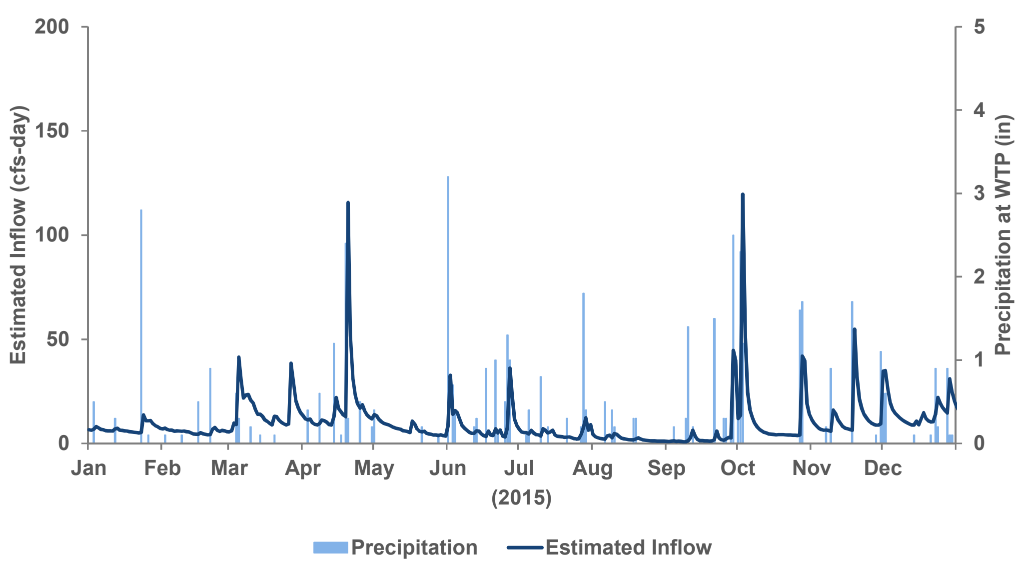


FIGURE 25.

2015 Estimated Daily Inflows and Recorded Precipitation for Beaver Creek Reservoir, 2015

2.4.7 : Totier Creek Reservoir

Estimated annual inflows, 1980–2010, for Totier Creek using the watershed area weighting method based on data from the Mechums River gage average 7,478 MG (22,949AF) with a minimum of 1,778 MG (5,456AF) and a maximum of 14,173 MG (43,495AF). Figure 26 shows the estimated historical inflows to Totier Creek Reservoir based on the watershed area weighting method and Figure 27 shows the estimated inflows for 2015. Note that not all of the high precipitation events recorded at the Scottsville WTP are reflected in the estimated inflows to the reservoir. This is likely the result of a more localized precipitation event at the WTP that did not also occur in the watersheds above the Mechums gage.

Flow in Totier Creek on 5 May, 2015

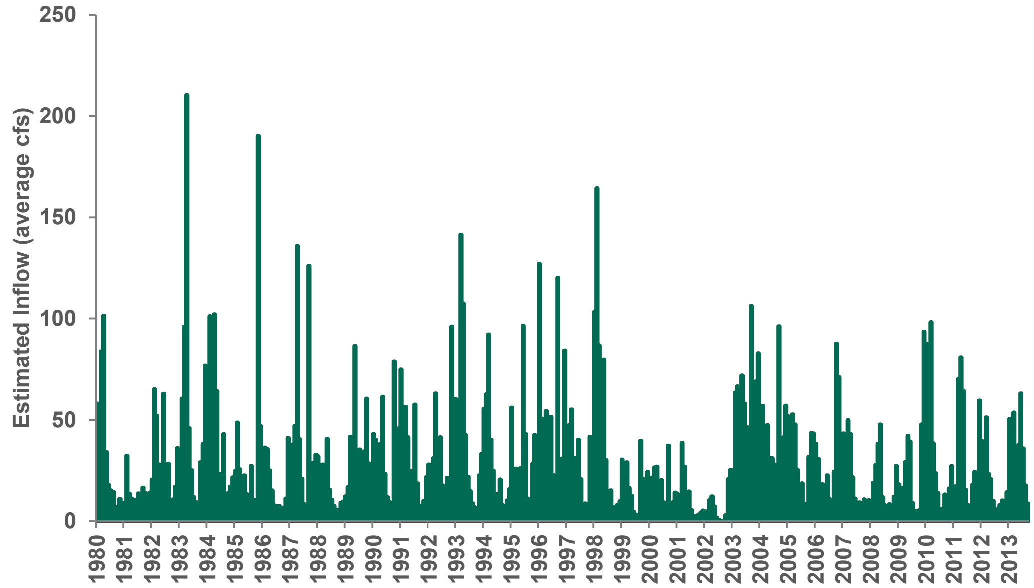


FIGURE 26.

Totier Creek Reservoir Estimated Monthly Inflows

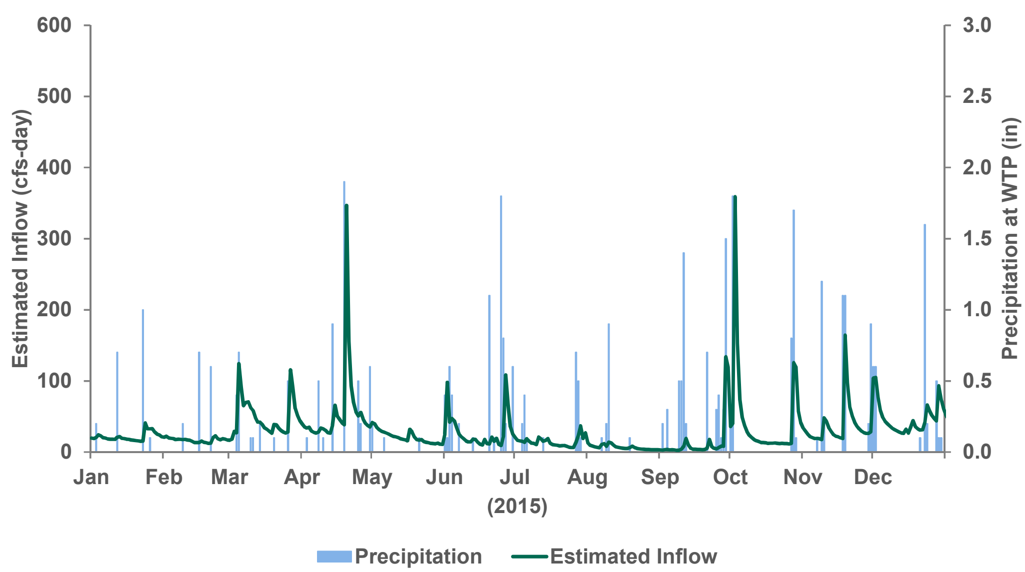


FIGURE 27.

Estimated Daily Inflows and Recorded Precipitation for Totier Creek Reservoir, 2015

2.5 : Water Treatment Plants

The following is a summary, based on our visits of two of the WTPs and discussions with plant operators, of historical water quality issues experienced at the Authority's WTPs that treat water from the five reservoirs. All of the Authority's WTPs have conventional treatment processes with coagulation, flocculation, sedimentation and filtration. The Authority is installing granular activated carbon (GAC) contactors at each WTP to address disinfection byproduct percursors. The GAC will also help remove T&O compounds, algal toxins, and various other contaminants.

2.5.1 : South Rivanna Water Treatment Plant

The South Rivanna WTP was constructed in the mid-1960s. This WTP has a total capacity of 12 mgd. sodium permanganate ($NaMnO_4$) is fed at the intake from South Fork Rivanna Reservoir, primarily for control of T&O, iron, and manganese in the water as a pretreatment process before the WTP. The operators' goal is to maintain a 0.5 mg/l permanganate residual coming into the plant.

Alum is the coagulant normally used at the WTP. Coagulation and floc formation are impacted by colder water temperatures in the winter months. Powdered activated carbon (PAC) is normally fed into the aeration basins at a rate of 5 to 10 mg/L and higher rates can be used as needed. The operators report no filter clogging problems. Most of the basins at the WTP are open and have leaves falling into the basins, primarily during the fall season, which can create operational concerns.

South Rivanna Water Treatment Plant, July 18, 2013

2.5.2 : Observatory Water Treatment Plant

The Observatory WTP was constructed in 1949 and some rehabilitation work was conducted in 1988. The WTP is permitted to treat 7.7 mgd, but is typically limited to 5 mgd due to operational constraints. The WTP treats water delivered from Ragged Mountain Reservoir. Treated water is delivered into the urban water system from this WTP. We did not visit this WTP, but the source water delivered to this WTP likely has the highest quality, since the source comes from Sugar Hollow as a pipeline flow into Ragged Mountain.

2.5.3 : Crozet Water Treatment Plant

The Crozet WTP was constructed in 1967 and treats water from Beaver Creek Reservoir. The WTP supplied water to the Morton Foods/Con Agra processing plant in Crozet until the processing plant was shut down approximately 15 years ago. The Crozet WTP, which has a capacity of 1 mgd, operates for approximately eight hours per day in the winter. During the hotter, drier summer period an operator shift is added two to three times a week for a run time of 16 hours per day. The operators report no filter clogging problems, despite the surface withdrawal from Beaver Creek Reservoir. The Crozet water system is separate from the urban water system and the only water supply is Beaver Creek Reservoir treated at the Crozet WTP.

Sodium permanganate is fed at the raw water pump station at Beaver Creek Reservoir for control of iron and manganese. There is approximately one mile of pipe from the pump station to the WTP. The feed rate is normally set at 1.0 mg/L and the operators' goal is to maintain a 0.5 permanganate residual coming into the plant. Maintaining this residual requires constant operator monitoring due to the changes in reservoir water quality.

The operators do not pre-chlorinate the water coming into the WTP. PAC, alum, lime and sodium hydroxide (NaOH) are used as treatment chemicals at different locations in the treatment train. PAC is fed at the rapid mix aeration basins, typically at a feed rate of approximately 5 mg/L.

Alum is the coagulant used. The Authority has tested ferric chloride as a coagulant, but it did not show any significant benefit over alum. Cold water in the winter results in less alum coagulation/floc formation.

If the pH of the raw water approaches 10, likely resulting from excessive algae blooms in the reservoir, alum usage increases.

2.5.4 : Scottsville Water Treatment Plant

Water delivered to the Scottsville WTP was originally via a diversion at a wooden dam in Totier Creek. The preferred water source continues to be water diverted from Totier Creek upstream of Totier Creek Reservoir. Algae, iron, and manganese levels are lower in the Creek than in the reservoir.

The Scottsville WTP has a capacity of 0.25 mgd. It is normally operated for six hours per day in the winter and eight hours per day in the summer. The plant uses PAC, alum and lime. PAC is fed at the rapid mix aeration basins, typically at a feed rate of approximately 5 mg/L.

Checking drinking water at South Rivanna

3 : Historical Water Quality

3.1 : Recent History of the Reservoirs and Drainage Basins Regulations

Some history of the drainage and water quality problems can assist in the characterization of the situation for South Fork Rivanna Reservoir (SFRR). Four of the five Rivanna reservoirs (Sugar Hollow, Beaver Creek, Ragged Mountain and SFRR) are contained within the larger South Rivanna River drainage though some are fed only by small sub-drainages within the larger drainage. The description below is partially taken from a summary of the South Fork Rivanna Reservoir and its watershed by Stephen P. Bowler, the Watershed Manager for the South Fork Rivanna Reservoir and Watershed. This 2003 report was prepared for the Rivanna Water and Sewer Authority, Albemarle County Service Authority, City of Charlottesville, VA and the County of Albemarle, VA. We have added a few additions and comments.

1962. Land for the site of the SFRR was purchased by City of Charlottesville.

1966. The reservoir was filled and water production began.

1960-80s. Algae problems for drinking water supplies from SFRR

1968. The first Albemarle Zoning Ordinance allows high density near SFRR.

1969. Four fish kills occurred in the reservoir, probably due to low dissolved oxygen at night.

1970. The reservoir was closed for two weeks after fish kill attributed to Endrin discharge at Crown Orchards. 1972 Rivanna Water and Sewer Authority (RWSA) formed. A fish kill in Lickinghole Creek was attributed to an ammonia spill at Morton Frozen Foods.

1972. Clean Water Act (1972 Federal Water Pollution Control Act - FWPCA) created the National Pollutant Discharge Elimination System, requiring reduction in discharge of common, point source pollutants.

1973. The RWSA formed an advisory committee on reservoir management.

1974. The City asked Albemarle to lower zoning density near SFRR. UVA says SFRR is "sick."

1975. The EPA concluded that "accelerated pollution" is occurring (in the SFR watershed) and suggested a point source interceptor. Albemarle adopted its first "Soil Erosion and Sedimentation Ordinance." State Water Control Board (SWCB) and Virginia Department of Health (VDH) urge protecting quality of SFRR. Temporary moratorium on intensive development. First reservoir study begins.

1977. The Albemarle Supervisors adopt "Runoff Control Ordinance" for water supply water.

1977. Clean Water Act amendments tightened restrictions on discharge of pollutants (particularly toxins).

1979. A Watershed Management Plan was developed by a County/City/regional committee.

1979. The position of Watershed Management Official created (now Watershed Manager).

1980. The Albemarle Supervisors finalized a comprehensive down-zoning of rural areas including SFRR Watershed. The down-zoning was appealed to Virginia Supreme Court. Albemarle eventually prevailed.

1982. Third SFRR study (funded by EPA) states that reservoir is still eutrophic and recommends regional sediment ponds, modification of "Runoff Control Ordinance", and further study.

1987. Water Quality Act of 1987. Primarily amended the 1972 Act to act on non-point (diffuse) sources of pollution including runoff from rural and urban areas.

1988. Crozet interceptor placed on-line removing Crozet's residential and commercial sewage from the SFRR Watershed.

1988. Nonpoint source pollution became the main target of watershed management and continued to be the thrust of both management and monitoring, particularly in light of the fact that sedimentation is almost exclusively a nonpoint source problem.

1991. Albemarle County became the first non-tidewater locality to adopt provisions of the Chesapeake Bay Preservation Act to protect stream buffers (Water Resource Protection Areas Ordinance).

1993. Lickinghole Basin, a regional stormwater basin serving Crozet, was completed.

1998. Albemarle County developed a new Water Protection Ordinance combining and improving previously developed erosion and sedimentation, stormwater, and stream buffer laws.

2002. RWSA adopted environmental policy. RWSA Board approves new water plan with continued use of SFRR as a central component.

2010. The State of Virginia banned phosphates in detergents.

3.2 : Water Quality

Discussions with Authority staff indicate that historical water quality management of the Authority's reservoirs tended to be reactive in nature to algae and T&O issues. In recent years, the Authority has taken a more proactive approach to addressing T&O. The Authority has a consultant, Solitude Lake Management, that responds to elevated algae counts with chemical lake treatments. When the algae count in an individual reservoir reaches a pre-defined level, treatment is initiated after a consultation between Solitude Lake Management and Authority staff. Solitude Lake Management then applies the treatment, usually copper sulfate. The Authority also uses a bi-weekly flavor profile panel for the early detection of T&O events.

At one point, Albemarle County employed a staff person dedicated to watershed/buffer zone awareness, but the position was eliminated from the County budget around 2010. The purpose of this position was to protect water quality by ensuring that new development maintained adequate buffers from surface streams. According to Authority staff, the information for buffer zone creation remains available, but there is no longer a dedicated County staff person to implement enforcement of the regulation.

The following is a summary of historical water quality derived from interviews with Authority staff and review of past water quality studies that we were provided. These summaries do not include water quality observations after 2014.

3.2.1 : Sugar Hollow Reservoir

There are limited water quality data available for Sugar Hollow Reservoir and the streams within the watershed. Historically, Sugar Hollow, as expected due to its relatively undeveloped watershed, had the highest quality water of any of Rivanna's reservoirs. Some algae blooms have been recorded in the past. The water has been described by Authority staff as turning pastel green at times, but is generally low in turbidity and alkalinity. The operators report that there have not been significant T&O issues in the past.

According to Authority staff, a major precipitation event in 1995 resulted in landslides within the immediate reservoir area and sediment and trees were washed into the reservoir. An estimated 17% of the reservoir capacity was lost due to landslide material brought into the reservoir.

3.2.2 : South Fork Rivanna Reservoir

There are limited water quality data available for South Fork Rivanna Reservoir and the streams within the watershed. South Fork Rivanna Reservoir consists of seven miles of flat water. According to Authority staff, the upper three miles of the reservoir is approximately three feet deep and silted in with grass and willows. This siltation has resulted in a loss of storage, a concern to the Authority. Dredging was previously evaluated, but the volume of dredging required to restore lost capacity was not financially feasible due to the high costs for dredging and disposal of the dredged material.

In the late 1970's a series of water quality studies were conducted on the reservoir (Betz, 1977, F.X. Browne, 1978, 1979, 1982 and 1983). According to Authority staff an aeration system was installed in the reservoir in the late 1970's or early 1980s. When the aeration system was operating, the pH was reportedly 6.8 to 7 year round. The dissolved oxygen (DO) levels near the intake of the reservoir were also reported to be good. The aeration system extended almost to the Earlysville Road Bridge, and used large air compressors with 2-inch outlet lines. There were about 12 to 14 aeration lines overall. The aeration system ceased operating in the 1980's due to concerns over high operations and maintenance costs. Fishermen reportedly noted better fishing when the aeration system was operational. Authority staff were unable to locate any of the design documents or data on operations of the aeration system.

About 10 years ago, Hydrilla, an invasive aquatic plant, became a problem in the reservoir, and then increased in intensity. The University of Virginia rowing team, which uses the lower portion of the reservoir near the dam for practice, and anglers using the reservoir complained about the Hydrilla interfering with their activities. In response, the Authority stocked the reservoir with grass carp, which alleviated the problem. According to Authority staff, the grass carp also diminished some of the other algae problems in the reservoir.

South Fork Rivanna Reservoir was not chemically treated between 2012–2014. In recent years, the reservoir experienced algae blooms, but not as severe as 10 years ago.

The operators report that the overflow is lost for a period in approximately four out of five years, likely the result of WTP withdrawals and evaporation and seepage exceeding the inflows during those periods. When the reservoir loses the overflow, meaning that there is no flow over the spillway and therefore it begins drawing on storage, the WTP operators observe immediate algae problems. The primary concerns with the algae have to do with T&O. According to Authority staff, only once, in 2002, did algae create a significant problem, resulting in excessive amounts of algae and slime going through the pipeline to the WTP. High iron and manganese levels in the raw water also posed a problem. The reservoir level dropped, and as a result, the operators needed to use the 15-foot level intake. The operators also investigated using floating pumps to pump water into the intake.

The WTP operators normally withdraw water from the reservoir at the 10-foot depth. The WTP operators are evaluating drawing from the 5-foot outlet as an experiment, but if algae become a problem, they would switch back to the 10 foot depth. The operators note that warmer water is better for treatment as it allows for better coagulation, however colder water tends to taste better to customers.

Historically the Authority used copper sulfate as the primary in-lake chemical treatment method. The reservoir was treated several times with PAK-27 several years ago, but the treatment applications were too late to prevent algae blooms.

2014 was particularly bad for reservoir water quality, which may have been due to rains and longer than usual warm spells.

3.2.3 : Ragged Mountain Reservoir

There are limited historical water quality data available for the reservoir and the stream within the watershed. With the recent reservoir enlargement, we anticipate water quality to differ from historical and the Authority commenced ongoing monitoring, which will allow for the development of a historical tend.

3.2.4 : Beaver Creek Reservoir

There are limited historical water quality data available for Beaver Creek Reservoir and the streams within the watershed. The WTP operators report that the reservoir has the largest algae blooms out of all the Authority's reservoirs. It is also the only reservoir that can supply water to the Crozet WTP. The Authority historically has the reservoir chemically treated when the pH spikes. The operators temporarily shut down the WTP directly after a treatment to keep the treatment chemicals in the reservoir from entering the WTP. Authority staff, in conjunction with Solitude Lake Management, set a blue green algae threshold of 5,000 cells/ml for triggering reservoir treatment. Beaver Creek Reservoir has reportedly experienced algae counts of 100,000 to 1,000,000 cells/ml in extreme algae blooms.

Beaver Creek Reservoir has periods of high pH and at times, according to the WTP operators, the reservoir is green in color. In the past, Authority staff believe they may have waited too long to treat the reservoir. They also expressed concerns over potential fish kills after treatment. Algae blooms were historically treated with blocks of copper sulfate. The highest amounts of copper ever used occurred in 2014, though it was copper as liquid SeClear. There are concerns that the algae may be becoming resistant to copper. The buildup of copper in the reservoir sediments was evaluated as part of a series of special studies and is discussed in Appendix L.

One alternative which has been employed in an attempt to improve water quality entering the water treatment plant is to pull water from different intake levels. At Beaver Creek, the use of one of the lower intakes, rather than the surface overflow, did not help water quality in 2014. Due to the intake structure, even when pulling water from a lower intake, water still typically flows into the surface intake at the same time. As a result, any leaves or other debris on the surface of the reservoir are drawn into the overflow. These leaves get stuck in the wet wells of the WTP, which presents a problem. The intake structure itself, makes use of the overflow problematic.

Diversions to the Crozet WTP are primarily via the intake tower surface overflow. When the overflow is lost, the 10 ft. outlet is normally used. Raw water is pumped to the WTP and there are screens at the pumps.

3.2.5 : Totier Creek Reservoir

No historical water quality data were located for Totier Creek Reservoir and Totier Creek within the watershed. The Reservoir was constructed to provide an additional water source to the Scottsville WTP when Totier Creek does not have flow sufficient to meet demand. The intake is located away from the spillway and it may be more stagnant. The reservoir is usually brown and turbid.

Canoes at Totier Creek Reservoir April 15, 2015

4 : Monitoring Program

Kelly DiNatale and Alex Horne conducted the on-site project kick off April 14–17, 2015. This included initial meetings with Andrea Terry, Water Resources Manager, and Stuart Wilson, Laboratory Director (retired in summer 2017), to discuss potential sample locations and lab capabilities for analysis of samples. Site visits and sampling were conducted, staff were trained on proper sampling techniques and use of equipment as part of the sampling, and several WTP operators and lab staff were interviewed. A workshop was held on April 17 with Authority management staff to discuss the development of the sampling program, initial observations and project schedule.

4.1 : Sampling Locations

Working with Authority staff, the project team identified initial sampling locations using aerial photos. The goals were to collect for each reservoir, one sample near the outlet structure, referenced as location No. 1, that would be representative of the water at the deepest part of the reservoir and withdrawn to the WTP. A second mid-reservoir location, referenced as location No. 2, was selected to be representative of water in the main body of the reservoir. A third sample location, referenced as location No. 3 was identified as a grab of the inflow to the reservoir from one tributary. These sampling locations, listed in Table 14, were refined during the site visits, after identification of access issues for location No. 3 samples. Andrea Terry, Water Resources Manager visited and participated in the sampling of each reservoir. Water Plant Supervisor Konrad Zeller visited and participated in the sampling of all but South Fork Rivanna Reservoir. Sample locations below are abbreviated to two letters (SH- Sugar Hollow, SR- South Fork Rivanna, RM- Ragged Mountain, BC- Beaver Creek, TC- Totier Creek) followed by the corresponding number as outlined in Table 14.

TABLE 14.

General sample locations

Sample Number	Location within Reservoir	Location within water column
1	Reservoir near dam. Intended to represent water quality near the intake to the WTP	S = just below the surface grab sample B = just off the bottom collected with Kemmerer sampler
2	Reservoir near midpoint. Intended to represent water quality in the main body of the reservoir, away from the dam	S = just below the surface grab sample B = just off the bottom collected with Kemmerer sampler
3	Inflow of one tributary into reservoir	just below the surface grab sample

4.2 : Sampling Methods

Monitoring for each reservoir consisted of samples taken for lab analyses to measure chlorophyll *a*, nutrients, and algae counts performed by the Authority. Lab analyses were performed on water sampled from both surface and bottom depths. Field sampling of temperature, dissolved oxygen, turbidity, and other parameters was conducted using in-lake sonde profiles. Secchi depth measurements were also taken. Sugar Hollow Reservoir was sampled via canoe due to the lack of a boat ramp. For South Fork Rivanna Reservoir, a flat-bottomed sampling boat was used. In summer 2017, the Authority purchased a pontoon boat, which is now used for sampling all of the reservoirs except Sugar Hollow. For Ragged Mountain, Totier Creek, and Beaver Creek Reservoirs, both a canoe and flat-bottomed boat were used. Surface samples were obtained by scooping water from just below the surface and bottom samples were obtained using a Kemmerer sampler. For bottom samples, the Kemmerer sampler was dropped until it hit bottom, the sampler was then raised one foot and sediment was flushed by raising and lowering the sampler small distances. After flushing sediment, the messenger was dropped to seal the sampler and the sampler was raised. All samples were placed into pre-labeled bottles and placed in an ice chest until delivered to the water quality laboratory.

Putting water from Kemmerer sampler into pre-labeled bottle

In-reservoir surface and bottom samples and inflows were analyzed for total phosphorous (TP), orthophosphate (OPO_4), total Kjeldahl nitrogen (TKN), nitrate-N (also referenced as nitrate, NO_3 or NO_3-N), ammonia (also referenced as NH_3+NH_4, NH_3, or NH_4), and total suspended solids. All data for lab analyses are available in Appendix B. Chlorophyll *a* was analyzed for the in-reservoir surface water samples only. Samples for algae count and identification were taken at the surface and at 5 ft and 10 ft below the surface. Beginning in 2016, these samples were taken as an integrated sample from the surface to the approximate bottom of the photic zone. Sample bottles were prepared and samples preserved and handled in accordance with the procedures described in the Authority's Laboratory Quality Assurance Manual, Version 4.0 (RWSA, 2015).

In-lake sonde profiles were performed using a YSI EXO2 sonde which recorded temperature, dissolved oxygen (DO), chlorophyll *a*, blue-green algae phycocyanin (BGA-PC), conductivity, total dissolved solids, salinity, pressure, pH, redox potential, turbidity, and total suspended solids. The sonde continuously recorded these parameters as it descended and subsequently ascended through the water column. While lowering the sonde, the Authority sometimes struck the ground surface at the bottom of the reservoirs. The fine sediment at the bottom of the reservoirs has the potential to cause error in the measurements taken during the sonde's ascent. In order to remove the potential effects from striking bottom, only measurements taken during the sonde's descent were used for analysis. Chlorophyll *a* and BGA-PC sensors were uncalibrated, however, the sensors still provided useful information on relative changes within each reservoir.

Secchi depth measurements were performed in each reservoir by lowering a Secchi disk on the shady side of the boat with the observer wearing no sunglasses for consistency. The disk was lowered until no longer visible by the observer and the depth was recorded.

Recording sonde profile at South Fork Rivanna Reservoir

4.3 : Analysis

Chlorophyll a, total phosphorous (TP), orthophosphate (OPO_4), total Kjeldahl nitrogen (TKN), nitrate/nitrite (NO_x), ammonia (NH_3NH_{4+}), and total suspended solids were analyzed by the Authority's laboratory. The laboratory procedures and quality assurance/ quality control protocol are listed in the Authority's Laboratory Quality Assurance Manual, Version 4.0 (RWSA, 2015). Algae counts and identification were performed by Stuart Wilson, Laboratory Director, until his retirement in 2017. Since Mr. Wilson's retirement, algae counts and identification are performed by SePro. The standard operating procedure for algae counts and identifications performed by Mr. Wilson are described in Appendix C.

TABLE 15.

Laboratory Analytical Methods

Parameter	Method	Report limit -Detection limit (UNITS)	Description
Chlorophyll a	SM 10200H	5.0 (µg/L) RL	Extraction/ Spectrophotometric
TKN	SM 4500 NH_3 C	200 µg/L-80 µg/L	Digestion/distillation/ titrimetric
Nitrate	SM 4500 NO_3- D	100 µg/L	Ion selective electrode
Ammonia	SM 4500 NH_3 D	125 µg/L-50 µg/L	Ion selective electrode
Total Phosphorus	EPA 365.3	50 µg/L-20 µg/L	Digestion/ spectrophotometric
Orthophosphorus	EPA 365.3	50 µg/L-20 µg/L	Spectrophotometric
Suspended Solids	SM 2540 D	1.0 mg/L	Gravimetric

Authority laboratory director analyzing water samples under a microscope

4.4 : Monitoring Schedule

The initial recommendation for the 2015 sampling season was to attempt to collect two samples per month per reservoir for April through October, with determination of the need for winter sampling at the end of the 2015 season. Due to staff constraints, equipment failures and other Authority priorities, all of the reservoirs were not able to be consistently sampled during 2015. After review of data collected in 2015, sampling schedules were adjusted based on Authority staffing constraints and priorities, with some reservoirs being sampled more frequently than others. Updated recommendations on the future monitoring schedule are presented in Section 10.

4.5 : Monitoring program Value

In 2015, the monitoring program performed analyses of ammonia, nitrate, total Kjeldahl nitrogen, ortho-phosphate, total phosphorous, and total suspended solids on 234 samples. Also performed were algae identification and counts on 174 samples and chlorophyll *a* measurements on 101 samples. All of these analyses, with the exception of chlorophyll *a*, were performed by the Authority's water quality laboratory staff. Two labs that have been used by the authority for these analyses were contacted for quotes and the average cost per parameter is shown in Table 16. The total cost of these analyses, if performed by an outside lab, not including Authority staff labor or shipping costs, was approximately $83,940. Accounting for cost of labor and shipping brings the value of the in-house sampling program and analyses to approximately $185,000.

TABLE 16.

Potential Sampling Laboratory Costs for 2015

Parameter	Cost/Sample	Samples Analyzed	Extended Cost
Ammonia	$ 35	234	$ 8,190
PO_4	$ 35	234	$ 8,190
TP	$ 25	234	$ 5,850
SS	$ 25	234	$ 5,850
Nitrate	$ 50	234	$ 11,700
TKN	$ 40	234	$ 9,360
Algae Count	$ 200	174	$ 34,800
Total	**$ 410**		**$ 83,940**

5 : Water Quality Monitoring Results

This section includes summaries and discussion of the data collected for each reservoir from April 2015 through December 2017 under the monitoring program discussed in Section 4. Appendix B contains all data for each of the following parameters at each monitoring site: Ammonia (NH3+NH4), Nitrate, TKN, TIN, TN, Chl *a*, TP, PO_4, TSS, and Secchi depth. Outliers that were removed from interpretations in this section are shown in Appendix B enclosed in parentheses and marked with an asterisk. At times, the reported concentration of PO_4 exceeds that of TP, this is often due to inherent analytical error, and is more likely to occur for samples near the detection limit of 20 µg/L. However, any time that the reported PO_4 concentrations was greater than or equal to three times the reported TP concentration, both values were removed due to the likely analytical error. Appendix F contains all algae count and ID data from each monitoring site. All aerial imagery below is from: ESRI, i-cubed, USDA FSA, USGS, AEX, GeoEye, Getmapping, Aerogrid, IGP.

For locations with enough sonde data, we created time-series image maps of temperature, dissolved oxygen, chlorophyll *a,* and phycocyanin using Surfer® 15 from Golden Software, shown in Appendix G. This software produces a grid of interpolated values to fill in areas between measurements. A grid spacing of 0.1 m was used for the y-axis (depth from full) and a spacing of 1 day was used for the x-axis (date). The interpolation method used was triangulation with linear interpolation due to the relatively even distribution of data. Triangulation with linear interpolation is an exact interpolator and, as such, the original data are closely honored. This method works by drawing lines between data points to create triangles in such a way that no edges are intersected by other triangles. Each triangle has a defined tilt and the elevations of the three original points are known allowing grid nodes to be interpolated linearly based on these triangles (Golden Software). Black areas on the top of these images represent the reservoir fill level, while black areas on the bottom represent depths with no data, which are likely the result of the sample boat or sonde drifting and/or a lack of anchored sample location buoys.

For sampling occurring from September–November 2017 the phycocyanin probe often indicated extremely high concentrations of phycocyanin throughout the water column in all reservoirs while the chlorophyll *a* sensor indicated relatively low concentrations. While the data from the phycocyanin probe can be compared relatively during the days where this anomaly occurred, we believe that the calibration may have shifted, and this data should not be compared to data outside of the period from September–November 2017.

5.1 : Sugar Hollow Reservoir

Authority staff sampled Sugar Hollow Reservoir (SHR) at three locations as shown in Figure 28. All three sites were sampled in 2015 but starting in 2016 sampling was typically only conducted at site SH1, with one additional sample taken at site SH3 in 2017.

5.1.1 : Temperature and Thermal Stratification

A weak thermal stratification formed in the reservoir by April 2015 with surface temperatures about 16°C and bottom (new hypolimnion temperatures) of about 7°C. The epilimnion steadily warmed to the upper 20°s by mid-August while the bottom waters remained cooler (10–20°C) despite the rapidly shrinking reservoir volume due to releases for the filling of the enlarged Ragged Mountain Reservoir. Due to thermal lag, the maximum temperatures in lakes and reservoirs in the region is usually mid-August. The thermocline briefly touched the bottom in mid-September 2015, but there was still a considerable temperature difference between the bottom (~ 15°C)

FIGURE 28.

Sampling Locations for Sugar Hollow Reservoir.

and the surface (~ 25°C), so while some mixing may occur, it would be slow. Though less sonde data were available for 2016 and 2017, the reservoir showed similar stratification patterns as those observed in 2015, with stratification developing in the early summer and lasting to the early fall.

5.1.2 : Dissolved Oxygen

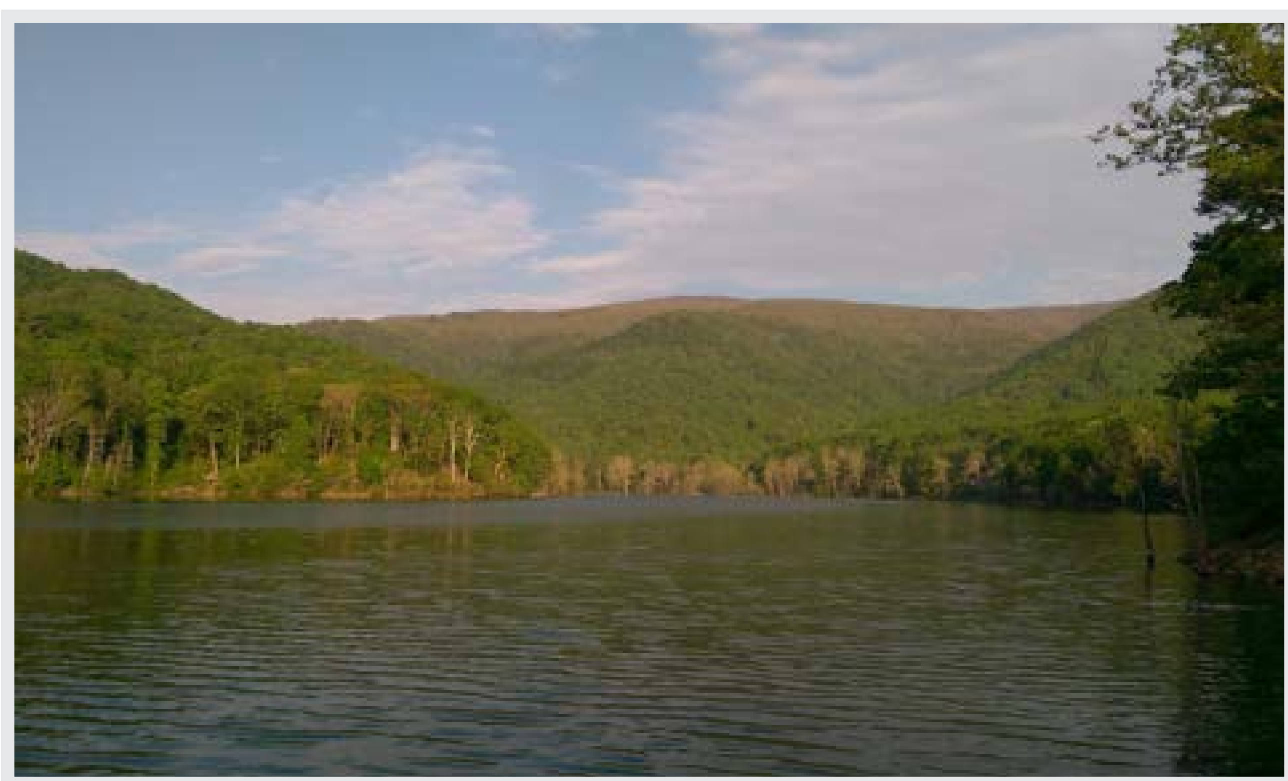
The DO profiles followed the inverse of the temperature profiles with DO dropping in April or May and the hypolimnion becoming functionally anoxic (< 2 mg/L) by July. Anoxia lasted until early fall when overturn occurred and DO rose in the entire water column.

5.1.3 : Nutrients

5.1.3.1 PHOSPHORUS

Despite the high chl *a* levels during August 2015 and the *Anabaena* bloom in July 2015, P was not as high as expected. Sampling occurred on only three dates in 2015 but did cover most of the growth season. Surface TP, a combination of bioavailable-P, algae, and detritus averaged 35 µg/L, not far above the mesotrophic range (< 30 µg/L) somewhat contradicting the other indicators (chl *a*, algae blooms) that suggest a eutrophic state. However, high values of TP of 54 and 67 µg/L at the surface on one of the three sampling

Sugar Hollow Reservoir, Summer 2015



dates indicates eutrophication. The average surface TP values at SH1 for 2016 and 2017 were 28 μg/L and 30 μg/L respectively, right around the eutrophic/mesotrophic border.

The surface soluble orthophosphate concentrations (PO_4), which are the most bioavailable, were higher than expected (range of 1–55 μg/L; means of 11–28 μg/L,). A more suitable concentration for a drinking water reservoir would be 5–10 μg/L. The concentrations of PO_4 at the surface indicate that P was in excess but also that there was a potential for further algae growth. The use of algaecides may release some P in various forms if the algae cells are lysed, rather than sinking as intact but dead cells, which could result in skewed data. The algaecide treatment in 2015 and resulting release of P suggest that caution should be exercised when evaluating the surface P data.

Bottom water TP was quite high (6–118 μg/L, means 30–59 μg/L) for all years. Soluble PO_4 was present at moderate levels (6–23 μg/L) in 2015 and at higher levels in 2016 (1–142 μg/L) and 2017 (14–108 μg/L). Despite the anoxia in Sugar Hollow Reservoir in 2015, bottom water PO_4 averaged 20 μg/L or less at the two sample locations. However, higher values were recorded in 2016 and 2017 with concentrations at SH1 of 142 μg/L on August 17, 2016, 108 μg/L on April 26, 2017 and 64 μg/L on September 26, 2017.

Most importantly, four measurements from the inflowing North Fork Moormans River showed mostly soluble PO_4 (mean 26 μg/L) but most of these values were near or below the method detection limit and thus not as reliable as samples with higher concentrations. The actual concentrations may have been lower. Regardless of the analytical concern, the main point is that inflowing P was lower than that in the bottom water. Thus, the main P-source of the *Anabaena* bloom that occurred in late summer 2015 was likely internal loading from the sediments, not inflow. This would be expected from the generally undisturbed nature of the drainage basin and focuses potential management on internal loading.

5.1.3.2 NITROGEN

Surface water ammonia concentrations in SHR (75–451 μg/L) were high enough to support algae blooms. The common pattern of a gradual increase in inorganic nitrogen in the drainages of all the Authority's reservoirs occurred even with Sugar Hollow watershed's undeveloped national forest. Ammonia increased 2 to 3-fold from the spring through the summer growing season in the reservoir, which is less than the increase observed in other Authority reservoirs.

Bottom water ammonia concentrations in 2015 (99–398 μg/L) were similar to surface values despite the anoxic conditions that occurred in mid-summer that might have been expected to elevate ammonia. However, the considerable lowering of the water level and early destratification also played a role in keeping ammonia at relatively low levels for anoxic zones of the reservoir in 2015. Bottom water ammonia values in 2016 (185–675 μg/L) and

2017 (95–425 µg/L) were typically higher than found in the surface waters, indicating some degree of internal loading under anoxic conditions.

Inflowing ammonia was, in contrast, not high, averaging 149 µg/L (based on four samples in all years combined) in North Fork Moormans River (SH3), again as might be expected from the undeveloped nature of the watershed and the well-aerated stream.

The surface water nitrate concentrations in SHR were lower than some other Rivanna reservoirs (surface mean 366 µg/L for all years), presumably due to the undisturbed drainage. However, there was still an adequate supply of nitrate in surface water for considerable algal growth. Bottom water nitrate showed similar concentrations indicating that the anoxia that lasted most of the summer was not severe enough to induce much ammonification or denitrification. The common pattern in the Rivanna reservoirs drainages of a gradual increase in inorganic nitrogen occurred, even with drainage from the undeveloped Shenandoah National Park, with nitrate in the reservoir and inflow increasing by the autumn.

Nitrate flowing in from the North Fork Moormans River (sample point SH3) was comparable to in-reservoir levels at 399 µg/L (range 141–586 µg/L, all years combined) and at lower concentrations than most of the measured inflows in the other Authority watersheds. For comparison, rainfall in the region could be expected to have nitrate concentrations ranging from < 50 to

Inflow to Sugar Hollow Reservoir, April 15, 2015

250 µg/L nitrate, so little nitrate appears to be eluting from the drainage into SHR.

The average seasonal bioavailable-TIN (nitrate + ammonia) was 472 µg/L in-reservoir at site SH1 — ample for algae growth. However, for the early part of the season in 2015, TIN was 183 µg/L meaning a somewhat lower actual available concentration could sometimes be limiting for the spring diatom bloom.

For SHR, winter and spring inflow, internal loading sources, or nitrogen-fixation by *Anabaena* were responsible for fueling the nitrogen needs of the algae blooms in July 2015.

5.1.4 : Phytoplankton: Algal Chlorophyll & Water Clarity

In August 2015, the period just prior to complete anoxia, surface water chlorophyll reached 17 µg/L at site SH1 and 44 µg/L at site SH2, indicating a major bloom. Surface water chlorophyll reached 10 µg/L at site SH1 in August of 2016 and reached 11 µg/L in October 2017. The chlorophyll concentrations observed in 2016 and 2017, though lower than those in 2015, do indicate eutrophication.

Sugar Hollow Reservoir looking from upper end toward dam on September 21, 2015, near lowest elevation for the year

Chlorophyll in Sugar Hollow Reservoir was not uniform over its surface, at least during some blooms. The upper station (SH2) was much richer in surface algae. This heterogeneity is characteristic of blue-green algal blooms but not expected in such a small reservoir. The site is possibly sheltered from some winds, which allow an accumulation.

A Secchi disc value from October 2015 indicates eutrophic conditions (0.80 m). Both Horne (1995) and Cooke and Welch (2007) indicate that Secchi values less than 2.0 m indicate eutrophic conditions. However, in 2016 and 2017, seven Secchi measurements were taken and showed an average Secchi depth of 3.19 m (range, 1.85–5.80 m).

5.1.5 : Phytoplankton: Algal Species

A change in the laboratory performing the algae enumeration and identification in June 2017 likely resulted in changes in some of the identified genera at all Authority reservoirs. The severe algae bloom in early July 2015 was due to the colonial blue-green algae, *Anabaena*. Between 22,000 and 24,000 cells/mL were present in the surface waters on July 7 and 14 and were reduced to 10% of that number in one week following treatment on July 16 with Phycomycin, a sodium carbonate peroxyhydrate-based algaecide and less than 1% by early August. As expected, the *Anabaena*, which usually forms pea-sized colonies that are very buoyant was confined to the upper 2 m with concentrations at 3 m being only 7–14% of the surface values on July 7 and 14. *Anabaena* was absent in the deeper stations below about 4 m. *Anabaena* did not recur again in 2015 despite the shallow anoxic reservoir conditions in September. Smaller blooms of *Anabaena* were observed in 2016 in 15 ft integrated samples taken at site SH1, with about 4,300 cells/mL present in the sample taken on August 17, rising to about 6,300 on August 23 and then declining to about 1,600 on October 21. On September 26, 2017 the integrated sample taken at site SH1 showed total blue-green algae present at about 18,000 cells/mL, predominately *Coelosphaerium* and *Anabaena*.

A small bloom of the colonial cryophyte or golden algae *Dinobryon* (~ 1,300 cells/mL) and *Synura* (~1,200 cells/mL) occurred in mid-September 2015 when the reservoir both deepened, following heavy rains, and contained more oxygen. Both of these genera can cause some water quality problems in the treatment plants (fishy odor & fish gill toxins– *Dinobryon*; cucumber odor -*Synura*) but since they would travel down the Moormans River to South Fork Rivanna River or via pipe to Ragged Mountain they would be unlikely to cause problems directly. As an inoculum, they could cause problems in Ragged Mountain if conditions were favorable to their growth.

5.1.6 : Conclusions for the July 2015 *Anabaena* bloom

The drainage of SHR is 97% forest covered with no other obvious source of nutrient pollution. As expected, the TP, PO_4, nitrate, and ammonia concentrations were at the low end of the spectrum for the Authority's reservoirs. However, higher values of nitrate in the autumn will promote blooms next growing season while the lower P-inflows should assist in keeping the reservoir potentially mesotrophic. In 2015, based on the limited sampling data, the reservoir was eutrophic suggesting the trophic state was fueled by internal nutrient loading. The original source of the nutrients is likely to have been occasional external pulses in the past, now stored as legacy nutrients in the sediments.

Some nutrients, especially nitrates, are released during logging and these nutrients enter the reservoir and can be stored in the reservoir sediments as organic-N or ammonia. These nutrients can then be released later during anoxic periods. Severe erosion during exceptional rains has been reported by Authority staff and a large amount of soil, which would contain phosphorus, was released into the reservoir during landslides in 1995. However, the concentration of P in forest soils is not usually very high.

SHR is quite small and, despite a deep section by the dam (up to 17 m) it was only 10m deep at maximum by July 2015 (*Anabaena* bloom time) due to releases mostly from the 9.7 m (32 ft) deep lower outlet. In early July, the water column was strongly stratified which is favorable to *Anabaena* and background levels of nutrients were adequate. The stratification is natural, and the nutrients cannot be from internal cycling at this time. Winter carryover of nutrients is a likely source of the July bloom along with some nutrients stirred up by waves on the shoreline as the reservoir was drained or from the bottom as the water destratified the previous winter.

Anabaena is a difficult alga to predict relative to some other common blue-green algae and sometimes appears to bloom randomly once the water is stratified. This seems to be the case for Sugar Hollow Reservoir in 2015. A similar unpredictable situation occurred in Upper San Leandro Reservoir (USL), owned by the East Bay Municipal Utility District in Oakland, CA, with blooms of small-celled *Anabaena* occurring in late spring and producing problem levels of geosmin. The USL reservoir also had summer *Aphanizomenon* and *Microcystis* blooms in summer and fall. For the later blooms, a hypolimnetic oxygenation system (HOS) was recommended and installed using oxygen bubbles in this case since the water is quite deep (> 35 m). However, the only effect of HOS on the spring *Anabaena* bloom would be via a lower carryover of nutrients after the winter. This strategy would not have an immediate effect, but instead would mitigate the internal loading of nutrients over the long term, eventually reducing nutrient levels available to algae. Since internal loading is so dominant, HOS would seem an ideal first management action for Sugar Hollow Reservoir if the problems that occurred in 2015 persist in the future.

A second strategy was devised using air-destratification for *Anabaena* in USL. The USL reservoir is a long narrow water body in a canyon and is very sheltered from winds. In the coastal California climate, USL mixes only from December through part of February. The concept was that extending mixing through May would favor diatoms and other algae over small-celled *Anabaena*. This concept was successful and there have been no problem geosmin outbreaks for the last 20 years. Since SHR will not be a long-term direct water supply for the Authority, the implementation of management methods is a low priority and not recommended unless the reservoir experiences recurring water quality issues.

Phycomycin treatment being applied at Sugar Hollow Reservoir, July 16, 2015

5.2 : South Fork Rivanna Reservoir

South Fork Rivanna Reservoir (SFRR) was sampled at three locations in 2015 (SR1-SR3), and at one additional location (SR4) in 2016 and 2017. Each sampling location is shown in Figure 29.

5.2.1 : Temperature and Thermal Stratification

The thermal stratification patterns in SFRR were similar from 2015–2017. Stratification was typically first apparent around mid-May at the main index station near the dam (SR1) where the water was about 11 m deep. In the upper station (SR2), where the water was 6–7 m deep, stratification began about the same time but at a slightly shallower depth as shown in Figure 30. The stratification became strong a month after onset ($\Delta > 10°C$; 29°C at the surface vs 12°C near the bottom) with the thermocline descending to about 6 m so the epilimnion encompassed most of the reservoir volume. The stratification effectively cut off the deeper, nutrient-rich hypolimnion water from the surface water. Algae growth in the spring soon depleted one or more essential nutrients in the epilimnion. However, stratification was not long-lived. By early August, the thermocline had descended to the bottom breaking down all "classical" reservoir stratification. The cooler hypolimnion water pool had vanished, and, since there is no bottom water outlet, was most likely

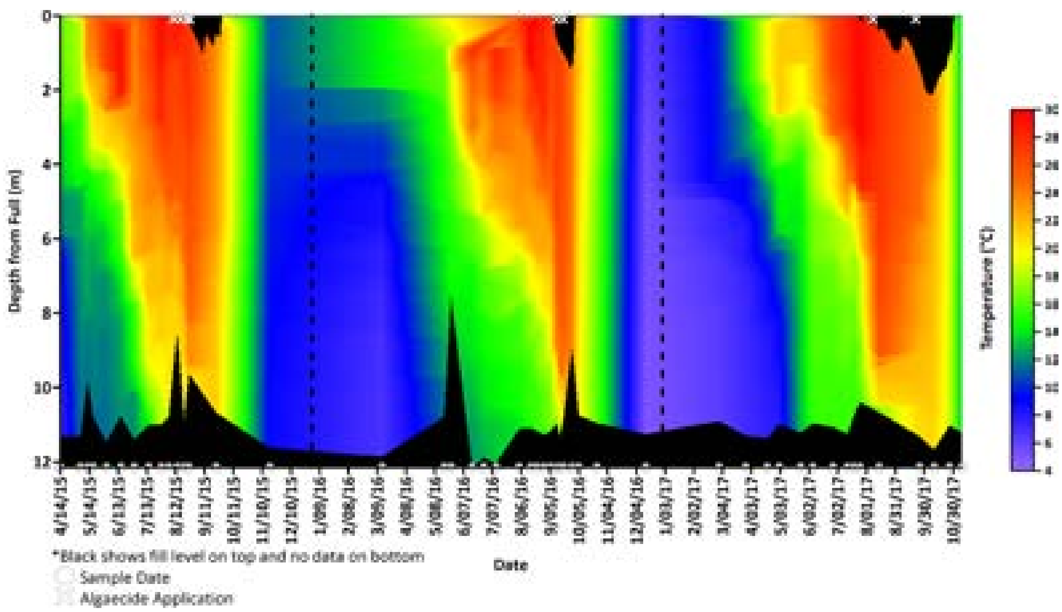
FIGURE 29.

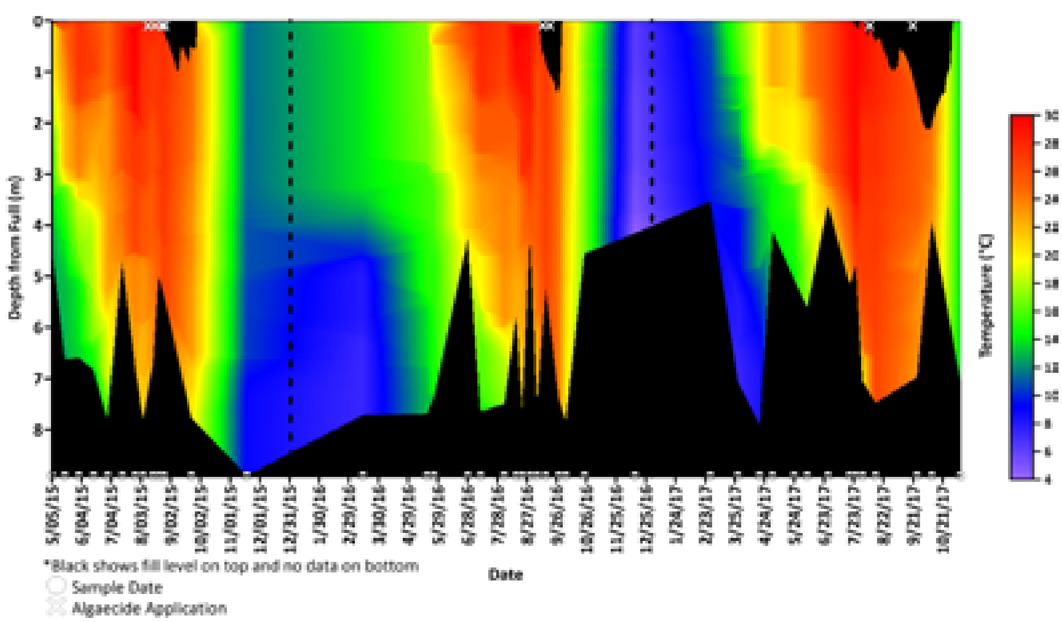
Sampling Locations for South Fork Rivanna Reservoir incorporated into the upper water with the resulting mixture rapidly heated by the sun.

The preservation of a cool, deep pool of hypolimnion water is a key for some kinds of lake management including HOS. The loss of the hypolimnion in SFRR is a little puzzling since the usual cause, withdrawal at depth, was not likely. The withdrawal depth has generally been 1.5 to 4.5 m (5 to 15 ft) for the last 15 years, generally at the 3 m depth near the middle of the epilimnion with a temperature of ~ 26°C. This would normally preserve the cool hypolimnion. The depth of the thermocline in freshwater lakes and reservoirs is set by the strength of the wind, the water temperature gradient, and the fetch (the longest uninterrupted distance over which the wind can blow). In typical temperate zone waters, the equilibrium thermocline is formed quickly

FIGURE 30.

Temperature vs. Depth over Time at SR1 (top image) and SR2 (bottom image)





in late spring and ranges from 6–10 m (20–33 ft). The thermocline is most stable at the hottest part of the year (August) and then gradually descends, incorporating hypolimnion waters until it reaches the bottom at the autumn turnover. SFRR has a long fetch for its area since it is a narrow, flooded valley. However, it is well sheltered from most wind by the trees and the steep bluffs on either side. The temperature difference in early summer was large, so it cannot account for the loss of the hypolimnion since even very strong winds would simply churn the surface water and not overcome thermal stratification and penetrate deeply. Wind energy at the surface is lost in an almost logarithmic way down the water column so that a wave of even 1 m at the surface is only 10%, or 10 cm, at one wavelength and as little as 1 cm at two wavelengths. The wavelengths in SFRR are not known but values of 5 m (wavelength) and 25 cm (wave height) are likely. The reservoir bed near the dam is thus two wavelengths and a storm would provide a mixing force of 0.25 cm on the bottom and 3.5 cm at the intermediate thermocline at 5–6 m in June 2015. These small deep waters would not be sufficient to mix the entire reservoir.

The other mixing force important for a long narrow reservoir like South Fork Rivanna is a seiche, or internal wave, a sloshing back and forth motion on the thermocline that follows when a prolonged wind piles up water at one end then releases it when the wind dies or changes direction. Surface seiches are not well visualized, impacting only a few inches at best, but that is because the surface wave crashes onto the shore and loses its energy. Internal seiches on the thermocline, by contrast, bounce back and forth with little energy loss. They gain energy from the resonant frequency of the reservoir — like a guitar string causing all plucking to produce one main note. These internal waves can eventually crest and break, interrupting the stratification and releasing cooler bottom water. These internal seiches can allow bottom water to travel to the epilimnion where it is soon warmed.

The exact mechanisms that caused the early overturn and column mixing in SFRR are not known. However, natural wind mixing forces, aligned with the relatively long fetch of SFRR, and the effects of releases were apparently sufficient to mix the warm epilimnion with the cool hypolimnion by mid-summer.

5.2.2 : Dissolved Oxygen

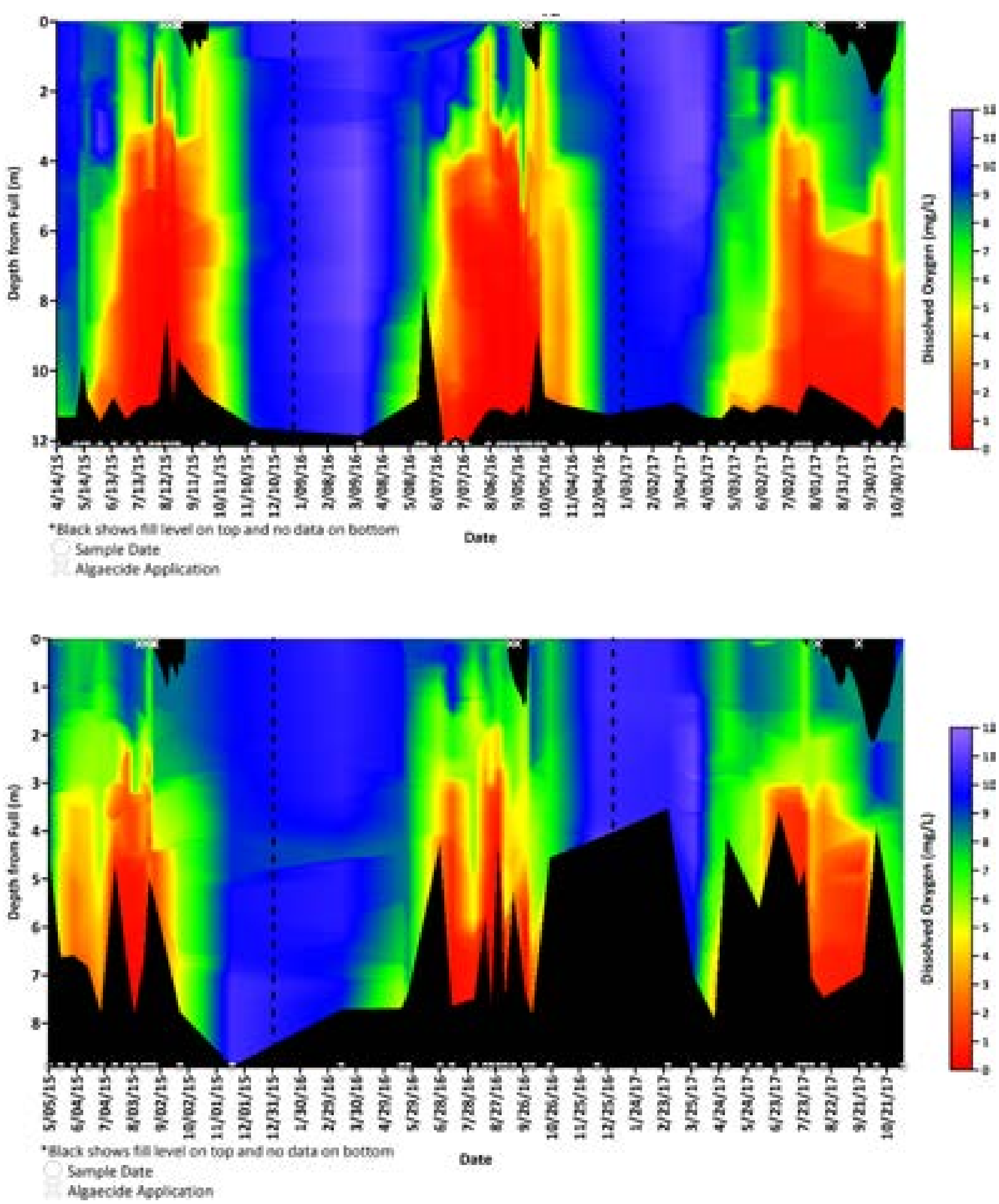
The decline in dissolved oxygen (DO) in the hypolimnion was almost the inverse of the temperature increase and commenced at the same time. Functional anoxia (< 2 mg/L in the water) began in the deepest water in mid-May and spread up throughout the hypolimnion (cooler, deeper water) by early July as shown in Figure **31**.

This situation was similar at both the dam (SR1) and upper (SR2) stations. The strong anoxia in the hypolimnion continued through the summer until mid-October. Despite the descent of the thermocline to the reservoir bed by mid-July, anoxia remained so that the rate of mixing of the entire water column was not adequate to provide oxygen to the bottom sediments until around mid to late October. At this time, anoxia began to reverse as the cooler autumn water set in and DO rose to 2–3 mg/L.

Historical temperature and dissolved oxygen profiles of SFRR displayed classic stratification throughout the summer in 1985 while in 1986 the profiles displayed periods of mixing during the summer (Bowler, 2003). The 2015–2017 data indicate a greater similarity to the more mixed (polymictic) condition observed in 1986.

FIGURE 31.

Dissolved Oxygen vs. Depth over Time at SR1 (top image) and SR2 (bottom image)



5.2.3 : Nutrients

5.2.3.1 PHOSPHORUS

Concentrations of TP above 30 µg/L in SFRR are considered high (eutrophic-mesotrophic border = 30 µg/L). Thus, the 2015–2017 average TP of 54 µg/L (range 16–191 µg/L at SR1 and 18–133 µg/L at SR2) in the entire surface waters indicates generally eutrophic conditions. In terms of directly usable-P, PO_4 is the most bioavailable of the P-species; there was a mean of 23 µg/L (range 4–73 µg/L) for the surface water and 24µg/L PO_4 (range 4–127 µg/L) in the bottom waters, these concentrations provide ample phosphorus for algae blooms. Blue-green algae form scums, producing the nuisance and poor water quality aspects of the bloom. These calculated averages and conclusions assume that the TP analyses for the 8/26/2015 samples were in some way faulty since the values for surface, bottom water and inflow samples were about an order of magnitude above the other measurements. If these August 26 concentrations were correct, then the seasonal averages increase, and the reservoir moves into highly eutrophic conditions in 2015.

Low dissolved oxygen (DO) concentrations in the deep water and at the water-sediment interface result in conditions that are generally suitable for the release of soluble nutrients (e.g. PO_4 and ammonia) and minerals (iron and manganese). Low bottom water DO was widespread by July each year. Despite this, in some instances PO_4 concentrations declined shortly after the onset of functionally anoxic conditions (when PO_4 typically becomes more soluble and increases in concentration). However, the generation of soluble nutrients as anoxia sets into the sediments can take some time. For example, if nitrate is present it will be used as an oxygen source (strictly as a terminal electron acceptor in bacterial respiration). This may have happened for a few weeks after the onset of anoxia, after which the bottom water typically showed an increase in soluble PO_4 as shown in Figure 32. The nutrient releases in

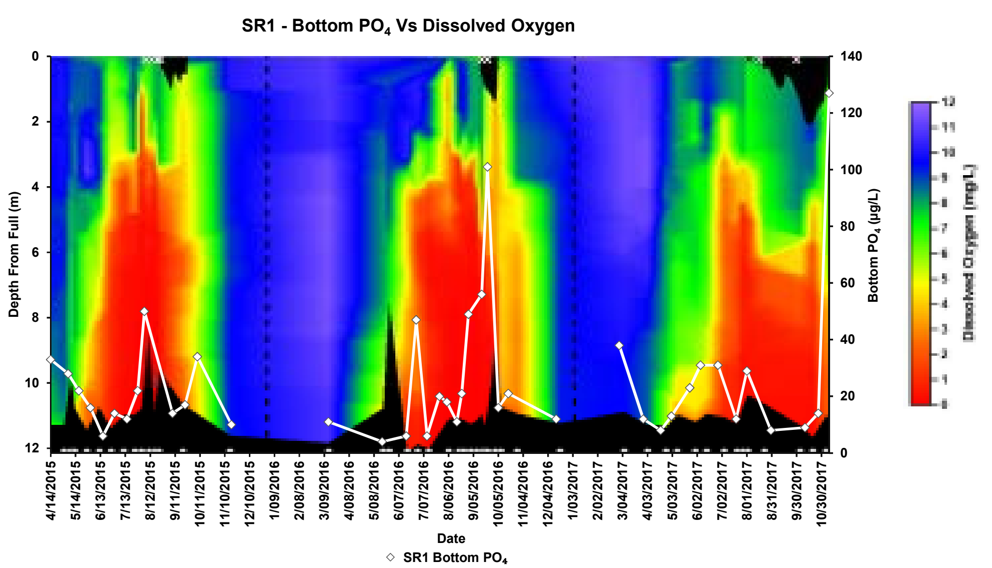


FIGURE 32.

Bottom Ortho-Phosphate Plotted Against DO vs. Depth for SR1.

Lab measurements of bottom ortho-phosphate are shown by the white line and right axis while the background and left axis shows DO vs. depth.

2015 in SFRR were more rapid than found in BCR where PO_4 releases were delayed until September. Simultaneously with the release of PO_4, the temperature of the bottom water over the sediments rose considerably (about 10°C to 20°C) and the hypolimnion disappeared, increasing the rate of bacterial decomposition and thus potential phosphate releases.

The subsequent rapid declines of bottom water soluble phosphate in the fall in 2015 and 2016 were likely due to the increase in dissolved oxygen to about 2–3 mg/L, which is adequate to slowly suppress phosphate releases. Thus, although SFRR does not have a typical stratification pattern, the release of phosphate from the sediments, vis-à-vis anoxia, was normal and the information can be used for management, especially the use of hypolimnetic oxygenation or whole-reservoir mixing.

The concern about soluble phosphate release from the sediments is that bottom water nutrients will pass to the surface and stimulate algal growth. In 2015–2017, the breakdown of thermal stratification by early fall made it easy for bottom waters and nutrients to reach the surface. In 2015, surface soluble PO_4 remained relatively unchanged at 15 to 20 µg/L even as the bottom phosphate increased, probably due to uptake by algae. Sometimes bottom water PO_4 can penetrate the epilimnion, but is rapidly incorporated into algae and shows up as increases in Total-P (TP), but no increase in TP occurred in August 2015 where values remained around 35 µg/L. The likely reason is that algaecide applications suppressed algal growth and biomass and thus TP (which is mostly algae in surface waters).

Soluble PO_4 in the bottom waters at the shallower SR2 station was more complicated. Bottom water PO_4 varied continually between <5 and 60 µg/L. However, on average, higher concentrations of PO_4 were typically observed during anoxia with lower concentrations observed when there were higher levels of DO in the hypolimnion.

On average, the TP arriving from the inflow was similar to that in the reservoir surface. Approximately 30 µg/L was present as instantly bioavailable PO_4 during the growing season, so in general the inflowing water was bio-stimulatory and would contribute to the algae blooms in SFRR.

The 2015–17 data showed a reversal in the trend of decreasing TP that is reported to have occurred between 1980 and 1996. Over that time, TP in the surface waters had declined from about 45 to 27 µg/L, moving the reservoir from eutrophic to just into the more desirable mesotrophic state, shown by Table 17. The decline was attributed by Bowler (2003) primarily to the construction of the 1988 Crozet interceptor removing Crozet's residential and commercial sewage from the SFRR Watershed. This was probably the most important effect on water quality, additionally, some land use practices also changed. In the period of TP decline, row crop agriculture gradually declined, some agricultural BMPs were carried out, and a sedimentation basin was constructed on Lickinghole Creek in 1994. In addition, the State of Virginia enacted a phosphate ban in domestic detergents (Bowler, 2003). All these factors would correlate to a decline in TP in surface waters.

Time period	TP
1980–83	45
1984–1987	35
1989–1992	31
1993–1996	27
2015–2017	54 (16–191)

Source: Bowler, 2003

TABLE 17.

Trends in Total Phosphorus (TP) over the last 35 years for South Fork Rivanna Reservoir.

The recent TP concentrations for the dam station SR1 have an annual average of 54 µg/L (range 16–191 µg/L) which place the reservoir well over the eutrophic-mesotrophic border of 30 µg/L. The reason for the significant increase in TP concentrations in the recent data versus data from the 1990s is unknown.

5.2.3.2 NITROGEN

The other main nutrient that promotes eutrophication is nitrogen, generally present as ammonia and nitrate. Soluble ammonia is also released under anoxic bottom conditions, like soluble PO_4. At SR1 there was a wide and erratic range of ammonia levels from ~100 to 750 µg/L in both surface and bottom waters until mid-summer. In August 2015, the bottom ammonia showed the same pattern of increase as soluble PO_4 and rose to over 1,000 µg/L at SR1 by 26 August. This pattern was less obvious in 2016, but the average bottom water ammonia at site SR1 during anoxia was still higher than periods where the bottom waters remained oxic. In 2017, there was no discernable increase in bottom water ammonia at sites SR1 or SR2, with ammonia concentrations fluctuation between ~300 to 600 µg/L prior to and during anoxia. Ammonia is only one of two forms of bioavailable nitrogen since nitrite (NO_2) is rare and nitrate is usually present in low concentrations in a reducing (low oxygen) environment. At the shallower upstream station (SR2), bottom ammonia varied throughout the season from 200 to 750 µg/L and paradoxically showed peaks before, during, and after the short mid-summer anoxic period.

Nitrate (the other bioavailable N-form) was present at unusually variable concentrations in 2015. In May 2015, nitrate was present in relatively low concentrations (~100–150 µg/L) in surface waters, then rose steadily through the year to reach a high value of 1,200 µg/L in October. The nitrate concentrations at the upper most sampling station, SR3, the Reas Ford Road bridge, downstream of the confluence of the Moormans and Mechums rivers followed the same general pattern. In most temperate climate lakes, nitrate is highest in winter and falls during the growth season, this pattern generally occurred in 2016 and 2017 though some large fluctuations were observed later in the growing season in 2016 where inflowing and in-reservoir nitrate concentrations increased about 3-fold in September (~500–1,500 µg/L). The source of the high concentration of nitrate in SFRR is most probably the inflowing water. In turn, the stream nitrate is washed from the land by the frequent rains. The SFRR watershed is large relative to its surface area (ratio 724:1), so is vulnerable to fertilizers applied to the crops that comprise about 24% of the drainage basin (~ 40,000 acres) most of which is located not far upstream from the reservoir. Assuming a loss rate from fertilized fields of 50 kg/ha (~ 50 lbs/acre) and that 25% of the fields are fertilized or grazed by cows that release urine and feces, approximately 500,000 pounds/yr of nitrate move from fields or about 250,000 pounds from May through October. The average annual inflow of water to SFRR is approximately 71,250 MG. As an illustration of the magnitude of this loading, a calculation of the 500,000 lb/year of nitrate divided by the total annual inflow from all sources of 71,250 MG produces an average annual nitrate concentration of 840 µg/L to the Reservoir inflows, not including nitrate contributions from the other 76% of the watershed. The measured nitrate values which ranged as high as 1,650 µg/L at site SR3, and 2,250 µg/L at site SR4 confirm that the upstream agriculture is a possible contributing source to the South Fork Rivanna.

Total Inorganic Nitrogen, TIN (nitrate + ammonia) represents the nitrogen resource available to algae. Some blue-green algae, especially the scum formers, can fix atmospheric N_2-gas and supplement their growth this way. However, in SFRR there would be no need for N_2-fixation since combined TIN was moderate to high providing an ample source of nitrogen year-round. The process of N_2-fixation is energetically costly for blue-green algae so the large supply of nitrate from the watershed makes them more likely to dominate the reservoir. Some studies have shown that N:P ratios decrease blue-green dominance if the N is high but the studies so far have used nitrate additions that give final concentrations that are much higher than those in SFRR so findings may not be applicable.

In terms of managing algal blooms, the SFRR system was saturated with bioavailable-N. For eutrophication and reservoir management, a concentration of TIN of > 250 µg/L is ample for algae growth and was exceeded for most of the summer in SFRR. The average mass ratio of surface water bioavailable N (TIN) to P (PO_4) in SFRR was approximately 50:1. A ratio of > 10:1 indicates a shortage of P relative to N. An alternative method for the ratio is to use TN: TP, although not all of this is bioavailable, the ratio would still show potential P-shortage. However, when considering a limiting nutrient, both PO_4 and TIN are in such high concentrations that there is effectively no limiting nutrient.

5.2.3.3 OTHER NUTRIENTS

A nutrient that sometimes can control nuisance levels of blue-green algae is iron. In South Fork Rivanna, the concentration of total iron, measured at the inflow to the South Rivanna WTP, was high and averaged about 500 µg/L. Values of < 10 µg/L can indicate iron shortage.

5.2.4 : Phytoplankton: Algal Chlorophyll & Water Clarity

Phytoplankton is free-floating algae. As measured by chlorophyll *a*, phytoplankton in South Fork Rivanna Reservoir showed two surface chlorophyll peaks in 2015 of about 30 µg/L in early May and about 70 µg/L in early August. In 2016, the highest measured chlorophyll *a* peak of 16 µg/L occurred in late August. A chlorophyll *a* peak of 44 µg/L was measured in mid-October of 2017. The YSI sonde used has a chlorophyll sensor, but the sensor was not calibrated in 2015, and while the sensor was calibrated in 2016 and 2017, it may have lost calibration at times in these years. Calibration of the chlorophyll sonde probe is difficult since the standards are unreliable. As is often the case with algae, the surface peaks were not the highest in the water column. The sonde data indicated irregular but frequent chlorophyll maxima between 1.5 and 6 m. Normally, sub-surface algal accumulations are found at around 25% of the incident surface light (Io) which would be at 1–2 m. The sonde data indicate that the concentrated algae are lingering in the dark or following the trend of bottom water soluble phosphate indicating transfer of nutrients from the now anoxic sediments to the epilimnion. An atypical high chlorophyll of about 30 µg/L was reported in early May 2015 at SR1 and could be due to an ephemeral bloom of diatoms or an error.

The algae during the summer chlorophyll peaks were almost entirely blue-green as shown by cell counts that were > 90% of all blue-green algae and the phycocyanin sensor which detects only blue-green algae pigments. Algae lab analyses results are shown in Appendix F and sonde measurements of phycocyanin are shown in Appendix G. A summary of algaecide applications is shown in Appendix H, the impacts of which are seen by the rapid decline in total algae counts following application. The higher chlorophyll *a* peaks observed in 2016 correlate with number of algaecide applications, with four applications occuring in 2015 and only two application each in 2016 and 2017.

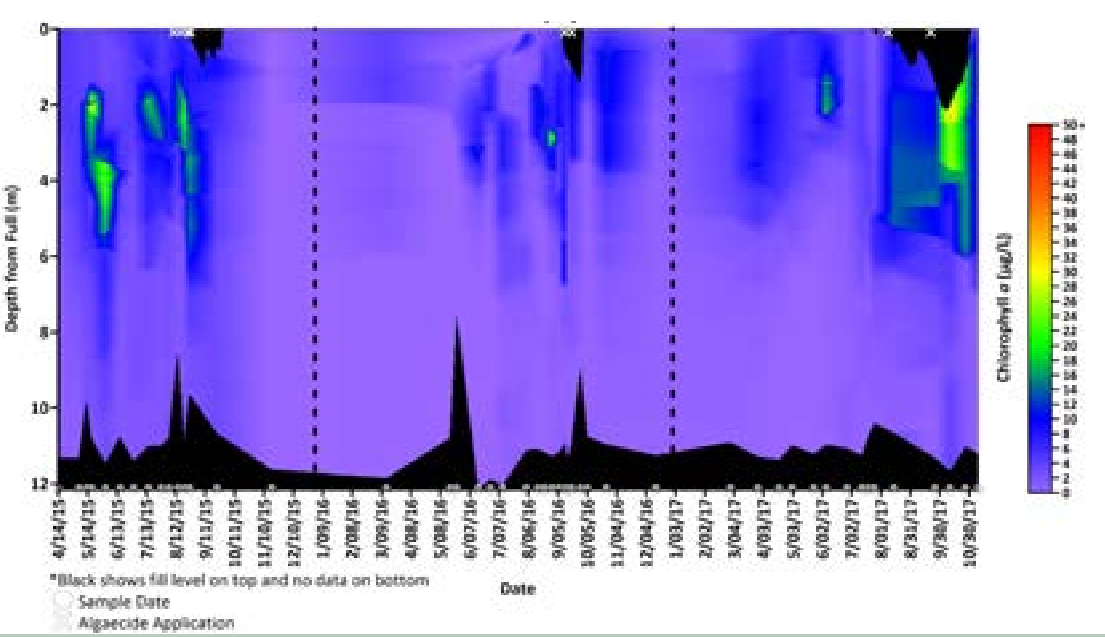


FIGURE 33.

Sonde Chlorophyll *a* vs. Depth over Time at South Fork Rivanna Reservoir

Water clarity, an important water quality variable in itself, also provides a good check on chlorophyll *a* analyses and algae counts. In South Fork Rivanna, the background eutrophic state is revealed by mean Secchi depths from 2015–2017 of 1.64 m at SR1 and 1.30 m at the shallower SR2 station. A good guide is that a Secchi depth of less than 2 m indicates a eutrophic state. In terms of water quality, SFRR is firmly eutrophic.

5.2.5 : Phytoplankton: Algal Species

As with most of the other Authority reservoirs, the phytoplankton of South Fork Rivanna Reservoir were dominated by blue-green algae (Cyanobacteria) for most of the period April–October. The dominant genus identified by the Authority's water quality lab was *Planktothrix* (formerly called *Oscillatoria*). Unlike many of the common nuisance algae, *Planktothrix* occurs only as single filaments, compared to the much larger bundles or coils of many filaments of algae like *Aphanizomenon* or *Anabaena*. Large colonies float to the surface more rapidly than small ones although both kinds of blue-greens contain gas vacuoles and are buoyant to some extent. In terms of management, disturbance of the water column is conventionally thought most likely to affect large colonial forms more than small ones. Nonetheless, the small size of the *Planktothrix* filaments means they are more easily stirred by artificial mixing. Photos of the July and August 2015 SFRR algae blooms are shown in Figure 34.

Although thermally stratified from May–July, the water column of South Fork Rivanna was somewhat mixed (small bottom-to-top temperature difference) from August on. Thus, one would expect *Planktothrix*, in its single filament form, to be well mixed down the short 10 m water column. However, the sampled algae showed a definite preference for the very upper water layer at both the dam and upstream stations. For example, counts of over 6,000 (bloom amounts) were concentrated in the upper 30 cm to 1.5 m (5 feet). Bloom concentrations were highest at the surface and fell with depth being totally absent at 4.5 m (15 feet). In contrast, another common species in eutrophic waters, the colonial diatom *Fragilaria* showed the opposite effect with "bloom" concentrations (> 25 cells/mL) increasing with depth. *Fragilaria* forms short colonies roughly comparable with *Planktothrix* in size but, being a diatom with a cell wall made of heavy silica, it sinks rather than floats. We note that following a change in laboratories performing the algae identification, the dominant genus for large blooms in 2017 was identified as *Planktolyngbya*. This may be the same algae that was previously identified under the genus *Planktothrix*, despite the change in identification, the impacts on management methods remain the same.

In terms of management, artificial mixing in addition to the natural mixing could decrease *Planktothrix* abundance. The asymmetric distribution suggests that this alga prefers the upper water so would lose its competitive advantage if mixed well. Methods such as conventional aeration or the most advanced VEM mixing would work in SFRR.

FIGURE 34.

Surface Film of the Blue-green Algae in South Fork Rivanna Reservoir, July and August 2015

5.2.6 : Spatial Variability

The thermal situation further up the reservoir at SR2, located just upstream of the Earlysville Road Bridge in only 5–8 m of water, was more fluid than at the deeper SR1. Although thermal stratification had established by May 2015 along with depressed DO in the hypolimnion, severe conditions conducive to the release of bottom water nutrients did not arise until late July 2015 at SR2, shown in Figure 30 and Figure **31**. However, this difference between the two stations is probably due to physical conditions (shallower water, different wind exposure) and similar differences were observed in 2016 and 2017. Partial mixing events occurred at SR2 that both deepened the existing epilimnion and injected some of its DO into the deeper waters right down to the bottom waters. These mixing events, such as the one at the end of June to early July in 2015, may be related to a rain or runoff event since there was 2 inches of rain recorded at the South Fork Rivanna WTP on 27 June and the estimated inflow was approximately 835 cfs. Note that precipitation at the WTP does not necessarily reflect precipitation occurring in the watershed draining to the Reservoir, as the WTP is located near the dam. However, functional anoxia at SR2 was nevertheless fully established by mid-July, in most of the hypolimnion.

In 2015, higher peak surface blue-green algae concentrations were observed at SR2 (51,593 cells/mL) than SR1 (28,245 cells/mL). This observation was reverse in 2016 and 2017 with peak blue-green algae concentrations of 56,585 cells/mL (2016) and 150,210 cells/mL (2017) at SR1 versus 38,763 cells/mL (2016) and 54,410 cells/mL (2017) at SR2. The higher algal concentrations were not clearly related to bottom water nutrients, which were similar at both sites. Surface water TP was typically higher at the station with a higher concentration of algae, but this could be due to the greater amount of algae (which dominate TP values), sampling heterogeneity, or influence of the rivers entering the Reservoir.

Transect measurements taken with the sonde at SFRR on July 12, 2017 indicated variable water quality throughout the reservoir and are discussed in more detail in Section 6. The spatial variability observed in the reservoir indicates the need for ongoing monitoring of both in-reservoir sampling locations.

5.2.7 : Effects of Precipitation

There has been some previous study on the effects of storm inflows into Beaver Creek Reservoir (Buelo, Wilkinson and Pace 2015). That study can be summarized as showing that algae blooms followed heavy rains — at least in Beaver Creek Reservoir during the fall. We note that the Buelo, et.al study used precipitation for the Charlottesville-Albemarle Airport, which is 12 miles from the Reservoir. Beaver Creek Reservoir, with a small watershed of 6,050 acres, generally has minor releases downstream of the Reservoir, except during large precipitation events, when releases increase. South Fork Rivanna Reservoir, which has a large watershed of 166,000 acres, spills water for most of the year, except during very dry periods, when inflows minus evaporation and seepage exceed the South Fork WTP withdrawals. Using data from SR1, there has been little observed effect of large storms with data available. On 19 August 2015, precipitation of 3.8 inches was recorded at the South Fork Rivanna WTP. This was by far the largest storm of the growing season during monitoring from 2015–2017. Before (5 August) and after this storm (26 August) the recorded TSS was at low values of 4–6 mg/L. The one parameter that showed the greatest increase on 26 August was TP, which increased from 41 µg/L on 5 August to the highest value recorded in 2015 on 26 August of 561 µg/L at site SR2, though the latter measurement may be in error. However, despite elevated TP, there was not an increase in chlorophyll as measured by the lab on 26 August, but algae counts were the highest of the season on that date for SR1 surface at 30,000 cells per mL where only 1,200 cells/mL reported at SR2 two days prior. There was also no observed effect of smaller storms of 0.5 inches or more over the summer. This may be a result of precipitation at the WTP not matching up with precipitation in the watershed and/or sampling not occurring at peak storm inflows or the lack of relationship of precipitation and chlorophyll. Figure 23, which shows estimated inflows based on the watershed weighting method using the upstream Mechums and Moormans rivers gages, illustrates that precipitation at the South Fork Rivanna WTP does not correlate well with the stream gages located upstream of the reservoir.

5.2.8 : Data from Older Documents

Previous reports indicate that sedimentation is an issue for SFRR and that sedimentation has been averaging 15.6 million gallons per year, 0.92% of the original reservoir drinking water storage capacity (Potter 2001). Another estimate was 1.1% per year (Bowler 2003). The measured value is not far from the original prediction of 19.6 million gallons per year (Potter 2001).

Prior to the present study, the typical median total suspended solids and Secchi depth in the South Fork Rivanna Reservoir at the surface near the dam in the summer (5 mg/L, 1.8 m) can be compared with two Piedmont Virginia reservoirs; Occoquan (3 mg/L, 1.4 m) and Manassas (2.8 mg/L, 1.4 m). The sources of the suspended sediment are not well understood. However,

South Fork Rivanna Reservoir Outlet Tower, April 14th, 2015.

one report suggests that “The Mechums watershed is thought to produce the highest sediment load to the downstream South Fork Rivanna Reservoir. Total water volume in 1966 was 1,700 MG with active pool for use of 1,200 MG. However, sediment reduced storage from over 1,200 MG to 800 MG in 2002“ (Bowler 2003).

Previous work also suggested that “because the SFRR is riverine in nature, it is subject to high flows during large rain events and can mix due to the action of those high flows. Thus, stratification is triggered by temperature conditions, but mixing can occur as a result of either storms or temperature conditions. At the height of summer, stratification may be maintained for some time, eliminated or reduced by a storm, and restored after mixing. Some storms may mix the upper reservoir but not the lower reservoir near the dam. During late fall, winter, and early spring the Reservoir may remain well mixed (no data are available). Ultimately, though stratification is an important aspect of SFRR ecology, the stratification period of SFRR is often shorter and less consistent than that of a classic lake” (Bowler, 2003). However, the 2015–2017 surveys found little or no effect of storms, even following a large storm with gage flows peaking on April 20, 2015. At this time, an estimated 3,850 cfs inflow occurred compared with a base summer flow of less than 500 cfs. This storm produced total estimated inflows of 5,030 MG into SFRR, more than three times the total volume of the reservoir (1,369 MG).

From an ecological perspective, the quality of the SFRR tailwater may be as large an issue as the quantity. A study by a biology student at Mary Baldwin College (Bond 1999) showed that there may be problems with low oxygen in the water flowing from SFRR. Based on what is known about the water in the SFRR and about reservoirs in general, this finding does not come as a surprise.

The past studies also indicated several specific issues that could be addressed in future watershed management efforts. Among these were the potential impact of septic systems on drinking water, risks associated with the possible US 29 western bypass, livestock access to the reservoir and its tributaries, and minimizing chlorination by-products (that are related to eutrophication).

5.3 : Ragged Mountain Reservoir

Ragged Mountain Reservoir had only two sample locations due to the lack of tributary inflows and the difficulty in accessing the discharge of the Sugar Hollow pipeline into the Reservoir watershed as shown in Figure 35. In 2016 and 2017, sampling at site RM2 was discontinued while site RM1 was sampled regularly.

5.3.1 : Temperature and Thermal Stratification

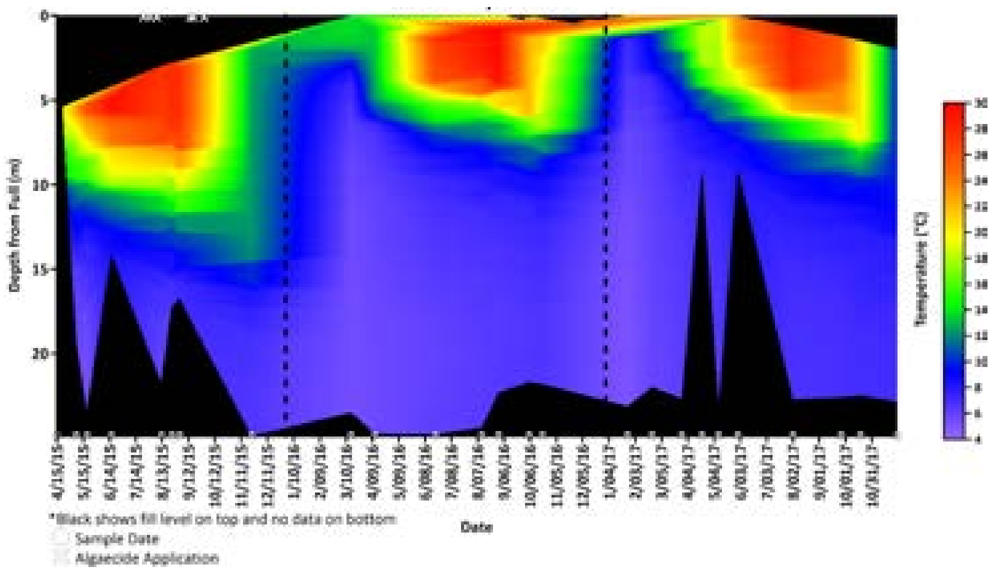
At the deep water sampling location, RM1, Ragged Mountain Reservoir was about 18 m deep early in the 2015 growth season increasing to about 22 m by September, with the first fill of the newly enlarged reservoir occurring by February 2016. A "classic" stratification began earlier than in the other reservoirs, and there was at least a 10°C difference top to bottom by the end of April to early May each year, shown in Figure 36. The thermocline typically established at about 5 m in late May with about 28°C at the surface and a cool 6°C over the sediments. The slightly deeper thermocline at Ragged Mountain relative to the other reservoirs in the Rivanna system was due to the larger reservoir area, which increases the fetch, which is the longest uninterrupted distance across the lake that the wind can blow. The depth of a thermocline is an outcome of wind mixing which is controlled by the fetch. Stratification was maintained with the thermocline gradually descending over the summer and was at about 7 m by early September. Stratification was maintained until around November, although the surface water cooled considerably in the fall to about 15°C.

FIGURE 35.

Sampling Locations for Ragged Mountain Reservoir

FIGURE 36.

Temperature vs. Depth over Time at RM1

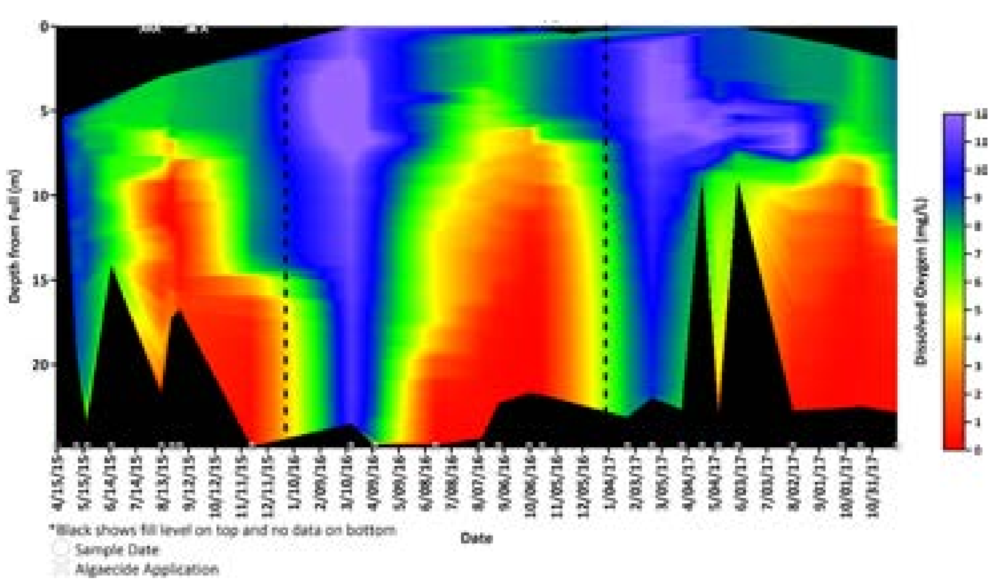


5.3.2 : Dissolved Oxygen

Dissolved oxygen in the bottom waters of Ragged Mountain typically showed the first signs of functional anoxia (< 2 mg/L) around early June, as shown in Figure 37. The increasing depth in 2015 resulted from filling the enlarged reservoir with water added from the pipeline from Sugar Hollow. Complete anoxia in the hypolimnion was typically not present until August. Because thermal stratification was maintained until around November, anoxia in the hypolimnion was also maintained.

FIGURE 37.

DO vs. Depth over Time at RM1



5.3.3 : Nutrients

Bioavailable phosphate was low in surface waters, averaging 14 µg/L for all years combined and many samples were near or less than the method detection limit. Bottom water PO_4 averaged slightly higher at 23 µg/L, again with many samples at or below the detection limit. TP showed slightly higher mean of 22 µg/L. Bottom TP was somewhat higher at 44 µg/L, but that concentration includes phosphorus from debris and dead algae.

Ammonia in the surface waters of Ragged Mountain Reservoir was present in moderate to high amounts with a mean value of 222 µg/L (all years) and a peak of 751 µg/L recorded on October 5, 2016. Bottom water ammonia averaged slightly higher with a mean of 344 µg/L and peaks over 1,100 µg/L recorded on October 5, 2016 and July 20, 2017. Nitrate in surface water at RM1 averaged 370 µg/L across all years with a peak of 1,240 µg/L recorded on October 5, 2016. Bottom nitrate was similar with an average of 407 µg/L and a peak of 2,800 µg/L recorded on October 5, 2016. Thus, bioavailable TIN was about 600 µg/L, an ample supply for algal growth.

Recent studies by Dr. Brett at the University of Washington Seattle indicate that not all, or even most of TP is bioavailable, so PO_4 may be a better guide. The average mass ratio of TIN:PO_4 of the surface waters during the growth season is approximately 90:1 and indicates that phosphorus may be the limiting nutrient.

5.3.4 : Phytoplankton: Algal Chlorophyll & Water Clarity

Algae, as measured by surface chlorophyll *a*, was generally low in Ragged Mountain Reservoir with a maximum value at RM1 of only 5 µg/L in late July 2015, and an average of only 2 µg/L (all years), although a value of 14 µg/L was recorded at RM2 in early August of 2015. A chlorophyll *a* value of < 8 or 9 µg/L indicates an oligotrophic condition which is ideal for drinking water quality purposes.

The uncalibrated sonde algae sensor also showed low chlorophyll with occasional indications of up to 15 µg/L at various depths, including below the thermocline in May 2015. A possible high value of > 50 µg/L detected by the sensor at the end of August 2015 at 9 m may have been a thin plate of algae caught in the density gradient at the bottom of the epilimnion (or top of the thermocline-metalimnion). The phycocyanin value reported by the sensor indicated that this small deep peak was composed mostly of blue-green algae, but this was not at a depth used for algae counts. Small amounts of *Anabaena* were recorded occasionally in this reservoir, so the deep peak may be due to the accumulation of small amounts of moribund *Anabaena* that could no longer regulate its depth. In mid-March of 2016, the sonde indicated chlorophyll *a* values >10 µg/L throughout the entire water column at RM1 with peaks of >50 µg/L around 5 to 10 m deep. Samples taken the same day indicated 5,136 cells/mL of the filamentous green algae *Ulothrix*.

One explanation is that the sonde may have become entangled in a floating algal mat which was then dragged with the sonde through the water column, which would explain the high chlorophyll a values recorded throughout the water column.

The water clarity at both stations on Ragged Mountain Reservoir was indicative of satisfactory water quality conditions. Secchi depth averaged 3.1 m and 3.0 m for RM1 and RM2, respectively in 2015 when the newly enlarged reservoir was being filled. In 2016 and 2017, site RM1 had an average Secchi depth of 4.7 m, with no values below 2.0 m (the border between the desirable mesotrophic conditions and undesirable eutrophic conditions). The highest value reached was 6.5 m in mid-October of 2017.

5.3.5 : Phytoplankton: Algal Species

Unlike the other reservoirs, the dominant algae in Ragged Mountain Reservoir were green algae rather than blue-greens. The Ragged Mountain algaecide treatments in 2015 were for surface scums of green algae, probably floating mats of Mougoetia (blanket weed) or similar filamentous green algae. In the open planktonic environment, algae, like chlorophyll values, were low with the filamentous green algae *Ulothrix* and the mucus-surrounded colonial green algae *Gleocystis* (now called *Chlamydocapsa*) being the most abundant genera. *Chlamydocapsa* is characteristic of more oligotrophic waters. The numbers of blue-green algae at the surface were 26–156 cells/mL at both surface sites, which is quite low relative to the thousands of blue-green algae that cause problem blooms. Green algae numbers at the surface were occasionally high, with concentrations around 9,000 cells/mL occurring in November 2015, while concentrations were generally lower in 2016 and 2017.

5.3.6 : Effects of Recent Reservoir Expansion

All reservoirs undergo changes when constructed and usually are more eutrophic for the first few years. Similar effects likely occurred in reservoir expansion and this is probably the reason for the need to treat surface green algae in Ragged Mountain Reservoir in 2015.

Sometimes when a reservoir is filling, the waves erode new soil around the shorelines giving high suspended solids. This did not appear to occur in 2015 as the water level rose 9+ feet into raw soil as the shoreline had been cleared of vegetation. Total suspended solids at the surface averaged 3 mg/L at the two stations with occasional values of 6 to 9 mg/L. The bottom water was also not very muddy with an average of 7 mg/L with occasional excursions of 14 to 17 mg/L and one value of 52 mg/L. The latter could be due to inflow disturbance but occurred at both stations and is probably when the sample container touched the bottom as sonde data did not indicate a large increase in turbidity of the bottom water. The reservoir was full in February 2016 so the shoreline erosion should now be stabilized if the reservoir is not drawn down more than five feet.

5.4 : Beaver Creek Reservoir

Beaver Creek Reservoir (BCR) was sampled in 2015 at two in-reservoir locations (BC1 and BC2) and one inflow location on Watts Creek (BC3). For sampling in 2016 and 2017, site BC2 was eliminated while an additional inflow location was added on Beaver Creek (BC4). Each of the sampling locations for Beaver Creek Reservoir are shown in Figure 38.

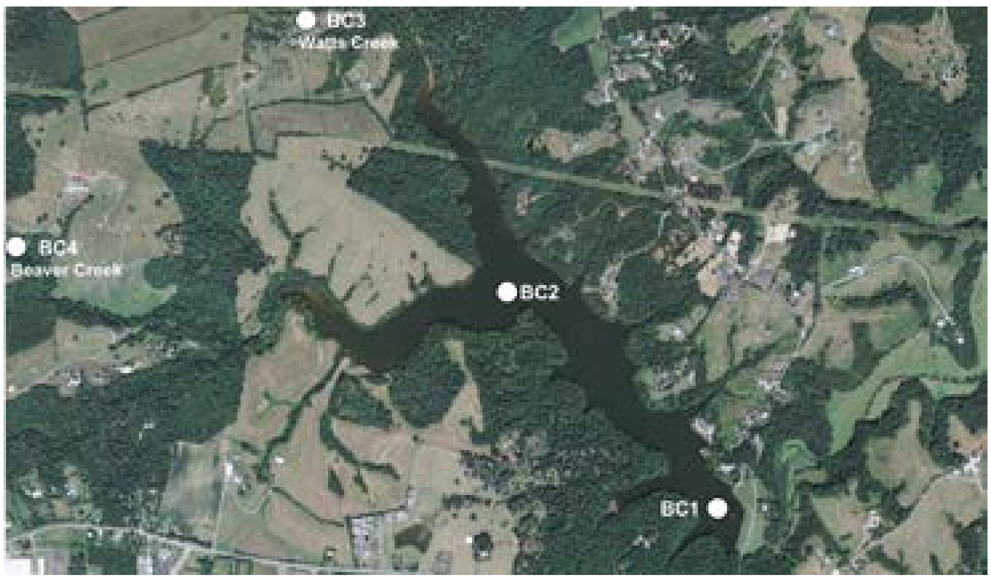


FIGURE 38.

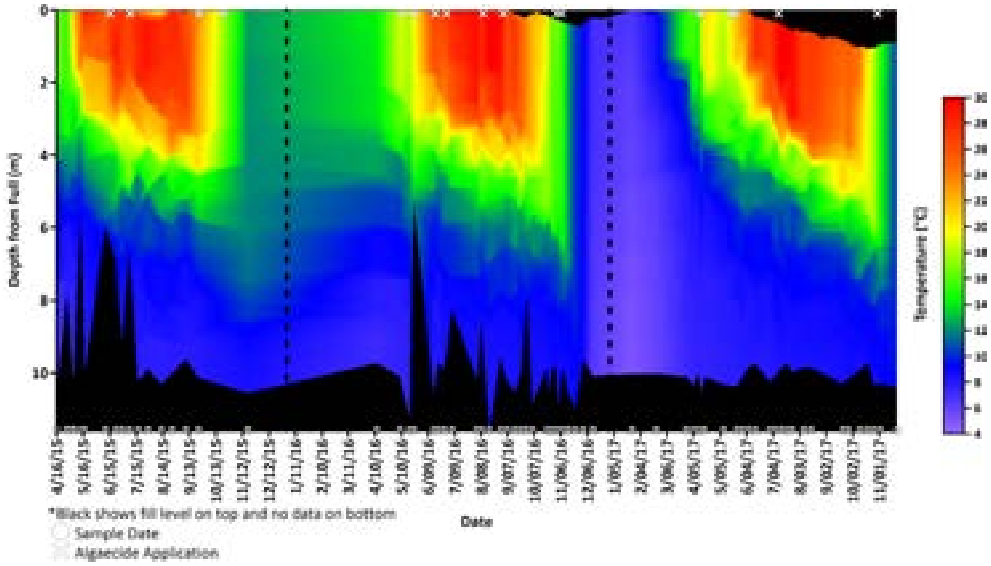
Sampling Locations for Beaver Creek Reservoir

5.4.1 : Temperature and Thermal Stratificaiton

Thermal stratification was well defined and had a long duration in Beaver Creek Reservoir. Although it is almost as deep (maximum depth ~10 m) as South Fork Rivanna Reservoir, Beaver Creek Reservoir is more sheltered from wind and showed a classic summer thermal stratification. Figure 39 shows that in 2015–2017, a stable thermocline formed at about 3 m in May and deepened to about 4–5 m at BC1 by August. Surface water temperatures in mid-summer reached high values of 28–29°C but the bottom water remained quite cold at 7–9°C, a difference that indicates stable stratification. Turnover occurred in late October to early November with a temperature of about 10°C.

BC2 is shallower (~ 8 m) than BC1, but in 2015 it also showed classic summer-long thermal stratification similar to BC1. However, the cool water layer at BC2 was very thin, < 1 to 2 m, and thermal stratification presumably broke down in early or mid-October.

FIGURE 39.



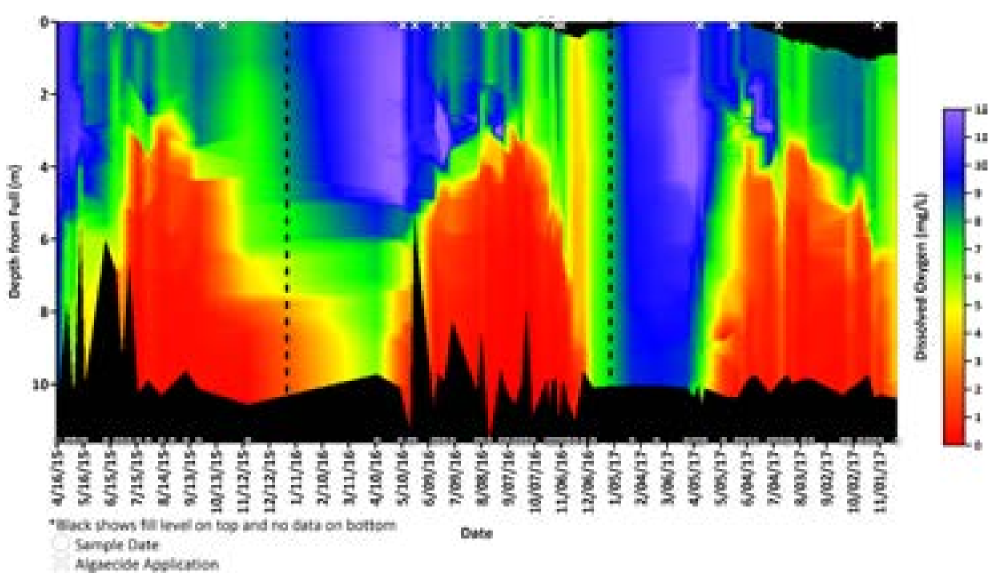
Temperature vs Depth over Time for BC1

The management implications of a strong thermal stratification are that it may be best to preserve the stratification and treat the hypolimnion pool. In this strategy, the nutrient-rich sediments are physically isolated from the upper waters where algae grow.

5.4.2 : Dissolved Oxygen

BCR showed a classic stratified oxygen pattern during the thermal stratification periods in 2015–2017 as shown in Figure 40. In the hypolimnion, DO fell quickly to functional anoxic levels (< 2 mg/L) by mid-May. Overturn occurred by early November, but the deepest part of the hypolimnion (bottom 2 m) remained anoxic for some time after turnover. This is not typical but could be due to the sheltered site and/or the continuing

FIGURE 40.



Dissolved Oxygen vs. Depth over time at BC1 decay of leaves on the bottom from nearby deciduous trees. In 2015, BC2 did not show anoxia in the hypolimnion after fall turnover in mid-November but presumably has a similar leaf load to BC1. The shallower water will mix more easily and satisfy oxygen demand.

5.4.3 : Nutrients

5.4.3.1 PHOSPHORUS

PO_4, or soluble phosphate concentrations were quite high in the bottom waters at BC1 in 2015, even prior to the onset of anoxia, ranging from 16–31 μg/L before and after the onset of anoxia. These concentrations are high for such a bioavailable molecule and would be expected to increase following anoxia. In addition, a peak of 81 μg/L occurred at BC2 at the end of July 2015 with BC1 much lower (31 μg/L). Concentrations did not rise consistently until after the middle of September 2015. At this time, bottom PO_4 rose rapidly and reached almost 100–156 μg/L depending on the site in the reservoir. The expected pattern of internal loading is that the bottom water PO_4 is low (< 5 μg/L) under fully oxidized conditions before stratification and then concentrations increase a few weeks after anoxia as the PO_4 becomes soluble in the absence of oxygen. In Beaver Creek Reservoir, PO_4 levels spiked in July before decreasing and then increasing rapidly beginning in September 2015 rather than a steady increase over time.

Prior to and shortly after the onset of anoxia in 2016, BC1 bottom water shows PO_4 concentrations of 2–34 μg/L before elevated concentrations were observed in late June. During anoxia, PO_4 concentrations fluctuated between high values >100 μg/L to values lower than the detection limit of 20 μg/L. It is not clear why these large fluctuations occurred, but the average PO_4 concentration following the rise in late June was 97 μg/L, indicating that PO_4 was accumulating in the hypolimnion during anoxia in 2016, with accumulation beginning more rapidly than in 2015.

In 2017, PO_4 concentrations in the bottom water at BC1 were generally less than the detection limit of 20 μg/L, averaging around 11 μg/L until increasing in July. Fluctuations between high and low values were again observed during anoxia in 2017, though lesser magnitude than those seen in 2016. The average PO_4 concentration from June through October 2017 was 74 μg/L, again indicating accumulation in the hypolimnion before decreasing after fall turnover.

Surface phosphate (PO_4) is the only phosphorus species that can be used directly by algae. It varied at moderate values between 6–27 μg/L through the growing season in 2015. From April through mid-August of 2016, surface PO_4 again varied at moderate values between 1–21 μg/L before reaching a level of 94 μg/L in late August. In 2017, the range in PO_4 concentrations was similar, fluctuating between 1–42 μg/L throughout the year with the peak of 42 μg/L occurring in late October. In all years, the soluble PO_4 was often present at about detection limit of 20 µg/L. A common practice by aquatic scientists is to use a concentration that is half the detection limit (i.e. 10 µg/L), a level that could be limiting for algae growth. However, limiting values may be closer to < 2 µg/L for PO_4. Whatever the real value, these concentrations were still adequate for algae blooms that occurred and triggered treatment by the Authority.

The timing of the surface increases was unexpected since it was earlier than the typical internal loading which increases PO_4 supply from the bottom water. An external source such as a runoff event in the watershed could account for the rise but reservoir inflow is not directly measured.

Surface water TP is used by most limnologists to interpret P-behaviors since PO_4 is often difficult to measure at low levels and cycles quickly to and from TP. Most TP in the growing season is inside algae but some other TP in the waters can easily be converted to bioavailable PO_4. In 2015, surface water TP averaged 1 µg/L (range 10–32 µg/L) in spring–summer. The low average of 17 µg/L would indicate mesotrophic conditions (i.e. < 30 µg/L) but this was only because copper was applied four times in Beaver Creek, three in summer. In early October, TP was sampled three days after the Mechums River gage showed a spike, TP rose to a peak of 55 µg/L at BC1 surface, during a moderate blue-green algae bloom before dropping rapidly to less than 20 µg/L in November. However, TP at BC2 surface did not show a corresponding increase in concentration. In spring–summer 2016 surface TP at BC1

Beaver Creek Reservoir May 2015

averaged higher than in 2015 at 31 μg/L, right around the mesotrophic-eutrophic boundary. Algaecides were applied to the reservoir eight times in 2016, with six applications throughout the summer, and two in the fall. The average spring–summer TP in 2017 was again higher in 2017, averaging 59 μg/L and indicating firmly eutrophic conditions, even with five applications of algaecide, four of which occurred during spring and summer. It is probable that if algaecides were not used the average TP concentrations would increase. If so, then the TP would indicate the eutrophic state.

Stream phosphorus in Beaver and Watts creeks are likely significant long-term external P-sources, the main sources in winter, and likely sources in the spring–fall growth season. In 2015–2017 between April and November, phosphorus in the creeks, as sampled at Watts Creek, BC3, was higher than desirable averaging 43–44 μg/L each year with high values of 601 μg/L and 520 μg/L on July 23 and August 3, 2016 removed. However, the high values appear to real based on the high TSS also recorded on those days, including these values would raise the average to 123 μg/L in 2016. The average TP measured at site BC4 in Beaver Creek was slightly lower than Watts Creek in 2016, averaging 32 μg/L from April–November with high values removed, and 45 μg/L including the high values. In 2017 the average April–November TP measured at BC4 was 43 μg/L, the same as the mean measured at Watts Creek. It would be preferable if the inflowing concentrations were lower, around 10–20 μg/L, but some of the stream TP may be in an inactive form such as calcium phosphate particles. High year-round inflows of P can mean that use of a one-time application of alum in the reservoir may not be effective for more than several years. Alum prevents release of PO_4 from the sediments but not from any new external P sources arriving in creek inflows.

Large rain events in the algal growth season could be a major occasional external source of P for the summer blooms because the alternative internal loading occurred later in the fall. In any case, looking at measured concentration values, a steady flow of water from the watershed was ample since it contained an average of >40 μg/L TP with frequent higher peaks. The volume of the streamflow would allow a loading calculation to see if the additional TP was sufficient to raise concentrations in the reservoir.

The Authority conducted sampling at eight locations in the BCR watershed during base flow (February 23, 2017) and storm flow (March 31, 2017) conditions. These measurements are discussed in greater detail in Section 6. The special study on the Beaver Creek watershed showed that an ample supply of phosphorus during base flow conditions and very high levels of phosphorus during storm flows were found throughout the entire watershed.

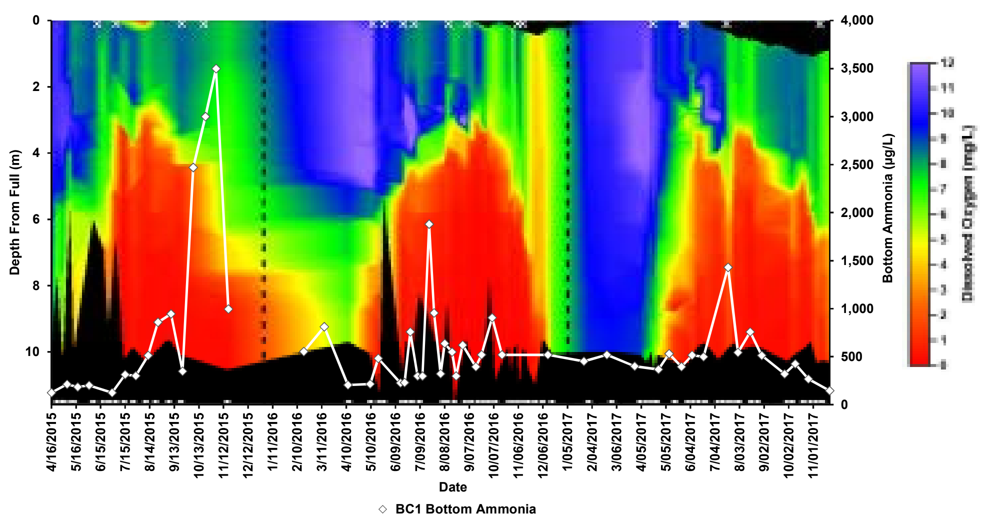
5.4.3.2 NITROGEN

Ammonia, like phosphate, is released when the sediments are anoxic. The classic thermal stratification in 2015–2017 in BCR soon produced anoxia. As with PO_4, there was a delay between the start of anoxia in June and rise in ammonia in 2015 but in this case, only for one month. Ammonia in the bottom waters remained low to moderate at 120–300 µg/L from April through July 2015 when it then began to rise, presumably in response to the anoxia that set in by the end of June. Ammonia then climbed rapidly in late September to reach the very high value of 3,500 µg/L by early November. The fall turnover in November reduced ammonia in the bottom water to 1,000 µg/L. The clear rise in ammonia that occurred in 2015 was not seen in 2016 or 2017. In 2016, ammonia fluctuated throughout the anoxic period between about 200–900 µg/L with a peak of 1,880 µg/L in late July. Bottom water ammonia levels at BC1 in 2017 remained around 400–500 µg/L in April–June before peaking at 1,430 µg/L in late July. Following this peak, ammonia levels began declining steadily, despite the strong anoxia, to levels around 250 µg/L just prior to turnover and around 150 µg/L after turnover. The nutrient flux study conducted in 2017, discussed in more detail in Section 6, showed ammonia release rates comparable to other eutrophic reservoirs, so it is unclear why an increase in bottom water ammonia was not observed in 2016 or 2017.

Surface ammonia varied from 75–685 µg/L between 2015–2017 (2015 mean: 168 µg/L, 2016 mean: 370 µg/L, 2017 mean: 299 µg/L) These concentrations are quite high for well-oxygenated surface waters and may reflect high excretion from fish and zooplankton.

Nitrate in the surface waters averaged a high value of 629 µg/L at the dam station BC1 in 2015, 960 µg/L in 2016, and 489 µg/L in 2017. There was an obvious seasonal accumulation in 2015 as nitrate increased from a moderate initial value of 300 µg/L rising to an even higher value of 1,160 µg/L by early October. The increase was tied to both the internal loading as bottom water ammonia is oxidized to nitrate in the upper water and stream inflow, both of which increased through the season. Surface water nitrate concentrations reached a peak of 1,930 µg/L at BC1 in February 2016 and generally continued to decline as it was taken up by algae through the growth season in

FIGURE 41.



Bottom Ammonia (black line, left axis) Plotted Against DO vs Depth (background, right axis) for BC1

2016 before rising again in the winter and declining through the 2017 growth season as well. This cycling pattern was also observed at sites BC3 and BC4.

A likely source for at least some of the nitrate in the hypolimnion is nitrification of ammonia released from the anoxic sediments in summer. Ammonia is easily converted to nitrate in the presence of oxygen and is just as useful for algae. Nitrate can also be converted to nitrogen gas in the hypolimnion close to the sediments where anoxic pockets can occur. While some blue-green algae can convert N_2-gas to protein, there is always ample nitrogen gas in lake water, so it plays no part in restricting nuisance growths.

Stream nitrate, an external source, was similarly high year-round with mean values at BC3 of 1,351 μg/L, 1,588 μg/L, and 740 μg/L in 2015, 2016, and 2017 respectively. Nitrate concentrations at BC4 were slightly lower than those at BC3 with mean values of 1,221 μg/L and 627 μg/L in 2016 and 2017 respectively. Though nitrate concentrations were lower in 2017 the values were still ample to fuel algal growth. Although high values from an algal viewpoint, the nitrate concentrations are not unusual for the region. The high nitrate indicates pollution by domestic waste (probably via septic tanks which do not remove nitrogen), agriculture (urine, feces from stock, fertilization by manure or inorganic fertilizer), and a possible elevated value from disturbed forests. Nitrate in the groundwater in Virginia and similar regions is often dominated by the longer-term cycles of groundwater, which can contain very high nitrate levels (up to 20,000 μg/L).

The general conclusion was that Total Inorganic Nitrogen (TIN = nitrate + ammonia) was present well above saturation levels for algae growth in BCR and its inflows. Ammonia production in the anoxic sediments showed classic timing and further added to TIN in the surface waters in 2015, but this was not as apparent in 2016 or 2017. Thus, control of nitrogen (TIN) to reduce algae would require considerable effort and low enough concentrations may not be reached without both reservoir and watershed management. However, it is possible with some combination of techniques which address both external and internal loading.

5.4.3.3 LIMITING NUTRIENTS

Phosphorus was likely the nutrient that limited algal growth in Beaver Creek Reservoir in 2015 since sometimes both TP and PO_4 concentrations were relatively low and nitrate was high. The statistical relationship of bottom water PO_4 and ammonia released during anoxic periods and the algae in the surface waters, (lagged one month or simultaneous) was poor. Regression coefficients were 7% for PO_4 and < 1% for ammonia, whereas a value of 75% would indicate a strong relationship. The poor statistical correlation was not unexpected since releases of bottom water nutrients were delayed until towards the end of the growth season.

The source of the P that supported most of the nuisance blue-green algae blooms early in the season was not obvious. P was most likely from the external source from Watts and Beaver Creeks rather than internal loading. Internal loading of PO_4 did not begin until late September but blooms occurred in June and July. The September bloom was also too early to be from the measured internal loading. The poor regression between chlorophyll and bottom PO_4 and/or ammonia also indicates that internal loading did not play as large a role in nuisance algae growth despite the rapid onset of anoxia.

5.4.3.4 LOADING OVERVIEW

The balance between nutrients recycled from the anoxic sediments in summer and those flowing in from summer runoff, especially storms, is critical in designing a management strategy. While temperature plays a large role in water density, the inflow from streams would be generally denser than the temperature alone suggests since streams carry both total suspended (TSS) and dissolved substances (TDS or salts) other than nutrients, which increase the density of the water. The resulting turbidity plume is quite stable and can travel along the upper shallow waters of the reservoir with little loss for some distance if there is a strong slope. In BCR, the inflowing water plume can be tracked by assuming that it flows at the matching density in the reservoir. To better determine the location of inflow water with the reservoir, we calculated inflow and reservoir densities from sonde data. Water densities were calculated using an equation derived by Chen and Millero (1986) for waters with salinities less than 0.6 psu. The equation used for water density (ρ_w) in kg/m³ as a function of salinity (S) and temperature (T) is:

$$\rho_w = \sum_{i=0}^{6} a_i T^i + S \sum_{i=0}^{2} b_i T^i$$

Where

a_i = [999.8395; 6.7914 × 10⁻²; -9.0894 × 10⁻³; 1.0171 × 10⁻⁴; -1.2846 × 10⁻⁶; 1.1592 × 10⁻⁸; -5.0125 × 10⁻¹¹]

b_i = [0.8181; -3.85 × 10⁻³; 4.96 × 10⁻⁵]

(Boehrer and Schultze, 2008)

Additionally, the density effect of total suspended solids, ignoring any effects on volume, was factored in as

$$\rho_b = \rho_w + c \times (\rho_s - \rho_w) / \rho_s$$

Where

ρ_b is the bulk density of the fluid, ρ_w is the calculated water density from above, ρ_s is the density of the suspended material, and c is the mass of suspended material per unit volume of water (Boehrer and Schultze, 2008). We assumed the density of the suspended material to be 2.65 g/cm³, the density of quartz, which provides a good estimation of the average soil particle density. We also assume that most of the suspended material was mineral particles rather than less dense soil organic matter.

This places the plume depth around the thermocline and is typical of inflowing stream waters which move along tree-shaded watercourses and are generally cooler than the open waters of reservoirs that heat up each day in the sun.

Beaver Creek Reservoir has little slope so the turbidity plume of creek water during higher flows enters the reservoir as a block of water up to the point where its density is greater than the reservoir water. This is the plunge point and is often visible to the naked eye. The turbidity plume then slides across the bottom and begins to widen and dilute as it mixes with the surrounding water. At some point, the turbidity plume will encounter denser bottom water and lift. As described earlier, in Beaver Creek the temperature and TSS of the creek indicate that the plume probably runs at the depth of the thermocline or bottom of the epilimnion. In terms of management, this is important as the inflowing water with its higher nutrient content enters the epilimnion it will directly stimulate algal growth. On the other hand, if the nutrients are delivered to the deeper water, management techniques like oxygenation (HOS) will be effective. Soluble PO_4 entering Beaver Creek averaged nearly twice the concentrations in the epilimnion and can be precipitated to the sediments if the water is fully oxygenated and supplied with naturally high levels of iron. However, TP is not directly converted to insoluble ferric phosphate by oxygen, so the TP content would be reduced more slowly with HOS.

The mean inflow of phosphorus to Beaver Creek (BC3 and BC4 combined) was partially made up of particulate matter. The TP averaged 59 µg/L of which soluble PO_4 was 51% (30 µg/L). There is a constant interplay in streams between inflowing soluble PO_4 and TP. For example, a particle of soil, such as a clay, will contain phosphate adsorbed both deep in the particle and on its surface. In soils, nutrient concentrations are high relative to those in water so once a soil particle enters the stream it will de-sorb some surface PO_4 rapidly (days) and deeper PO_4 slowly (weeks), depending on the background concentration of the stream and the size of the particle. Any soluble PO_4 present in the soil water will also be subject to absorption, but most likely will remain free as other PO_4 is lost from the soil particles. The net result is an equilibrium concentration of PO_4 in streams that can reach as high as 50 µg/L. In Beaver Creek, where the hydraulic residence time can be short, the inflow was only about 30 µg/L PO_4, so the remaining 29 µg/L was mostly in the particulate form.

5.4.3.5 NUTRIENT LOADING ESTIMATES IN BEAVER CREEK RESERVOIR

It was expected that the higher levels of winter TP would be consumed by the spring diatom bloom. Large diatoms depend on mixing and when stratification occurred, they would have sunk to the bottom, leaving some unused TP in the newly formed epilimnion. The next blooms, nuisance blue-green algae, could use the small remaining TP and nitrate in the epilimnion, but this would be unlikely to support large blooms. New TP could come from internal and external sources (sediments and streams) since the sediments become anoxic starting in early summer and the inflowing streams run year-round. Because internal loading of PO_4 did not begin until after several blue-green blooms were treated, algae must have used nutrients arriving from the inflowing streams. In addition, the moderate PO_4 concentrations in the surface waters supports the presence of either an external source such as river inflow partially reaching the epilimnion and/or a high rate of P-cycling from fish and zooplankton excretion in the warm water.

The Authority provided raw outflow data from April through October of 2015 for Beaver Creek Reservoir. The Authority listed the reservoir fill level as "full" for the duration of this time period except for a five-day period from September 5 through September 9 where the level fell to 0.2 ft below full. With the reservoir remaining full almost the entire period, we made an initial hypothesis that the reservoir outflow volume should be roughly equal to inflows over the time period, minus some minor deductions for evaporation and seepage. Figure 42 shows recorded precipitation at the Crozet WTP (bars), water outflow from the outlet tower as measured and reported by the Authority (solid line), and watershed weighted estimated inflows (dashed line). As shown in the figure, there were gaps in outflow data recorded by the Authority. When the outflow data are compared to watershed weighted inflow estimates using the Mechums River at White Hall gage and precipitation data recorded at the Crozet WTP, it is apparent that the outflow data do not provide as good of an inflow estimate as the watershed weighted method. This is likely a result of the reservoir acting as a temporary stormwater retention pond when reservoir levels may be above full, and the outflows are limited by the capacity of the reservoir outlet structure.

FIGURE 42.

Precipitation at Crozet WTP, Raw Outflows, and Watershed Weighted estimated inflows

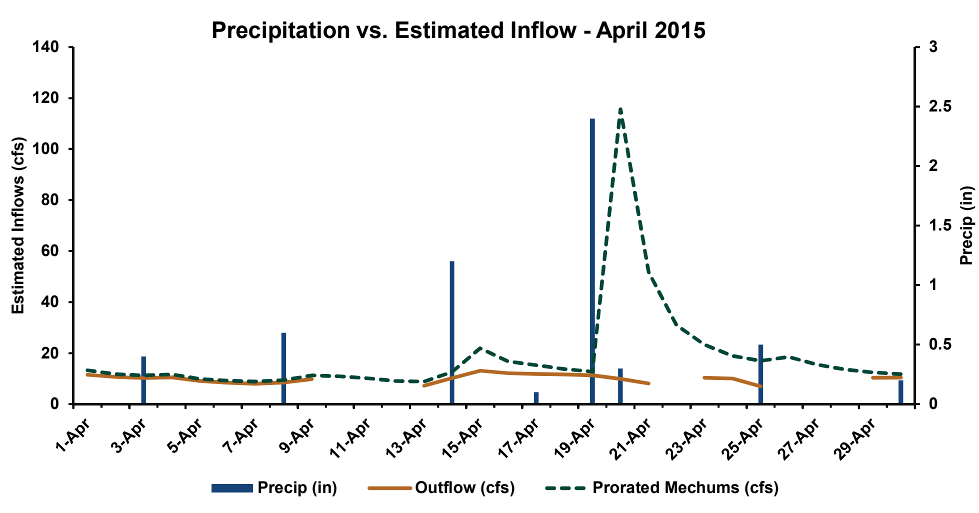


Figure 43 shows two sides of the intake tower and the limited openings in the outlet tower. When inflows during storm events exceed the capacity of the flow through the screens, water is temporarily detained in the reservoir and slowly released over time.

Using the estimated inflows from the watershed weighted method, nutrient loading for Beaver Creek Reservoir from April–October in 2015–2017 was estimated for TP, PO_4, ammonia, and nitrate. Authority staff collected samples from Watts Creek and analyzed the concentrations of each nutrient. Pictures of the Watts Creek sampling location are shown in Figure 44.

FIGURE 43.

Beaver Creek Reservoir Outlet Tower at Full Reservoir Level

FIGURE 44.

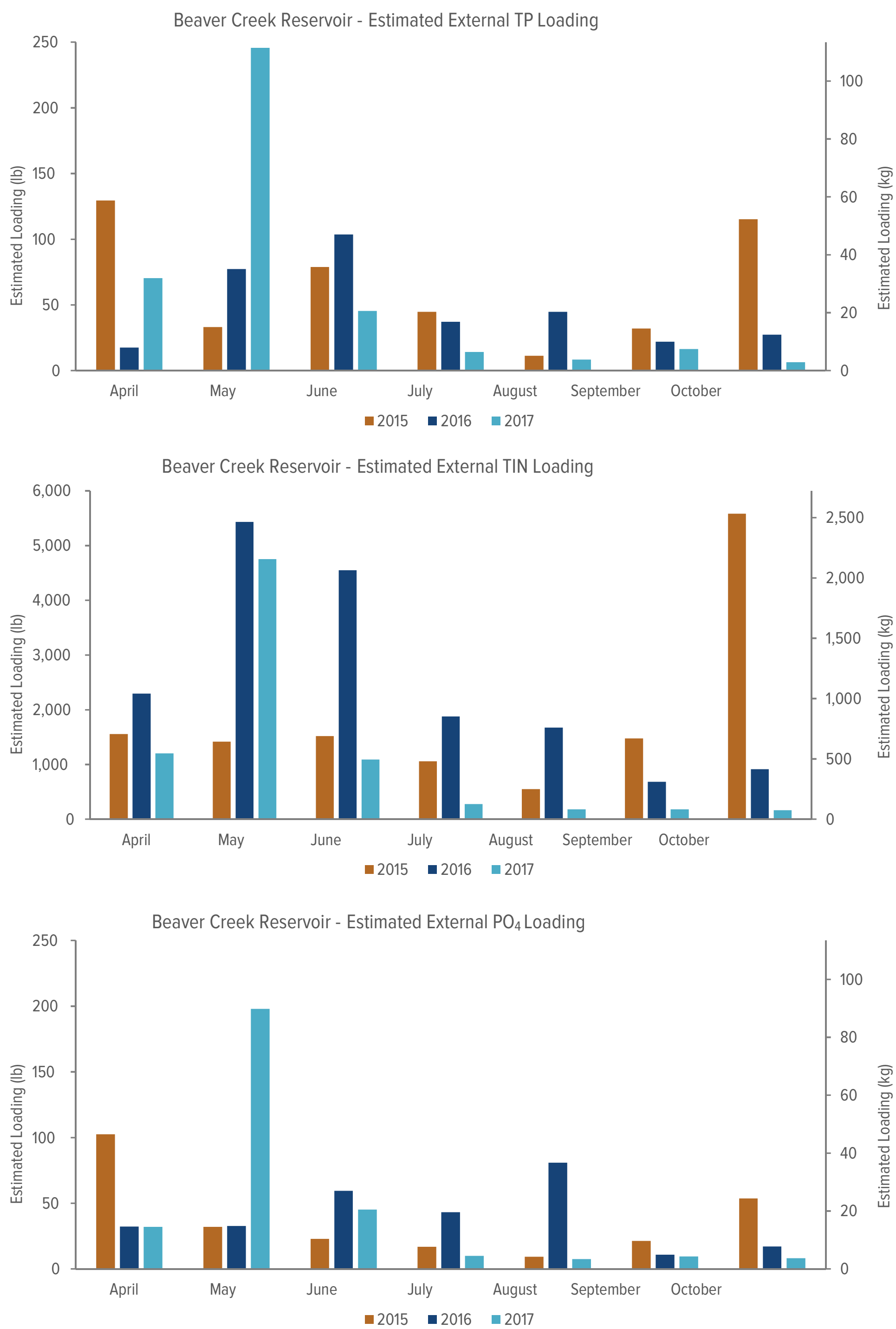
Watts Creek Sampling Location into Beaver Creek Reservoir.

Photo on Right is Looking Downstream from the Road Shown in the Picture on the Left.

Lab results for samples taken at Watts Creek were used as a midpoint date and extended to dates halfway to the next sampling date on either side and multiplied through by the estimated inflows to estimate nutrient loading. Figure 45 shows the estimated loading in lbs (left axis) and kg (right axis) for each month.

FIGURE 45.

Average Nutrient Loading in Pounds per Day



EXTERNAL LOADING

Inflow TP to BCR was calculated from watershed-weighted creek flows and nutrient concentrations during the June–August algae growth period as approximately 1.4 lb/d (635 g/d) on average and PO_4 as approximately 1.1 lb/d (499 g/d). The estimated loading was highly variable depending on the amount of flow (June–August range 0.3–3.4 lb/d TP, 0.2–2.7 lb/d PO_4). The full reservoir volume is approximately 2.2×10^9 L, so 635g TP/d × 60 (days) = 38,100 g/2 months ≈ 38×10^9 µg/2 month diluted into 2.2×10^9 L = 38/2.2 ≈ 17 µg/L total increase over two critical summer months. If diluted into only the epilimnion (assuming 2/3 of total volume) the approximate increase would be 26 µg TP/L/2 months.

INTERNAL LOADING

Bottom rise in TP from the time prior to anoxia to the period from June–August each averaged around 50 µg/L, though highly variable (≈20 µg/L in 2015, 80 µg/L in 2016 and 43 µg/L in 2017). Assuming 1/3 of the reservoir was hypolimnion ≈ 730×10^6 L 50 µg/month × (730×10^6) L = 36,500 × 10^6 µg = 36,500 g/mo ≈ 1,200 g/d. Based on the results from the sediment flux study described in Section 6, using a maximum flux of 0.6 mg-P/m²/d, approximately 0.3 lb/day (136 g/d) of PO_4 could be added to the hypolimnion.

CONCLUSION FROM INTERNAL AND EXTERNAL LOADING ESTIMATES

Based on nitrate-chlorophyll relations in other surface waters, it can be assumed that only approximately 14% of the nutrient in the water makes it to living algae at any one time. The rest is lost via incorporation into higher trophic levels, sinking out of the trophic zone as fecal pellets, and excretion. In a typical algal cell, phosphorus comprises about 0.3% of algae dry weight and chlorophyll *a* about 1% of dry weight, so TP × 1/0.3 = 3.3 chl *a* (TP: chl *a* ratio of 1:3.3). Thus, the added 26 µg/TP due to inflow from the streams could produce up to 86 µg/L chl *a* (26*3.3). Assuming as above that only 14% of this is actually present at any one time results in approximately 12 µg/L chl *a*. Measured chl *a* peaks (when not killed with copper algaecide treatments) were 11–21 µg/L so were of comparable size to those that might have been created by inflowing TP alone. Any released PO_4 from the sediments needs to get up to the epilimnion, so not all the internal releases will feed algae. The inflowing stream plume must mix into the epilimnion if it is to stimulate algae. The density indicates that it probably entered in the bottom of the epilimnion so could mix in during stormy or windy periods. Reduction in TP and/or PO_4 in the inflow streams is a potential candidate for a management method. However, watershed best management practices at present rarely accomplish this goal. Reduction in nitrate or ammonia could assist in making the P-reduction work more efficiently.

In most of the summer, the main nutrient supplies for algae blooms in the epilimnion in BCR came from inflow and recycling in the epilimnion (decay and excretion from algae, fish, zooplankton) and not from releases from the sediments. The amounts added via inflow gave an estimated average increase of 26 µg/L in the epilimnion over two months, so added TP from Watts Creek and other inflowing streams was likely a substantial contributor to the total TP. However, phosphorus is typically accumulated in the hypolimnion and can at times provide an additional source for algal growth when incorporated into the epilimnion. Larger relative contributions from phosphorus released from BCR sediments likely occur during more dry conditions. Though only three data points, the number of algaecide applications each year and the average concentration of PO_4 in the hypolimnion during anoxia are well correlated ($R^2>0.9$).

5.4.4 : Phytoplankton: Algal Chlorophyll & Water Clarity

Chlorophyll *a* peaks of 9–14 µg/L were observed during spring blooms in early May of each year with the sonde indicating potentially higher concentrations a couple of meters below the surface. Higher chlorophyll *a* peaks were observed at BC1 later in the season each year with peaks of 14 µg/L in late July 2015, 18 µg/L in late July 2016, and 21 µg/L in late June 2017. The full potential of the algae blooms was not observed as the reservoir was treated for algae through the summer each year. Blue-green algae have several unique pigments, one of which is phycocyanin which can be detected by the sonde. Following calibration of the phycocyanin probe in 2016, the phycocyanin and chlorophyll *a* sensors showed high concentrations right around the thermocline, however the timing of these peaks does not closely agree with the data from the algae counts or lab chlorophyll measurements. It is not clear why the probe did not always detect the algae that were detected by counts and chlorophyll. It could be that the tendency of these colonial buoyant algae kept them at the surface while the probe at the surface is actually measuring about 30 cm down. A test holding the probe just below the surface would be informative.

Water clarity, an important water quality variable in itself, also provides a good check on chlorophyll *a* analysis and algae counts. In Beaver Creek Reservoir, the background trophic state is revealed as mixed with a mean Secchi depth of 2.6 m (all years) and 2.9 m at the shallower BC2 station (2015), despite several algaecide applications each year. A Secchi depth of less than 2 m indicates a eutrophic state. Thus, the Reservoir is borderline mesotrophic but that is likely due to improved water clarity from the repeated use of algaecides each year.

5.4.5 : Phytoplankton: Algal Species

Algae counts through the spring–fall were dominated by blue-green algae. As might be predicted from the Reservoir's strong thermal stratification, the two most common blue-greens near the water surface were large colonial species, mostly *Aphanizomenon* with some *Anabaena* that float and sink rapidly. Both *Aphanizomenon* and *Anabaena* were already present in fair numbers (>1,000 cells/mL) by the first count of 6 July 2015. *Coelosphaerium* often occurred in high higher concentrations in the late summer and fall, including a peak concentration of approximately 38,000 cells/mL on August 30, 2016. *Planktothrix* (formerly *Oscillatoria*) which was identified by the Authority's laboratory as the dominant form in the partially mixed South Fork Rivanna Reservoir was totally absent in Beaver Creek. The other blue-green algae found at moderate concentrations was again a colonial genus, *Gomphosphaeria* but this is not normally a nuisance for drinking water supplies.

The dominant blue-green algae for most of the period April–October was typically *Aphanizomenon* or *Coelosphaerium*, with *Anabaena* as the sub-dominant genus. Both form colonies, which can be so large as to be visible to the naked eye when looking into the water. *Aphanizomenon* grows as long and straight single filaments containing dozens of cells but these soon form large colonies reminiscent of a bundle of sticks. *Anabaena* also begins as a single filament but these soon coil giving a ball-like gross appearance that is generally smaller than *Aphanizomenon*. *Coelosphaerium* grows in spherical to oval colonies held together by fine mucilage. Planktonic blue-green algae contain gas vacuoles, tiny air-filled spaces bounded by spiral bound proteins. The vacuoles can occupy up to 10% of the cell volume and set an average upwards buoyancy. The speed of rising depends on the size and shape of a blue-green algal colony; the larger the colony, the more rapidly it will float to the surface where they will cause problems for water intakes near the surface. Most of the Rivanna water intakes are near the surface. In terms of management, disturbance of the water column is likely to affect large colonial forms more than small ones.

The water column of Beaver Creek Reservoir is strongly stratified from June through October. This favors buoyant blue-green algae. The net result is that large Aphanizomenon colonies rise and sink more rapidly than the smaller Anabaena colonies and often dominate warm, eutrophic lakes. This is shown as the Aphanizomenon dominated in summer 2015 where 77% of the alga's concentrations of > 1,000 cells/mL were found in the surface waters.

The less buoyant Anabaena showed 57% of cells of similar concentration in the surface. In contrast, another common species in eutrophic waters, the colonial diatom Fragilaria showed the opposite effect with "bloom" concentrations (> 50 cells/mL) more or less constant with depth in the mixed upper 10 feet of the epilimnion. Individual Fragilaria cells are much larger than those of blue-green algae and form short colonies. However, being a diatom with a cell wall made of heavy silica, it sinks rather than floats and needs well-mixed waters to grow near the surface.

The surfacing tendencies of the nuisance blue-green algae is the reason why they were readily kept under control by surface and near-surface copper applications in Beaver Creek. Despite a similar number of applications, the more diffuse *Planktothrix* populations in South Fork Rivanna were unaffected by copper in the deeper water, as seen in Figure 33, though reduced in surface layers.

The seasonal distribution of the two dominant nuisance species was modified by the four copper algaecide applications but the high numbers in summer (BC1, 28,000 to 105,000 cells/mL) and mid-September 2015 show the potential for taste and odor and filter clogging. The vertical distribution of *Aphanizomenon* was also affected by the copper applications, which tend to kill surface algae but rarely affect deeper water. The chemistry of copper toxicity for blue-green algae indicates that the effect is short-lived, perhaps the toxic effect lasts for only a few minutes to half an hour. The likely loss routes for the initially toxic copper are chelation with natural organic matter in the water and precipitation as copper phosphate. Thus, the toxic copper fraction works very well for the surface scums but not the entire epilimnion that mixes perhaps once per day or less. That was the situation at Beaver Creek following a copper treatment on September 9, 2015. Nine days after application of copper, the surface *Aphanizomenon* abundance was relatively low (3,230 cells/mL) and possibly was comprised of lightly treated individuals that recovered from the copper toxicity or floated up from below. In contrast, the 5 and 10 feet samples on September 18, 2015 showed quite elevated concentration of between 34,000 and 38,000 cells/mL.

5.4.6 : Spatial Variability

In 2015, when both sites BC1 and BC2 were sampled, temperature and DO showed little variation over the reservoir though the volume of the hypolimnion was much smaller in the shallower upper station BC2. Nitrate in the surface waters was similar at both stations (629 µg/L, BC1 & 579 µg/L at BC2). Total-P was even more similar with values of 21 and 20 µg/L at the two surface stations.

In terms of algae, there was little difference with the upper station's annual growth season average of 4.3 µg/L chlorophyll *a* (BC2-S) and 4.5 µg/L found at the dam station (BC1-S). These were both low chlorophyll *a* values and were strongly influenced by the location of the copper sulfate algaecide application.

In contrast with the chlorophyll *a* data, there were unexpectedly fewer overall blue-greens at the surface at the upper stream station BC2. Phytoplankton at this site were dominated by the same algal species as at BC1 but cell numbers at BC2 were about a third to a half until the fall when concentrations between the two stations varied, again possibly due to copper applications.

Based on the relative similarity between stations BC1 and BC2 and due to resource constraints, site BC2 was not sampled during monitoring in 2016 or 2017. However, in June 2017 a series of transect measurements were taken on the reservoir, discussed in more detail in Section 6, and showed higher sonde measured chlorophyll *a* concentrations further up in the reservoir, suggesting that monitoring of BC2 should be resumed if resources are available.

5.5 : Totier Creek Reservoir

Each of the three sampling locations for Totier Creek Reservoir (TCR) are shown in Figure 46. All three locations were sampled each year from 2015 through 2017 during the growth season.

5.5.1 : Temperature and Thermal Stratification

Due to its shallow max depth of about 5 m, the water column was weakly stratified on the few occasions that measurements were made. Stratification patters were similar from 2015–2017, though temperature profiles are limited, so patterns may be more complex than suggested by the limited data. The warm 17°C water column in the spring was soon warmed further to 25°C in upper meter of the surface water during early-summer. However, cooler denser water below probably maintained some degree of resistance to vertical mixing.

By mid-summer, the water column was almost isothermal at 24–28° C. The bottom sediments were thus hot and conducive to the release of nutrients when other factors were favorable. The reservoir was mixed by mid-fall, with perhaps some other mixing events occurring throughout the spring and summer.

FIGURE 46.

Sampling Locations for Totier Creek Reservoir

5.5.2 : Dissolved Oxygen

Because the shallow water column was only partially mixed for most of the summer, dissolved oxygen was soon depleted in the lower water zone (approximately 1.5–5 m). Anoxia in the bottom water generally ran from July to mid-September and was terminated when overturn occurred.

5.5.3 : Suspended Solids

The most obvious feature of Totier Creek Reservoir is the amount of sediment in the water, the reasons for which are discussed further in Section 6. The reservoir TSS averaged 10 mg/L (range 3–20 mg/L) for the two surface sites compared with 4 mg/L for similar sites in Beaver Creek Reservoir. The inflowing river, surprisingly, is often less turbid than the reservoir (mean TSS = 5 mg/L, range 1–25 mg/L). The mean TSS for the Beaver Creek Reservoir inflow measured at site BC3 was surprisingly much higher at 9 mg/L (ignoring high values of 67, 150, and 237 mg/L).

Here the "dam" site TC1 is to the side of the dam in a cove where the outlet structure is located. The "upper" site TC2 is in the upper part of the dam but has a riverine character.

Despite the very different locations of the two stations there was little difference in suspended sediments in TCR. The deep part of the reservoir is still shallow, and the reservoir is riverine for most of its length so re-suspension of sediments occurs right up to the dam.

5.5.4 : Nutrients

5.5.4.1 PHOSPHORUS

The TP values in Totier Creek were quite high. High seasonal surface TP averages were found in all years (2015: 52 μg/L, 2016: 71 μg/L, 2017: 63 μg/L) with little difference between the two sampling sites. This average TP value places Totier Creek firmly in the eutrophic class. This may be due to the turbid reservoir water that was observed during the sampling events. Trophic state classification based on P should generally not be used in lakes with high clay turbidity because algae may be unable to utilize a large portion of the measured phosphorus. Bottom water TP was typically similar or even higher (2015: 75 μg/L, 2016: 65 μg/L, 2017: 71 μg/L) again with little difference between stations. The inflowing water had a slightly lower TP than the in-reservoir samples. This is not surprising since the TSS, which might be expected to contain P-rich particles, was much lower in the inflow than in the reservoir.

5.5.4.2 NITROGEN

The concentrations of nitrate in Totier Creek Reservoir were higher than in the other authority reservoirs. Nitrate levels were high in all years, with surface water means of 1,106 µg/L, 1,773 µg/L, and 834 µg/L in 2015, 2016, and 2017 respectively. Individual measurements in the surface waters of the reservoir were as high as 3,510 µg/L in 2016. Bottom waters showed similar high nitrate levels (mean in 2015: 1,072 µg/L, 2016: 1,646 µg/L, 2017: 812 µg/L)

The inflowing waters of Totier Creek followed a similar pattern with high nitrate concentrations, which is not surprising since the hydraulic residence time of the reservoir is low. However, the nitrate was not the same in the river and reservoir. Totier Creek nitrate averaged significantly higher than the in-reservoir nitrate (mean in 2015: 1,495 µg/L, 2016: 3,520 µg/L, 2017: 1,215 µg/L) showing that some removal of nitrate, possibly by algae, had occurred in the reservoir waters.

These nitrate values are very high and would fully saturate algal uptake systems. In a virgin ecosystem, an expected background concentration would be 100–200 µg/L nitrate for much of the algal growing season. The likely source of high nitrate concentrations is agriculture, row crops or manure application, and residences which also produce nitrate from septic tanks as it flows easily through shallow groundwater. In any case, Totier Creek Reservoir is classified as eutrophic based on its nitrate loading alone.

Ammonia in the surface waters of the two index stations was also high with seasonal averages between 152 and 429 µg/L. Given the anoxic conditions found in the reservoir for part of the summer, the increase in ammonia to a seasonal average for the bottom waters of between 383 and 783 µg/L was not unexpected, except for the highest values. A concentration of 2,940 µg/L recorded from the bottom waters at TC2 in August 2015 was potentially problematic if correct. This is a toxic level for many fish and also stimulates some undesirable blue-green algae, particularly Microcystis. Surface ammonia concentrations on this date showed only 72–131 µg/L and the bottom waters at TC1 showed 825 µg/L. Ammonia Concentrations higher that 1,000 µg/L have not been recorded at any site since.

Inflowing ammonia, in contrast was lower with seasonal averages between 132 and 277µg/L which indicates that internal loading is important in the growth of algae in Totier Creek.

5.5.5 : Phytoplankton: Algal Chlorophyll & Water Clarity

Totier Creek Reservoir averaged 7 µg/L of chlorophyll at the two surface sites in 2015, 12 µg/L in 2016, and 18 µg/L in 2017. Peak values of chlorophyll were 16–45 µg/L, which is indicative of a nuisance algae bloom. The high peak of 45 µg/L was recorded at site TC1 in early May, though this value does not seem to be supported by the algae counts, only 1,751 cells/mL, or the sonde, which recorded little chlorophyll *a* or phycocyanin.

The sonde data indicated narrow bands of chlorophyll confined to the metalimnion (thermocline area) in May 2015, June 2016, August 2016, and October 2017. The calibrated sonde indicated chlorophyll *a* values as high as 25–40 µg/L in 2016 present in narrow bands. The data indicate that small amounts of blue-green algae were often present in these narrow bands.

5.5.6 : Phytoplankton: Algal Species

The main algae in Totier Creek in 2015–2017 were blue-green algae. The dominant genus, identified by the Authority's laboratory in 2015, was *Planktothrix* (formerly *Oscillatoria*) in August (approximately 23,000 cells/mL) which is not surprising since ammonia was high at this time (bottom water approximately 3,000 µg/L), though surface waters did not rise to high levels until September. However, in August 2015 this species was accompanied by two other sub-dominant nuisance blue-green algae, *Microcystis* and *Anabaena* (concentrations ~ 2,500 cell/mL). Turnover in September substantially reduced algae concentration, though *Planktothrix* continued at lower numbers (approximately 1,500 cells/mL) through September. Most blue-greens had declined by October. In 2016, the dominate blue-greens were identified as *Aphanizomenon* and *Planktothrix*, and in 2017 the dominant blue-greens were identified as *Merismopedia* and *Planktolyngbya*.

6 : Special Studies

To help refine management recommendations for the Rivanna Water and Sewer Authority's (Authority) reservoirs, special studies were conducted on Beaver Creek (BCR), Totier Creek (TCR), and South Fork Rivanna Reservoirs (SFRR). These studies included sediment nutrient flux, sediment coring, spatial heterogeneity, and watershed evaluations. The methods and results of each study are described in this section.

6.1 : Sediment Studies

Internal loading of nutrients from the anoxic sediments, together with external loading, are the two likely causes of eutrophication and nuisance algae blooms in the Authority reservoirs. In reservoirs where external nutrient loading is controlled, internal loading may persist and continue to degrade water quality. Oxygenation or aeration can suppress anoxia to reduce internal loading, but an alternative is to immobilize or remove the surface sediment layer that contains most of the nutrients. To evaluate the potential for internal loading, the vertical and areal extent of sediment nutrients and historical changes in water quality, analyses of sediment samples from SFRR and BCR were performed.

6.1.1 : Sediment Nutrient Flux

Anoxic conditions at the bottom of a reservoir typically results in releases of phosphate, ammonia, iron, and manganese from sediment. Oxygen uptake or fluxes of these soluble substances from lake or reservoir sediments is primarily due to activity in the upper few millimeters (mm) of the sediment-water interface or micro zone. The surface of the sediment in eutrophic reservoirs in summer is usually covered with a fine network of anaerobic (anoxic) bacteria that are decomposing the sunken algae from that year's spring bloom. Other processes deeper in the sediment can have an effect but are usually much slower than those at the very surface.

Sediment sample from Beaver Creek Reservoir (above) and a sealed and plugged incubation chamber (below). June 14. 2017

In conjunction with the consulting team and Authority Staff, Dr. Marc Beutel at the University of California Merced, conducted sediment nutrient flux studies for two sites each in SFRR and BCR to evaluate the release of nutrients and metals from the sediments under anoxic conditions to inform how the reservoirs may respond to oxygenation of the hypolimnion. A summary of the method and results is provided in this section, and Dr. Beutel's full report is provided as Appendix I.

6.1.1.1 METHOD

The sediment samples were collected with an Ekman clam dredge at the sites shown in Figure 47. Samples were collected on June 13, 2017 at SFRR and on June 14, 2017 in BCR. The dredge was deployed, the messenger was sent down to close the sampler jaws and the device was slowly and gently brought to the surface and onto the boat. Most overlying water drained from the sampler immediately but a small amount remaining on the mud surface was carefully poured off. The incubator tube was slid down into the intact sediment to a depth of about 10 cm. The bottom seal/lid was slid from the side by hand into the mud and over the bottom of the incubator tube. The tube was then carefully lifted from the dredge and placed on the rigid plastic base. A foam plug with a plastic barrier was inserted to stabilize the sediment for shipping. Duplicate sediment samples were collected for each site. Bottom water samples were collected at each site using a Kemmerer sampler and placed into containers for shipping. Sediment and bottom water samples were placed in ice chests and shipped to Dr. Beutel's lab in California.

Upon arrival at the lab, each incubation chamber was filled with reservoir bottom water and allowed to acclimate for one day in a dark incubator at 10°C, the approximate temperature of bottom water in BCR, though bottom water at SFRR can exhibit higher temperatures, around 12°C. Chambers were incubated for a 10-day oxic period and a 23-day anoxic period. During the oxic period, water was bubbled with air and samples were collected on days 0, 3, 5, 7, and 10.

During the anoxic period, water was bubbled with nitrogen gas and samples were collected on days 0, 4, 7, 10, 15, and 23. During the final anoxic phase, a nearby wildfire forced evacuation and a power outage, subjecting chambers to temperatures on the order of 30°C. The collected samples were analyzed for nitrate, ammonia, phosphate, iron, and manganese. Detection limits were 15 µg/L for phosphate, 30 µg/L for ammonia, and 50 µg/L for nitrate. Samples below the detection limits were set equal to half of the detection limit for flux calculations. Samples collected on oxic day 5 were incorrectly preserved and as a result, only the ammonia analyses were retained in the data set.

FIGURE 47.

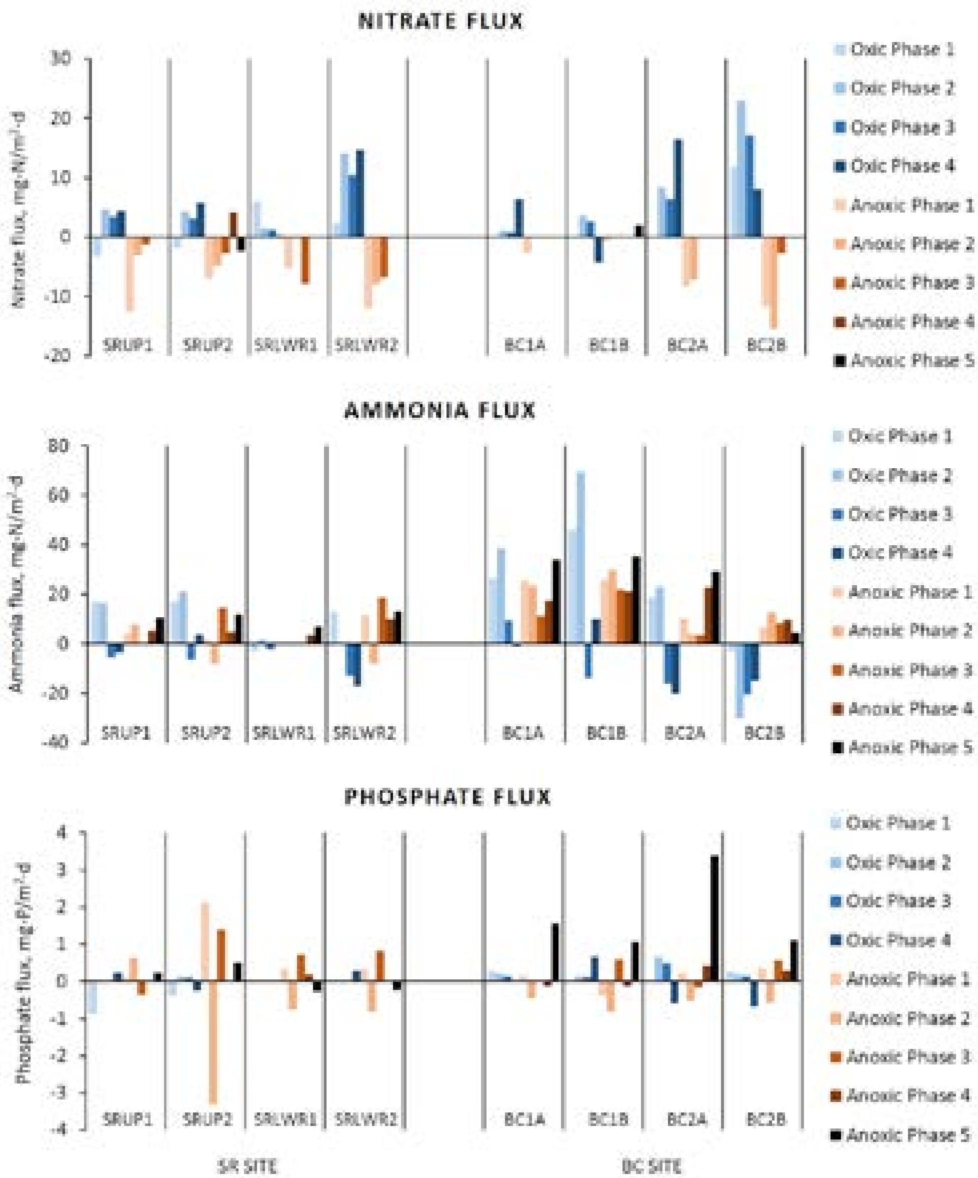
Sediment nutrient flux sampling locations for Beaver Creek Reservoir (top) and South Fork Rivanna Reservoir (bottom)

6.1.1.2 RESULTS

Figure 48 through Figure 51 come directly from Dr. Beutel's report and illustrate the fluxes and concentrations of nitrate, ammonia, phosphate, iron, and manganese from the sediment. Both Beaver Creek and South Fork Rivanna Reservoirs tend to release ammonia and manganese under anoxic conditions following expected patterns. Sediment in BCR tends to release iron as expected under anoxic conditions, but SFRR showed no consistent increase in iron flux, as shown in Figure 48 and Figure 49. Phosphate fluxes from both reservoirs were low and showed no consistent pattern, as shown in Figure 48. During the 5th anoxic period, days 15–23, column water temperatures increased to around 30°C; BCR columns showed a greater phosphate flux, but this was not seen in the SFRR columns. While a bottom water temperature of 30°C is unrealistic for BCR, the result does suggest that the sediment phosphate is more labile in BCR than in SFRR. Figure 49 shows

FIGURE 48.

Nutrient fluxes from sediment during oxic and anoxic phases.



that mean phosphate concentrations in all samples were typically higher under anoxic than oxic conditions, but the differences were not large enough or consistent enough to show a pattern of high phosphate flux under anoxic conditions. The expected behavior of metals and ammonia, and the lack of change in phosphate concentrations from columns SRUP1 and BC1A can be seen in Figure 51. The results indicate that sediment in BCR has a higher potential to release reduced compounds than SFRR, especially under warmer conditions. SFRR does not appear to have significant pool of phosphate liable to release under anoxic conditions. Results suggest that internal loading of ammonia and metals could be reduced in both reservoirs by maintaining an oxygenated sediment-water interface, although the phosphate fluxes under anoxic conditions are not as high as expected.

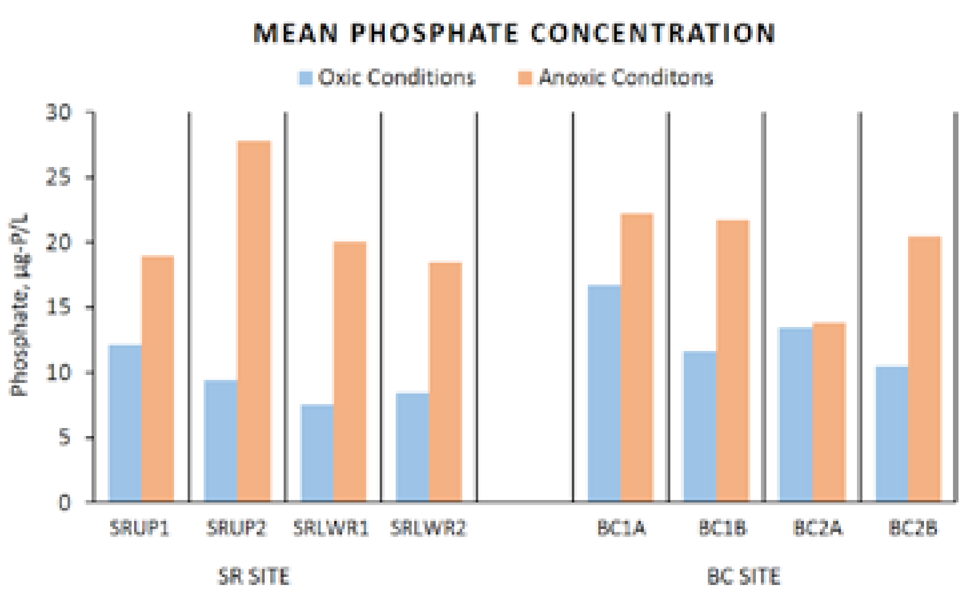
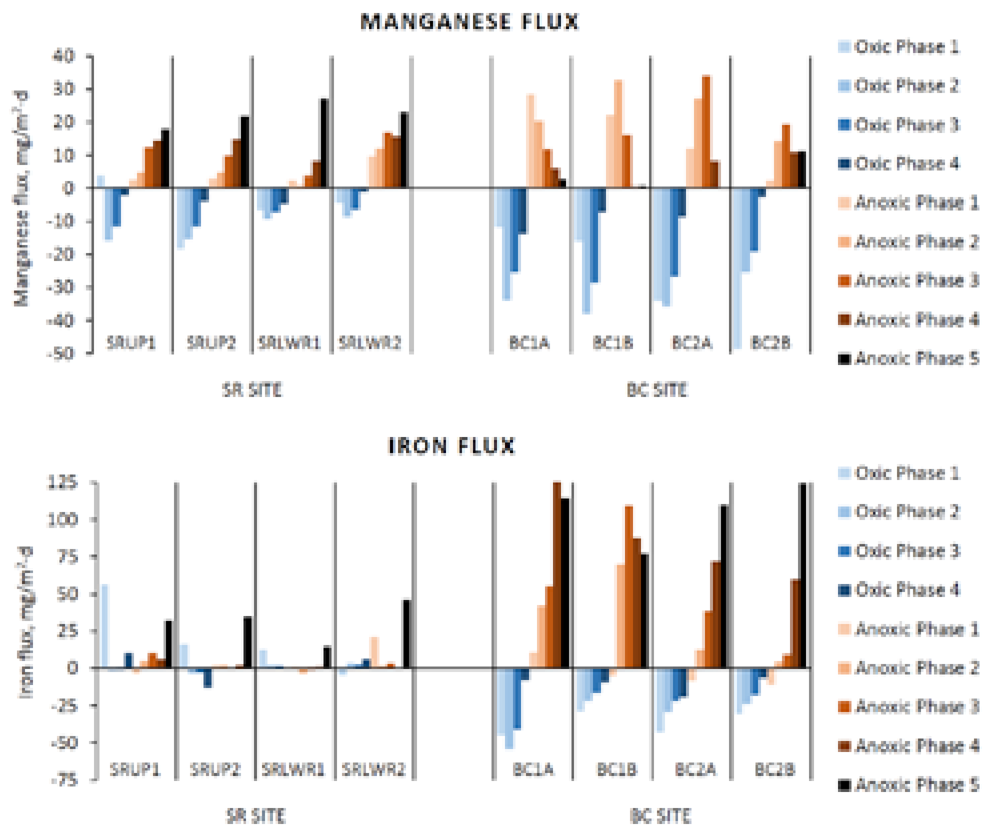


FIGURE 49.

Mean phosphate concentrations in chamber water during oxic and anoxic phases.

FIGURE 50.

Metal fluxes from sediment during oxic and anoxic phases.



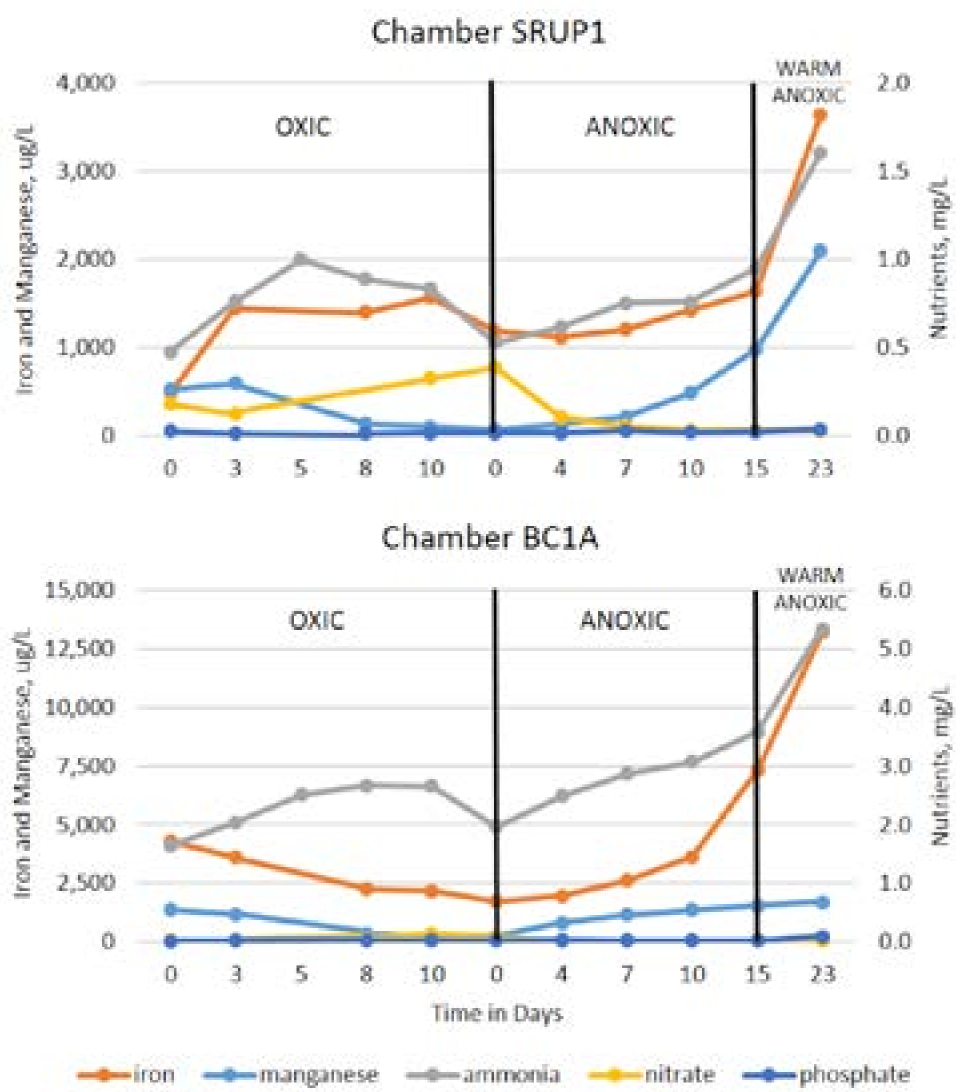


FIGURE 51.

Water quality data from SRUP1 (top) and BC1A (bottom) columns.

6.1.2 : Sediment Core Samples

One purpose for the sediment core sampling in SFRR was to determine if there was a major change in nutrients and thus algae before and after the 1988 removal, via the Crozet Interceptor, of treated but nutrient-rich wastewater from the SFRR watershed. There is little firm data about the change on water quality in SFRR, but anecdotal accounts state that the water quality improved. If confirmed by the sediment cores, then a sufficient decrease in nutrients could improve water quality in SFRR in the future. A change at SFRR and not at BCR would suggest that any improvement observed in the SFRR sediments was due to nutrient diversion and not some other event since BCR was upstream of the wastewater discharge.

In conjunction the consulting team and Authority staff, Dr. Steven Kuehl at the Virginia Institute of Marine Science (VIMS), with assistance from Authority staff, collected sediment cores and estimated the sedimentation rates in South Fork Rivanna and Beaver Creek Reservoirs from measured

^{210}Pb and ^{137}Cs. Duplicate cores were collected at sites near the dam in both reservoirs and analyzed for changes in several variables vs depth: total nitrogen, total Kjeldahl nitrogen, nitrate, ammonia, total phosphorus, total copper, relic algal chlorophylls and accessory pigments, and diatom frustules. Summaries of the methods and results are provided in this section, and Dr. Kuehl's full memo on the sedimentation rates is provided as Appendix J.

6.1.2.1 SEDIMENTATION RATES

On July 13, 2017, VIMS collected core samples using a manual push corer from two predetermined sites in SFRR at approximately the same locations as the samples for the nutrient flux study. Core samples were collected at three sites in BCR, a lower near dam site, below the confluence of the Beaver and Watts Creek arms, and an upper site in the Watts Creek arm. The core recovery depths ranged from 65–85 cm in SFRR and from 20–35 cm in BCR. Due to a malfunction of the Authority's GPS unit, coordinates of the sampling sites were not recorded. Approximate sample locations are shown in Figure 52. Each core was extruded in 5-cm intervals and placed in a drying oven. Once dry, the samples were ground and homogenized. ^{210}Pb and ^{137}Cs were determined using non-destructive gamma counting.

At all sites in BCR (BC-D, WC, and BC-B), and the upper site in SFRR (LF-U), sedimentation rates were calculated using linear regression of the ln(activity) versus depth in the core. The near dam site in SFRR showed non-steady-state characteristics, probably a result of changes in the textural characteristics of the sediment. For this site, sedimentation rate was estimated based on the ^{137}Cs maxima at 80 cm core depth, which may represent a time near 1963/64 when atmospheric fallout from nuclear testing peaked.

As shown in Table 18, sedimentation rates in SFRR were approximately four times higher than those at Beaver Creek Reservoir. This result is consistent with field observations, the recovery depths, and the lack of ^{137}Cs at the bottom of cores taken in BCR, which suggests that material at the bottom of the cores was deposited prior to significant atmospheric fallout of ^{137}Cs in the mid 1950's, and likely represents a thin pre-dam veneer of alluvial sediment.

FIGURE 52.

Sediment core locations in Beaver Creek (top) and South Fork Rivanna (bottom) Reservoirs

South Fork Rivanna Reservoir	Sedimentation Rate (cm/yr)
SF-D (near dam)	1.5
LF-U (upper)	1.7
Beaver Creek Reservoir	**Sedimentation Rate (cm/yr)**
BC-D (near dam)	0.35
WC (Watts Creek branch)	0.40
BC-B (below branch confluence)	0.39

TABLE 18.

Summary of calculated Sedimentation Rates (error estimate ± 20%)

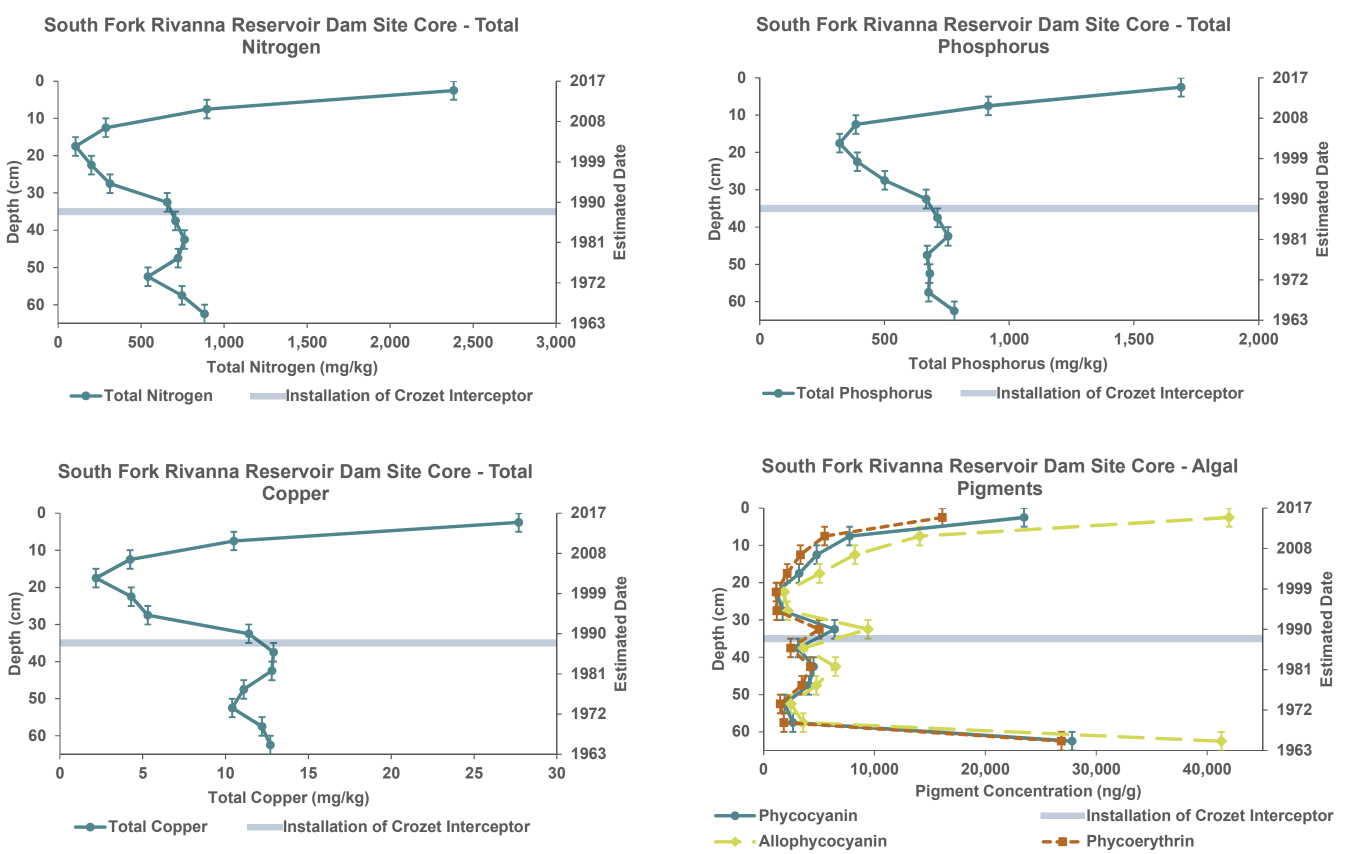
The recovery depths of the SFRR cores closely agree with transect measurements taken by HDR Engineering Inc. in the 2010 bathymetric survey and volume analysis report.

6.1.2.2 PALEOLIMNOLOGY RESULTS

The sedimentation rates above were adjusted to the depth of material recovered in the duplicate cores from sites SF-D and BC-D to estimate the dates of deposition. These estimates assume a steady sedimentation rate and negligible compaction of older sediment.

The depth/age profiles from SFRR show a dramatic change at the time of sewage diversion in 1988. All variables showed a change at this date which was about 35 cm below the current sediment surface. Total-N decreased from over 700 mg/kg to 105 mg/kg by the mid-2000s. Similar clear declines occurred in nitrate, ammonia, and TP. Phycocyanin is a pigment found only in blue-green algae and some seaweeds so will indicate blue-greens in this case. The changes in phycocyanin following wastewater diversion were not as clear as those found for nutrients but did show a decline from about 3,000 to 6,000 ng/g to 1,200 ng/g. Two other pigments characteristic of blue-greens showed a similar decline. Relic chlorophyll and those of some other accessory pigments were at levels too low for trends to be seen. Total nitrogen, phosphorus, copper, and blue-green algae pigments in the SFRR dam site core vs. core depth are shown in Figure 53.

FIGURE 53. Select parameters vs core depth at SFRR dam site

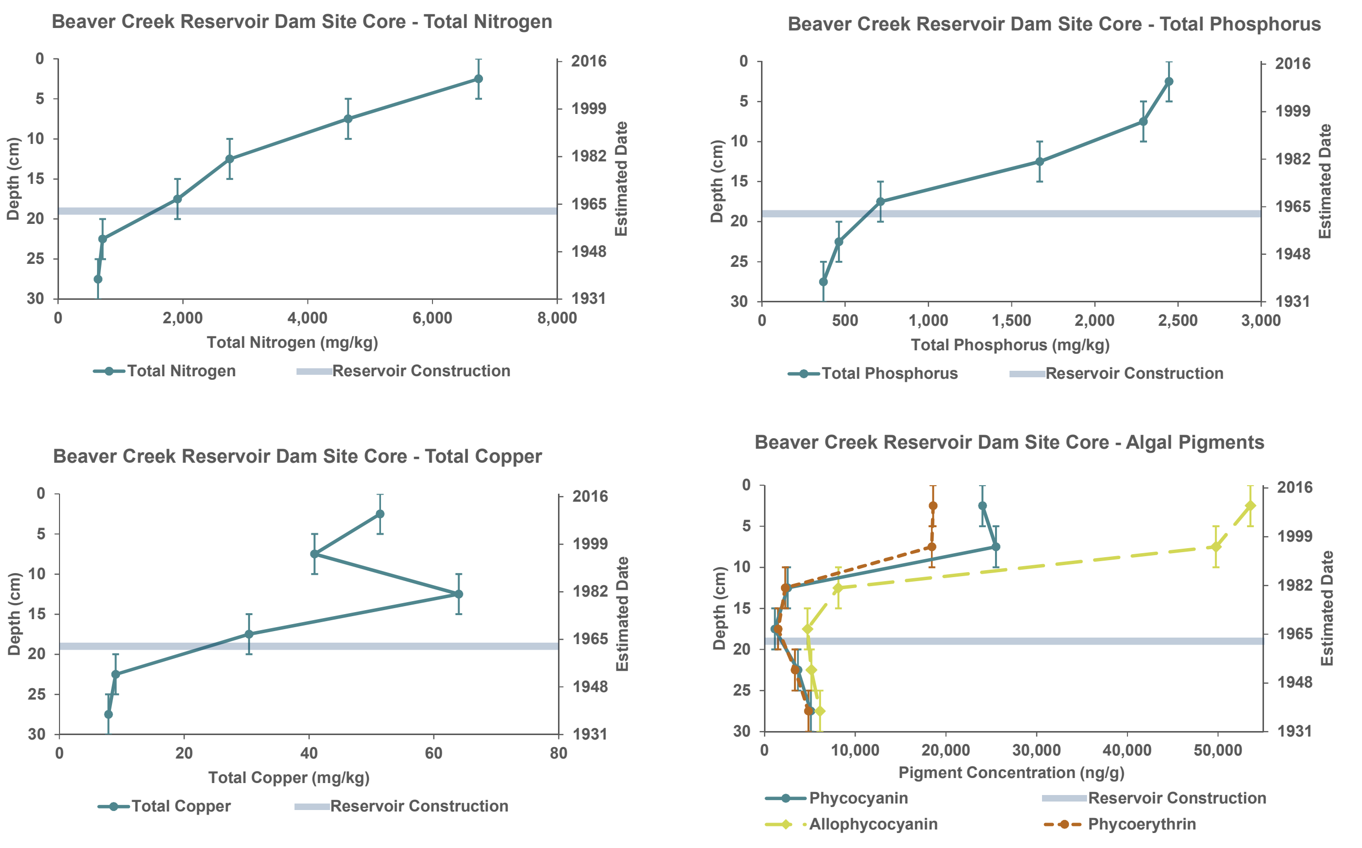


The copper profile over time followed the same trends; relatively high (10–13 mg/kg) up to 1987 and then dropping gradually to only 2 mg/kg in 2005. Since copper in various forms was the main form of algae bloom treatment until recently when it was supplemented at times by peroxide, the copper trend indicates that the anecdotal accounts (together with a few data points) of a large and sustained decline in nutrients did decrease nuisance blue-green algae blooms in the 1990s.

The core profiles show higher surface concentrations of all variables. However, modern (surface) concentrations of most nutrients and pollutants in cores are always much larger than historical values partially because most degradation of organic bulk fractions occurs over the first few years.

In BCR, the depth-age profiles for nutrients, algae, and copper are very different from SFRR. The BCR profiles show a gradual increase in all parameters. Total nitrogen, phosphorus, copper, and blue-green algae pigments in the BCR dam site core vs. core depth are shown in Figure 54. This indicates a gradual buildup characteristic of sediments when converted from river to reservoir conditions. The gradual change supports the idea that changes seen in the SFRR profiles are due to the removal of nutrients in 1988.

FIGURE 54. Select parameters vs core depth at BCR dam site



6.1.3 : Additional Sediment Sampling

During the same time as the collection of the cores, Authority staff collected additional dredge samples in both BCR and SFRR. These samples were analyzed for total lead, total nitrogen, total Kjeldahl Nitrogen, nitrate/nitrite, phosphorus, ammonia, and total copper. The results of the analyses are presented in Table 19.

TABLE 19.

Results from sediment grab sample analyses, July 13, 2017, mg/kg dry weight

	Total Lead	Total Nitrogen	Total Kjeldahl Nitrogen	Nitrate/ Nitrite	Phosphorus	Ammonia	Total Copper
BC Upper	35.1	5,515	5,515	<7.47	1,830	265	292
BC 1	50.7	8,042	8,042	<10.7	4,062	512	203
SR Dam	26.5	2,970	2,970	<4.26	1,986	128	36.5
SR Early	22	2,832	2,832	<3.46	1,452	131	26.6

While copper toxicity can vary by species and lake chemistry, MacDonald et al. (2000) established a consensus-based probable effect concentration (PEC) of copper, based on other published freshwater sediment quality guidelines, of 149 mg/kg dry weight above which harmful effects on benthic organisms are likely to be observed. The total copper taken at the two sites in BCR on 13 July 2017 show sediment copper concentrations well in excess of 149 mg/kg. However, the top 5cm of the near-dam sediment core show a total copper concentration of only 51 mg/kg, well below the PEC. Total lead concentrations in both reservoirs are well below the PEC of 128mg/kg established by MacDonald et al. (2002). Levels of nitrogen and phosphorus in the upper sediment of both reservoirs are sufficient to stimulate internal loading.

Table 20 shows the phosphorus fractions from sediment grab samples taken near the dam at BCR and SFRR. Much of the sediment phosphorus in both reservoirs is present as Fe oxide and hydrous oxide bound P which may be released under anoxic conditions. Ca-Bound P is only released at low pH which has not been observed in SFRR or BCR.

TABLE 20.

Sediment phosphorus fractions in BCR and SFRR, mg/kg dry weight

Location	Non-Occluded Al- and Fe- Bound P	Carbonate Sorbed P	Fe oxide and Hydrous Oxide Bound P	Ca-Bound P
BC Dam	8.4	254.2	244.6	496.7
SR Dam	3.0	252.4	161.8	131.0

Because of the high copper levels in the BCR sediment grab sample, Authority staff collected additional sediment samples within the BCR watershed and in-reservoir at the upper ends of the Beaver and Watts Creek arms. The sample locations are shown in Figure 58 as BC3 and BC8–BC13. Because orchards and vineyards often use copper as a fungicide, high levels of copper in the reservoir could be due to high levels within the watershed. Samples from BC3, BC8, BC9, BC10, and BC13 had an average total copper concentration of 6.8 mg/kg dry weight, while the two samples in the reservoir arms, BC 11 and BC12, had an average total copper concentration of 69.2 mg/kg dry weight. These results suggest that the application of copper algaecides may be the source of elevated copper levels within the reservoir compared to the watershed. However, the levels measured in reservoir are still well below the PEC of 149 mg/kg.

6.1.4 : Conclusions for Sediment Samples

Oxygenation/aeration can suppress anoxia and the release of reduced compounds/nutrients such as soluble phosphate, ferrous iron, and ammonia from the sediment. Phosphorus inactivation methods such as Alum or Phoslock will suppress only the release of PO_4, and in-reservoir treatments would be needed at an estimate 2–5 year interval due to external loading. An alternative is to remove the surface sediment layer that contains most of the nutrients. The nutrient removal process is akin to municipal street sweeping or cutting brush to prevent wildfires but has rarely been adopted for reservoirs due to cost, despite higher costs that come with eutrophication. However, while shallow suction dredging could potentially be cost effective, the large external loads would necessitate frequent removal of sediment to be affective in addressing eutrophication. Based on the sediment nutrient flux results, we estimate that internal loading could account for up to 50 percent of the monthly nutrient loads to BCR and up to 15 percent of the monthly loads to SFRR in drier months.

If the nutrient load in SFRR can be reduced to 1988 levels, there should be less algae. Since regular monitoring of nutrients before and after the wastewater diversion was not conducted, only a theoretical estimate can be made. Internal loading can be reduced to low levels with various management methods (alum for PO_4, oxygenation-aeration for PO_4, NH_4, Fe, Mn). External loading occurs in the Authority reservoirs as waters flows in year-round, but its contribution is not well known. Studies on storm flows and algae blooms in summer-fall are so far inconclusive and may be complicated with deeper mixing. Reduction of external loading is effective for point sources, like the 1988 diversion, but will be harder for non-point sources, which appear to constitute a large majority of nutrient sources within the watersheds. However, a 50 percent decline in external TP would likely reduce algae blooms and the corresponding need for algaecide treatments, improve water quality including the reduction of potential taste and odor events, and reduce water treatment costs. Any benefits to water quality should also carryover when the transfer of water from SFRR to Ragged Mountain Reservoir occurs.

The core paleolimnology work suggests that substantial nutrient reduction can reduce many of the water treatment problems and result in water quality improvements in the Authority reservoirs. Given the high cost of some advanced water treatment processes, such as granular activated carbon (GAC), substantial watershed and/or in-reservoir nutrient removal may be cost-effective depending upon the selected management method.

6.2 : Spatial Heterogeneity

Nuisance blue-green algae are both vertically and horizontally mobile and may be present elsewhere in the reservoir while not present at the index sampling sites. A knowledge that high concentrations of blue-green or other algae, or turbidity plumes can occur in other parts of the reservoir assists in making recommendations for management technuiqes.To determine the spatial variability, measurements were rapidly taken at stations along transects in South Fork Rivanna and Beaver Creek Reservoirs, shown in Figure 55.

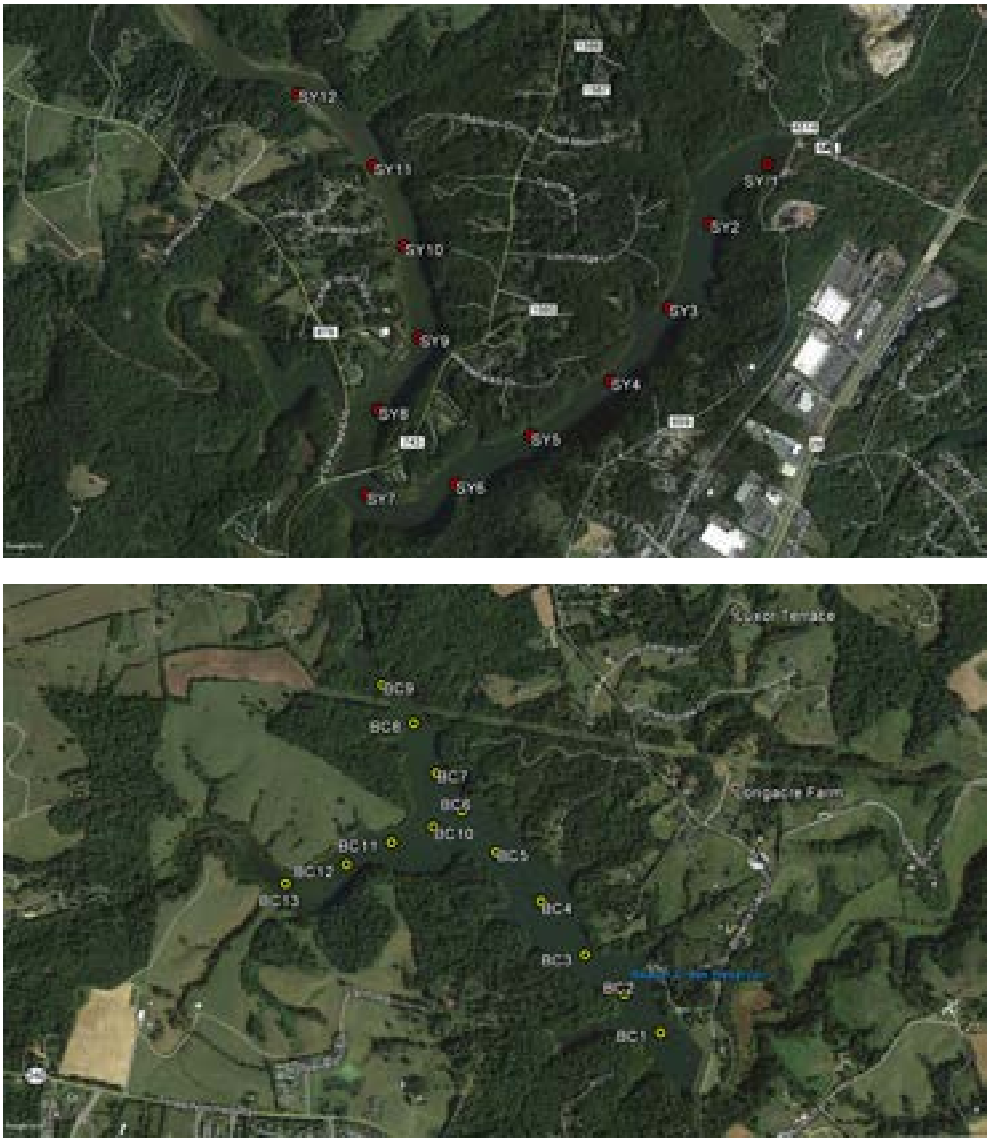
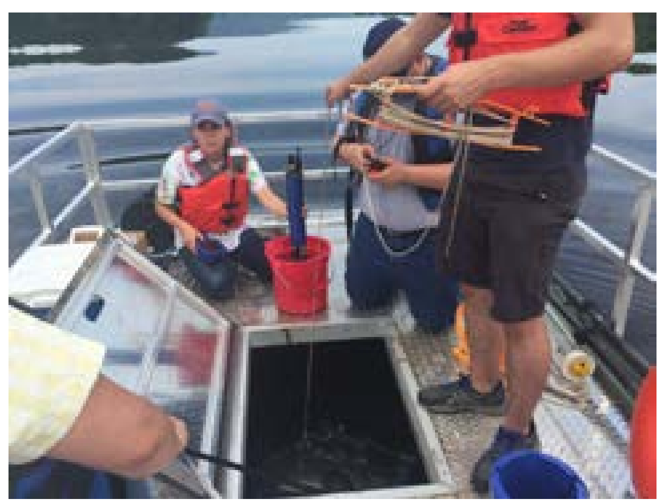


FIGURE 55.

Location of transect stations in South Fork Rivanna (top) and Beaver Creek (bottom) Reservoirs

At each station along the transect, we measured secchi depth and performed a sonde measurement in water grabbed from the surface. Figures 56 and 57 show the Secchi depth (left, yellow) in meters, the sonde measured chlorophyll a (center, green) in µg/L, and the sonde measured turbidity (right, brown) in FNU for the transect measurements taken on BCR and SFRR respectively. Additional sonde parameters for each site are presented in Table 21 for Beaver Creek, and Table 22 for SFRR. Note that data for sites BC2 and SY4 were not saved by the sonde.



Secchi and sonde measurements being performed as part of Beaver Creek Reservoir transect. June 14. 2017

FIGURE 56.

Secchi depth and sonde measured chlorophyll *a* and turbidity along Beaver Creek Reservoir transect

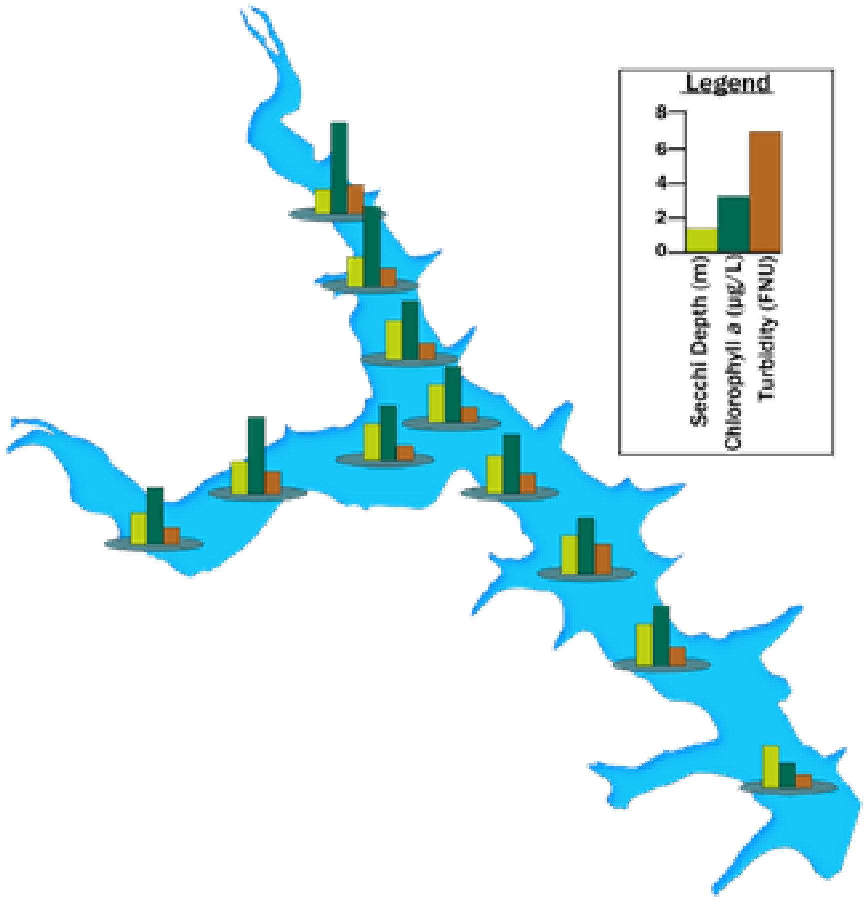
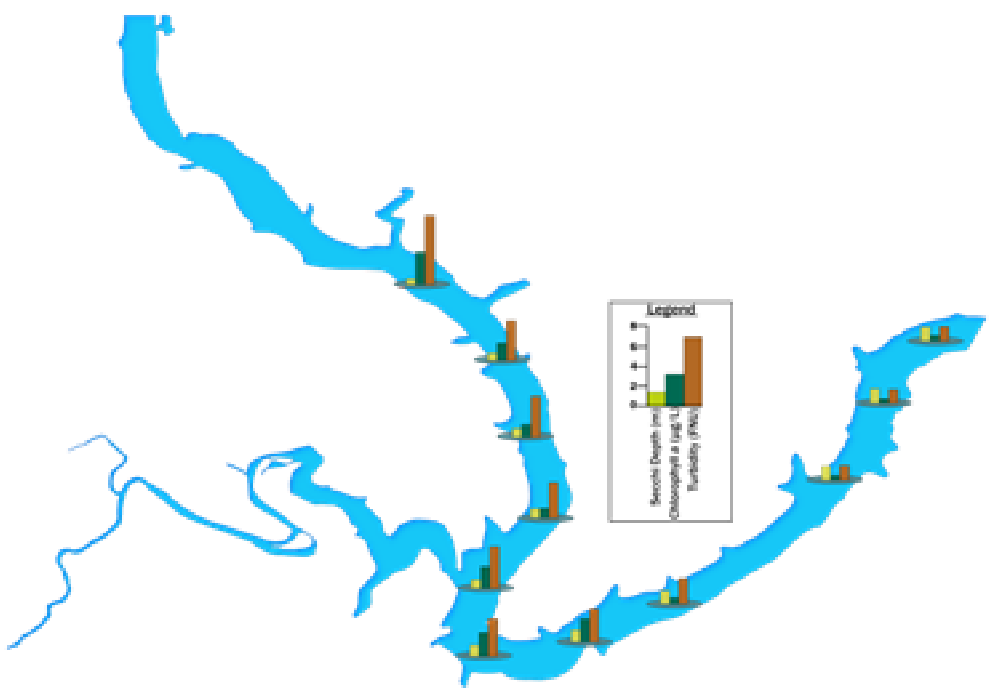


FIGURE 57.

Secchi depth and sonde measure chlorophyll *a* and turbidity along SFRR transect



The Beaver Creek Reservoir Transect measurements were conducted on June 14, 2017 over a span of approximately 32 minutes. Secchi depths in Beaver Creek Reservoir ranged from 1.4 m in the upper area of the Watts Creek branch to 2.48 m near the dam with an average depth of 2.1 m. Sonde chlorophyll *a* ranged from 5.3 µg/L in the upper area of the Watts Creek branch to 1.4 µg/L near the dam with an average concentration of 3.6 µg/L. Turbidity ranged from 1.8 FNU in the upper area of the Watts Creek branch to 0.8 FNU near the dam with an average value of 1.2 FNU.

The SFRR transect measurements were conducted on June 12, 2017 over a span of approximately 37 minutes. Secchi depths in SFRR ranged from 0.65 m at the uppermost station to 1.50 m near the dam with an average depth of 1.1 m. Sonde chlorophyll *a* ranged from 3.3 µg/L at the uppermost station to 0.5 µg/L near the dam with an average concentration of 1.5 µg/L. Turbidity ranged from 7.1 FNU at the uppermost station to 1.4 FNU near the dam with an average value of 3.4 FNU. In addition to secchi and sonde measurements at SFRR, grab samples were taken at each station and tested for microcystin using Abraxis test strips; all stations returned a negative result for the presence of microcystin.

On the days of the transects, both reservoirs showed higher concentrations of chlorophyll *a*, higher turbidity, and lower secchi depths at the upper ends. Due to the spatial variability, the dam stations alone may not provide a good estimate of reservoir wide conditions on any given day, so both the upper and lower reservoir index stations should be utilized for routine monitoring.

TABLE 21.

Secchi and sonde data for transect sites in Beaver Creek Reservoir

Site	Temp °C	Sp Cond µS/cm	DO mg/L	pH	Turbidity FNU	Chlorophyll µg/L	BGA-PC µg/L	Secchi m
BC1	27.24	148.09	8.98	7.06	0.81	1.44	-0.01	2.48
BC3	27.51	149.00	9.25	7.61	1.09	3.52	0.10	2.45
BC4	27.38	148.07	9.25	7.77	1.80	3.33	0.11	2.3
BC5	27.57	148.47	9.20	7.95	1.16	3.45	0.13	2.2
BC6	27.55	148.19	9.16	7.99	0.90	3.26	0.13	2.24
BC7	27.63	148.70	9.37	8.06	0.97	3.41	0.12	2.29
BC8	27.52	148.28	9.39	8.11	1.10	4.72	0.19	1.76
BC9	27.47	148.43	9.09	7.92	1.69	5.34	0.24	1.45
BC10	27.68	149.20	9.21	7.77	0.89	3.20	0.10	2.15
BC12	27.73	149.61	9.02	7.98	1.34	4.51	0.18	1.93
BC13	27.78	149.15	9.03	7.97	0.98	3.33	0.03	1.85

TABLE 22.

Secchi and sonde data for transect sites in South Fork Rivanna Reservoirs

Site	Temp °C	SpCond µS/cm	ODO mg/L	pH	Turbidity FNU	Chlorophyll µg/L	BGA-PC µg/L	Secchi m
SY1	27.27	145.15	9.35	7.33	1.47	0.58	-0.03	1.45
SY2	27.78	145.36	9.30	7.34	1.43	0.51	-0.02	1.5
SY3	27.48	145.65	9.22	7.37	1.54	0.52	-0.04	1.45
SY5	27.69	145.37	8.99	7.24	2.61	0.65	-0.03	1.35
SY6	25.70	145.00	9.44	7.26	3.41	2.40	0.09	1.3
SY7	26.39	143.97	9.14	7.21	3.82	2.44	0.08	1.15
SY8	27.08	144.22	9.11	7.12	4.28	2.21	0.07	0.9
SY9	28.79	144.72	8.70	7.08	3.65	1.01	-0.09	0.95
SY10	28.60	145.53	8.68	7.08	4.19	1.28	-0.04	0.9
SY11	28.82	145.13	8.59	7.10	4.16	1.82	-0.05	0.8
SY12	29.86	145.01	8.86	7.12	7.12	3.34	-0.01	0.65

6.3 : Beaver Creek Reservoir Watershed Study

Beaver Creek Reservoir receives a significant amount of external nutrients. To determine if external nutrient loads could be effectively addressed through best management practices (BMPs) at select sites within the watershed, sampling of creeks within eight sub-watersheds was conducted during base flow and storm flow conditions. Base flow samples were taken on 23 February 2017 and storm flow samples were taken on 31 March 2015. Sub-watersheds were chosen and delineated based on land use and accessibility to the sampling point. Each stormflow and baseflow sample from BC3–BC10 was analyzed for TP, PO_4, Ammonia, Nitrate, TKN, TSS, and *E. coli*. The sampling locations and boundaries of each sub-watershed are shown in Figure 58 and the results of the analyses are shown in Figure 59. Sites BC3, BC9, and BC10 flow into the Watts Creek branch of the reservoir and sites BC4, BC5, BC6, BC7, and BC8 flow into the Beaver Creek Branch. Sediment samples from sites BC3, and BC8–BC13 were taken on 19 November 2017 and analyzed for total copper. The results of those analyses are discussed in Section 1.3.

FIGURE 58.

Beaver Creek Reservoir sub-watersheds and sampling locations

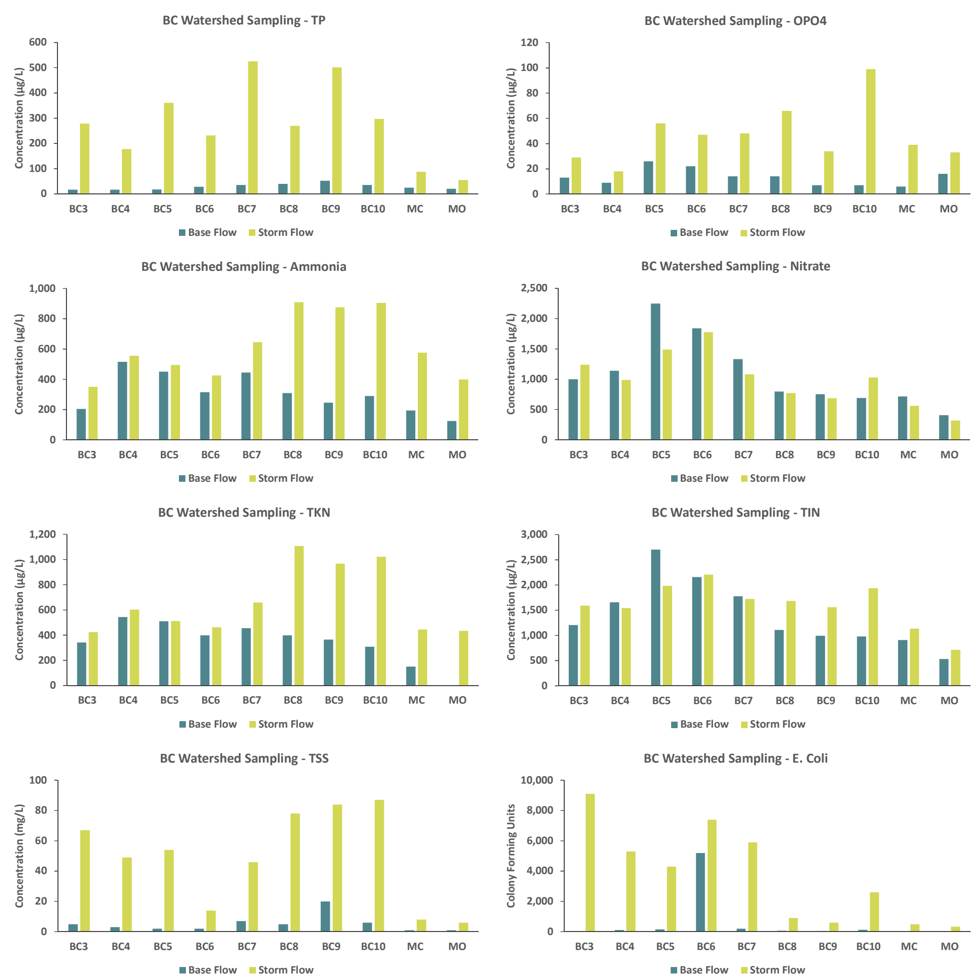
Algae grow using inorganic nutrients only (phosphate, nitrate, and ammonia). Phosphate is easily liberated from TP by an algal enzyme, alkaline phosphatase, so TP is a good measure of all the P available for growth. Since algae do not have the nitrogen equivalent of alkaline phosphatase, total Inorganic Nitrogen (TIN = ammonia + nitrate) is the best measure of bioavailable N for algal growth.

The maximum desirable concentration of TP within the creeks and reservoir is 32 µg/L and preferably less on average. During base flow conditions, TP ranged from 17–52 µg/L on the Watts Creek branch and 17–40 µg/L on the Beaver Creek branch. During storm flow, TP ranged from 270–519 µg/L (Watts Creek) and 270–526 µg/L (Beaver Creek). The total average TP was 31 µg/L and 331 µg/L during base and storm flows respectively. TP was lower in the lower part of the watershed, with an average of base flow TP of 23 µg/L and average storm flow TP of 315 µg/L, approximately 10 times more than the maximum desirable.

The maximum desirable concentration of TIN within the creeks and reservoir is 300 µg/L or less. TIN ranged from 979–1,206 µg/L on the Watts Creek branch and 1,106–2,701 µg/L on the Beaver Creek branch during base flow

FIGURE 59.

Laboratory results from Beaver Creek watershed sampling



and 1,560–1,935 µg/L (Watts Creek) and 1,681–2,201 µg/L (Beaver Creek) during storm flow. The average TIN across the watershed was 1,571 µg/L and 1,778 µg/L during base and storm flows respectively. During both base and storm flow, TIN concentrations are more than five times the maximum desirable, with no individual site falling below this limit.

PO_4 concentrations averaged 14 µg/L during base flow and 50 µg/L during storm flow. The maximum desirable concentration of PO_4 is 10 µg/L or less. The average TSS during base flow was 6 mg/L and 60 mg/L during storm flow.

6.3.1 : Beaver Creek Reservoir Watershed Conclusions

Coliforms, nitrate, and phosphate indicate some effect of wild and/or domestic animals (on-going), septic system leachate, and/or fertilizer (old or new) on creek nutrients. General watershed sanitary behavior is needed. Examples include stream buffers, small detention ponds, enforcement of existing regulations on horse stabling/manure handling, fertilizer applications guidelines for the public (farmers should already have some), rain gardens, creek fences to keep cattle from directly accessing stream (with water troughs as replacement), and limitations on construction during rain. However, such sanitary behavior is hard to enforce, is unpopular, invades privacy, and is generally ineffective for soluble nutrients.

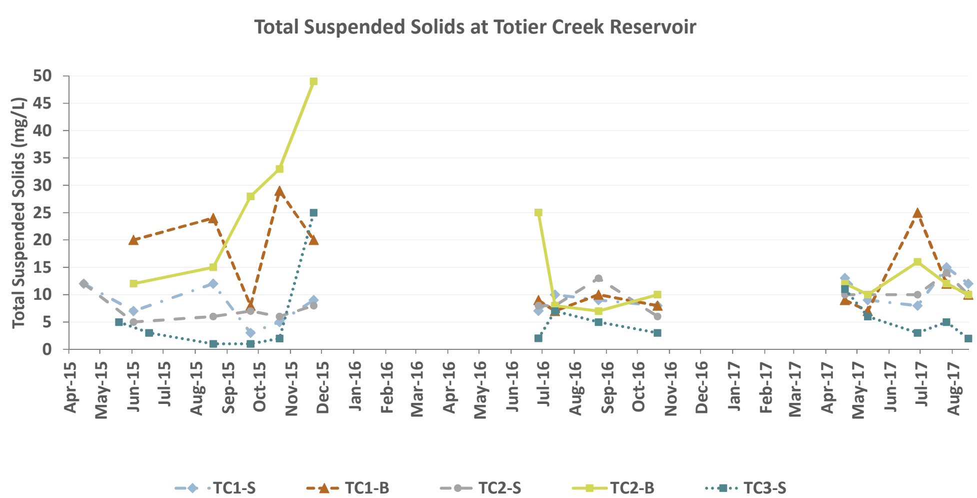
Construction of unit process nutrient-removal wetlands using water diverted from, cleaned up, and returned to the stream have proven successful in some applications and have good public acceptance, especially since they can be designed for wildlife and public access if needed. Since water is diverted from the creek, the availability of suitable land is better since the wetland does not have to be adjacent to the creek on private land. Nitrate and many other undesirable pollutants, including particulate TP, can be removed by unit process wetlands but removal of soluble PO_4 is poor unless special steps are made, such as alum addition. The wetlands also are less effective during colder months.

6.4 : Totier Creek Watershed

Totier Creek Reservoir often experiences issues with high TSS and turbidity. The reservoir often appears brown and murky, even during periods of low flow. TSS samples taken at sites TC1 and TC2 from 2015 through 2017 are shown in Figure 60 and show that the TSS in bottom water is typically higher than that in the surface water, with mean values of 16 mg/L and 9 mg/L for bottom and surface water respectively. One outlier of 204 mg/L at site TC1–B on April 15, 2015 was removed from the data to better show differences. While measurements taken in 2015 show a significant difference in bottom vs surface water TSS, this difference is not so apparent in the measurements in 2016 and 2017. The average TSS of the inflow was lower than that of both the surface and bottom water at 7 mg/L.

FIGURE 60.

Total suspended solids at Totier Creek Reservoir surface (dashed), bottom (solid), and inflow (dotted)



The high TSS in bottom water when compared to the relatively low TSS of the inflow, and the high TSS in both surface and bottom water when compared to the TSS of the inflow, as well as the reservoir's shallow and riverine nature suggests that bottom sediment is being resuspended throughout the entire reservoir. However, this is likely not the only source of the turbid appearance. As shown in Figure 61, based on data from the USDA NRCS soil survey, the Totier Creek watershed contains approximately 30% group D soils, particularly adjacent to creeks. Due to poor infiltration capacities, these soils are prone to producing overland flow when thoroughly wetted, which delivers considerable sediment loads to the creeks during storms.

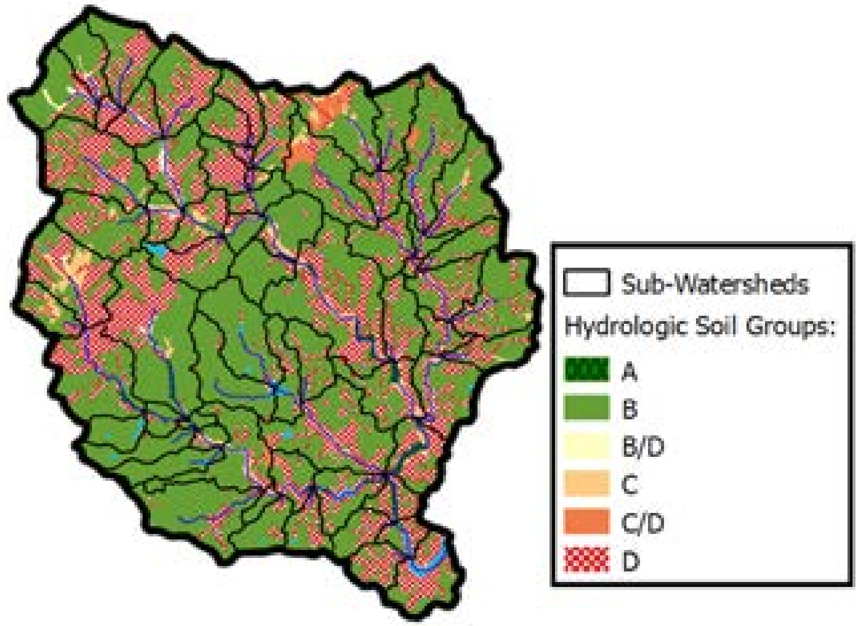


FIGURE 61.

Hydrologic soil groups in Totier Creek Reservoir watershed

Much of the Totier Creek Reservoir watershed lies within a Triassic Basin known as the Scottsville Basin. The Scottsville basin is one of many early Mesozoic rift basins that appear in the eastern United States running roughly parallel to the Appalachian orogen. The rocks within these basins are assigned to the Newark Supergroup (Luttrell, 1989). The Triassic sedimentary units in the Scottsville basin are comprised of sandstone, siltstone, shale, and conglomerates that non-conformably overlie older metamorphic rocks, schists, phyllites, and slates (Johnson et al., 1985), which can be seen in outcrop by the reservoir spillway. The Triassic rocks within the basin are likely more readily weathered and eroded than the metamorphic rocks to the east and west of the basin and provide the dominant sediment source to the streams and ultimately to the reservoir. While some sediment comes from direct erosion of the basin bedrock, most comes from developed soils. Totier series soils formed in the material weathered from the red Triassic shales and siltstones and, based both on NRCS Soil Survey data and field observations, typically contains a large amount of fine particles.

The fine particles contained in the soils surrounding Totier Creek and its tributaries are typically not easily eroded due to cohesive forces between particles. However, at higher flow velocities these particles are entrained by the river flow or by overland flow and carried into the reservoir. Due to their small size and plate-like morphology, the fine particles can remain suspended for extended periods of time, even in waters with very low flow velocities. Based on field observations and aerial imagery, most of the soil is protected by vegetative cover, which helps to anchor soils and prevent splash erosion from raindrop impact and subsequent erosion from sheetwash. Instead, the majority of the sediment likely comes from erosion of the banks during high flow, with contributions from mass wasting events in areas with steep slopes.

While the effect of cattle in the area is likely relatively minor, based on tracks observed on a tributary of Totier Creek, there are areas where cattle have direct access to streams, which can accelerate bank erosion, and stir up material on the riverbed, providing additional sediment to the stream load during lower flow conditions.

Soils derived from Triassic rocks in the Scottsville Basin on a tributary of Totier Creek upstream of the reservoir (left) and mass wasting occurring on steep slope downstream of the reservoir (right). June 15, 2017.

7 : Case Studies

To help refine the recommended management strategies for the five Rivanna Water and Sewer Authority (Authority) reservoirs, DiNatale Water Consultants conducted a survey of nine separate water utilities that operate reservoirs with similar characteristics to those operated by the Authority. To the extent that answers were known and the utility was willing to provide them, each utility was asked questions about the following:

1. Basic utility information
2. Basic reservoir information
3. Basic reservoir hydrology
4. Reservoir access and uses
5. Sampling program
6. Water quality issues
7. Management methods used
    a. Effectiveness
    b. Capital and operating and maintenance costs
1. Watershed management and monitoring

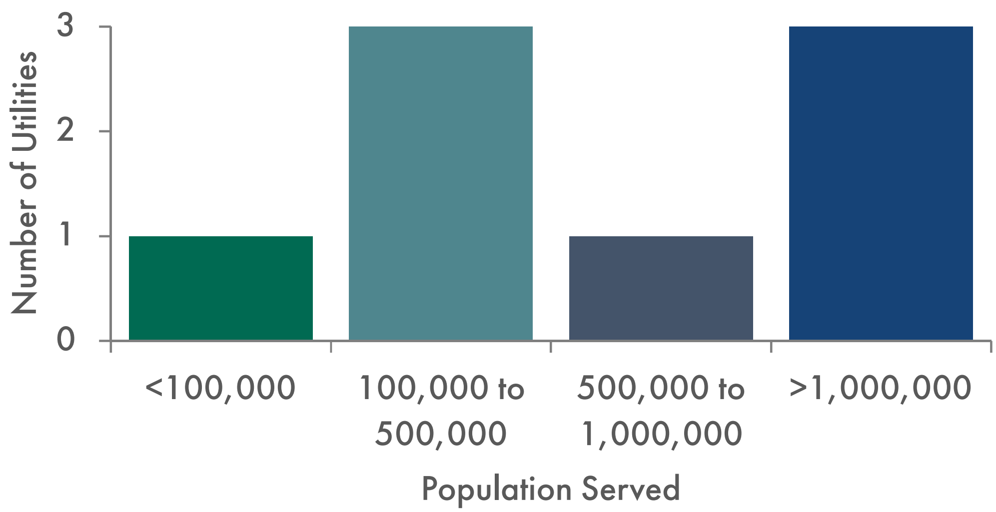
Each reservoir has its own unique characteristics and dynamics, and methods that work in one reservoir may not work in others. The results of this survey are intended to show how various utilities manage their reservoirs, and their satisfaction with these management methods to help inform decisions on continued monitoring and the practicability of the management methods that have been identified for each reservoir.

7.1 : Summary

A total of eight utilities provided information for the reservoir management survey. The utilities surveyed range from smaller utilities serving less than 20,000 customers to utilities which operate in several different states with over 15,000,000 customers. Figure 62 shows the number of utilities surveyed based on the population served. Due to different demands in different geographic locations, average annual demand may provide a better classification of utilities. Average annual demands range from about 2 MGD to over 1 BGD. The number of utilities surveyed based on their average daily demand is shown in Figure 63. For the purpose of this case study, very large utilities are those with an average demand greater than 200 MGD, large utilities are those with an average demand between 100–200 MGD, mid-sized utilities are those with an average demand between 50–100 MGD, mid-small sized utilities are those with an average demand between 25–50 MGD, and small utilities are those with an average demand less than 25MGD.

FIGURE 62.

Number of utilities by population served



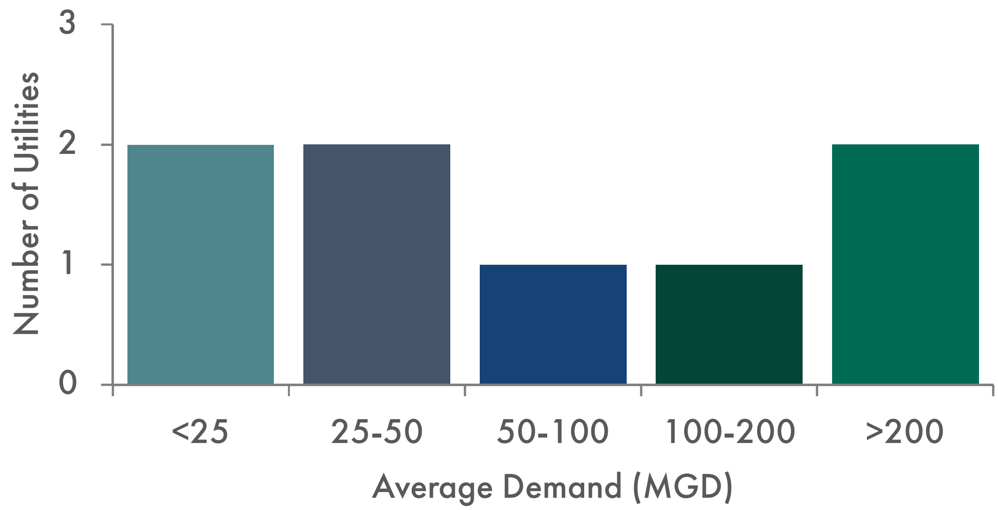


FIGURE 63.

Number of utilities by average demand

The surveyed utilities used a wide variety of methods to maintain water quality within their reservoirs. The percentage of utilities actively utilizing or planning to utilize in-lake management methods is shown in Figure 64.

The majority of those surveyed utilize algaecide, either as a primary or supplementary method, to maintain water quality. On average, the utilizes ranked the importance of algaecide in maintaining water quality a 5 out of 10, with responses ranging from 1 to 10. While those utilities that utilized other management methods in conjunction with algaecide rated it less important and only used algaecides as final measure, other utilities relied more heavily upon its use, finding it crucial to maintain water quality. The one utility that did not use algaecide had used it previously, but after the installation of a hypolimnetic oxygenation system (HOS) in 2012 has not applied algaecide since. Typically, utilities utilize copper based algaecides, with one smaller utility utilizing a peroxide based algaecide. Peroxide based algaecides typically cost significantly more than their copper based counterparts, which may explain their lack of use by the surveyed utilities.

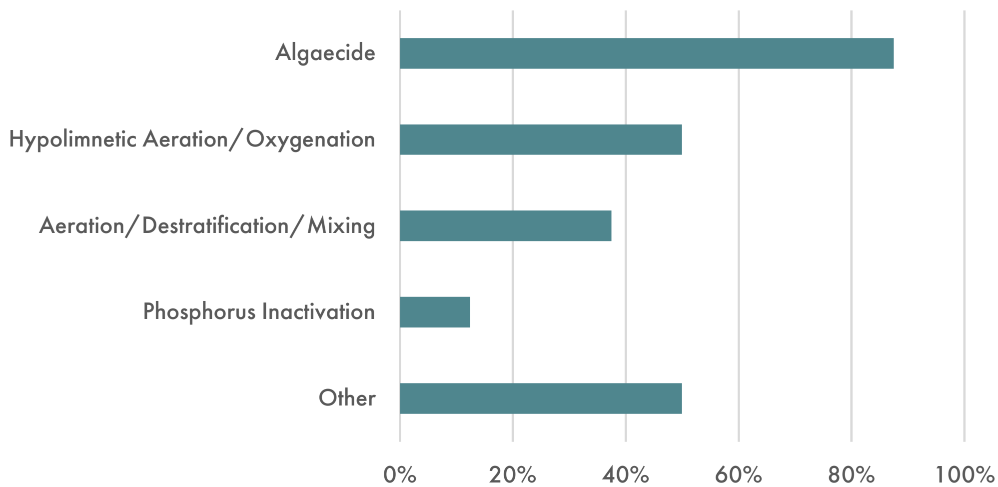
Hypolimnetic aeration/oxygenation systems are used by four of the surveyed utilities in seven different reservoirs. Three utilities utilize hypolimnetic oxygenation using either side stream supersaturation, downflow bubble contactors (Speece cone), or line diffusers and one utility uses a hypolimnetic aeration chambers. On average, the utilities rated the importance on the hypolimnetic aeration/oxygenation systems an 8.5 out of 10 in maintaining water quality with ratings ranging from 7 to 9 on individual reservoirs.

Three of the utilities survey utilize aeration/destratification/mixing methods. Two utilities utilize Solar Bees, and one utilizes aeration to destratify shallower portions on the reservoir in conjunction with the use of a side-stream super saturation hypolimnetic oxygenation system. On average, the utilities rated the systems a 5.75 out of 10 in maintaining water quality with ratings ranging from 5 to 8 on individual reservoirs.

Other methods utilized include ultrasonic algae control buoys, flow curtains, dilution/flushing, selective intake/outlet depths, drawdown, and grass carp. One utility planned to apply lanthanum modified bentonite (Phoslock) to a reservoir, but at the time of survey had not completed the application. Each of these methods was only utilized by one utility surveyed, and typically used in conjunction with other management methods.

FIGURE 64.

Percentage of surveyed utilities using select management methods



Every utility surveyed conducted routine in-lake monitoring of their terminal supply reservoirs. The percentage of surveyed utilities that monitor for common parameters is shown in Figure 65. The most common monitoring interval for both the growing season and winter was once per month. During the growing season, one utility noted sampling twice per week, two utilities noted sampling once per week, and one utility noted sampling every other week, the rest noted typically sampling once per month and commonly increased frequency if water quality issues arise. During the winter, one utility noted weekly sampling, one noted sampling every other week, and two noted that sampling only occurs should water quality issues arise. Every utility surveyed made use of at least one multi-parameter sonde for monitoring purposes, and most relied upon in-house labs for the majority of other analyses.

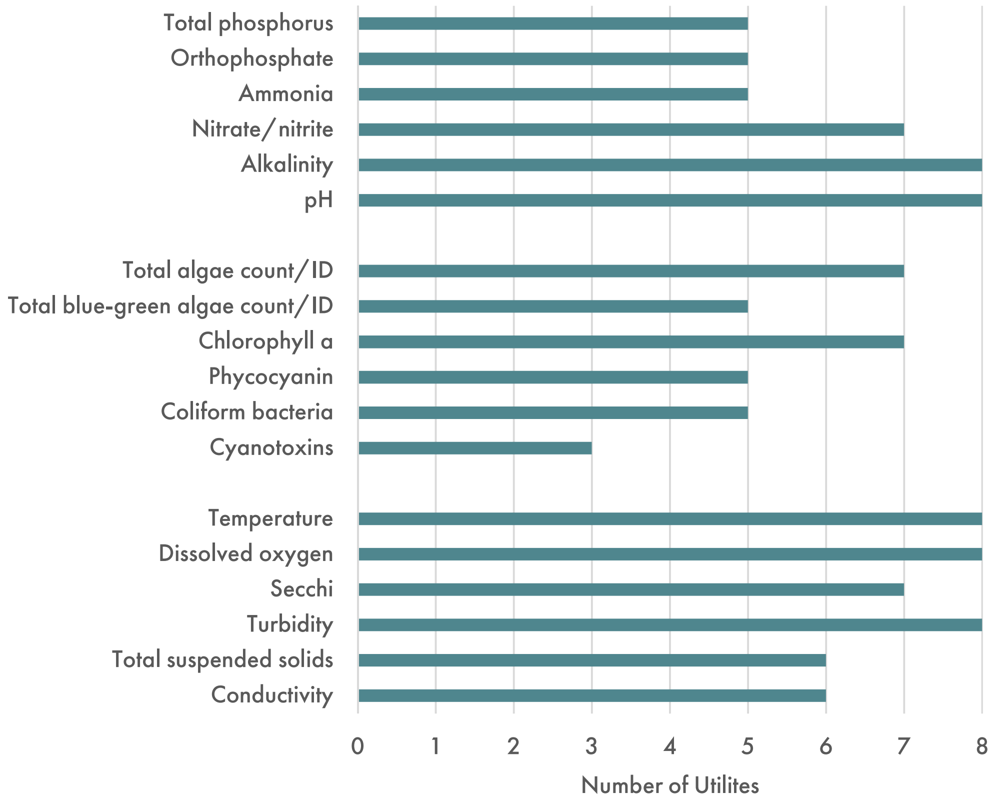


FIGURE 65.

Percentage of surveyed utilities monitoring for select parameters

7.2 : Mid-Sized Virginia Utility 1

This mid-sized Virginia utility provides raw and treated water to approximately 1 million total customers within multiple cities with an annual demand of approximately 27 BG (74 MGD). The utility operates a total of nine reservoirs for raw water supply, 5 "Intown" reservoirs, and 3 "Western" Reservoirs. The Western Reservoirs account for more than 90% of the raw water supply while the Intown Reservoirs serve predominately as backup.

The Intown Reservoir system consists of five reservoirs; the physical characteristics for each reservoir are shown in Table 23. These reservoirs are the result of damming former small tributaries of a large bay. The reservoirs are shallow, with an average mean depth of less than 6 feet.

The Western Reservoirs are a system of three interconnected reservoirs; the physical characteristics for each reservoir are shown in Table 24. Starting in 1977, water has been imported via a trans-basin pipeline to the Western Reservoirs.

TABLE 23. Physical characteristics of the Intown Reservoirs

	Surface Area when Full (Acres)	Length of Shoreline (Miles)	Storage Capacity (BG)	Watershed Area (Acres)	City Owned Land (Acres)	Mean Depth (Feet)	Year Acquired
Intown Reservoir No. 1	193	11.2	0.295	1,912	229	4.7	1885
Intown Reservoir No. 2	193	5.3	0.372	1,048	213	5.9	1898
Intown Reservoir No. 3	480	22.0	1.033	2,603	686	6.6	1898
Intown Reservoir No. 4	49	3.2	0.130	791	67	8.1	1871
Intown Reservoir No. 5	77	6.0	0.108	1,200	194	4.3	1871
Totals	**992**	**47.7**	**1.938**	**7,554**	**1,389**		
Average	331	15.9	0.646	2,518	463	5.9	

TABLE 24. Physical characteristics of the Western Reservoirs

	Surface Area when Full (Acres)	Length of Shoreline (Miles)	Storage Capacity (BG)	Watershed Area (Acres)	City Owned Land (Acres)	Mean Depth (Feet)	Year Acquired
Western Reservoir No. 1	946	62.4	3.6	19,040	2,307	12.0	1918
Western Reservoir No. 2	711	36.1	3.2	15,840	1,126	14.7	1918
Western Reservoir No. 3	1,265	39.9	6.5	6,540	2,011	15.0	1918
Totals	**2,922**	**138.4**	**13.3**	**41,420**	**5,444**		
Average	974	46.1	4.433	13,807	1,815	13.9	

7.2.1 : Water Quality Concerns and In-lake Management

The Intown Reservoirs experience frequent issues with aquatic plants, which are removed with an aquatic weed harvester, and algae blooms. In the past, these reservoirs were frequently treated with crystalline copper sulfate, with one reservoir being treated each day on a rotation. This method of managing these reservoirs has since been abandoned. The current practice involves sampling twice weekly at 17 separate locations. Each sample undergoes a smell test to identify potential problems, such as geosmin or 2-Methylisoborneol (MIB). The samples are then examined under a microscope, and the reservoirs are only treated when a problem is identified, drastically reduced the use of algaecides. The algaecide currently used for all reservoirs is EarthTec, a liquid copper sulfate solution that is applied by in-house personnel and has provided good results.

Because the source of imported trans-basin water is a known to harbor Hydrilla, sampling for Hydrilla at the Western Reservoirs was immediately implemented and has so far shown no invasion. In the early 1990s, the Western Reservoirs were experiencing problems with high iron and manganese. To address the high iron and manganese, six aerators, designed by Bob Kortmann, were installed in one Western Reservoir in 1991 with an additional four aerators installed in 1996. Additionally, 17 aerators were subsequently installed along the deepest part of another Western Reservoir. 12 units were recently upgraded at a cost of approximately $1.1 million, including installation. The original aerators were run at a rate of approximately 100 SCFM, while the new aerators provide compressed air at a rate closer to 80 SCFM.

The aerators are operated using compressed air rather than pure oxygen. The system was designed to maintain approximately 2mg/L of DO in the bottom waters, and runs from April, as soon as a thermocline develops, through fall turnover in October. Aeration system requirements to meet the oxygen demand were determined through several studies by an outside firm. The aeration system includes a total of eight 125 HP compressors, two of which are only used as backup, which result in high electrical costs of several thousand dollars per month. The utility states that the aeration system is able minimize internal loading, resulting in far fewer algae blooms since their installation. Though algae blooms are infrequent, in recent years the reservoirs have experienced haptophyte blooms in the late winter, and occasional Lyngbya blooms in the summer, which are treated with EarthTec as necessary.

7.2.2 : Recreation and Watershed

The utility allows boating, with up to a 12 hp motor, and fishing on all reservoirs with a permit. No body contact is allowed at any reservoir, and for this reason the utility prohibits the use of sailboats, paddle boards, surf boards, jet skis, and similar devices on the reservoirs.

The Intown Reservoirs are surrounded by highly urbanized land with watersheds dominated by residential, commercial, and industrial land uses. The watersheds of the Western Reservoirs are dominated by forest, agriculture, and residential land uses.

Although there is little that the utilitycan do to actively protect the watersheds, they are often allowed to review and comment on permitting for large projects and promote public education through household programs. These programs promote the protection and restoration of waterways by providing resources and action items for households to reducing nutrient loading and pollution within the watershed.

7.2.3 : Monitoring

The utility collects samples from the Intown Reservoir system at seven locations, including at least one from each reservoir, one in a connecting canal, and one in a smaller pond with five locations sampled from a boat and two from shore. All samples in the Intown Reservoirs are collected at 1 m depth. In-lake samples are collected at 11 sites in the Western Reservoirs, and additional samples are collected at one site at the headwaters of reservoir where trans-basin water is delivered, two rivers, and the source of imported trans-basin water. In addition to samples collected at 1 m depth, 9 of the 11 in-lake sites have samples collected 1 m from the bottom. All in-lake samples are collected with a boat, and river samples collected from the shore. Samples are collected once per month, and are analyzed for the parameters presented in Table 25.

TABLE 25.

Parameters monitored by the utility

	Surface	Depth
Algae Count	✓	
Alkalinity	✓	
Conductivity	✓	✓
DO, Dissolved Oxygen	✓	✓
Fecal Coliform	✓	
Fluorescence	✓	✓
Iron	✓	✓
Manganese	✓	✓
Nitrate/Nitrite-N, Total	✓	✓
pH, field	✓	✓
Phycocyanin	✓	✓
Secchi Disk	✓	
Temperature, C	✓	✓
Thermocline	✓	✓
TOC, Total Organic Carbon	✓	✓
TP, Total Phosphorus	✓	✓
Turbidity	✓	✓

7.3 : Large Virginia Utility

This large Virginia utility serves approximately 2 million customers with an annual demand of 62.6 BG (171.5 MGD). Approximately 60% of customers are served using raw water from intakes on the a nearby river with the remaining 40% served by the reservoir, which delivers water directly to the treatment plant. The reservoir is a run of the river impoundment with a storage volume of 8.33 BG, a surface area of 1,538 acres, a maximum depth of 65 feet, an average depth of 16 feet and a mean annual inflow of approximately 411 MGD.

7.3.1 : Water Quality Concerns and In-lake Management

The utility indicated that both internal and external nutrient loading contributes to water quality issues in the reservoir. From 1970–2010, a line aeration system was installed with 32 aeration lines, totaling 7,500 feet, along the bottom of the reservoir. The system was intended to mix and destratify the water, and was fed with compressed air at a rate of 150 SCFM. The aeration system required a large amount of maintenance, with frequent blow outs of the diffuser pipes, and did not greatly improve water quality. Poor DO conditions through the water column persisted, with the reservoir appearing on the state's 303(d) list from 2002–2010 for DO impairment for aquatic life use. While the old system was operational, excessive blue-green algae and high plankton counts necessitated the use of copper sulfate.

A hypolimnetic oxygenation system (HOS), designed by Marc Mobley and Gantzer Engineering, was installed in the reservoir in 2012 primarily to address issues with high manganese. The current system was installed at a cost of $2.16 million and was designed to supply pure oxygen to the hypolimnion at an average rate of 35 SCFM with a maximum rate of approximately 100 SCFM. The goal is to maintain an average DO level of 5 mg/L within the hypolimnion, and at least 1 mg/L at the sediment/water interface. The oxygenation system is supplied with liquid oxygen trucked in by an outside contractor rather than generated on site. The previous aeration system, which laid directly on the reservoir bottom, had some issues with the transportation of sediment from the bottom to the surface. The current system utilizes one 2,500 feet line, along the thalweg of the old river, suspended above the reservoir bottom, and in addition to resolving the high manganese, staff believes that the system helps keeps the reservoir relatively free of algae, noting that algaecide has not been applied since 2011.

7.3.2 : Recreation and Watershed

The reservoir has a contributing watershed area of 590 square miles with forest, agriculture, residential, commercial and industrial land uses. Hiking, fishing, and boating, with gasoline motors up to 10 hp, are allowed in and around the reservoir. In the late 1960's, several wastewater treatment plants in the watershed were found to be a significant source of degraded water quality in the reservoir. In 1971, a policy was adopted requiring the construction of a regional water reclamation facility to replace the existing treatment plants. The reclamation facility came online in 1978, and currently releases high quality reclaimed water to a tributary of the dammed river, providing approximately 30 MGD of inflow to the reservoir.

7.3.3 : Monitoring

The utility takes water quality samples at various locations in-reservoir, and in addition to in-reservoir sampling, the utility analyses water quality samples at various depths off of the dam, corresponding to the intake levels. The sample parameters that are analyzed are shown in Table 26. Samples are typically taken every other week during the growing season, though may be taken weekly if deemed necessary, and approximately once per month during the winter. In addition, the utility has three buoys with sondes that provide real-time data during the growing season.

TABLE 26.

Parameters monitored by the utility

Parameter	In-house Lab	Outside Lab	Sonde
Orthophosphate	✓	✓	
Ammonia	✓ 1,2		
Nitrate	✓		
Alkalinity	✓		
pH	✓ 1		✓
Total algae count/ID	✓		
Blue-green algae count/ID	✓		
Phycocyanin			✓
Chlorophyll *a*			✓
Coliform Bacteria	✓		
Temperature	✓ 1		✓
Dissolved Oxygen	✓ 1		✓
Secchi	✓		
Turbidity	✓ 1		✓
Total Suspended Solids	✓ 1		
Conductivity	✓ 1		✓
Other	✓ 1,3	✓ 3	

1 At intake only as part of monthly sampling

2 Total ammonia

3 Additional parameters are monitored at the WTP intake as part of monthly sampling. Surfactants are measured at the intake annually.

In addition to sampling performed by the utility, a separate laboratory, run by a nearby university, also monitors water quality within the reservoir and watershed. The program monitors for the parameters shown in Table 27.

Parameter	In-house Lab	Outside Lab	Sonde
Nitrate	✓		✓
Alkalinity		✓	
pH			✓
Chlorophyll *a*	✓		
Temperature			✓
Dissolved Oxygen			✓
Secchi		✓	
Total Suspended Solids	✓		
Conductivity			✓
Other	✓ 1		

TABLE 27.

Parameters monitored by the Watershed Monitoring Laboratory

1 Other parameters: TN, Phenolphthalein Alkalinity, Pheophytin A, Cl, SO_4, TOC, DOC, TDS, Na, K, MG, Ca, Soluble Reactive SiO_2 (surface only)

7.4 : Small Virginia Utility

This small Virginia utility provides water to a population of 150,000 with an annual water demand of approximately 7.08 BG. (19.3 MGD) The Authority operates four reservoirs; the physical parameters for these reservoirs are shown in Table 28. The reservoirs typically become stratified in March, with anoxia developing in June. The reservoirs typically turnover in November, at which point anoxia no longer remains.

	Storage Volume (Million Gallons)	Surface Area (Acres)	Max Depth (Feet)	Average Depth (Feet)	Contributing Watershed Area (Acres)
Reservoir No. 1	6,420	630	70	35	12,672
Reservoir No. 2	3,200	158	215	70	540
Reservoir No. 3	435	69	49	16	
Reservoir No. 4	85	21	33	10	

TABLE 28.

Physical parameters of the utility's reservoirs

7.4.1 : Water Quality Concerns and In-lake Management

Reservoir No. 1, which serves approximately 100,000 customers, has experienced issued with blue-green algae blooms, low dissolved oxygen in the hypolimnion, and high iron and manganese. Water from Reservoir No. 1 goes directly to a water treatment plant. A hypolimnetic oxygenation system (HOS), designed by Mark Mobley and Gantzer Engineering, was installed in 2005 to address issues with high iron and manganese and to control internal loading. 2,000 feet of diffuser lines were installed along the deepest part of the reservoir, approximately 2 feet from the sediment-water interface. The total startup costs, including equipment, engineering, and installation was approximately $200,000, with an annual operating cost of approximately $60,000. The utility indicated that the oxygenation system is crucial to maintaining water quality in the reservoir, rating its importance a 9 out of 10.

Reservoir No. 2 serves approximately 25,000 customers and an average annual inflow of 2.9 BG, which is predominately pumped from a nearby river. Water from Reservoir No. 2 goes directly to a water treatment plant. The reservoir has experienced issues with blue-green blooms, low DO in the hypolimnion, and high iron and manganese. A hypolimnetic aeration system was installed in 1996, predominately to address high manganese, for a cost of approximately $185,000, but was not able to control the issue. In 2002, the system was modified to run on pure oxygen, and testing was conducted using both air and oxygen, until in 2006, the system began running only on oxygen and has an annual operating cost of approximately $10,000.

Reservoirs Nos. 3 and 4 have experienced problems with algae blooms, including blue-green blooms, low DO in the hypolimnion and at the surface, and high iron and manganese. Nutrient loading in Reservoir No. 4 appears to be both internal and external. Reservoir No. 3 acts as upstream detention area for Reservoir No. 4. Water from Reservoir No. 4 then goes directly to a water treatment plant. When depth samples indicate an increase in algae count, in-house personal apply copper sulfate algaecide to Reservoir No. 4, and note that algaecide applications are fairly important to maintaining water quality within the reservoir. Algaecide is typically applied two to three times per year at an annual cost of approximately $1,000. In addition to algaecide treatments, Reservoir No. 4 utilizes a side-stream super saturation HOS system and diffusers that were installed in 2012 at a cost of $175,000 with an annual operating cost of approximately $10,000. The diffusers are designed to break stratification in shallower areas of the reservoir, and the utility continues research on their efficacy. Currently, the importance of the diffusers is rated as a 5 out of 10 for maintaining water quality and the HOS system is rated as a 10 out of 10.

7.4.2 : Recreation and Watershed

All of the reservoirs have predominately undisturbed forested watersheds, though some contain small developments which may significantly contribute to nutrient loads in the reservoirs.

Reservoir No. 1 lies within a 12,700-acre park, most of which is owned by the city. Within the natural area, there are trails that allow biking hiking and horseback riding. Fishing and boating, with less than a 10 hp motor, are permitted in the reservoir. Stand-up paddle boarding has recently been allowed, providing the operator obtains a certification badge. Fishing is permitted at Reservoir No. 2, while Reservoirs 3 and 4 do not offer recreation opportunities.

7.4.3 : Monitoring

The utility maintains an active monitoring program. In-reservoir sampling is conducted at locations near the dams and near the intakes. Main tributaries for the reservoirs are also sampled. The parameters that the utility analyzes are shown in Table 29. Samples are taken twice per week during the growing season, and twice per month during the winter.

TABLE 29.

Parameters monitored by the utility

Parameter	In-house Lab	Outside Lab	Sonde
Total Phosphorus	✓		
Ammonia	✓		
Nitrate	✓		
Alkalinity	✓		
pH	✓		
Chlorophyll *a*			✓
Temperature			✓
Dissolved Oxygen			✓
Secchi	✓		
Turbidity			✓

7.5 : Mid-small Sized Virginia Utility

This mid-small sized Virginia utility provides water to approximately 400,000 people, with an annual demand of approximately 12.5 BG (34 MGD). The utility operates a system of five reservoirs. All of the reservoirs are interconnected via a series of pipelines and pump stations, to allow any one reservoir to serve the demand in any part of the system. The physical characteristics of each reservoir are shown in Table 30. The reservoirs typically develop thermal stratification by May with bottom anoxia setting in by early June. The reservoirs usually turn over, and anoxia is broken, in October.

TABLE 30.

Physical parameters of the utility's reservoirs

	Storage Volume (Million Gallons)	Surface Area (Acres)	Max Depth (Feet)	Average Depth (Feet)	Contributing Watershed Area (Acres)
Reservoir No. 1	7,480	947	60	15	2,944
Reservoir No. 2	3,490	1,110	24	7	28,544
Reservoir No. 3	846	265	22	7	5,504
Reservoir No. 4	876	493	19	5.5	9,024
Reservoir No. 5	230	94	12	5	3,840

7.5.1 : Water Quality Concerns and In-lake Management

Reservoir No. 1, which contains approximately half of the useable storage in the system, is typically the last reservoir in the system to be utilized, functioning predominately as emergency storage. The reservoir has very little natural inflow, and water is pumped in from either a nearby river or from Reservoir No. 2. Reservoir No. 1 is not a terminal supply reservoir, so when needed, water is transferred to a terminal reservoir prior to treatment. Due to the source water, and low natural inflows, Reservoir No. 1 typically acts a phosphorus sink, and experiences few problems with water quality, so no in-lake management methods are utilized.

Reservoir No.2 is not a terminal water supply reservoir, but discharges may go to one of the two terminal reservoirs in the system. The reservoir does not typically experience problems with algal blooms, though under calm conditions, small blue-green algae blooms, not at problematic levels, may occur in areas. The reservoir experiences issues with high iron and manganese only when significantly drawn down, so no in-reservoir management is used. Invasive species, particularly hydrilla and occasionally purple loosestrife, present some problems within the reservoir. Newport

News has attempted to control the hydrilla with 1–2 grass carp per acre, but have not found the carp to be a significant help, potentially due to understocking.

Reservoir No. 3 is a terminal reservoir that can supply approximately 70 percent of the service area. Water is imported into the reservoir from multiple sources, which are selectively utilized to maintain water quality. Reservoir No. 3 has experience problems with algae blooms, including blue-green blooms, low DO in the hypolimnion, and high iron and manganese. Nutrient loading is predominately external. Copper sulfate algaecide is currently applied to this reservoir as spot treatment by in-house personnel approximately once per year, and in the past, had been applied heavily, up to 3,500 lbs/year. There was concern about copper buildup under the heavy applications in the past, but now that less copper is added, that concern has subsided. If copper is not used, grazers will typically manage to quickly reduce the bloom, but copper is still used when deemed necessary. Algaecide applications are triggered by a tiered approach based on the algal speciation, filter run times, and concentration. Reservoir No. 3 also contains a hypolimnetic withdrawal drain that can be used to maintain water quality, but it is very rarely utilized.

Reservoir No. 4 is the other terminal reservoir in the system, and can serve the entire service area. Reservoir No. 4 receives approximately 3,800 MG of water per year as natural inflow. The reservoir has experienced problems with algae blooms, including blue-green blooms, low DO in the hypolimnion, high iron and manganese, and invasive species. Copper sulfate algaecide is applied in the same manner as at Reservoir No. 3. Grass carp are utilized to manage very small concentrations of hydrilla.

Reservoir No. 5 is used only as an auxiliary source for Reservoir No. 4. The reservoir has experienced problems with blue-green algae, green algae, and diatom blooms. Because the reservoir only operates as an alternate source of water, the reservoir is taken offline when water quality problems arise, and no direct in-lake management methods are used.

7.5.2 : Recreation and Watershed

Fishing and boating, with electric motors only, are allowed on all reservoirs in the system, paddle boarding and windsurfing, due to the probability of incidental body contact, are not allowed. In addition to fishing and boating, hiking is allowed around Reservoirs Nos. 3 and 4. Reservoir No. 4 is located within a roughly 8,000 acre municipal park, that is a popular destination for hikers, mountain bikers, and campers.

The types of land use within each watershed are shown in Table 31. Forest represents the largest land use within all watersheds, with some residential use in each. Commercial and industrial use also occurs in three of the five watersheds. The Reservoir No. 2 watershed contains a wastewater treatment plant, most of the effluent is reused, but approximately 0.1 MGD of rejected water is discharged within the watershed. Only one watershed, Reservoir No. 5, contains a significant amount of septic systems.

Some methods of watershed management assist in maintaining reservoir water quality, such as: erosion control during construction, mandatory septic tank maintenance, stormwater quality detention/retention ponds, and ownership of land surrounding the reservoirs. In addition to state and county regulations, local protection ordinances and regional BMPs are instituted.

TABLE 31.

Land uses within Newport News reservoir watersheds

	Watershed Land Uses
Reservoir No. 1	Forest, agriculture, residential
Reservoir No. 2	Forest, residential, some forest harvest
Reservoir No. 3	Forest, agriculture, residential, commercial/industrial
Reservoir No. 4	Forest, grassland, residential, commercial/industrial, military
Reservoir No. 5	Forest, residential, commercial/industrial, military, transportation

7.5.3 : Monitoring

In-reservoir sampling is conducted monthly during the growing season at multiple sites, including near the dam, near the intake, and at the center of the reservoir. Sampling may be conducted more frequently as needed. The parameters that are sampled are shown in Table 32. Watershed sampling is not conducted regularly, but is done when needed and previous studies have characterized storm and baseflows within the watersheds. Implementation of a cyanotoxin monitoring program using a combination of methods is currently being developed.

TABLE 32.

Parameters monitored by the utility

Parameter	In-house Lab	Outside Lab	Sonde
Total Phosphorus	✓		
Orthophosphate	✓		
Ammonia	✓		
Nitrate	✓		
Alkalinity	✓		
pH	✓		✓
Total Algae Count/ID	✓		
Blue-green Algae Count/ID	✓		
Chlorophyll *a*	✓		✓
Phycocyanin			✓
Coliform Bacteria	✓		
Temperature			✓
Dissolved Oxygen			✓
Secchi	✓		
Turbidity			✓
Total Suspended Solids		✓	
Conductivity			✓

7.6 : Very Large Utility

This very large utility provides service to approximately 1 billion gallons of water per day to 15 million people in 45 states and in parts of Canada. For the proposes of this survey, we spoke the management of two reservoirs in New Jersey, and one in Illinois. Reservoir No.1 is located in New Jersey and holds 750 MG, covers approximately 200 acres, has a maximum depth of 18 feet, and an average depth of 12 feet. Reservoir No. 2 is located in New Jersey and the physical parameters of the reservoir were unknown at the time the survey was conducted. Reservoir No. 3, a recently acquired series of cells in Illinois was also discussed, for which physical parameters were unknown at the time the survey was conducted.

7.6.1 : Water Quality Concerns and In-lake Management

Reservoir No. 1 supplies approximately 12 MGD to a nearby treatment plant. Water is typically pumped from a nearby river into a separate storage reservoir, mostly during winter months, and then released to Reservoir No. 1 as needed, though small amounts of natural inflows do flow into the reservoir. Reservoir No. 1 has experienced issues with algae blooms, including blue-green blooms, low DO in the hypolimnion and at the surface, high iron and manganese, invasive species (milfoil), and taste and odor. Nutrient loading to the reservoir appears to be predominately external, and can lead to severe seasonal blue-green algae blooms.

Prior to 2010, approximately 2–3 copper ethanolamine algaecide treatments were applied to Reservoir No. 1 per year by an outside contractor at a cost of approximately $60,000 per year, and these treatments were crucial to maintaining water quality. Algaecide use has drastically decreased since 2012, due to the construction of a new treatment plant which includes processes to remove algae during the coagulation/clarification stage. The heavy use of copper based algaecide in the past brought up concerns about the possible development of copper resistance in algae. In 2010, four SolarBees were installed in the reservoir, which were found to have a marginal effect on the water quality. Four ultrasonic treatment (sonication) buoys were installed in the reservoir in 2014. The sonication buoys are currently though to be a key factor in maintaining water quality in the reservoir. During year one of use, Secchi depth increased from about 1.5 feet to about 8 feet and taste and odor issues were greatly reduced. Due to the increase in depth of the photic zone, an abundance of aquatic weeds developed, and algae may still be problematic at greater depth. The frequency of the ultrasound waves is adjusted based on the speciation of the algae, and some learning curve is required. A Phoslock treatment is planned for Reservoir No. 2 in 2018. In addition to Reservoir No. 1, American Water installed sonication buoys in a reservoir in Kentucky, but did not experience the same success and the buoys were subsequently removed.

Reservoir No. 2 supplies water to a treatment plant capable of treating 40 MGD. The reservoir receives a significant amount of runoff from horse farms, which may contribute to large external nutrient loads, but internal loading still presents a problem. The reservoir has experience issues with algae blooms, including blue-green blooms, low DO in the hypolimnion, and high iron and manganese. Troublesome types of algae include blue-green algae, green algae, and diatoms. Algaecides are applied by an outside contractor 1–2 times per year, based on algae counts, for an annual cost of approximately $30,000–40,000. Flow routing curtains were installed in the reservoir approximately 10 years ago. These curtains are designed to prevent oxygen loss, and control water temperature to promote the growth of diatoms later into the season to outcompete blue-greens, and have been moderately successful in promoting diatom growth into late June. In addition, SolarBees were installed and have been a moderate help to maintaining water quality.

The utility recently acquired an un-named reservoir system in Illinois. The system consists of approximately 19 separate cells in an old, likely limestone, quarry. Nutrient loading is predominately external, and the reservoirs have experienced issues with blue-green algae blooms, low DO in the hypolimnion and at the surface, and high nitrate levels. A terminal cell provides water to a treatment plant with a capacity of approximately 5 MGD. Copper sulfate is added, nearly continuously, as part of a pre-treatment process. American Water, working in conjunction with others, is in the process of developing guidelines for the use of remote sensing data to determine where algaecide treatments are needed.

7.6.2 : Recreation and Watershed

No forms of recreation are allowed on any of the reservoirs. The Reservoir No. 1 watershed consists of forest, grassland, agriculture, residential, and commercial/industrial uses. The Reservoir No. 2 watershed consists of forest, grassland, agriculture, and residential land uses, with several nearby horse farms. Land use in the Reservoir No. 3 watershed appears to be predominately agriculture. No watershed management methods are currently instituted by the utility. However, the utility typically owns the land around the reservoir, which may help prevent excess loading in the direct vicinity.

7.6.3 : Monitoring

While sampling programs typically vary for each reservoir across the utility's system, the parameters that are often monitored are shown in Table 33. Samples are typically taken near the intake, twice per month during the growing season, and less often than monthly during the winter. Cyanotoxins are monitored at some reservoirs using ELISA field tests, and HPLC when the field tests come up positive. While most plants in the utility's system typically send algae count samples to outside labs, Reservoir No. 1 utilizes a FlowCam.

TABLE 33.

Parameters often monitored by American Water

Parameter	In-house Lab	Outside Lab	Sonde
Total Phosphorus	✓		
Orthophosphate	✓		
Alkalinity	✓		
pH	✓		✓
Total Algae Count/ID		✓	
Blue-green Algae Count/ID		✓	
Chlorophyll *a*			✓
Phycocyanin			✓
Coliform Bacteria	✓		
Cyanotoxins	✓	✓	
Temperature			✓
Dissolved Oxygen			✓
Oxidation/Reduction Potential			✓
Secchi	✓		
Turbidity	✓		✓
Total Suspended Solids	✓		✓
Conductivity			✓

7.7 : Very Large Colorado Utility

The utility operates several reservoirs and provides water for approximately 1.4 million people and has an average demand of about 97 BG (268 MGD) per year. This reservoir is a 6.45 BG impoundment with a surface area of 621 acres, a maximum depth of 66 feet, and an average depth of 26 feet. The reservoir typically provides water to about 15% of the customers. The reservoir has a small natural watershed that is highly urbanized, and water in this watershed is diverted around the reservoir, with a mean annual inflow of approximately 40 MG. Instead, the reservoir is typically filled from a nearby river.

7.7.1 : Water Quality Concerns and In-lake Management

This reservoir supplies water to a 250 MGD water treatment plant. The reservoir has experienced issues with algae blooms, including blue-green blooms, low DO in the hypolimnion, high iron and manganese, and invasive species (milfoil). Blue-green algae and diatoms have been the most problematic types of algae. Nutrient loading to the reservoir is both internal and external. Thermal stratification typically sets in by May, with anoxic conditions developing by June. The lake typically turns over in October, at which point anoxic conditions are removed. Crystalline copper sulfate algaecide is applied to the reservoir by in-house personnel only in emergencies, approximately 1 application per 10 years. The utility has concerns about copper accumulation with excessive treatment. An HOS system was installed in order to address high iron and manganese and internal recycling of nutrients. The ECO_2 Speece Cone was installed with a total project cost of $2 million. HOS has been an important factor in maintaining water quality in the reservoir. Occasionally, the reservoir is drawn down to address issues with milfoil. This is done infrequently, is not critical to maintaining water quality, and residents close to the reservoir have expressed their disapproval with the drawdown.

7.7.2 : Recreation and Watershed

There are no forms of recreation allowed on or around the reservoir. The natural watershed for the reservoir is small and highly urbanized, and would be inflows are diverted around the reservoir. Instead, most the water is imported from a nearby river, and occasionally a smaller creek. The rivers from which water is imported drain a combined area of approximately 1,792,000 acres that include forest, grassland, residential, commercial/industrial, and a ski area. Additionally, wastewater treatment plants discharge treated effluent to the river upstream of the diversion point. Watershed management includes erosion control during construction.

7.7.3 : Monitoring

The utility samples terminal and secondary reservoirs at least once per month during the growing season, with reservoirs that are more prone to water quality issues being samples twice per month. Sampling during the winter typically only occurs when specific issues arise. In-lake sampling locations for the utility's reservoirs are loosely established as follows: The deepest location with the maximum potential for stratification, near treatment plant intakes or reservoir outlets, and near inflows, typically within the reservoir arm that receives the greatest inflow. The locations for inflow sampling vary across reservoirs as some reservoirs receive inflows from natural streams while others receive inflows from manmade conduits or canals. For reservoir monitoring purposes, no direct sampling of inflows takes place, instead samples are collected within the reservoir arms, where mixing of the inflow and reservoir water occurs. However, inflows are sampled separately through water monitoring, with samples collected from varying locations along the inflowing stream or canal. Additional watershed sampling occurs at various locations which are generally chosen to satisfy one or more of the following criteria:

- To capture the characteristics of reservoir inflows and outflows
- To monitor the impacts of tributaries of main streams
- To monitor point source impacts
- To monitor the quality of water used in trans-basin trades

The parameters that are monitored by the utility are shown in Table 34. Algae count/IDs are conducted both via Flowcam and via microscopy. When blue-green algae counts are high, the utility screens for cyanotoxins using Abraxis test strips. When the strips indicate the presence of cyanotoxins, the samples are analyzed using LC/MS/MS. Treatment plant influents and effluents are monitored at least once per year for cyanotoxins in the months where they are most likely to occur.

Parameter	In-house Lab	Outside Lab	Sonde
Total Phosphorus	✓		
Orthophosphate	✓		
Ammonia	✓		
Nitrate/nitrite	✓		
Alkalinity	✓		
pH			✓
Chlorophyll *a*			✓
Total Algae Count/ID	✓		
Blue-green Algae Count/ID	✓		
Coliform Bacteria	✓		
Cyanotoxins	✓	✓	
Temperature			✓
Dissolved Oxygen			✓
Secchi	✓		
Turbidity			✓
Total Suspended Solids	✓		
Conductivity			✓

TABLE 34.

Parameters monitored by the utility

7.8 : Mid-small sized Colorado Utility

This mid-small sized Colorado utility provides about 9.8 BG (27 MGD) each year to 140,000 customers. The city operates a series of reservoirs within old gravel mines, adjacent to a nearby river, that are now lined. The terminal cell has storage of 561 MG, a surface area of 57 acres, a maximum depth of 30 feet, and an average depth of about 25 feet.

7.8.1 : Water Quality Concerns and In-lake Management

The reservoirs supply water directly to a water treatment plant, and are able to serve the entire service area. The reservoirs have experienced problems with algae blooms, including blue-green blooms, and low DO in the hypolimnion. Nutrient loading is predominately external, and blue-green algae are the most troublesome variety of algae. When blue-green algae numbers are abnormally high, copper sulfate is applied by in-house personal, usually targeted to a small area. This typically occurs about 1 to 2 times per year. The utility does have concerns about the potential buildup of resistance to algaecide, but algaecide is somewhat important to maintaining the reservoir water quality. In addition to algaecide, SolarBees were installed for a total cost of approximately $100,000 with an annual operating and maintenance cost of about $10,000. The utility indicated that the SolarBees have done well in maintaining the water quality, and their importance was rated as an 8 out of 10.

7.8.2 : Recreation and Watershed

Fishing is allowed in these reservoirs, but boating, and other forms of recreation are not. Water is diverted into the lakes from a nearby river, which drains approximately 368,000 acres. The river's watershed includes forest, grassland, agriculture, residential, and commercial/industrial land use, and contains point source discharges from wastewater treatment plants, and industrial/factory uses. No watershed management methods are used by the utility.

7.8.3 : Monitoring

The utility monitors the lakes with weekly samples taken year-round at the pump station, and the other reservoirs that feed the terminal cell. The parameters that are monitored are shown in Table 35. Cyanotoxins are measured by an outside lab using gas chromatography and mass spectrometry (GC-MS). In addition to the in-lake samples, multiple locations and tributaries within the watershed are also sampled.

TABLE 35.

Parameters monitored by the utility

Parameter	In-house Lab	Outside Lab	Sonde
Orthophosphate	✓		
Ammonia	✓		
Nitrate	✓		
Alkalinity	✓		
pH			✓
Total Algae Count/ID	✓		
Blue-green Algae Count/ID	✓		
Chlorophyll *a*	✓		✓
Coliform Bacteria	✓		
Cyanotoxins	✓	✓	
Temperature			✓
Dissolved Oxygen			✓
Secchi	✓		
Turbidity			✓
Total Suspended Solids	✓		✓
Conductivity			✓
Other			✓

7.9 : Small Virginia Utility

This small Virginia utility provides about 700 MG (1.9 MGD) each year to 18,000 customers. The town operates two reservoirs for raw water supply. The main water supply reservoir has a capacity of 653 MG, and covers an area of 254 acres when full. The maximum depth of the reservoir is 14 feet and the average depth is 8 feet. The reservoir typically becomes thermally stratified in June and turns over in October.

7.9.1 : Water Quality Concerns and In-lake Management

The reservoir receives water from a smaller upstream reservoir. Water from this reservoir goes directly to a water treatment plant. The reservoir experiences problems with algae blooms, particularly green algae, and high iron and manganese. Based on visual analysis and water quality results, nuisance algae blooms are treated by in-house personnel with a liquid peroxide based algaecide. The number of algaecide treatments per year varies significantly depending on water quality and environmental factors. The utility has no concerns about the application of algaecides, and rated the importance of algaecide applications an 8 out of 10 in maintaining water quality.

7.9.2 : Recreation and Watershed

The contributing watershed area of this reservoir is approximately 16,800 acres and includes forest, grassland, agriculture, residential, and commercial/industrial land uses. Fishing and boating with electric motors only, and hiking are allowed in and around the reservoir. Nonpoint source controls within the watershed include erosion control during construction, and the use of stormwater detention/retention ponds. Inflows to the reservoir are treated using wetlands and sedimentation ponds.

7.9.3 : Monitoring

The utility conducts monthly sampling with a multiparameter sonde at set sample points within the reservoir, and at inflows. A list of parameters that are measured is provided in Table 36. Watershed monitoring is not currently in place, but the utility does visually monitor other lakes within the watershed that impact this reservoir.

Parameter	In-house Lab	Outside Lab	Sonde
Nitrate/nitrite			✓
Alkalinity			✓
pH			✓
Chlorophyll *a*			✓
Phycocyanin			✓
Temperature			✓
Dissolved Oxygen			✓
Turbidity			✓
Total Suspended Solids			✓
Conductivity			✓

TABLE 36.

Parameters monitored by the utility

Aerial view of South Fork Rivanna Reservoir. Photo: Rivanna Conservation Alliance

8 : Reservoir Management Strategies

At present the established reservoir management plan calls for algaecide applications when certain algae count trigger levels have been exceeded. The Authority also varies the depth from which water is withdrawn to avoid heavy concentrations of undesirable algae. In-reservoir management may be appropriate for all five reservoirs. The 17 general methods of lake or reservoir management are reviewed below for each of the five reservoirs. Methods are adapted from Horne, 2002 and 2005, and some methods may be combined.

8.1 : General Methods of Lake and Reservoir Management

There are 17 general methods of lake and reservoir management. Two or more of the 17 methods may be used together. The general classes of management are:

- Physical, such as dredging or mixing to alter the physical environment of the water
- Chemical, such as algaecides, alum additions, to bind phosphate that will modify the water chemistry directly
- Biological, such as addition of fish that will eat macrophyte weeds
- Ecological, such as biomanipulation or oxygen-aeration that use natural processes.

The 17 methods and the classification of each method are summarized in Table 37.

TABLE 37.

Methods of Lake and Reservoir Management

No.	Method	Class of Method
1	N & P sediment remediation	Physical
2	Water level fluctuation-stabilization	Physical
3	VEM, destratification & lake mixing	Physical
4	Macrophyte (water weed) harvesting	Physical
5	Wetland algae filters (passive or active in-lake & near-shore)	Ecological
6	Phytoplankton harvesting	Physical
7	Withdrawal of hypolimnion water	Physical
8	Dilution/flushing	Ecological
9	Sediment sealing (fabric liners, barriers)	Physical
10	Algaecides and herbicides (for algae or macrophytes)	Chemical
11	Oxygenation or aeration	Ecological
12	Shading (dyes)	Chemical
13	Sediment P-immobilization (alum, Phosloc)	Chemical
14	Pathogens of algae or macrophytes	Biological
15	Fish grazers on algae or macrophytes	Biological
16	Nutrient harvesting from fish or other biota	Biological
17	Biomanipulation (shallow or deep water options)	Ecological

8.2 : Methods Not Recommended for Further Study

Nine of the 17 methods are not recommended for further study. These nine methods and the reason for elimination from further study are described in Table 38.

TABLE 38.

Lake and Reservoir Management Methods Not Recommended for Study

No.	Method	Reason for elimination
2	Water level fluctuation	Authority has limited ability to vary water levels without impacting water yields
4	Macrophyte harvesting	Currently macrophytes are adequately controlled by grass carp
6	Phytoplankton harvesting	Algae are too small for easy collection
7	Withdrawal of hypolimnetic water	Many of the reservoirs have small hypolimnions and intake structures limit the ability to withdraw significant volumes from the hypolimnion
8	Dilution and flushing	No spare clean water available
9	Sediment sealing (fabric liners, barriers)	No benthic nuisance weeds
12	Shading (dyes)	Not applicable for drinking water supplies
14	Pathogens of algae or macrophytes	No pathogens available for algae species found in Authority reservoirs
16	Nutrient harvesting from fish or other biota	Insufficient harvestable biomass relative to other inputs

8.3 : Methods Recommended for further Evaluation

There are eight methods recommended for further consideration, summarized in Table 39. Not all of the methods are applicable for all of the reservoirs. The individual methods applicable for each reservoir are discussed in the management section for each reservoir.

TABLE 39.

Recommended Management Methods

No.	Method	General Applicability for Authority Reservoirs
1	N & P sediment remediation	Internal loading seems to be critical in some of the reservoirs. Shallow sediment cores for N&P vs depth are needed to determine if internal loading is a significant source of loading.
3	VEM, destratification & lake mixing	Will attack the early summer blooms found in several of the reservoirs before internal loading kicks in that year. The reservoir must have sufficient depth with small enough external loads for VEM &/or whole-reservoir destratification to reduce algae and nutrients.
5	Wetland algae filters (passive or active in-lake & near-shore)	Possible but sites for wetlands in lower reservoir areas are needed and pumping rates need to be calculated. Filter wetlands would be tiered and awkward to design.
10	Algaecides and herbicides (algaecides for algae or herbicides for macrophytes)	Copper and peroxide-based algaecides are the current lake management method used by the Authority. Ideally, algaecides should be reserved for infrequent or severe events.
11	Oxygenation or aeration	Could be a good method for those reservoirs where external loading is low relative to internal source.
13	Sediment P-immobilization (alum, Phosloc)	Potential method if continued monitoring indicates that internal loading dominates the annual nutrient budgets and if external P loads can be reduced substantially.
15	Fish grazers on algae or macrophytes	Potential method if macrophytes become a concern in those reservoirs where grass carp are not currently used
17	Biomanipulation (shallow or deep water options)	Potential Method. However, trout stocking will probably graze down large *Daphnia* & reduce the beneficial effect unless more & larger piscivores such as large big trout are added.

8.4 : Descriptions of Recommended Methods

8.4.1 : Nitrogen and Phosphorus Remediation

Remediation of nitrogen and phosphorus in sediments is accomplished by dredging. The required amount of dredged material is normally about the top 25 cm of the lake or reservoir bottom. This dredging is not a large volume of sediment relative to the lake surface area and does not increase reservoir volume. It can also be expensive, depending on the area to be dredged and the ability to dispose of the dredged sediments.

8.4.2 : Vigorous Epilimnetic Mixing, Desctratification and Lake Mixing

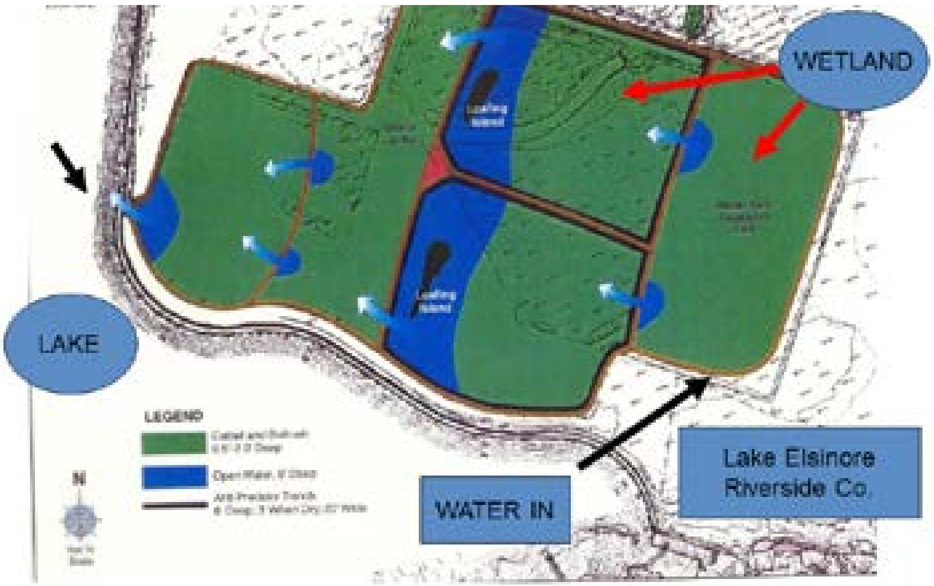
Vigorous epilimnetic mixing, VEM, stirs the surface water layers where the blue-green algae grow. VEM is a relatively new method. The mixing is not very vigorous for humans but it is for tiny algae. VEM and destratification by air bubbles is barely noticeable, with only small air bubbles at the surface. VEM, mixing and destratification can be effective for changing the algae species from blue-greens to a less harmful species such as green algae. At Cherry Creek Reservoir in Colorado, VEM was shown to be an effective method for reducing the percent of blue-green algae present in the reservoir.

8.4.3 : Wetland Algae Filters

Algae-filtering wetlands are well suited for floating nuisance algae such as blue-green algae. They can remove up to 90% of particles in the water. The operating cost can be low since natural processes do the work. However, the challenge is to find adequate shoreline area near the location of the floating algae to construct the wetlands and to install the pumps that are needed to skim the floating algae for treatment. A schematic of a proposed algae-filtering wetland is shown in Figure 65.

FIGURE 65.

Algae-filtering Wetland Schematic



8.4.4 : Algaecides and Herbicides

Algaecides, primarily copper sulfate in the form of SeClear, is part of the Authority's reservoir management strategy. The Authority also varies the depth from which water is withdrawn to avoid heavy concentrations of undesirable algae. When algae counts at any of the Authority reservoirs hit predetermined thresholds at Beaver Creek and SFRR, a contractor, Solitude Lake Management is notified. Solitude, in coordination with Authority staff, determines the area and frequency of treatments. In 2014, two reservoirs, Beaver Creek and Ragged Mountain were treated at a total contractor cost of $59,092. In 2015, all five of the Authority's reservoirs were treated at a total contractor cost of $94,000. The 2015 cost of treatment of Sugar Hollow was reduced by the Authority providing the peroxide-based chemical that it had on hand from previous years. A summary of the number of treatments and cost is shown in Table 40.

TABLE 40.

Costs of Algaecide Treatments, 2014–2015

	2014		2015	
	No. Of Applications	Cost	No of Applications	Cost
Beaver Creek	5	$ 46,477	4	$ 32,628
South Fork Rivanna	0	$ —	5	$ 37,200
Sugar Hollow	0	$ —	1	$ 3,300
Ragged Mountain	2	$ 12,615	6	$ 15,110
Totier Creek	0	$ —	1	$ 5,946
Total	**7**	**$ 59,092**	**17**	**$ 94,184**

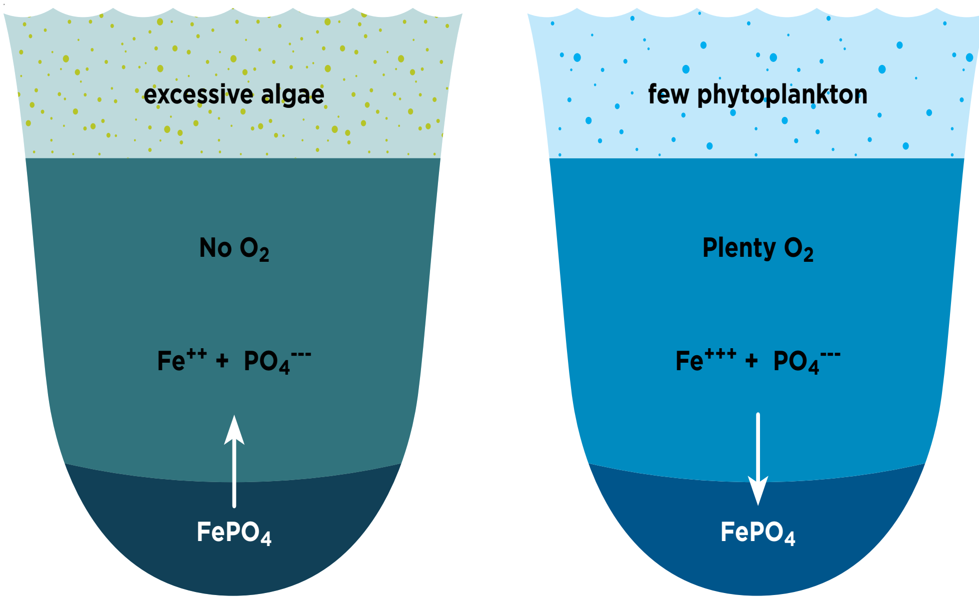


FIGURE 66.

Reversing Eutrophication through Oxygenation

8.4.5 : Oxygenation or Aeration

Hypolimnetic oxygenation systems (HOS), or aeration, can be used for several purposes including creation of habitat for fish in the reservoir or its releases, suppression of hydrogen sulfide or methyl-mercury generation, or reversal of eutrophication. Oxygen is general preferred over aeration since the oxygen transfer is more efficient than aeration, which is only approximately 20% oxygen. For the Authority's reservoirs, the main purpose of HOS is to reverse eutrophication. To do this, HOS needs to prevent internal loading and provide a stable layer of oxygen-rich water that blankets the previously-anoxic sediments as shown in Figure 66. The higher the oxygen concentration in this layer, the more nutrient suppression is reduced. The method has been very successful in reversing eutrophication in firmly stratified reservoirs where internal loading is high and extremal loading low. Sampling indicates that several of the Authority's reservoirs have internal loading of PO4 and ammonia following the onset of anoxia.

8.4.6 : Sediment Phosphorus Immobilization

Soluble phosphate is the only species of P that can be used by algae. Soluble phosphate can be removed by precipitation most commonly with a trivalent ion. There are two common ways to achieve precipitation. The addition of oxygen will cause soluble ferrous iron to become ferric iron which binds with phosphate to form a precipitate. So long as oxygen is present this precipitate will remain in the sediments. The other method is to add excess aluminum (another trivalent ion) which will bind with phosphate with or without oxygen. In lakes alum (aluminum sulfate) is added to the water and sinks to the sediments. Once on the sediments it forms a layer and will bind to any phosphate produced under anoxic conditions deeper down in the sediments. Alum can reduce the pH of some waters to low levels and must then be balanced by the addition of alkalinity. Alum layers on the sediments can be covered with new sediments containing phosphate which will not be treated by the alum layer below and so more alum must be added. Successful alum treatments can last over 10 years but due to high cost and eventual obsolescence are normally used only in small lakes and reservoirs. Alum is widely used to remove all kinds of contaminants in drinking water treatment plants so has a long safety record.

8.4.7 : Fish grazers on Macrophytes

Most fish do not feed on algae or larger aquatic plants since they have low food value. The food chain usually goes via zooplankton or aquatic insects, snails and similar small animals. There are a few exceptions, the most common of which is the Asian grass carp or while amur native to China. These large fish feed on almost any kind of plants in the water including those that fall in from the land. They are used in fixed amounts to reduce, but not eliminate, nuisance plants. If too many carp per acre are used, all plants will be consumed and nuisance blue-green algae may increase. Normally, sterile triploid carp are used and live for 10–30 years depending on the temperature of the water. Grass carp should not be confused with the similar large European common carp which feeds on insects grubbed from the bottom. The common carp may rip up submerged plants but does not feed on them.

8.4.8 : Biomanipulation

This method of lake management is the most sustainable and natural method of control of algae in natural waters. It relies on keeping a balance between algae, zooplankton, fish and submerged aquatic vegetation (SAV). Large zooplankton, especially *Daphnia*, feed on algae more efficiently than small zooplankton. So biomanipulation aims for large numbers of large *Daphnia*. Unfortunately, large *Daphnia* are the preferred food of small fish so large numbers of small fish mean lots of algae. In the early forms of biomanipulation large predatory fish were added to eat the small fish. This worked in terms of better water quality but was not stable since small fish came in from outside waters and large fish have small babies. The provision of about 30% of the lake in SAV provides a refuge for large *Daphnia* in the daylight hours when they are prey for fish. The large *Daphnia* will feed on algae at night using their sense of smell. Plant (SAV) roots also stabilize the sediments from wind mixing, provide sites for denitrification, provide calm zones where algae sink and die, support a biofilm of small organisms that filter out algae and finally a place for periphyton algae to live. Attached algae, periphyton, can outcompete nuisance plankton algae for nutrients. Two more recent additions make biomanipulation better; harvesting small fish when they get too numerous and removing the common European carp. Fish have good and bad years as far as reproduction goes and if small fish sometimes get too abundant or swim in from other lakes and rivers, they can be harvested with nets in mid-summer at low cost. Common carp grub up the SAV, excrete nutrients from the sediments after they eat their bottom food and generally stir mud up, making the water less clear. Carp are very difficult to remove but can be reduced by angling, netting and winter aeration or oxygenation. Under ice, fish kills of many large fish including predators often occur as oxygen is depleted and not supplied. Carp eggs can survive low oxygen or are in shallow water where oxygen does not decline as much. Since the predators of the baby carp are gone, they thrive.

Sugar Hollow Reservoir

9 : Summary of Recommendations

The objectives of this Reservoir Water Quality Management Project were to:

1. Evaluate existing watershed and reservoir data
2. Identify factors and sources of existing or potential water quality concerns primarily related to algae
3. Develop a monitoring plan focused on establishing baseline data for long-term trending
4. Develop strategies for management of water quality in each reservoir
5. Recommend additional studies as appropriate

The evaluation of existing watershed and reservoir data are discussed in Sections 2.1 and 2.2. The factors and sources of existing water quality concerns and the monitoring program that was developed are described in Sections 3, 4, 5, and 6. This section integrates the information described in the previous sections, identifies and prioritizes potential strategies for management of water quality in each reservoir, and in some cases recommends additional studies before final lake management methods are selected and implemented.

The evaluation and development of watershed management strategies were not included in the scope of work for this project. However, since external watershed loading appears to be a significant source of nutrient inputs to several of the reservoirs, a brief discussion of potential watershed management strategies is included. The Authority, under a separate project, is evaluating the watershed and source water protection for several of its reservoirs. After the completion of that project, recommendations on prioritized and coordinated in-reservoir and watershed management can be evaluated.

Significant algae blooms were observed at four of the five Authority reservoirs, with Ragged Mountain experiencing the least number and intensity of algae-related concerns. The Authority has limited staff and financial resources, and we propose a phased approach for consideration in implementation of lake management methods as described in this report section.

Beaver Creek Reservoir is the sole source of water supply for the Crozet WTP, and there is not the ability to divert directly from the two creeks that flow into Beaver Creek and bypass the reservoir. Beaver Creek Reservoir routinely requires the greatest number of algaecide treatments annually. South Fork Rivanna is a major water source for the urban water system and will eventually also be the source for Ragged Mountain Reservoir once the South Fork to Ragged Mountain transfer pipeline is constructed. Both Beaver Creek and South Fork Rivanna reservoirs experienced significant blue-green blooms in 2015-2017.

The recently enlarged Ragged Mountain Reservoir completed its first fill in February 2016 and several years of data are required to develop a water quality baseline. Sugar Hollow experienced an unusual algae bloom in 2015 that may be related to the low water levels resulting from the transfer of water to fill Ragged Mountain. Additional monitoring is required to determine if the Sugar Hollow blooms were an infrequent event related to low water level, or if it will become a more frequent event requiring long-term management. Our recommendation is to first concentrate on Beaver Creek and South Fork Rivanna reservoirs.

Totier Creek Reservoir, which supplies the Scottsville water system, is a shallow and turbid reservoir. The current practice is to bypass Totier Creek Reservoir and divert directly from Totier Creek upstream and directly feed the Scottsville WTP and this practice may be the best option going forward.

As described in this report, algae can cause problems such as taste and odor compounds, cyanotoxins, natural organic matter (DBP precursors), filter clogging, and it can also have recreational impacts. Chemical treatments are currently required to manage the algae. The purpose of the following reservoir management recommendations are to provide guidance on potentially more effective approaches to managing the reservoir water quality concerns.

Starting in spring, in many reservoirs, including the Authority's, the water stratifies thermally into a warm, light upper layer — the epilimnion — and a cooler, denser deep layer, the hypolimnion. Algae in the spring bloom soon use up most of the nutrients in the epilimnion, so algae growth then becomes dependent on other sources of nutrients; inflows and incorporation from the hypolimnion, which is usually too dark for algal growth. The Authority reservoirs, like most in Virginia, are generally saturated with nitrate from various sources leaving phosphorus as the likely limiting nutrient for algal growth. However, if nutrients are high enough they will not limit actual algae growth. Growth may instead be limited by light, CO_2 availability, inter-species competition, or disease. The monitoring and studies over the last three years have shown inflow nutrient concentrations to be moderate, but high enough to stimulate algae growth if the inflowing stream water can reach the epilimnion. The density of the inflowing stream water in most situations is greater than that of the epilimnion.

A summary of the management recommendations by year is shown in Table 41. This table also includes recommendations for continued monitoring to provide a comprehensive list of our recommendations. However, additional information and more recommended modifications to the monitoring program are included in Section 10.

In 2018, we recommend the following activities:

- Evaluate installing anchored buoys at all sampling locations.
- Monitor Beaver Creek Reservoir (BCR) and Ragged Mountain Reservoir (RMR) bi-monthly from April through November and monthly from December through March.
- Monitor South Fork Rivanna Reservoir (SFRR) bi-monthly from May through November and monthly from December through April.
- Monitor Sugar Hollow Reservoir (SHR) monthly from June through August. During the months of September through May, sample the outflow of the RMR pipeline, if in use, once per month.
- Monitor Totier Creek Reservoir (TCR) monthly from April through November, with no monitoring December through March.
- Prepare an annual report on reservoir conditions and water quality trends.
- Evaluate the data needs, and begin data collection, and construction of a CE-QUAL-W2 hydrodynamic and water quality reservoir model for RMR.
- Improve the boat ramp at SFRR for ease of launching the sampling boat.

For 2019–2023 we recommend the following:

- Continuation of monitoring plan and annual report
- Continue data collection, construction, and calibration of RMR CE-QUAL-W2 water quality model.
- Bid and install hypolimnetic oxygenation system in BCR.
- Connect the Crozet WTP backwash decant water and the WTP wastewater flow that is currently on a septic system to the sewer.
- Begin a feasibility-level analysis of wetlands and/or alum treatment at BCR for addressing external watershed loads.
- Design and construction of the new intake at BCR as part of the dam improvement project
- Data collection and calibration of the RMR water quality model.
- Based on performance of HOS system installed at BCR evaluate installation of HOS at RMR.

For 2023–2027, we recommend:

- Continuation of the monitoring plan and annual report.
- Installation of hypolimnetic oxygenation at RMR in advance of the transfer of water from SFRR.

- Recalibration of the RMR CE-QUAL-W2 model after commencing oxygenation.
- Based on performance of HOS systems installed at BCR and RMR evaluate installation of HOS at SFRR, including physical stability during high flows.
- Analysis of the SFRR and RMR water quality data and RMR water quality model output to determine what level of pretreatment, if any, is needed for the water to be transferred from SFRR to RMR.

For 2027–2032, we recommend:

- Bid and install hypolimnetic oxygenation system in SFRR if supported by results of oxygenation at BCR and RMR.
- Continuation of the monitoring plan and annual report.
- Begin design and installation of the intake structure at SFRR that will transfer water to RMR.
- If pretreatment of water transferred from SFRR to RMR is needed, design and install pretreatment at South Rivanna WTP.
- Begin a feasibility-level analysis of wetlands and/or alum treatment at SFRR for addressing external watershed loads.

TABLE 41. Recommended Reservoir Monitoring and Management Actions

Activity	Reservoir	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
Annual report on reservoir condition and trends	All	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Bi-monthly sampling Apr–Nov Monthly sampling Dec–Mar	Beaver Creek and Ragged Mountain	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Bi-monthly sampling May–Nov Monthly sampling Dec–Apr	South Rivanna	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Monthly sampling Jun–Aug Monthly sampling of pipeline inflow to RMR Sep–May	Sugar Hollow	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Monthly sampling Apr–Nov No winter sampling	Totier Creek	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Evaluate installing anchored buoys at all sampling locations	All	x													
Connect decant water from filter backwash basins at Crozet WTP to sewer	Beaver Creek		x	x											
Bid and install hypolimnetic oxygenation system (HOS)	Beaver Creek		x	x	x	x	x								
Design and install new intake structure	Beaver Creek		x	x	x	x	x								
Feasibility evaluation of wetlands/ alum treatment	Beaver Creek		x	x	x	x	x								
Improve boat ramp for launching pontoon sampling boat	South Rivanna	x													
Evaluate installing HOS based on performance at BCR and RMR	South Rivanna						x	x	x	x	x				
Feasibility evaluation of wetlands/ alum treatment	South Rivanna										x	x	x	x	x
Bid and install hypolimnetic oxygenation system (HOS)	South Rivanna										x	x	x	x	x
Design and install new intake structure	South Rivanna										x	x	x	x	x
Design and install pretreatment at South Rivanna WTP if RMR modeling and SFRR sampling indicate the need	South Rivanna										x	x	x	x	x
Evaluate data requirements for RMR water quality model	Ragged Mountain	x													
Collect data for RMR model	Ragged Mountain	x	x	x	x	x	x								
Construction and ongoing calibration of RMR model	Ragged Mountain	x	x	x	x	x	x	x	x	x	x				
Evaluate installing HOS based on performance at BCR	Ragged Mountain		x	x	x	x	x								
Bid and install hypolimnetic oxygenation system (HOS)	Ragged Mountain						x	x	x	x	x				
Evaluate if pretreatment requirements of SFRR to RMR water	Ragged Mountain						x	x	x	x	x				

9.1 : Background

Starting in spring, in many reservoirs, including the Authority's, the water stratifies thermally into a warm, light upper layer—the epilimnion—and a cooler, denser deep layer, the hypolimnion. Algae in the spring bloom soon use up most of the nutrients in the epilimnion, so algae growth then becomes dependent on other sources of nutrients; inflows and incorporation from the hypolimnion, which is usually too dark for algal growth. The Authority reservoirs, like most in Virginia, are generally saturated with nitrate from various sources leaving phosphorus as the likely limiting nutrient for algal growth. However, if nutrients are high enough they will not limit actual algae growth. Growth may instead be limited by light, CO_2 availability, inter-species competition, or disease. The monitoring and studies over the last three years have shown inflow nutrient concentrations to be moderate, but high enough to stimulate algae growth if the inflowing stream water can reach the epilimnion. The density of the inflowing stream water in most situations is greater than that of the epilimnion so any inflow, base flow or storms, will move at a depth between the bottom and just below the thermocline that separates epi- and hypolimnion layers. This inflow can reach the epilimnion in the same way that winter nutrients stored in the hypolimnion do. After the peak of the sun's heating the water, sometime around August, the thermocline begins to drop slowly incorporating nutrient-richer water. This is the source of nutrients for the fall bloom in most waters. The incorporated water will contain both internal and external nutrients.

One clear indicator of eutrophication in the Authority reservoirs is the rapid onset of anoxia in the hypolimnia. Once anoxia occurs, the conditions are usually suitable for the release of reduced compounds such as soluble phosphate, ferrous iron, and ammonia. These usually accumulate in the hypolimnion and promote algae growth as the summer proceeds and the thermocline descends. A reduction in the availability of nutrients feeding algal growth is key to the management of the Authority reservoirs.

Using the management methods presented below, the current management practice of algaecide application should be reduced and reserved only for infrequent events.

9.2 : Beaver Creek Reservoir

The existing and potential water quality concerns for Beaver Creek Reservoir (BCR) are summarized and discussed in Table 42.

TABLE 42.

Current water quality issues and concerns at Beaver Creek Reservoir

Issue/Concern	Discussion
Taste & odor—organics	Blue-green algae blooms stimulated by excessive nutrients can produce geosmin and MIB (earthy and musty odors). Regulation and induction of odor production is not well understood.
Color & staining — inorganics	Iron and manganese released from sediments when hypolimnion is anoxic. If this water were to be delivered to the Crozet WTP, can lead to color in finished water and staining of plumbing fixtures and clothing. Iron and manganese chemistry is well understood.
Release of nutrients from sediments	Nitrogen and phosphorus releases from sediments when hypolimnion is anoxic can lead to algae blooms when the hypolimnion becomes mixed with the surface waters. Transport from near sediments to upper water is not always clear.
Algal toxins	Some blue-green algae can produce toxins which can cause human and animal health problems. If present outside the cells, microcystins pass standard filtration but substantial reduction is possible with well-maintained GAC or ozone.
Filter clogging algae	Large colonies of the blue-green algae *Aphanizomenon, Anabaena,* and *Gomphosphaeria* and large diatoms and dinoflagellates can lead to filter-clogging at the WTP and reduce filter run times. Temporal and species variation in algae blooms is understood only in a general way though there is an overall regularity.
Impacts to recreation and fisheries	Surface blooms could affect shoreline and on-lake recreation. Low dissolved oxygen can affect fisheries and can lead to fish kills.
Chemical treatments	Up to approximately $72,000 annual cost for BCR for treatment with copper algaecide. There is a concern among some scientists and utilities over potential buildup of copper resistance by algae and accumulation in reservoir sediments. However, sediments are not likely to be toxic when in situ and resistance will be slow in the Rivanna reservoirs.

The findings from the monitoring program and special studies for Beaver Creek Reservoir are summarized as follows:

- Water quality is dominated by blue-green algae species; primarily large colonial forms.
- The lower depths of the reservoir became anoxic (no oxygen) from May through late fall.
- Nitrogen (as NO_3) is present well above levels needed for algae growth.
- Phosphorus (as PO_4 and/or TP) is likely the potential limiting nutrient for algal growth.
- Both nitrogen and phosphorus are often present in excess.
- Mass balance estimates indicate that the annual load of nutrients comes from external non-point sources spread throughout the entire watershed.
- Anoxia causes significant releases of Fe, Mn, and NH_4 and some release of PO_4 from reservoir sediment in summer–fall that are sufficient to stimulate nuisance algae blooms.
- Addressing watershed sources of nutrients is challenging but may be beneficial given the estimated external loading.

Based on these findings, we recommend the following phased approach in the management of BCR:

1. Hypolimnetic oxygenation

Moderate reductions of PO_4 in the hypolimnion alone should reduce algae. This can be accomplished through a hypolimnetic oxygenation system (HOS), which provides a longer-term solution over the use of alum treatments. HOS will help to suppress the release of reduced compounds/nutrients from the anoxic reservoir sediment and potentially the inflow as well. Hypolimnion PO_4 is well correlated (R2>0.9) with the number of algaecide treatments in BCR, so a reduction of hypolimnetic PO_4 should reduce the need for treatment. An HOS coupled with the intake modifications would allow the withdrawal of high quality water from the hypolimnion to the Crozet WTP for most of the growing season.

2. Modification or construction of a new intake structure

The intake structure at BCR does not allow for separation of the surface overflow from the water withdrawn through other gates. In 2015 there was some surface overflow through the intake tower on approximately 99 percent of days, 70 percent in 2016, and 40 percent in 2017. The intake structure should be modified or replaced to allow the prevention of the surface overflow from reaching the treatment plant at times of poor surface water quality.

The deepest intake gate in BCR is at a depth of 20 feet, resulting in approximately 105 MG of dead storage. Approximately 68 MG of this storage was designed as the sediment pool. Sediment cores taken in July of 2017 indicate that only about 25 cm of sediment have accumulated near the dam since the reservoir was constructed in 1963. The sedimentation rate near the dam was calculated to be about 0.35 cm/y ± 20 percent. Assuming sedimentation volumes remain similar in the future, the depth of sedimentation each year may decrease slightly. A deeper gate could be added to the new intake tower and allow for greater withdrawal from the hypolimnion during low reservoir levels while maintaining a reasonable sediment pool.

The separation of withdrawals between hypolimnetic releases to the WTP and surface overflow or upper withdrawals for downstream releases will preserve the cooler hypolimnetic water for delivery to the WTP for most of the growing season, except for prolonged droughts when the hypolimnion volume may be fully depleted due to WTP withdrawals and drought conditions. Modeled inflows provided by Hydrologics indicate full depletion of the hypolimnion volume during the growing season would rarely occur. In order to maintain a cool hypolimnetic pool, adaptive management is needed. If water quality within the epilimnion is good, withdraws should be made from the epilimnion to preserve the hypolimnetic pool for withdraw during times of poor surface water quality. Establishment of a minimum volume of hypolimnetic water at a defined maximum temperature is needed to prevent early fall overturn. This minimum hypolimnetic pool volume should be determined based on monitoring data collected during operation of HOS. This will be less important if HOS is run until after turnover.

Hypolimnetic oxygenation, coupled with the modified intake structure will provide the following benefits:

- Large reductions in dissolved iron and manganese in the hypolimnion and water delivered to the WTP.
- Cooler and more esthetically palatable bottom waters can be provided to customers.
- The bottom waters delivered to the WTP will be relatively free of algae and the associated taste and odor compounds. They will also have a lower pH.
- Nutrients and algae in the surface water in the fall should be reduced due to the reduction of internal loading.
- The water quality of the release to Beaver Creek downstream of the reservoir will essentially remain unchanged or improve, since the current releases to the creek are overflow or water withdrawn from higher reservoir depths and this practice will remain unchanged.

3. Discharge of WTP backwash decant water and wastewater to sewer system

Backwash water from the Crozet WTP filters is placed into settling lagoons. The decant water from the lagoons is tested for pH and total chlorine residual before discharge to a tributary of BCR that enters the reservoir near the southwest end of the dam. Tying in the decant water discharge and the WTP wastewater into the sewer system is recommended.

4. Inflow treatment wetland or alum feed feasibility study

While a reduction in hypolimnetic PO_4 should reduce algae at BCR, large external nutrient loads enter the reservoir from much of the watershed. If additional measures are needed to further improve reservoir water quality following the implementation of HOS and the new intake structure, construction of a summer treatment wetland in the upper very shallow inflow channels of Beaver and Watts Creeks, where there is virtually no storage, is an option to address external watershed loadings. This wetland can also be designed to treat the pollutant-loaded first flush of even large storms by using a system of diverting the first flush to the wetlands with a bypass of higher flows. Since TP is the least concentrated nutrient, a passive flow-weighted, low dose alum treatment should be included with the wetland, acting as the micro-floc sedimentation basin. Where possible, reduction of other non-point nutrient sources, like private and public fertilization, should be continued. Proper design of the wetlands should also result in some reduction in nitrogen and organic sediments.

An alternative to an inflow treatment wetland is a flow-paced alum feed for the Watts Creek and Beaver Creek inflows. Unlike the inflow treatment wetland, alum treatment would not address nitrogen. Although now an accepted lake management method in many states and countries, direct alum treatment of the inflow with settling in the reservoir may result in permitting and public perception issues.

9.2.1 : Planning Level Cost Estimates for Beaver Creek Reservoir

Based on the oxygen depletion rate of the hypolimnion from 2015–2017, the HOS system should be designed for a volume weighted hypolimnetic oxygen depletion rate of 0.12 mg/L/d plus increases for sediment oxygen demand and a factor of safety. A previous capital cost estimate, shown in Table 3, was prepared as part of the Phase 1 Reservoir Water Quality and Management Assessment report in June 2016. Annual operating and maintenance costs are estimated to be between $50,000–100,000. This capital and O&M cost estimate was based on preliminary prices provided by ECO_2, the supplier of the Speece Cone technology. Section 7 includes reported costs for several diffuser-type HOS systems designed and installed by Mobley Engineering with installation costs less than the estimate shown in Table 43. Mobley Engineering also recently provided a planning-level cost estimate for BCR. Based on this information, for CIP planning purposes we believe a capital project budget number of $1,000,000 is adequate. An annual O&M budget of $35,000 should be sufficient based on costs reported by other utilities, but this cost should be confirmed based on the selected HOS system.

Speece cone to be submerged,
Marston Reservoir, CO

TABLE 43.

Capital cost estimate for HOS at Beaver Creek Reservoir (from 2016 report)

A.	**Construction**	
	Subtotal 1 — Raw Estimate of Construction	$ 640,000
	Construction Contingency for Unknown Costs (20%)	$ 128,000
	Subtotal 2 — Expected Bid Price	$ 768,000
	Construction Contingency for Change Orders (10%)	$ 76,800
	Total Construction	**$ 844,800**
B.	**Design/Construction Management/Other**	
	Engineering Design (10% of Subtotal 2)	$ 76,800
	Engineering Design Contingency (10%)	$ 7,680
	Admin (2% of Subtotal 2)	$ 15,360
	Legal (3% of Subtotal 2)	$ 23,040
	Land & Permitting	$ 40,000
	Construction Management (10% of Sub 2)	$ 76,800
	CM Contingency for Change Orders (10% of CM)	$ 7,680
	Total Design/CM/Other	**$ 247,360**
	Total Capital Budget	**$ 1,092,160**

A proposed capital improvement plan schedule is shown in Table 44.

TABLE 44.

Proposed Beaver Creek Reservoir CIP

Year	Item	Budget	Notes
2019–2023	Hypolimnetic Oxygenation	$1,000,000	Allow vendors to propose different systems. Consider performance requirements.
2019–2023	New Intake Structure	Included in the existing Beaver Creek Dam Alteration CIP	Construct as part of the planned Beaver Creek Dam Alteration Project. New intake structure will allow withdrawal of cooler, low algae, low Fe and Mn water to WTP and maintains current discharge practice downstream.
2019–2021	Remove backwash decant discharge	Included in planned Crozet WTP improvements	Crozet WTP is on septic and filter backwash decant water is discharged to tributary of Beaver Creek Reservoir. Discharge both into sewer system as part of planned WTP improvements.
2019–2020	Wetland/Alum feasibility study	$75,000	Evaluate land acquisition, permitting, and construction feasibility.

Mobley system installation in Upper San Leandro Reservoir, CA

9.3 : South Fork Rivanna Reservoir

The existing and potential water quality concerns for South Fork Rivanna Reservoir (SFRR) are summarized and discussed in Table 45.

Issue/Concern	Discussion
Taste & odor — organics	Blue-green algae blooms stimulated by excessive nutrients can produce geosmin and MIB (earthy and musty odors). Regulation and induction of odor production is not well understood.
Color & staining — inorganics	Iron and manganese released from sediments when hypolimnion is anoxic. If this water is delivered to the WTP, can lead to color in finished water and staining of plumbing fixtures and clothing. Iron and manganese chemistry is well understood
Release of nutrients from sediments	Nitrogen and phosphorus releases from sediments when hypolimnion is anoxic can lead to algae blooms when the hypolimnion becomes mixed with the surface waters. Transport from near sediments to upper water is not always clear.
Algal toxins	Some blue-green algae can produce toxins which can cause human and animal health problems. If present outside the cells, microcystins pass standard filtration but substantial reduction is possible with well-maintained GAC or ozone.
Filter clogging algae	Large numbers of single filament blue-green algae, large colonies of the blue-green algae *Aphanizomenon, Anabaena,* and *Normophosphatemia,* and large diatoms and dinoflagellates can lead to filter-clogging at the WTP and reduce filter run times. Temporal and species variation in algae blooms is understood only in a general way though there is an overall regularity.
Impacts to recreation and fisheries	Surface blooms affect shoreline and on-lake recreation Low dissolved oxygen affects fisheries and can lead to fish kills.
Chemical treatments	Up to approximately $40,000 annual cost for SFRR for treatment with copper algaecide. There is a concern over potential buildup of copper resistance by algae and accumulation in reservoir sediments. However, sediments are not likely to be toxic when in situ and resistance will be slow in the Rivanna reservoirs.

TABLE 45.

Current water quality issues and concerns at South Fork Rivanna Reservoir

The findings from the monitoring program and special studies for South Fork Rivanna can be summarized as follows:

- Water quality is dominated by blue-green algae species; primarily single filaments.
- The lower depths of the reservoir became anoxic (no oxygen) from June through mid-fall. The upper reservoir station, SR2, mixes earlier (late July) compared to the deeper dam sampling station, SR1, which usually mixes in late August.
- Nitrogen (as NO_3) is present well above levels needed for algae growth.
- Phosphorus (as PO_4 and/or TP) is likely the potential limiting nutrient for algal growth, though current supply rates are high enough for saturation.
- Mass balance estimates indicate that the annual load of nutrients comes from external non-point sources though internal loading is likely important in the fall.
- Addressing watershed sources of nutrients is challenging but may be beneficial given the estimated external loading. This is more challenging due to the large watershed area.

Data from sediment cores indicate that the significant reduction in nutrients in SFRR from the construction of the Crozet sewer interceptor improved water quality in the past. However, in recent years nutrient levels in SFRR appear to be increasing. Currently, a substantial reduction in nutrients is needed before algae reduction can occur. While most of the nutrient loading in SFRR appears to be from external sources, this is very difficult to address given the size of the watershed and distributed nature of the loadings within the watershed. A reduction in internal loading will be more cost-effective per unit of nutrients removed, although it will not completely address the excessive nutrient loading concerns.

For the three years of data, 2015–2017, the soluble phosphate concentration in bottom water prior to spring stratification ranged from 10 to almost 40 µg/L. Once stratification and anoxia set in, PO_4 in the hypolimnion rose to 30-50 µg/L and then fluctuated between 10–50 µg/L before reaching high peaks of over 100 µg/L between September and November. After this time destratification occurred and it would be too dark for much algae growth, even with the elevated nutrients mixed throughout the water column. In anoxic hypolimnia, almost all TP is present as PO_4 and since the stream data show that almost all inflowing TP is present as PO_4, the TP and PO_4 can be considered equivalent for the purpose of the following discussion. For perspective, a value of about 30 µg/L TP at any time would be a good maximum for drinking water reservoirs. Ideally, TP would average less than 20 µg/L to maintain conditions with minimal water quality concerns, but this is likely not achievable for SFRR. A more achievable TP target for SFRR is < 25 µg/L, although 20 µg/L is preferred. The average TP in the inflow at site SR3 is currently about 53 µg/L — roughly 2.5 times the < 20 µg/L postulated for minimal water quality concerns.

Based on these findings, we recommend the following phased approach in the management of SFRR. The recommended timing of implementation is discussed in Section 1.

1. Hypolimnetic oxygenation

Moderate reductions of PO_4 in the hypolimnion should reduce algae. Based on the observed patterns of PO_4 in the hypolimnion and the results of the sediment nutrient flux study, this can be accomplished in part through a hypolimnetic oxygenation system (HOS), which provides a longer-term solution over the use of alum treatments. Average PO_4 in the hypolimnion was observed to generally increase during bottom water anoxia. As the thermocline descended, some of the accumulated PO_4 is incorporated into the epilimnion and made available for algal growth. HOS would serve to reduce this accumulation of PO_4, and thus reduce the subsequent incorporation into the epilimnion. Our estimate is that HOS would be used from about April–November every year while alum treatment would be needed at an estimated 2–5 year interval due to the high continued external P-loading. Alum will only suppress PO_4 and not affect oxygen while HOS will add oxygen and help to suppress the release of all reduced compounds/nutrients from the anoxic reservoir sediment (PO_4, NH_4, Fe, Mn) and potentially the inflow when it is incorporated into the upper waters. Because HOS adds oxygen to the water, it provides an additional benefit to the fishery in the reservoir. In the middle of the summer SFRR is often anoxic below 3 m, forcing fish into the warm upper water of the reservoir. Oxygenation of the hypolimnion would improve fishery habitat in the deeper parts of the reservoir. In addition to the direct benefits at SFRR, a reduction in PO_4 at SFRR can potentially reduce the pre-treatment needs for water that will be exported to RMR.

Since HOS can help suppress Fe and Mn as well as PO_4 and NH_4, when surface water quality is poor an HOS coupled with the use of a lower intake within the hypolimnion will allow the withdrawal of higher quality water from the hypolimnion to the South Rivanna WTP during the early summer. HOS would need to be coupled with a method to reduce external loads, such as a treatment wetland with micro-alum and/or direct alum injection in the shallow inflow areas, to meet in-reservoir phosphorus levels of less than 20 to 25 µg/L. A wetland would also reduce NO_3 and other pollutants.

2. Intake Structure

In conjunction with the construction of the SFRR to RMR water transfer project, a new SFRR intake structure will need to be constructed to accommodate the planned 25 MGD water transfer. Enhancements to consider include intake gates that can be controlled from the South Rivanna WTP and a permanent real-time sonde installation to allow selection of withdrawal depth based on water quality.

Similar to BCR, the addition of a deeper intake gate should be evaluated to allow the withdrawal of the cool, oxygenated hypolimnetic waters. The current deepest intake depth is 15 feet. Even though sedimentation at SFRR is greater than BCR, a deeper intake could be added while maintaining a reasonable volume for the sediment pool. Due to the relatively small size of the hypolimnion in SFRR versus the demand, withdrawal of the cool hypolimnion pool would only last partway through the growing season but would be able to provide higher quality water to the plant when water quality in the epilimnion is poor.

These improvements, together with the HOS, can optimize the water quality delivered to the South Rivanna WTP for treatment as well as the water transferred to RMR and the Observatory WTP in the future.

3. Inflow treatment wetland feasibility study

A feasibility study should be conducted on the construction of an inflow treatment wetlandThe goal is to reduce average inflowing TP to SFRR in the spring–fall period to 20 µg/L — less than half of present values — using terraced inflow treatment wetlands and HOS. This wetland can also be designed to treat the pollutant-loaded first flush of even large storms by using a system of diverting the first flush to the wetlands with a bypass of higher flows. Since TP is the least concentrated nutrient, a passive flow-weighted alum treatment should be included with the wetland, acting as the micro-floc sedimentation basin. Where possible, reduction of other non-point nutrient sources, like private and public fertilization, should be continued. Proper

Alum Treatment of Lake Stevens, WA Source: AquaTechnex.com

design of the wetlands should also result in some reduction in nitrogen and other emerging organic trace pollutants.

A flow-paced alum feed for the South Fork Rivanna River inflow may not be practical given the high volume and rate of inflow, which would require significant amounts of alum. Unlike the inflow treatment wetland, alum treatment would not address nitrogen. Although now an accepted lake management method in many states and countries, direct alum treatment of the inflow with settling in the reservoir may result in a public perception issue. Given the large amounts of sediment in the upper reaches of SFRR, siting and permitting of an alum feed may be challenging.

9.3.1 : Planning Level Cost Estimates for South Fork Rivanna Reservoir

Based on the oxygen depletion rate of the hypolimnion from 2015–17, the HOS system should be designed for a volume weighted hypolimnetic oxygen depletion rate of 0.15 mg/L/d plus increases for sediment oxygen demand and a factor safety. We recommend a capital cost planning estimate of $1,500,000 (2018 dollars) be used for capital improvement plan budgeting purposes. A proposed capital improvement plan schedule is shown in Table 46.

TABLE 46.

Proposed South Fork Rivanna Reservoir CIP

Year	Item	Budget	Notes
2027–2032	Hypolimnetic Oxygenation	$1,500,000	Allow vendors to propose different systems. Consider performance requirements.
2027–2032	Wetland/Alum Feasibility Study	$200,000	During initial years of HOS operation. Evaluate land acquisition, permitting, and construction feasibility for wetland/alum treatment options for external loads.
2027–2032	Intake Structure	Included with Transfer Pipeline Project	Construct as part of the SFRR to RMR transfer project. Include remote controlled intake gates and permanent sonde installation to allow better control of water quality at South Rivanna WTP and water transferred to RMR and to Observatory WTP.
2027–2032	Pretreatment	Included with Transfer Pipeline Project	Design and install pretreatment system at South Rivanna WTP for water to be transferred to RMR. Cost estimated at $8M.

9.4 : Ragged Mountain Reservoir

The existing and potential water quality concerns for Ragged Mountain Reservoir (RMR) are summarized and discussed in Table 47.

TABLE 47.

Current water quality issues and concerns at Ragged Mountain Reservoir

Issue/Concern	Discussion
Floating weed mats near shore	Filling reservoir and waves may have released nutrients as shoreline was newly eroded. Small plants around shoreline may have provided required “anchors” for *Mougeotia*.
Anoxic conditions in hypolimnion	Anoxic conditions were recorded at Ragged Mountain in 2015–2017. In the future, this could lead to internal recycling and issues related to algae and inorganic compounds as described for BCR and SFRR.

The findings from the monitoring program for Ragged Mountain Reservoir can be summarized as follows:

- The first fill of the enlarged reservoir occurred in 2015.
- The lower depths of the reservoir became anoxic (no oxygen) from May through November after the fill of the enlarged reservoir.
- Nutrients likely are from external sources, since it is a new reservoir and the shoreline was cleared and graded. Newly-flooded soils often release nutrients for a year or two after flooding.
- Internal loading may become a more important factor over time if external loading produces algae and anoxic conditions are not addressed. In larger reservoirs and those with small inflows, the hydraulic residence time increases, decreasing the relative magnitude of external loading.
- The potential impacts of the future water transfer from SFRR must be considered and management methods evaluated with this future high nutrient load taken in consideration.

A significant concern for RMR is the future change in source. Flows directly from SHR will in the future be delivered to SFRR via the Moormans River and water transferred from SFRR to RMR. With the import of more nutrient rich water from SFRR, nutrient levels in RMR will likely increase in the future. If these levels produce algae blooms, and the anoxic conditions are not addressed, internal loading may become a problem. HOS will decrease the risk of internal loading becoming problematic and should be installed prior to change in source water to SFRR to help prevent the development of future problems. Section 1 proposes installation in 2023. The cost of an HOS system in Ragged Mountain Reservoir is expected to be between the costs presented above for BCR and SFRR.

We recommend that the Authority evaluate constructing a CE-QUAL-W2 hydrodynamic and water quality reservoir model of RMR. RMR contains the majority of useable storage for the Urban Water System, so a firm understanding of how management methods, and operational changes will impact RMR water quality is desirable. Since the inflow to RMR comes from one source, the model would helpful in evaluating the effects of the change in source from SHR to SFRR and the potential pretreatment needs prior to the transfer. Some of the data requirements for this model would include:

- Daily or continuous measurements of inflow and release rates and temperatures (and ideally DO and conductivity)
    - HOBO temperature data loggers are inexpensive, and data could be collected during sampling outings. Data loggers for other parameters would be more expensive

- Weekly measurements of inflowing PO_4, TP, Nitrate, and Ammonia plus storm-sampling
    - Bi-monthly measurements may suffice

- Monthly in-reservoir sonde profiles (temperature, DO, pH, conductivity)

- Monthly in-reservoir chl *a,* PO_4, TP, Nitrate, Ammonia, and Sonde profiles
    - May be needed at more than one station

- Hourly meteorological data: air temperature, dew point, wind speed, wind direction, cloud cover.
    - There may be a near enough weather station with these data.

More frequent data collection would result in a better calibrated model, but a model calibrated with less frequent data would still be able to offer insights into large changes in water quality.

9.5 : Sugar Hollow Reservoir

The existing and potential water quality concerns for Sugar Hollow Reservoir (SHR) are summarized and discussed in Table 48.

TABLE 48.

Current water quality issues and concerns at Sugar Hollow Reservoir

Issue/Concern	Discussion
Taste & odor — organics	Occasional blue-green algae blooms stimulated by excessive nutrients produce geosmin and MIB (earthy and musty odors). Watershed is pristine but adds enough nutrients along with rare nutrient pulses from soils washed in from landslides. Deeper water may increase likelihood of internal loading and provide nutrients for algae growth.
Color & staining — inorganics	Iron and manganese released from sediments when hypolimnion is anoxic. If this water is delivered to the WTP, can lead to color in finished water and staining of plumbing fixtures and clothing. However, dissolved iron and some manganese will precipitate in the Moormans River or in the receiving reservoirs before they reach the water treatment plants.
Release of nutrients from sediments	Nitrogen and phosphorus releases from sediments when hypolimnion is anoxic can lead to algae blooms when the hypolimnion becomes mixed with the surface waters. Does not explain spring *Anabaena* bloom which may be due to winter carryover of nutrients from turnover
Algal toxins	Some blue-green algae can produce toxins which can cause human and animal health problems. Dissolved microcystin is not broken down in natural waters for at least a few weeks so some toxins may survive the transport to RMR, or in the future to SFRR. However, dilution should reduce risk in terminal reservoir unless it has a bloom.
Impacts to recreation and fisheries	Surface blooms affect shoreline and on-lake recreation. Possible dog deaths if allowed close to shoreline algae accumulations (anatoxin deaths occur each year but are rare). Low dissolved oxygen affects fisheries and can lead to fish kills.
Chemical treatments	Treated once in 2015 with a peroxide-based algaecide. An additional bloom of similar magnitude occurred in 2017, but no treatment was applied.

The findings from the monitoring program for Sugar Hollow Reservoir can be summarized as follows:

- Inflow nutrients were low.
- Occasional blue-green algae blooms.
- The lower depths of the reservoir became anoxic from late summer to early fall. Large fluctuations in water level can lead to entire water column becoming anoxic at times.
- Nutrients likely are primarily from internal sources, perhaps related to the landslides that washed soils into the reservoir.

Because Sugar Hollow reservoir is not a terminal water supply reservoir and experiences fewer water quality issues than other Authority reservoirs there is less available data and less need to address the relatively minor issues. The use of algaecides to manage the infrequent algae blooms can be continued. Sugar Hollow will no longer be a source of direct supply once the SFRR to RMR transfer pipeline is operational. Until the transfer pipeline is constructed, monitoring of water quality at SHR is needed to determine the water quality of the inflow to RMR.

SFRR looking upstream from the UVA boat ramp, March 23, 2016

9.6 : Totier Creek Reservoir

The existing and potential water quality concerns for Totier Creek Reservoir (TCR) are summarized and discussed in Table 49.

TABLE 49.

Current water quality issues and concerns at Totier Creek Reservoir

Issue/Concern	Discussion
Taste & odor — organics	Blue-green algae blooms stimulated by excessive nutrients can produce geosmin and MIB (earthy and musty odors).
Color & staining — inorganics	Iron and manganese released from sediments when hypolimnion is anoxic. If this water is delivered to the WTP, can lead to color in finished water and staining of plumbing fixtures and clothing.
High turbidity — muddy water	The high TSS is originally from the watershed but is often higher in the reservoir than the inflow due to resuspension and slow settling rates of the fine clay particles. The shape of the reservoir and location of the outlet works contribute to this issue at the treatment plant.
Algal toxins	Even though the reservoir is turbid, there were several significant algae blooms, including blue-green algae blooms. Colonial blue-greens can be very buoyant and float near the surface in turbid water. Some blue-green algae can produce toxins which can cause human and animal health problems.
Filter clogging algae	Large colonies of algae can lead to filter-clogging at the WTP and reduce filter run times.
Impacts to recreation and fisheries	High turbidity affects shoreline and on-lake recreation and fisheries
Chemical treatments	Algaecides are applied as needed to maintain the reservoir water at acceptable quality in case it is needed as a supply.

The findings from the monitoring program for Totier Creek Reservoir can be summarized as follows:

- The reservoir is shallow and turbid.
- High TSS in the reservoir is an effect of highly erodible and clay soils in the watershed and re-suspension of deposited reservoir sediment.
- Despite the shallow depth, the bottom waters experience anoxic conditions.
- Water quality is dominated by blue-green algae species.

High sediment loads enter the reservoir during storm flows and are slow to settle out, these sediments are then resuspended making the TSS in the reservoir significantly higher than that of the inflowing stream during normal and low flows. The Scottsville WTP can produce high quality finished water from the reservoir, however, the current practice of direct stream diversion from Totier Creek should be continued with the reservoir predominately used as a backup supply when needed. The reservoir pumps should continue to be exercised regularly and water periodically treated at the Scottsville WTP to ensure proper operation and treatment processes.

Moormans River downstream of Sugar Hollow Dam, September 2, 2015

10 : Recommended Ongoing Monitoring Program

The Rivanna Water and Sewer Authority (Authority) has requested recommendations on modifications to the ongoing reservoir monitoring program. Section 9 contains a proposed timeline showing recommended actions related to both reservoir management and the monitoring program. Recommendations for the monitoring program to best utilize limited staff and financial resources are discussed in this section. Section 9 includes a recommendation that the Authority consider the development of a water quality and hydrodynamic model of Ragged Mountain Reservoir. Note that the recommendations in this section do not include the additional monitoring that would be needed to develop this model, but the data requirements are discussed in Section 9.

The original recommendations for the monitoring program in 2015 included samples taken from the surface and at depth at two sites in each reservoir with additional sampling at one inflow tributary. The Authority laboratory staff currently analyzes all collected samples for total phosphorus, orthophosphorus, ammonia, nitrate, total Kjeldahl nitrogen, and total suspended solids. Surface samples are additionally analyzed for Chlorophyll *a* (sent to an outside lab) and algae count/identifications. In addition to laboratory analyses, Authority staff conducts Secchi depth measurements and sonde profiles at each location using a YSI EXO2 multiparameter sonde.

Routine monitoring of reservoirs is important to understanding how the water quality in the reservoirs responds to a wide range of conditions and allows for identification of issues before they become major problems.

10.1 : Monitoring Locations and Frequency

More frequent monitoring should be conducted on reservoirs that are more prone to water quality issues and that serve as terminal water supply reservoirs. The recommended sampling frequency for each reservoir and the suggested monitoring locations are outlined in Table 50. The approximate locations of the recommended monitoring stations are shown in Section 5.

TABLE 50.

Recommended monitoring frequency and locations

	Beaver Creek	South Fork Rivanna	Ragged Mountain	Sugar Hollow	Totier Creek
Growing season frequency	bi-monthly (Apr–Nov)	bi-monthly (May – Nov)	bi-monthly (Apr–Nov)	monthly (Jun–Aug)	monthly (Apr–Nov)
Winter frequency	monthly (Dec–Mar)	monthly (Dec–Apr)	monthly (Dec–Mar)	monthly* (Sep–May)	None (Dec–Mar)
Sites	BC1, BC2, BC3	SR1, SR2, SR3	RM1	SH1, SH Outflow*	TC1, TC3

* Winter Sugar Hollow sampling is outflow only

10.1.1 : Beaver Creek Reservoir

We recommend that Beaver Creek Reservoir (BCR) be sampled bi-monthly at sites BC1, BC2, and BC3 during its growing season of April-November and monthly during the winter (December-March). While site BC2 was not monitored in 2016 or 2017, the spatial heterogeneity study performed in 2017 indicated that samples at site BC1 may not be representative of water quality in the upper portion of the reservoir. Site BC4 was generally similar to site BC3 and captured inflow from parts of the watershed with similar areas and land uses as BC3. BC3 is typically slightly more nutrient rich. BC4 also omits the two more "urbanized" areas that flow into the Beaver Creek branch. Additionally, the watershed sampling performed in 2017 showed that sufficient nutrients are well distributed and come from all portions of the watershed. Resources allocated to monitoring of site BC4 would be better allocated to monitoring site BC2.

10.1.2 : South Fork Rivanna Reservoir

Authority staff indicated that water quality issues do not tend to arise until at least May in South Fork Rivanna Reservoir (SFRR). Should this pattern continue, we recommend that SFRR be sampled bi-monthly at sites SR1, SR2, and SR3 during its growing season of May-November and monthly during the winter. Sample point SR4 can be eliminated. Though nitrogen concentrations appear to be slightly higher at site SR4, phosphorus concentrations are similar, and the site contributes smaller flow volumes compared to SR3. Site SR4 can be removed to better allocate resources to other monitoring locations. The spatial heterogeneity study performed in 2017 indicated that samples at site SR1 may not be representative of water quality in the upper portion of the reservoir. Given the morphometry of SFRR, all three sites should continue to be monitored, if possible.

10.1.3 : Ragged Mountain Reservoir

We recommend that Ragged Mountain Reservoir (RMR) be sampled bi-monthly at sites RM1 and RM2 during the growing season and monthly during the winter. Because RMR was recently enlarged and reservoir dynamics are not yet well understood, the growing season should be considered as April-November. Additional monitoring requirements, if needed, for construction and calibration of the RMR water quality and hydrodynamic model would be separate from these requirements. While RMR does not currently suffer from significant water quality issues, the hypolimnion is anoxic during the summer and routine monitoring is needed to establish solid baseline conditions and help prevent future issues as the reservoir receives water transfers from SFRR and become a more important source of supply within the Urban Water System.

10.1.4 : Sugar Hollow Reservoir

We recommend that Sugar Hollow Reservoir (SHR) be sampled monthly from June-August at site SH1 with no in-reservoir sampling during the winter. The SHR outflow (RMR inflow) should be sampled monthly when the pipeline is in use. The primary reason for continued sampling of SHR is to establish baseline monitoring and understand the response of RMR to the water quality from the SHR pipeline, which is the primary source of supply for RMR until the SFRR transfer pipeline project is complete. Due to the limited boat access at SHR, samples can be taken directly from the dam. The outlet from SFRR also feeds the RMR pipeline that currently fills RMR. To the extent access is possible, the outlet of the pipeline into RMR should be sampled. To the extent access is not possible or difficult, the release from SHR to the Moormans River should be collected monthly as a surrogate for the inflow to RMR while SHR remains the primary water source for RMR.

Once the SFRR to RMR pipeline is complete and operational, the monitoring program for SHR can be significantly reduced.

10.1.5 : Totier Creek Reservoir

Since Totier Creek Reservoir (TCR) serves primarily as a secondary supply with the primary water supply coming from a direct diversion on Totier Creek upstream of the reservoir, we recommend that monitoring be performed monthly during the growing season with no monitoring during the winter months unless specific problems arise. Sites TC1 and TC2 have shown similar water quality, and since site TC1 is located nearer the WTP intake, monitoring of site TC2 can be removed. Since the primary water source for the Scottsville WTP is creek diversion, sampling of site TC3 should be continued.

10.2 : Parameter Recommendations

1. Each sample collected should continue to be analyzed for TP, PO_4, NO_3, NH_4, and algae count/IDs.
2. Secchi disk measurements should be taken at each in-reservoir sampling location during each outing.
3. Surface samples from each reservoir site should be analyzed at least once per month for chlorophyll *a* during the growing season. During bi-monthly and winter sampling, chlorophyll *a* samples should be taken if the calibrated sonde indicates levels higher than 5 µg/L.
4. While the measurement of TKN in conjunction with nitrate allows for the calculation of total nitrogen (TN), total inorganic nitrogen (TIN, nitrate + ammonia) is a better measure of bioavailable-N. Accordingly, as a time and cost saving measure, TKN can be dropped if nitrate and ammonia continue to be measured.
5. Alkalinity should be sampled at sites BC3 and SR3 at least quarterly to evaluate the chemistry impacts on alum treatment for the inflows. If several years of monitoring indicates consistent alkalinity concentrations seasonally and under base and stormflow conditions, then monitoring can be reduced.
6. Soluble iron and manganese should be measured once per month in the surface and bottom water at the near-dam site in SFRR, BCR, and RMR. These metals can cause color and staining issues in finished water. Additionally, iron is the main metal to precipitate PO_4 out of solution when using HOS and soluble iron is a factor in algal growth, especially in times of nitrogen stress. Low detection level are needed as iron limitation will set in at <10 µg/L.

10.3 : Other Recommendations

1. All sonde probes should be calibrated using appropriate reference standards, particularly the total algae sensor (chlorophyll *a*/ phycocyanin probe). It is best practice to check the probe calibrations before each sampling outing, however, the calibrations should be checked once per month at a minimum.
2. Sonde data should be downloaded and reviewed the same or next day that sampling occurs. This assures that any errors in the data or failure of the probes or the ongoing problem with downloading data can be rectified prior to the next sampling day.
3. Use the recently installed depth finder with GPS to locate the exact sampling locations and the proper depth, ensuring that measurements are taken in a similar location each time. Additionally, some depth finders using GPS with WAAS can be utilized to generate lower cost bathymetric data if desired.
4. The sampling buoy at site SR2 is located away from the deepest part of the channel and should be relocated to ensure that sampling is occurring throughout the entire water column at site SR2. Given the high water velocities in SFRR during high storm inflows, this may be an annual operation.
5. Calibrate or fix a short metric or US tape measure to the Secchi disk line or acquire a pre-measured line to facility easier, more accurate Secchi measurements.
6. Take sonde measurements on the way down and verify that measurements are similar on the way up, paying attention to the depth of the thermocline, which will help in calculating oxygenation requirements. Some sensors may supply erroneous data on the way up if the probe was lowered into the sediment.
7. Make field notes of general weather conditions, including rain/ sun/cloudy, general wind speed and direction, waves, algae (color, locations, any scums), and sediment. Small waterproof field note books are available to record the notes. Photos are helpful as well.
8. Prepare a quick summary of sonde sampling data and other observations that is distributed to water treatment operators and other staff within a couple of days of sampling to ensure that data collected are distributed in a timely manner to be useful for adjusting treatment processes and addressing any customer calls. The summary should include field notes of interest, algae counts if available and any recent algaecide treatments.
9. An annual report should be prepared with the monitoring quality data to summarize the year's water quality and any trends compared to previous years.

Confluence of North and South Forks of the Rivanna River, as seen from the air. Photo: Rivanna Conservation Alliance

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Beaver Creek Reservoir in winter

Appendix A: 2015 Precipitation and Gage Data

Date (2015)	South Fork Rivanna Reservoir				Beaver Creek Reservoir			Totier Creek Reservoir			Sugar Hollow Reservoir			Ragged Mtn Reservoir
	Mechums near Whitehall Discharge (CFS)	Moormans near Free Union Discharge (CFS)	Watershed Weighted Estimated Inflows (CFS)	Precipitation at WTP (in)	Mechums near Whitehall Discharge (CFS)	Watershed Weighted Estimated Inflows (CFS)	Precipitation at WTP (in)	Mechums near Whitehall Discharge (CFS)	Watershed Weighted Estimated Inflows (CFS)	Precipitation at WTP (in)	Moormans Near Free Union	Watershed Weighted Estimated Inflows (CFS)	Precipitation at WTP (in)	Precipitation at WTP (in)
1-Jan	66	60	189		66	7		66	20		60	14		
2-Jan	64	55	179		64	6		64	19		55	13		
3-Jan	68	60	192	0.3	68	7	0.5	68	20	0.2	60	14	0.3	0.3
4-Jan	81	67	223		81	8		81	24		67	15		
5-Jan	75	68	215		75	7		75	22		68	15		
6-Jan	67	61	192		67	7		67	20		61	14		
7-Jan	66	59	188		66	7		66	20		59	13		
8-Jan	62	50	168		62	6		62	19		50	11		
9-Jan	61	56	176		61	6		61	18		56	13		
10-Jan	60	57	176		60	6		60	18		57	13		
11-Jan	59	47	159		59	6		59	18		47	11		
12-Jan	70	57	191	0.5	70	7	0.3	70	21	0.7	57	13	0.38	
13-Jan	72	62	202		72	7		72	22		62	14		
14-Jan	64	52	174		64	6		64	19		52	12		
15-Jan	63	49	168		63	6		63	19		49	11		
16-Jan	61	49	165		61	6		61	18		49	11		
17-Jan	60	45	158		60	6		60	18		45	10		
18-Jan	56	42	147		56	6		56	17		42	10		
19-Jan	55	44	149		55	5		55	16		44	10		
20-Jan	54	41	143		54	5		54	16		41	9		
21-Jan	52	41	140		52	5		52	16		41	9		
22-Jan	51	35	129		51	5		51	15		35	8		
23-Jan	52	33	128	0.8	52	5	2.8	52	16	1	33	8	0.6	
24-Jan	137	89	340	0.3	137	14		137	41		89	20	0.1	
25-Jan	109	86	293		109	11		109	33		86	20		
26-Jan	109	95	307	0.3	109	11	0.1	109	33	0.1	95	22	0.3	0.3
27-Jan	110	95	308		110	11		110	33		95	22		

Date (2015)	South Fork Rivanna Reservoir				Beaver Creek Reservoir			Totier Creek Reservoir			Sugar Hollow Reservoir			Ragged Mtn Reservoir
	Mechums near Whitehall Discharge (CFS)	Moormans near Free Union Discharge (CFS)	Watershed Weighted Estimated Inflows (CFS)	Precipitation at WTP (in)	Mechums near Whitehall Discharge (CFS)	Watershed Weighted Estimated Inflows (CFS)	Precipitation at WTP (in)	Mechums near Whitehall Discharge (CFS)	Watershed Weighted Estimated Inflows (CFS)	Precipitation at WTP (in)	Moormans Near Free Union	Watershed Weighted Estimated Inflows (CFS)	Precipitation at WTP (in)	Precipitation at WTP (in)
28-Jan	94	82	265		94	9		94	28		82	19		
29-Jan	85	70	233		85	8		85	25		70	16		
30-Jan	80	67	221		80	8		80	24		67	15		
31-Jan	71	59	195		71	7		71	21		59	13		
1-Feb	70	55	188		70	7		70	21		55	13	0.1	
2-Feb	74	63	206	0.1	74	7	0.1	74	22		63	14	0.2	
3-Feb	67	58	188		67	7		67	20		58	13		
4-Feb	64	55	179		64	6		64	19		55	13		
5-Feb	63	Ice			63	6		63	19		Ice			
6-Feb	Ice	Ice			Ice			Ice			Ice			
7-Feb	Ice	Ice			Ice			Ice			Ice			
8-Feb	Ice	Ice			Ice			Ice			Ice			
9-Feb	59	51	165		59	6	0.1	59	18	0.2	51	12		
10-Feb	60	52	168		60	6		60	18		52	12		
11-Feb	57	47	156		57	6		57	17		47	11		
12-Feb	56	46	153		56	6		56	17		46	10		
13-Feb	50	Ice			50	5		50	15		Ice			
14-Feb	Ice	Ice			Ice			Ice			Ice			
15-Feb	Ice	Ice			Ice			Ice			Ice			
16-Feb	Ice	Ice		0.5	Ice		0.5	Ice		0.7	Ice		0.2	0.4
17-Feb	Ice	Ice			Ice			Ice			Ice		0.2	0.1
18-Feb	Ice	Ice			Ice			Ice			Ice			
19-Feb	Ice	Ice			Ice			Ice			Ice			
20-Feb	Ice	Ice			Ice			Ice			Ice			
21-Feb	Ice	Ice		0.8	Ice		0.9	Ice		0.6	Ice		0.6	0.5
22-Feb	Ice	Ice			Ice			Ice			Ice		0.3	
23-Feb	Ice	Ice			Ice			Ice			Ice			
24-Feb	Ice	Ice			Ice			Ice			Ice			
25-Feb	Ice	Ice			Ice			Ice			Ice			
26-Feb	Ice	Ice			Ice			Ice			Ice		0.1	0.1
27-Feb	Ice	Ice			Ice			Ice			Ice			
28-Feb	Ice	Ice			Ice			Ice			Ice			
1-Mar	Ice	Ice			Ice			Ice			Ice			
2-Mar	61	56	176		61	6		61	18		56	13		
3-Mar	98	78	265		98	10		98	29		78	18		
4-Mar	91	85	265	0.3	91	9	0.6	91	27	0.4	85	19	0.4	0.3

Date (2015)	South Fork Rivanna Reservoir				Beaver Creek Reservoir			Totier Creek Reservoir			Sugar Hollow Reservoir			Ragged Mtn Reservoir
	Mechums near Whitehall Discharge (CFS)	Moormans near Free Union Discharge (CFS)	Watershed Weighted Estimated Inflows (CFS)	Precipitation at WTP (in)	Mechums near Whitehall Discharge (CFS)	Watershed Weighted Estimated Inflows (CFS)	Precipitation at WTP (in)	Mechums near Whitehall Discharge (CFS)	Watershed Weighted Estimated Inflows (CFS)	Precipitation at WTP (in)	Moormans Near Free Union	Watershed Weighted Estimated Inflows (CFS)	Precipitation at WTP (in)	Precipitation at WTP (in)
5-Mar	415	398	1223	1	415	41	0.3	415	124	0.7	398	90	0.8	1.1
6-Mar	306	349	985		306	31		306	92		349	79	0.1	
7-Mar	218	266	728		218	22		218	65		266	60		
8-Mar	234	251	729		234	23		234	70		251	57		
9-Mar	236	242	719		236	24		236	71		242	55		
10-Mar	209	228	657	0.1	209	21	0.2	209	63	0.1	228	52	0.2	0.2
11-Mar	195	227	635	0.1	195	19		195	58	0.1	227	52	0.1	
12-Mar	163	204	552		163	16		163	49		204	46		
13-Mar	141	174	474	0.1	141	14		141	42		174	40	0.1	0.1
14-Mar	141	168	465	0.1	141	14	0.1	141	42	0.2	168	38	0.1	0.3
15-Mar	130	151	423		130	13		130	39		151	34		
16-Mar	113	130	365		113	11		113	34		130	30		
17-Mar	106	121	341		106	11		106	32		121	28		
18-Mar	97	110	311		97	10		97	29		110	25		
19-Mar	89	98	281		89	9		89	27		98	22		
20-Mar	130	121	377	0.3	130	13	0.1	130	39	0.1	121	28	0.5	0.6
21-Mar	128	114	364		128	13		128	38		114	26		
22-Mar	112	103	323		112	11		112	33		103	23		
23-Mar	101	95	295		101	10		101	30		95	22		
24-Mar	94	88	274		94	9		94	28		88	20		
25-Mar	89	85	262		89	9		89	27		85	19		
26-Mar	94	83	266	0.3	94	9		94	28	0.5	83	19	0.42	0.42
27-Mar	386	283	1006	0.75	386	38	0	386	115		283	64	1	0.95
28-Mar	300	263	847		300	30		300	90		263	60		
29-Mar	205	210	624		205	20		205	61		210	48		
30-Mar	172	183	534		172	17		172	51		183	42		
31-Mar	149	152	453		149	15		149	45		152	35		
1-Apr	133	132	398		133	13		133	40		132	30		
2-Apr	118	110	343		118	12		118	35		110	25		
3-Apr	113	105	328	0.1	113	11	0.4	113	34	0.1	105	24	0.6	0.2
4-Apr	117	126	365		117	12		117	35		126	29		
5-Apr	99	112	317		99	10		99	30		112	25		
6-Apr	92	102	292		92	9		92	28		102	23		
7-Apr	89	100	284		89	9		89	27		100	23		
8-Apr	95	104	299	0.3	95	9	0.6	95	28	0.5	104	24	0.3	0.3
9-Apr	113	121	352		113	11		113	34		121	28		
10-Apr	109	122	347		109	11		109	33	0.1	122	28		0.2

Date (2015)	South Fork Rivanna Reservoir				Beaver Creek Reservoir			Totier Creek Reservoir			Sugar Hollow Reservoir			Ragged Mtn Reservoir
	Mechums near Whitehall Discharge (CFS)	Moormans near Free Union Discharge (CFS)	Watershed Weighted Estimated Inflows (CFS)	Precipitation at WTP (in)	Mechums near Whitehall Discharge (CFS)	Watershed Weighted Estimated Inflows (CFS)	Precipitation at WTP (in)	Mechums near Whitehall Discharge (CFS)	Watershed Weighted Estimated Inflows (CFS)	Precipitation at WTP (in)	Moormans Near Free Union	Watershed Weighted Estimated Inflows (CFS)	Precipitation at WTP (in)	Precipitation at WTP (in)
11-Apr	102	119	332		102	10		102	31		119	27		
12-Apr	91	113	307		91	9		91	27		113	26		
13-Apr	89	104	290		89	9		89	27		104	24		
14-Apr	126	165	438	1	126	13	1.2	126	38	0.9	165	38	1.2	1.2
15-Apr	220	329	826		220	22		220	66		329	75		
16-Apr	168	281	675		168	17		168	50		281	64	0.1	
17-Apr	153	235	583		153	15	0.1	153	46		235	53	0.5	0.1
18-Apr	138	209	522		138	14		138	41		209	48		
19-Apr	128	173	453	1	128	13	2.4	128	38	1.9	173	39	1	1.6
20-Apr	1160	1400	3850	0.7	1160	116	0.3	1160	347		1400	318	0.9	1.1
21-Apr	520	663	1779		520	52		520	156		663	151		
22-Apr	311	410	1084		311	31		311	93		410	93		
23-Apr	234	327	844		234	23		234	70		327	74		
24-Apr	190	270	692		190	19		190	57		270	61		
25-Apr	170	231	603	0.3	170	17	0.5	170	51	0.5	231	53	0.3	0.3
26-Apr	186	245	648	0.1	186	19		186	56	0.2	245	56	0.1	0.1
27-Apr	156	160	475		156	16		156	47		160	36		
28-Apr	136	141	417		136	14		136	41		141	32		
29-Apr	125	129	382		125	12		125	37		129	29		
30-Apr	118	123	362	0.3	118	12	0.2	118	35	0.6	123	28		0.8
1-May	139	133	409	0.3	139	14	0.4	139	42	0.2	133	30	0.3	0.3
2-May	133	121	382		133	13		133	40		121	28		
3-May	115	102	326		115	11		115	34		102	23		
4-May	104	92	295		104	10		104	31		92	21		
5-May	97	84	272		97	10		97	29		84	19		
6-May	93	84	266		93	9		93	28	0.1	84	19		0.1
7-May	89	82	257		89	9		89	27		82	19		
8-May	84	73	236		84	8		84	25		73	17		
9-May	78	68	220		78	8		78	23		68	15		
10-May	74	64	208		74	7		74	22		64	15		
11-May	71	64	203		71	7		71	21		64	15	0.2	0.2
12-May	69	62	197		69	7		69	21		62	14		
13-May	62	50	168		62	6		62	19		50	11		
14-May	60	44	156		60	6		60	18		44	10		
15-May	58	42	150		58	6		58	17		42	10		
16-May	53	42	143	0.5	53	5		53	16		42	10	0.4	0.2
17-May	107	57	247	0.3	107	11		107	32		57	13	0.2	0.4

Date (2015)	South Fork Rivanna Reservoir				Beaver Creek Reservoir			Totier Creek Reservoir			Sugar Hollow Reservoir			Ragged Mtn Reservoir
	Mechums near Whitehall Discharge (CFS)	Moormans near Free Union Discharge (CFS)	Watershed Weighted Estimated Inflows (CFS)	Precipitation at WTP (in)	Mechums near Whitehall Discharge (CFS)	Watershed Weighted Estimated Inflows (CFS)	Precipitation at WTP (in)	Mechums near Whitehall Discharge (CFS)	Watershed Weighted Estimated Inflows (CFS)	Precipitation at WTP (in)	Moormans Near Free Union	Watershed Weighted Estimated Inflows (CFS)	Precipitation at WTP (in)	Precipitation at WTP (in)
18-May	94	57	227		94	9		94	28		57	13	0.8	0.2
19-May	70	80	226		70	7		70	21		80	18		
20-May	59	54	170		59	6		59	18		54	12		
21-May	56	45	152	0.1	56	6	0.2	56	17	0.1	45	10	0.1	0.2
22-May	59	45	156		59	6		59	18		45	10		
23-May	49	38	131		49	5		49	15		38	9		
24-May	46	35	122		46	5		46	14		35	8		
25-May	44	33	116		44	4		44	13		33	8		
26-May	40	31	107		40	4		40	12		31	7		
27-May	40	35	113		40	4		40	12		35	8		
28-May	39	32	107		39	4	0.1	39	12		32	7		
29-May	42	29	107	0.1	42	4		42	13		29	7		
30-May	37	29	99		37	4		37	11		29	7		
31-May	36	35	107		36	4		36	11		35	8		
1-Jun	84	46	195	0.6	84	8	3.2	84	25	0.4	46	10	0.4	0.3
2-Jun	328	132	692		328	33		328	98	0.1	132	30		
3-Jun	141	66	311	0.5	141	14	0.7	141	42	0.6	66	15	0.4	0.3
4-Jun	158	93	377	0.5	158	16	0.4	158	47	0.4	93	21	0.4	0.8
5-Jun	147	101	373		147	15		147	44		101	23		
6-Jun	113	76	284		113	11		113	34		76	17		
7-Jun	85	58	215		85	8		85	25	0.2	58	13	0.2	
8-Jun	73	50	185		73	7		73	22		50	11		
9-Jun	62	44	159		62	6		62	19		44	10		
10-Jun	53	38	137		53	5		53	16		38	9		
11-Jun	48	35	125		48	5		48	14		35	8		
12-Jun	48	53	152	0.5	48	5	0.2	48	14		53	12	1	
13-Jun	60	56	174		60	6	0.3	60	18	0.1	56	13		
14-Jun	60	39	149		60	6		60	18		39	9	0.5	
15-Jun	47	32	119		47	5		47	14		32	7		
16-Jun	37	27	96		37	4		37	11		27	6		
17-Jun	33	24	86		33	3	0.9	33	10		24	5		
18-Jun	60	37	146	0.3	60	6		60	18		37	8		
19-Jun	40	29	104		40	4		40	12		29	7		
20-Jun	38	27	98	0.4	38	4		38	11	1.1	27	6	0.5	0.3
21-Jun	71	46	176	0.4	71	7	1	71	21		46	10	0.1	0.1
22-Jun	50	29	119	0.1	50	5	0.1	50	15	0.1	29	7		0.1
23-Jun	65	25	135	0.1	65	6		65	19		25	6		

Date (2015)	South Fork Rivanna Reservoir				Beaver Creek Reservoir			Totier Creek Reservoir			Sugar Hollow Reservoir			Ragged Mtn Reservoir
	Mechums near Whitehall Discharge (CFS)	Moormans near Free Union Discharge (CFS)	Watershed Weighted Estimated Inflows (CFS)	Precipitation at WTP (in)	Mechums near Whitehall Discharge (CFS)	Watershed Weighted Estimated Inflows (CFS)	Precipitation at WTP (in)	Mechums near Whitehall Discharge (CFS)	Watershed Weighted Estimated Inflows (CFS)	Precipitation at WTP (in)	Moormans Near Free Union	Watershed Weighted Estimated Inflows (CFS)	Precipitation at WTP (in)	Precipitation at WTP (in)
24-Jun	36	22	87		36	4		36	11		22	5		
25-Jun	31	20	77	0.3	31	3	0.5	31	9	1.8	20	5	0.2	0.4
26-Jun	75	34	164	0.3	75	7	1.3	75	22	0.8	34	8	0.1	0.1
27-Jun	363	192	835	2	363	36	1	363	109	0.2	192	44	0.9	1.6
28-Jun	226	125	528		226	23		226	68		125	28		
29-Jun	118	62	271		118	12		118	35		62	14		
30-Jun	85	46	197		85	8		85	25	0.6	46	10		
1-Jul	67	38	158		67	7		67	20		38	9		
2-Jul	55	33	132		55	5		55	16		33	8		
3-Jul	53	32	128		53	5		53	16		32	7		
4-Jul	51	32	125		51	5	0.1	51	15	0.2	32	7		
5-Jul	46	29	113	0.1	46	5	0.4	46	14	0.4	29	7	0.4	0.2
6-Jul	63	38	152		63	6		63	19	0.1	38	9		
7-Jul	51	33	126		51	5		51	15		33	8		
8-Jul	42	28	105		42	4		42	13		28	6		
9-Jul	41	27	102		41	4		41	12		27	6		
10-Jul	35	23	87	0.1	35	3	0.8	35	10		23	5		0.8
11-Jul	70	70	211	0.7	70	7		70	21		70	16	0.5	0.5
12-Jul	63	56	179	0.1	63	6		63	19		56	13	0.1	
13-Jul	51	41	138	0.1	51	5	0.2	51	15	0.1	41	9	0.1	0.3
14-Jul	55	41	144	0.7	55	5		55	16		41	9	0.1	
15-Jul	64	41	158		64	6		64	19		41	9		
16-Jul	41	29	105		41	4		41	12		29	7		
17-Jul	35	25	90		35	3		35	10		25	6		
18-Jul	33	24	86		33	3		33	10		24	5		
19-Jul	32	23	83		32	3		32	10		23	5	0.1	
20-Jul	29	20	74		29	3		29	9		20	5		
21-Jul	30	19	74	0.1	30	3	0.3	30	9		19	4	0.7	0.1
22-Jul	31	24	83		31	3		31	9		24	5		
23-Jul	27	17	66		27	3		27	8		17	4		
24-Jul	23	15	57		23	2		23	7		15	3		
25-Jul	21	14	53		21	2		21	6		14	3		
26-Jul	22	13	53		22	2		22	7		13	3		
27-Jul	45	14	89	0.5	45	4	0.2	45	13	0.7	14	3	0.4	
28-Jul	77	65	214	1.3	77	8	1.8	77	23	0.5	65	15	1.1	0.5
29-Jul	123	79	304	0.1	123	12	0.4	123	37	0.1	79	18	1	0.2
30-Jul	64	47	167		64	6		64	19		47	11		

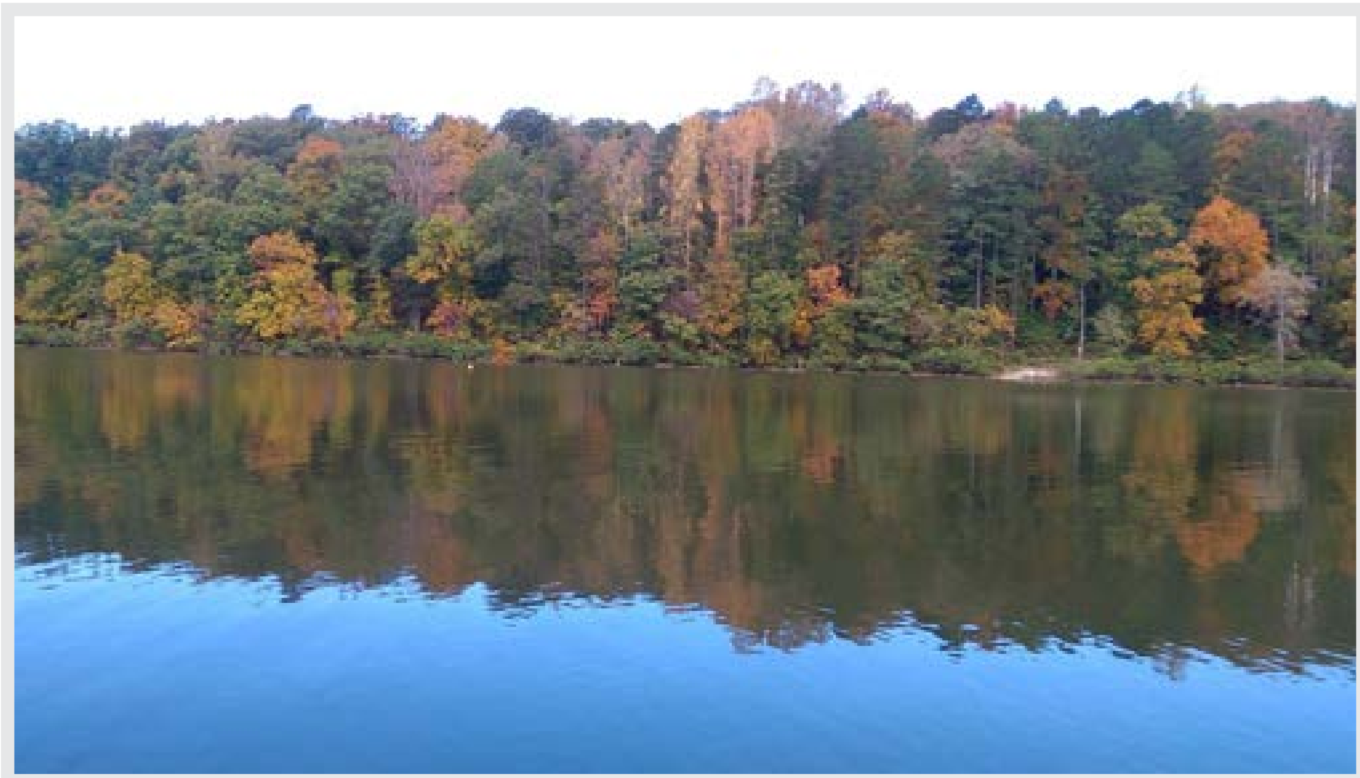
Date (2015)	South Fork Rivanna Reservoir: Mechums near Whitehall Discharge (CFS)	South Fork Rivanna Reservoir: Moormans near Free Union Discharge (CFS)	South Fork Rivanna Reservoir: Watershed Weighted Estimated Inflows (CFS)	South Fork Rivanna Reservoir: Precipitation at WTP (in)	Beaver Creek Reservoir: Mechums near Whitehall Discharge (CFS)	Beaver Creek Reservoir: Watershed Weighted Estimated Inflows (CFS)	Beaver Creek Reservoir: Precipitation at WTP (in)	Totier Creek Reservoir: Mechums near Whitehall Discharge (CFS)	Totier Creek Reservoir: Watershed Weighted Estimated Inflows (CFS)	Totier Creek Reservoir: Precipitation at WTP (in)	Sugar Hollow Reservoir: Moormans Near Free Union	Sugar Hollow Reservoir: Watershed Weighted Estimated Inflows (CFS)	Sugar Hollow Reservoir: Precipitation at WTP (in)	Ragged Mtn Reservoir: Precipitation at WTP (in)
31-Jul	90	97	281		90	9		90	27		97	22		
1-Aug	43	40	125		43	4		43	13		40	9		
2-Aug	32	29	92		32	3		32	10		29	7		
3-Aug	28	24	78		28	3		28	8		24	5		
4-Aug	25	19	66		25	2		25	7		19	4		
5-Aug	22	16	57		22	2		22	7		16	4		
6-Aug	20	14	51		20	2	0.5	20	6		14	3		
7-Aug	36	23	89	0.3	36	4		36	11	0.1	23	5	0.6	0.6
8-Aug	40	25	98		40	4		40	12		25	6		
9-Aug	27	19	69		27	3	0.4	27	8	0.2	19	4		
10-Aug	47	24	107	0.3	47	5	0.2	47	14	0.9	24	5	0.7	0.4
11-Aug	43	26	104	0.1	43	4		43	13		26	6		0.2
12-Aug	33	20	80		33	3		33	10		20	5		
13-Aug	25	16	62		25	2		25	7		16	4		
14-Aug	22	14	54		22	2		22	7		14	3		
15-Aug	20	13	50		20	2		20	6		13	3		
16-Aug	19	12	47		19	2		19	6		12	3		
17-Aug	17	12	44		17	2		17	5		12	3		
18-Aug	17	11	42	0.1	17	2	0.3	17	5		11	3	0.3	
19-Aug	21	13	51	3.8	21	2	0.3	21	6	0.1	13	3		
20-Aug	28	17	68	0.1	28	3		28	8		17	4		
21-Aug	21	14	53		21	2		21	6		14	3		
22-Aug	17	11	42		17	2		17	5		11	3		
23-Aug	15	10	38		15	1		15	4		10	2		
24-Aug	14	9.5	35		14	1		14	4		9.5	2		
25-Aug	13	8.7	33		13	1		13	4		8.7	2		
26-Aug	12	7.9	30		12	1		12	4		7.9	2		
27-Aug	12	7.1	29		12	1		12	4		7.1	2		
28-Aug	11	6.4	26		11	1		11	3		6.4	1		
29-Aug	11	6.2	26		11	1		11	3		6.2	1		
30-Aug	11	6.2	26		11	1		11	3		6.2	1		
31-Aug	11	6.3	26		11	1		11	3		6.3	1		
1-Sep	10	5.9	24		10	1		10	3		5.9	1		
2-Sep	9.4	5.7	23		9.4	1		9.4	3	0.2	5.7	1	0.2	
3-Sep	11	12	35		11	1		11	3		12	3		
4-Sep	12	7.9	30		12	1	0.2	12	4	0.3	7.9	2	0.1	

Date (2015)	South Fork Rivanna Reservoir				Beaver Creek Reservoir			Totier Creek Reservoir			Sugar Hollow Reservoir			Ragged Mtn Reservoir
	Mechums near Whitehall Discharge (CFS)	Moormans near Free Union Discharge (CFS)	Watershed Weighted Estimated Inflows (CFS)	Precipitation at WTP (in)	Mechums near Whitehall Discharge (CFS)	Watershed Weighted Estimated Inflows (CFS)	Precipitation at WTP (in)	Mechums near Whitehall Discharge (CFS)	Watershed Weighted Estimated Inflows (CFS)	Precipitation at WTP (in)	Moormans Near Free Union	Watershed Weighted Estimated Inflows (CFS)	Precipitation at WTP (in)	Precipitation at WTP (in)
5-Sep	11	7.4	28		11	1		11	3		7.4	2		
6-Sep	11	7.1	27		11	1		11	3		7.1	2		
7-Sep	10	6.2	24		10	1		10	3		6.2	1		
8-Sep	8.4	5.7	21		8.4	1		8.4	3		5.7	1		
9-Sep	7.7	5.3	20		7.7	1	0.3	7.7	2	0.5	5.3	1	0.1	
10-Sep	13	8.9	33	1.5	13	1	1.4	13	4	0.5	8.9	2	0.5	0.5
11-Sep	27	34	92		27	3		27	8	1.4	34	8		
12-Sep	64	24	132	1.3	64	6	0.2	64	19	0.2	24	5	0.4	1.1
13-Sep	34	18	78		34	3		34	10		18	4		
14-Sep	18	11	44		18	2		18	5		11	3		
15-Sep	14	9.6	35		14	1		14	4		9.6	2		
16-Sep	13	8.5	32		13	1		13	4		8.5	2		
17-Sep	12	7.3	29		12	1		12	4		7.3	2		
18-Sep	12	6.2	27		12	1		12	4		6.2	1		
19-Sep	12	5.5	26		12	1		12	4		5.5	1		
20-Sep	12	4.9	25		12	1		12	4		4.9	1		
21-Sep	18	8.8	40	2.4	18	2	1.5	18	5	0.7	8.8	2	0.9	2.1
22-Sep	60	19	119		60	6		60	18		19	4		
23-Sep	26	10	54		26	3		26	8		10	2		
24-Sep	18	7.4	38		18	2		18	5		7.4	2		
25-Sep	16	6.7	34		16	2	0.3	16	5	0.3	6.7	2	0.1	
26-Sep	22	11	50	0.5	22	2	0.3	22	7	0.4	11	3	0.3	0.5
27-Sep	28	12	60		28	3		28	8	0.1	12	3	0.1	0.1
28-Sep	27	12	59	0.1	27	3	0.4	27	8	0.3	12	3	0.6	0.3
29-Sep	448	385	1253	2.8	448	45	2.5	448	134	1.5	385	88	2.1	3.1
30-Sep	398	276	1014		398	40		398	119		276	63		
1-Oct	120	96	325		120	12	0.3	120	36	0.2	96	22		0.1
2-Oct	135	100	353	1	135	13	2.3	135	40	1.8	100	23	2.1	1.1
3-Oct	1200	760	2947	2	1200	120	1.2	1200	359		760	173	0.9	0.4
4-Oct	511	659	1759		511	51		511	153		659	150	0.1	0.1
5-Oct	246	318	848		246	25		246	74		318	72		
6-Oct	164	145	465		164	16		164	49		145	33		
7-Oct	124	136	391		124	12		124	37		136	31		
8-Oct	97	104	302		97	10		97	29		104	24		
9-Oct	79	85	247		79	8		79	24		85	19	0.1	
10-Oct	68	75	215		68	7		68	20		75	17		
11-Oct	60	61	182		60	6		60	18		61	14		

Date (2015)	South Fork Rivanna Reservoir				Beaver Creek Reservoir			Totier Creek Reservoir			Sugar Hollow Reservoir			Ragged Mtn Reservoir
	Mechums near Whitehall Discharge (CFS)	Moormans near Free Union Discharge (CFS)	Watershed Weighted Estimated Inflows (CFS)	Precipitation at WTP (in)	Mechums near Whitehall Discharge (CFS)	Watershed Weighted Estimated Inflows (CFS)	Precipitation at WTP (in)	Mechums near Whitehall Discharge (CFS)	Watershed Weighted Estimated Inflows (CFS)	Precipitation at WTP (in)	Moormans Near Free Union	Watershed Weighted Estimated Inflows (CFS)	Precipitation at WTP (in)	Precipitation at WTP (in)
12-Oct	53	55	162		53	5		53	16		55	13		
13-Oct	50	50	150		50	5		50	15		50	11		
14-Oct	45	46	137		45	4		45	13		46	10		
15-Oct	45	47	138		45	4		45	13		47	11		
16-Oct	44	41	128		44	4		44	13		41	9		
17-Oct	41	39	120		41	4		41	12		39	9		
18-Oct	42	36	117		42	4		42	13		36	8		
19-Oct	42	35	116		42	4		42	13		35	8		
20-Oct	43	36	119		43	4		43	13		36	8		
21-Oct	41	35	114		41	4		41	12		35	8		
22-Oct	40	34	111		40	4		40	12		34	8		
23-Oct	41	33	111		41	4		41	12		33	8		
24-Oct	40	33	110		40	4		40	12		33	8		
25-Oct	40	32	108		40	4		40	12		32	7		
26-Oct	38	31	104		38	4		38	11		31	7		
27-Oct	41	34	113	0.5	41	4	1.6	41	12	0.8	34	8	0.6	0.5
28-Oct	420	247	1003	3	420	42	1.7	420	126	1.7	247	56	2.1	2.4
29-Oct	399	342	1114		399	40		399	119	0.1	342	78		
30-Oct	192	227	630		192	19		192	57		227	52		
31-Oct	139	154	441		139	14		139	42		154	35		
1-Nov	114	115	344	0.1	114	11		114	34		115	26		
2-Nov	97	90	281		97	10		97	29		90	20		
3-Nov	83	78	242		83	8		83	25		78	18		
4-Nov	73	69	214		73	7		73	22		69	16		
5-Nov	67	65	198		67	7		67	20		65	15		
6-Nov	64	62	189		64	6		64	19		62	14		
7-Nov	65	62	191	0.1	65	6	0.2	65	19	0.1	62	14	0.2	0.2
8-Nov	63	60	185		63	6		63	19		60	14		
9-Nov	59	58	176	0.6	59	6	0.9	59	18	1.2	58	13	0.6	0.64
10-Nov	161	114	414	0.4	161	16	0	161	48	0.2	114	26	0.5	0.41
11-Nov	145	130	414		145	14	0	145	43		130	30		
12-Nov	113	139	379		113	11		113	34		139	32		
13-Nov	97	117	322		97	10		97	29		117	27		
14-Nov	82	96	268		82	8		82	25		96	22		
15-Nov	74	79	230		74	7		74	22		79	18		
16-Nov	71	72	215		71	7		71	21		72	16		
17-Nov	66	66	198		66	7		66	20		66	15		

Date (2015)	South Fork Rivanna Reservoir				Beaver Creek Reservoir			Totier Creek Reservoir			Sugar Hollow Reservoir			Ragged Mtn Reservoir
	Mechums near Whitehall Discharge (CFS)	Moormans near Free Union Discharge (CFS)	Watershed Weighted Estimated Inflows (CFS)	Precipitation at WTP (in)	Mechums near Whitehall Discharge (CFS)	Watershed Weighted Estimated Inflows (CFS)	Precipitation at WTP (in)	Mechums near Whitehall Discharge (CFS)	Watershed Weighted Estimated Inflows (CFS)	Precipitation at WTP (in)	Moormans Near Free Union	Watershed Weighted Estimated Inflows (CFS)	Precipitation at WTP (in)	Precipitation at WTP (in)
18-Nov	64	62	189	0.1	64	6	1.7	64	19	1.1	62	14	0.17	0.07
19-Nov	549	435	1480	1.3	549	55		549	164	1.1	435	99	1.39	1.3
20-Nov	325	371	1047		325	32		325	97		371	84		
21-Nov	212	266	719		212	21		212	63		266	60		
22-Nov	169	209	568		169	17		169	51		209	48		
23-Nov	141	155	445		141	14		141	42		155	35		
24-Nov	121	118	359		121	12		121	36		118	27		
25-Nov	106	99	308		106	11		106	32		99	23		
26-Nov	97	84	272		97	10		97	29		84	19		
27-Nov	89	78	251		89	9		89	27		78	18		
28-Nov	84	74	238		84	8	0.1	84	25		74	17		
29-Nov	83	74	236	0.1	83	8		83	25	0.2	74	17	0.2	0.2
30-Nov	92	76	253	0.5	92	9	1.1	92	28	0.9	76	17	0.5	0.5
1-Dec	348	241	886	0.9	348	35	0.6	348	104	0.6	241	55	0.9	1
2-Dec	351	347	1050	0.3	351	35	0.6	351	105	0.6	347	79	0.2	0.3
3-Dec	258	285	817		258	26		258	77		285	65		
4-Dec														
5-Dec	164	176	511		164	16		164	49		176	40		
6-Dec	146	146	439		146	15		146	44		146	33		
7-Dec	134	128	394		134	13		134	40		128	29		
8-Dec	122	114	356		122	12		122	37		114	26		
9-Dec	111	99	319		111	11		111	34		99	23		
10-Dec	104	90	295		104	11		104	32		90	20		
11-Dec	98	82	274		98	10		98	30		82	19		
12-Dec	92	77	259		92	9		92	28		77	18		
13-Dec	86	73	244		86	9		86	27		73	17		
14-Dec	85	74	245	0.1	85	9	0.1	85	27		74	17	0.2	
15-Dec	105	82	284		105	11		105	32		82	19		
16-Dec	90	72	244	0.5	90	9		90	27		72	16	0.78	0.5
17-Dec	118	101	329		118	12		118	35		101	23		
18-Dec	148	125	411		148	15		148	44		125	28		
19-Dec	120	101	332		120	12		120	36		101	23		
20-Dec	109	92	302		109	11		109	33		92	21		
21-Dec	103	85	283		103	10	0.1	103	31	0.1	85	19		
22-Dec	104	85	284		104	10		104	31		85	19	0.1	0.1
23-Dec	139	115	382	0.9	139	14	0.9	139	42	1.6	115	26	0.7	1
24-Dec	221	210	648	0.3	221	22	0.2	221	66	0.2	210	48	0.32	0.3

Date (2015)	South Fork Rivanna Reservoir				Beaver Creek Reservoir			Totier Creek Reservoir			Sugar Hollow Reservoir			Ragged Mtn Reservoir
	Mechums near Whitehall Discharge (CFS)	Moormans near Free Union Discharge (CFS)	Watershed Weighted Estimated Inflows (CFS)	Precipitation at WTP (in)	Mechums near Whitehall Discharge (CFS)	Watershed Weighted Estimated Inflows (CFS)	Precipitation at WTP (in)	Mechums near Whitehall Discharge (CFS)	Watershed Weighted Estimated Inflows (CFS)	Precipitation at WTP (in)	Moormans Near Free Union	Watershed Weighted Estimated Inflows (CFS)	Precipitation at WTP (in)	Precipitation at WTP (in)
25-Dec	194	219	621		194	19		194	58		219	50		
26-Dec	173	208	573		173	17		173	52		208	47		
27-Dec	159	187	520		159	16		159	48		187	43		
28-Dec	147	164	468	0.4	147	15	0.9	147	44	0.5	164	37	0.2	0.4
29-Dec	311	289	902		311	31	0.1	311	93	0.1	289	66	0.3	0.5
30-Dec	245	273	779		245	24	0.1	245	73	0.1	273	62	0.02	0.02
31-Dec	204	239	666		204	20		204	61		239	54		



South Rivanna Reservoir in fall

Appendix B: Nutrient Data Tables

South Fork Rivanna 1 - Surface

Date	Ammonia µg/L	Nitrate µg/L	TKN µg/L	TIN µg/L	TN µg/L	Chlorophyll *a* µg/L	TP µg/L	O-PO4 µg/L	TSS mg/L	Secchi (m)
4/14/15	25	163	34	188	197	5	26	29	2	
5/5/15	104	135	6	239	141	30	27	23	6	
5/18/15	124	441	1,120	565	1,561	ND	18	13	2	
6/1/15	225	315	ND	540		3	16	44	2	2.50
6/16/15	95	294	218	389	512	9	23	9	4	
6/30/15	585	428	1,047	1,013	1,475	7	80	19	8	
7/15/15	254	527	918	781	1,445	10	33	13	3	1.40
7/28/15	212	550	952	762	1,502	22	28	15	4	1.80
8/5/15	545	497	974	1,042	1,471	30	34	18	6	0.90
8/26/15	97	545	146	642	691	4	(429)*	(16)*	4	1.80
9/8/15	150	635	162	785	797	2	35	8	3	1.80
9/23/15	356	578	470	934	1,048	4	35	20	4	1.45
10/8/15	356	1,260	470	1,616	1,730	1	47	46	5	1.10
10/22/15	345	1,030	409	1,375	1,439	2	19	25	3	
11/18/15	345	577	431	922	1,008	1	23	14	2	
3/14/16	237	1,260	330	1,497	1,590		64	14	5	
5/18/16	252	1,020		1,272		3	191	6	7	
5/25/16	215						59		11	
6/16/16	350					11	29	6	6	
6/28/16	107	1,310		1,417		8		9	5	1.15
7/11/16	147	1,370		1,517		8	41	10	4	2.20
7/26/16	356	291		647		7	20	31		1.95
8/4/16	750	239		989		7	181	22	50	
8/16/16	100	355		455		9	44	12	13	
8/22/16	525	364		889		8	117	13	4	1.80
8/30/16	215	576		791		16	(46)*	(297)*	4	1.80
9/6/16										2.10
9/15/16	299	919		1,218		1	181	13	5	1.80
9/22/16	315	770		1,085		1	(23)*	(214)*	4	
10/5/16	225	488		713			36	10	5	
10/17/16	195	806		1,001		7	38	18	9	1.40
12/14/16	195	618	330	813	948	3	49	13	5	1.45

*Values removed from calculations

ND = Non-detect

Any time OPO4 was ≥ 3x TP, both values removed due to high analytical error

South Fork Rivanna 1 - Surface

Date	Ammonia µg/L	Nitrate µg/L	TKN µg/L	TIN µg/L	TN µg/L	Chlorophyll *a* µg/L	TP µg/L	O-PO4 µg/L	TSS mg/L	Secchi (m)
2/28/17	207	1,740	269	1,947	2,009	2	41	20	7	1.55
3/29/17	293	557	67	850	624	2	72	70	11	1.55
4/19/17		448	171		619	3	60	19	18	1.65
5/2/17	312	1,660	176	1,972	1,836	6	45	8	4	1.85
5/24/17	248	525	210	773	735	8	46	17	7	1.45
6/6/17	418	530	205	948	735	17	46	42	9	2.45
6/27/17	318	425	350	743	775	7	31	39	10	1.70
7/19/17	55	338		393		7	49	7	5	2.33
8/1/17	403	269	400	672	669		45	42	7	1.10
8/11/17						10				
8/30/17	208	100	235	308	335	8	36	13	6	
10/10/17	520	370	140	890	510		83	29	9	0.95
10/13/17						16				
10/26/17	128	271	307	399	578		53	40	9	1.30
11/8/17	115	197	494	312	691	10		19	6	1.20
2015 mean	255	532	526	786	1,001	9	32	21	4	1.59
2015 min	25	135	6	188	141	1	16	8	2	0.90
2015 max	585	1,260	1,120	1,616	1,730	30	80	46	8	2.50
2016 mean	280	742	N/A	1,022	N/A	7	81	14	9	1.74
2016 min	100	239	N/A	455	N/A	1	20	6	4	1.15
2016 max	750	1,370	N/A	1,517	N/A	16	191	31	50	2.20
2017 mean	268	572	252	850	843	8	47	28	8	1.59
2017 min	55	100	67	308	335	2	31	7	4	0.95
2017 max	520	1,740	494	1,972	2,009	17	83	70	18	2.45
all mean	268	614	394	885	988	8	54	21	7	1.64
all min	25	100	6	188	141	1	16	6	2	0.90
all max	750	1,740	1,120	1,972	2,009	30	191	70	50	2.50
all sd	154	406	318	433	520	7	43	14	7	0.43
all CV%	58%	66%	81%	49%	53%	87%	80%	67%	106%	26%

*Values removed from calculations

ND = Non-detect

Any time OPO4 was ≥ 3x TP, both values removed due to high analytical error

South Fork Rivanna 1 - Bottom

Date	Ammonia µg/L	Nitrate µg/L	TKN µg/L	TIN µg/L	TN µg/L	TP µg/L	O-PO4 µg/L	TSS mg/L
4/14/15	12	284		296		31	33	11
5/5/15	194	217	25	411	242	29	28	18
5/18/15	225	417	291	642	708	31	22	5
6/1/15	325	290	224	615	514	26	16	5
6/16/15	185	219	325	404	544	112	6	28
6/30/15	187	203	325	390	528	48	14	7
7/15/15	335	451	314	786	765	79	12	3
7/28/15	395	462	364	857	826	38	22	4
8/5/15	300	447	549	747	996	79	50	8
8/26/15	1,080	733	1,590	1,813	2,323	(530)*	(68)*	28

*Values removed from calculations

ND = Non-detect

South Fork Rivanna 1 - Bottom

Date	Ammonia µg/L	Nitrate µg/L	TKN µg/L	TIN µg/L	TN µg/L	TP µg/L	O-PO4 µg/L	TSS mg/L
9/8/15	502	417	764	919	1,181	44	14	6
9/23/15	758	745	784	1,503	1,529	96	17	19
10/8/15	758	1,440	890	2,198	2,330	106	34	13
10/22/15	700	766	890	1,466	1,656	45	ND	9
11/18/15	249	549	381	798	930	19	10	9
3/14/16	184	1,440	291	1,624	1,731	14	11	4
5/18/16	612	860		1,472		18	4	4
5/25/16	675					32		5
6/16/16	415					44	6	4
6/28/16	585	975		1,560			47	4
7/11/16	215	1,330		1,545		14	6	1
7/26/16	645	278		923		26	20	
8/4/16	1,010	23		1,033		69	18	5
8/16/16	206	209		415		91	11	5
8/22/16	615	308		923		98	21	3
8/30/16	399	432		831		74	49	9
9/15/16	375	1,370		1,745		150	56	23
9/22/16	495	660		1,155		46	101	11
10/5/16	465	569		1,034		46	16	5
10/17/16	359	659		1,018		50	21	10
12/14/16	300	770	291	1,070	1,061	71	12	21
2/28/17	393	1,550	314	1,943	1,864	28	38	3
3/29/17	362	598	ND	960		20	12	3
4/19/17	425	436	210	861	646	20	8	3
5/2/17	508	1,540	216	2,048	1,756	18	13	2
5/24/17	325	542	238	867	780	56	23	18
6/6/17	512	483	233	995	716	54	31	6
6/27/17	483	426	484	909	910	32	31	5
7/19/17	428	248	126	676	374	27	12	4
8/1/17	496	234	423	730	657	39	29	5
8/30/17	325	99	280	424	379	27	8	6
10/10/17	512	242	1,098	754	1,340	38	9	5
10/26/17	215	249	352	464	601	25	14	6
11/8/17	195	225	565	420	790		127	4
2015 mean	414	509	551	923	1,077	56	21	12
2015 min	12	203	25	296	242	19	6	3
2015 max	1,080	1,440	1,590	2,198	2,330	112	50	28
2016 mean	472	706	N/A	1,168	N/A	57	21	8
2016 min	184	23	N/A	415	N/A	14	4	1
2016 max	1,010	1,440	N/A	1,745	N/A	150	56	23
2017 mean	398	529	378	927	832	32	27	5
2017 min	195	99	126	420	374	18	8	2
2017 max	512	1,550	1,098	2,048	1,864	56	127	18
all mean	430	581	458	1,006	1,024	49	23	8
all min	12	23	25	296	242	14	4	1
all max	1,080	1,550	1,590	2,198	2,330	150	127	28
all sd	219	415	338	494	577	32	21	7
all CV%	51%	72%	74%	49%	56%	65%	92%	83%

*Values removed from calculations

ND = Non-detect

South Fork Rivanna 2 - Surface

Date	Ammonia µg/L	Nitrate µg/L	TKN µg/L	TIN µg/L	TN µg/L	Chlorophyll *a* µg/L	TP µg/L	O-PO4 µg/L	TSS mg/L	Secchi (m)
4/14/15	ND	141	17		158	8	35	36	5	
5/5/15	130	132	10	262	142	ND	37	33	7	
5/18/15	154	426	1,394	580	1,820	7	42	22	5	
6/1/15	125	315	ND	440		6	23	18	4	1.80
6/16/15	130	233	140	363	373	16	32	11	5	
6/30/15	325	428	560	753	988	8	77	22	10	
7/15/15	195	479	549	674	1,028	11	72	8	6	0.90
7/28/15	245	464	554	709	1,018	28	41	20	5	1.40
8/5/15	254	495	694	749	1,189	69	41	39	5	1.20
8/26/15	73	545	190	618	735	5	(561)*	(29)*	4	1.80
9/8/15	95	365	446	460	811	6	50	31	4	1.35
9/23/15	300	563	549	863	1,112	2	60	50	7	1.20
10/8/15	300	1,400	437	1,700	1,837	1	46	27	6	0.80
10/21/15									3	
10/22/15	299	1,010	437	1,309	1,447	6	18	4	3	
11/18/15	137	562	202	699	764	3	41	10	4	
3/14/16	195	1,130	375	1,325	1,505		(28)*	(67)*	5	
5/18/16	215	1,020		1,235		6	38	6	8	
5/25/16	354						128			
6/28/16	278	1,260		1,538		9		28		0.85
7/11/16	125	1,230		1,355		10	37	38		
7/26/16	796	235		1,031		8	19	15		1.40
8/4/16	851	209		1,060		6	133	42	18	
8/6/16						9				
8/16/16	325	429		754			57	11	9	
8/22/16						3				1.35
8/30/16	452	459		911		2	103	9	5	2.00
9/15/16	399	1,300		1,699		1	78	18	25	0.80
9/22/16						1				
10/5/16	789	523		1,312			88	8	4	
10/17/16	545	648		1,193		5	42	12	21	1.30
12/14/16	299	660	375	959	1,035	5	45	9	5	1.35
2/28/17		683	263		946	1	45	53	10	1.30
3/29/17		443	67		510	2	38		7	1.45
4/19/17	495	322	322	817	644	5	55	11	9	1.20
5/2/17	415	1,270	311	1,685	1,581	4	43	16	5	1.55
5/24/17	359	458	333	817	791	7	50	22	7	1.80
6/6/17	534	550	328	1,084	878	9	68	73	8	1.60
6/27/17	600	405	613	1,005	1,018	8	39	33	7	1.41
7/19/17	119	237	85	356	322	7	55	15	8	1.24
8/1/17	456	197	473	653	670		45	62	5	1.25
8/11/17						10				
8/30/17	300	170	230	470	400	11	70	23	15	
10/10/17	514	248	106	762	354		65	11	22	0.85
10/13/17						44				
10/26/17	213	216	285	429	501		28	30	17	0.95
11/8/17	89	207	503	296	710			36	6	1.10
11/11/17						10				

*Values removed from calculations

ND = Non-detect

Any time OPO4 was ≥ 3x TP, both values removed due to high analytical error

South Fork Rivanna 2 - Surface

Date	Ammonia µg/L	Nitrate µg/L	TKN µg/L	TIN µg/L	TN µg/L	Chlorophyll *a* µg/L	TP µg/L	O-PO4 µg/L	TSS mg/L	Secchi (m)
2015 mean	197	504	441	679	895	13	44	24	5	1.31
2015 min	73	132	10	262	142	1	18	4	3	0.80
2015 max	325	1,400	1,394	1,700	1,837	69	77	50	10	1.80
2016 mean	402	700	N/A	1,106	N/A	5	64	16	10	1.13
2016 min	125	209	N/A	754	N/A	1	19	6	4	0.80
2016 max	851	1,300	N/A	1,699	N/A	10	133	42	25	2.00
2017 mean	372	416	301	761	717	9	50	32	10	1.31
2017 min	89	170	67	296	322	1	28	11	5	0.85
2017 max	600	1,270	613	1,685	1,581	44	70	73	22	1.80
all mean	328	552	374	890	872	9	54	25	8	1.30
all min	73	132	10	262	142	1	18	4	3	0.80
all max	851	1,400	1,394	1,700	1,837	69	133	73	25	2.00
all sd	202	364	270	407	457	13	26	16	6	0.32
all CV%	61%	66%	72%	46%	52%	133%	49%	67%	68%	25%

*Values removed from calculations

ND = Non-detect

Any time OPO4 was ≥ 3x TP, both values removed due to high analytical error

South Fork Rivanna 2 - Bottom

Date	Ammonia µg/L	Nitrate µg/L	TKN µg/L	TIN µg/L	TN µg/L	TP µg/L	O-PO4 µg/L	TSS mg/L
5/5/15	400	239	286	639	525	180	37	15
5/18/15	521	574		1,095		60	36	6
6/1/15	500	322	218	822	540	80	9	22
6/16/15	245	317	347	562	664	36	8	6
6/30/15	654	206	582	860	788	62	32	15
7/15/15	215	799	577	1,014	1,376	56	11	11
7/28/15	281	469		750		135	44	55
8/5/15	190	486	470	676	956	56	40	23
8/26/15	271	449	353	720	802	(507)*	(13)*	10
9/8/15	367	426	484	793	910	127	47	41
9/23/15	699	542	484	1,241	1,026	168	36	6
10/8/15	699	1,490	554	2,189	2,044	158	27	54
10/22/15	754	754	778	1,508	1,532	22	2	12
11/18/15	109	591	190	700	781	31	12	7
3/14/16	118	1,640	465	1,758	2,105	(11)*	(39)*	10
5/18/16	251	1,420		1,671		29	4	6
5/25/16	815					253		11
6/28/16	240	1,310		1,550			54	7
7/11/16	203	779		982		22	26	10
7/26/16	999	174		1,173		14	10	
8/4/16	637	265		902		302	39	39
8/16/16	451	590		1,041		(154)*	(14)*	9
8/30/16	599	375		974		67	8	15
9/15/16	425	1,290		1,715		130	19	42
10/5/16	815	680		1,495		51	13	11

*Values removed from calculations

ND = Non-detect

South Fork Rivanna 2 - Bottom

Date	Ammonia µg/L	Nitrate µg/L	TKN µg/L	TIN µg/L	TN µg/L	TP µg/L	O-PO4 µg/L	TSS mg/L
10/17/16	645	608		1,253		(175)*	(13)*	72
12/14/16	512		465			41	13	13
2/28/17		1,030	319		1,349	(44)*	(126)*	7
3/29/17		516	17		533	20	7	4
4/19/17	515	409	428	924	837	24	23	6
5/2/17	512	1,200	456	1,712	1,656	27	15	4
5/24/17	219	515	428	734	943	45	29	8
6/6/17	615	556	423	1,171	979	(36)*	(100)*	14
6/27/17	559	288	602	847	890	35	47	48
7/19/17	234	207	126	441	333	144	21	49
8/1/17	587	179	412	766	591	55	62	8
8/30/17	395	185	286	580	471	57	25	9
10/10/17	678	205	1,389	883	1,594	52	34	8
10/26/17	425	203	391	628	594	(12)*	(37)*	11
11/8/17	175	191	335	366	526		23	6
2015 mean	422	547	444	969	996	90	26	20
2015 min	109	206	190	562	525	22	2	6
2015 max	754	1,490	778	2,189	2,044	180	47	55
2016 mean	516	830	N/A	1,319	N/A	101	21	20
2016 min	118	174	N/A	902	N/A	14	4	6
2016 max	999	1,640	N/A	1,758	N/A	302	54	72
2017 mean	447	437	432	823	869	46	29	14
2017 min	175	179	17	366	333	20	7	4
2017 max	678	1,200	1,389	1,712	1,656	144	62	49
all mean	461	592	440	1,031	975	82	25	18
all min	109	174	17	366	333	14	2	4
all max	999	1,640	1,389	2,189	2,105	302	62	72
all sd	223	409	247	427	484	71	16	17
all CV%	48%	69%	56%	41%	50%	87%	62%	96%

*Values removed from calculations

ND = Non-detect

South Fork Rivanna 3 - S. Fork Rivanna River Inflow

Date	Ammonia µg/L	Nitrate µg/L	TKN µg/L	TIN µg/L	TN µg/L	TP µg/L	O-PO4 µg/L	TSS mg/L
5/19/15	325	471	56	796	527		17	16
6/17/15	25	387	39	412	426	41	14	5
6/30/15	248	455	286	703	741	70	34	11
7/15/15	95	685	280	780	965	72	29	14
8/26/15	190	545	252	735	797	(549)*	(26)*	8
9/23/15	258	732	386	990	1,118	62	28	7
10/8/15	205	1,330	302	1,535	1,632	40	26	7
10/22/15	195	678	269	873	947	16	1	6
11/18/15	94	502	185	596	687	(9)*	(29)*	4
3/14/16	100	1,110	129	1,210	1,239	17	21	4
5/18/16	195	1,020		1,215		23	8	4
6/28/16	159	1,460		1,619			27	13
7/11/16	107	1,240		1,347		45	78	7

*Values removed from calculations

ND = Non-detect

South Fork Rivanna 3 - S. Fork Rivanna River Inflow

Date	Ammonia µg/L	Nitrate µg/L	TKN µg/L	TIN µg/L	TN µg/L	TP µg/L	O-PO4 µg/L	TSS mg/L
7/26/16	245	457		702		34	22	
8/4/16	510	269		779		113	17	18
8/30/16	525	621		1,146		43	39	5
9/15/16	215	1,650		1,865		92	18	28
9/29/16	500					73	81	15
10/5/16	625	597		1,222		65	37	15
10/17/16	315	472		787		32	16	12
12/14/16	325	755	129	1,080	884	27	32	8
1/25/17								8
2/28/17	155	427	90	582	517	25	78	4
3/29/17	125	406	28	531	434	31	25	7
4/19/17	235	259	ND	494	239	93	46	6
5/2/17	100	1,420	56	1,520	1,476	41	22	6
5/24/17	212	498	126	710	624	74	18	12
6/6/17	335	419	121	754	540	60	49	19
6/27/17	215	354	277	569	631	29	24	3
7/19/17	70	236	ND	306	222	120	27	9
8/1/17	200	244	232	444	476	51	89	5
8/30/17	152	214	56	366	270	35	18	12
11/8/17	56	173	128	229	301		28	4
2015 mean	182	643	228	824	871	50	21	9
2015 min	25	387	39	412	426	16	1	4
2015 max	325	1,330	386	1,535	1,632	72	34	16
2016 mean	318	877	N/A	1,179	N/A	51	33	12
2016 min	100	269	N/A	702	N/A	17	8	4
2016 max	625	1,650	N/A	1,865	N/A	113	81	28
2017 mean	169	423	124	591	521	51	39	8
2017 min	56	173	28	229	222	25	18	3
2017 max	335	1,420	277	1,520	1,476	120	89	19
all mean	228	648	171	868	713	53	32	9
all min	25	173	28	229	222	16	1	3
all max	625	1,650	386	1,865	1,632	120	89	28
all sd	145	408	106	415	390	28	22	6
all CV%	63%	63%	62%	48%	55%	54%	68%	60%

*Values removed from calculations

ND = Non-detect

South Fork Rivanna 4 - Ivy Creek

Date	Ammonia µg/L	Nitrate µg/L	TKN µg/L	TIN µg/L	TN µg/L	TP µg/L	O-PO4 µg/L	TSS mg/L	Secchi (m)
5/18/16	296	1,510		1,806		(373)*	(4)*	9	
6/28/16	279	1,570		1,849			106	12	0.75
7/11/16	125	1,410		1,535		67	17	15	
7/26/16	205	418		623		42	10		0.75
8/4/16	451	273		724		104	10	17	
8/16/16	145	461		606		26	11	9	
8/22/16									0.65
8/30/16	194	669		863		74	15	13	1

*Values removed from calculations

ND = Non-detect

South Fork Rivanna 4 - Ivy Creek

Date	Ammonia µg/L	Nitrate µg/L	TKN µg/L	TIN µg/L	TN µg/L	TP µg/L	O-PO4 µg/L	TSS mg/L	Secchi (m)
9/6/16									0.6
9/15/16	194	1,720		1,914		97	12	36	0.75
10/5/16	525	570		1,095		84	16	12	
10/17/16	156	696		852		38	15	15	0.6
12/14/16	145	1,400	302	1,545	1,702	46	8	3	0.5
1/25/17								8	
2/28/17	195	960	34	1,155	994	35	29	9	0.6
3/29/17	232	766	3	998	769	58	20	12	0.8
4/19/17	185	539	ND	724	519	59	16	11	0.93
5/2/17	200	2,250	68	2,450	2,318	74	19	15	0.85
5/24/17	175	695	260	870	955	66	8	13	0.95
6/6/17	212	720	255	932	975	60	55	12	0.65
6/27/17	195	470	199	665	669	64	17	19	0.72
7/19/17	69	271	ND	340	264	(161)*	(13)*	15	0.72
8/1/17	245	245	210	490	455	84	45	16	0.96
8/30/17		234				18			
11/8/17	11	207	131	218	338		4	12	
2016 mean	247	972	N/A	1,219	N/A	64	22	14	0.7
2016 min	125	273	N/A	606	N/A	26	8	3	0.5
2016 max	525	1,720	N/A	1,914	N/A	104	106	36	1
2017 mean	172	669	145	884	826	58	24	13	0.8
2017 min	11	207	3	218	264	18	4	8	0.6
2017 max	245	2,250	260	2,450	2,318	84	55	19	0.96
all mean	211	821	162	1,060	905	61	23	13	0.75
all min	11	207	3	218	264	18	4	3	0.5
all max	525	2,250	302	2,450	2,318	104	106	36	1
all sd	112	572	108	582	617	24	24	6	0.15
all CV%	53%	70%	67%	55%	68%	39%	104%	46%	19%

*Values removed from calculations

ND = Non-detect

Beaver Creek 1 - Surface

Date	Ammonia µg/L	Nitrate µg/L	TKN µg/L	TIN µg/L	TN µg/L	Chlorophyll *a* µg/L	TP µg/L	O-PO4 µg/L	TSS mg/L	Secchi (m)
6/1/15	98	400	ND	498		4.81	10	8	3	
6/29/15	100	401	56	501	457	3.20	18	19	3	1.70
7/15/15	254	706	134	960	840	2.72	32	6	2	3.80
7/28/15	202	695	67	897	762	13.62	17	7	2	
8/12/15	200	751	241	951	992	2.14	ND	14	3	4.25
8/24/15	115	392	185	507	577	1.07	ND	23	2	4.30
9/8/15						1.60				
9/9/15	215	482	476	697	958		(22)*	(88)*	1	5.40
9/23/15	178	680	224	858	904	6.41	20	15	3	1.50

*Values removed from calculations

ND = Non-detect

Any time OPO4 was ≥ 3x TP, both values removed due to high analytical error

Beaver Creek 1 - Surface

Date	Ammonia µg/L	Nitrate µg/L	TKN µg/L	TIN µg/L	TN µg/L	Chlorophyll *a* µg/L	TP µg/L	O-PO4 µg/L	TSS mg/L	Secchi (m)
10/6/15	200	1,160	409	1,360	1,569	1.07	55	13	2	
10/8/15										2.40
10/21/15	117	881	297	998	1,178	2.14	24	9	4	
11/3/15	215	770	291	985	1,061	11.48	11	20	1	
11/18/15	325	725	269	1,050	994	3.47	26	11	4	
2/18/16	215	1,930	425	2,145	2,355	1.60	(13,092)*	(4,287)*	5	
3/14/16	345	1,750	358	2,095	2,108		ND	39	4	
4/2/16						5.61				
4/12/16	251	1,390		1,641			32	18	7	
5/9/16		992				10	(364)*	(10)*	4	
5/19/16	315	962		1,277		3	10	2	4	
6/15/16	525					6	35	9	8	
6/20/16	515	1,430		1,945		4	26	7	5	2.40
6/27/16	500	1,400		1,900		5		1	4	2.90
7/6/16	212	1,080		1,292		4	22	7	2	
7/12/16	200	1,200		1,400		2	21	10	4	
7/20/16	299	1,240		1,539		1	(14)*	(64)*	2	
7/26/16	575	466		1,041		1	(2)*	(7)*		3.20
7/31/16						18				
8/3/16	625	99		724			35	21	5	2.10
8/8/16	575					14	44	8	9	
8/17/16	325	488		813		5	31	16	3	
8/22/16	197	532		729		6	68	94	2	2.20
8/30/16	450	903		1,353		6	22	24	5	2.45
9/6/16										2.15
9/15/16	250	607		857		1	26	7	9	1.80
9/22/16	354	779		1,133		1	21	26	9	
10/5/16	515	747		1,262			(17)*	(56)*	4	
10/17/16	314	624		938		2	25	12	7	2.30
12/1/16										2.30
12/12/16	212	610	358	822	968		25	31	5	1.45
1/25/17	204	356	263	560	619	1	60	17	8	
2/22/17	295	814	454	1,109	1,268	2	28	17	5	2.10
3/28/17	351	890	179	1,241	1,069	7	40	11		1.65
4/26/17	207	713	202	920	915	3	39	25	4	1.95
5/9/17	345	779	361	1,124	1,140	14	55	14	9	1.80
5/24/17	425	513	238	938	751	6	35	11	4	
6/6/17	475	508	233	983	741	13	49	34	6	3.00
6/20/17	347	448	199	795	647	21	37	10	9	2.45
7/19/17										2.67
7/20/17	273	217	70	490	287	2	116	16	8	
8/1/17	685	222	462	907	684		44	29	5	1.85
8/16/17	215	759	302	974	1,061	9	25	11	5	4.30
8/30/17	452	234	140	686	374	2	130	15	4	
9/27/17	175		200				15	22	2	4.80
10/10/17	215	225	140	440	365	3	28	38	4	2.30
10/26/17	195	377	195	572	572		54	42	9	
11/21/17	92		307	92	307	5	37	1	8	1.05
12/7/17	131	278		409			37	15	9	1.20

*Values removed from calculations

ND = Non-detect

Any time OPO4 was ≥ 3x TP, both values removed due to high analytical error

Beaver Creek 1 - Surface

Date	Ammonia µg/L	Nitrate µg/L	TKN µg/L	TIN µg/L	TN µg/L	Chlorophyll *a* µg/L	TP µg/L	O-PO4 µg/L	TSS mg/L	Secchi (m)
2015 mean	168	629	207	797	865	5	21	15	3	3.32
2015 min	75	205	12	322	231	1	10	6	1	1.50
2015 max	325	1,160	476	1,360	1,569	14	55	27	8	5.40
2016 mean	370	961	N/A	1,311	N/A	5	29	19	5	2.30
2016 min	197	99	N/A	724	N/A	1	10	1	2	1.45
2016 max	625	1,930	N/A	2,145	N/A	18	68	94	9	3.20
2017 mean	299	458	247	765	720	7	49	19	6	2.39
2017 min	92	217	70	92	287	1	15	1	2	1.05
2017 max	685	890	462	1,241	1,268	21	130	42	9	4.80
all mean	290	720	243	982	886	5	35	18	5	2.59
all min	75	99	12	92	231	1	10	1	1	1.05
all max	685	1,930	476	2,145	2,355	21	130	94	9	5.40
all sd	152	401	128	446	477	5	24	15	3	1.07
all CV%	52%	56%	53%	45%	54%	91%	69%	82%	52%	41%

*Values removed from calculations

ND = Non-detect

Any time OPO4 was ≥ 3x TP, both values removed due to high analytical error

Beaver Creek 1 - Bottom

Date	Ammonia µg/L	Nitrate µg/L	TKN µg/L	TIN µg/L	TN µg/L	TP µg/L	O-PO4 µg/L	TSS mg/L
8/12/15	512	470	1,417	982	1,887	102	14	7
8/24/15	859	308	1,282	1,167	1,590	38	21	1
9/9/15	945	369	1,400	1,314	1,769	35	11	4
9/23/15	348	636	370	984	1,006	37	34	11
10/6/15	2,470	1,010	3,354	3,480	4,364	122	61	1
10/21/15	3,000	355	3,265	3,355	3,620	87	62	6
11/3/15	3,500	431	3,259	3,931	3,690	207	98	11
11/18/15	995	362	1,943	1,357	2,305	226	225	8
2/18/16	552	2,040	352	2,592	2,392	(1,990)*	(1,003)*	17
3/14/16	812	1,830	523	2,642	2,353	21	31	5
4/12/16	205	1,650		1,855		16	27	5
5/9/16	215	1,180		1,395			4	3
5/19/16	482	755		1,237		18	ND	16
6/15/16	226					29	2	5
6/20/16	230	1,200		1,430		71	39	2
6/27/16	759	774		1,533			65	4
7/6/16	298	610		908		38	15	3
7/12/16	298	696		994		26	4	6
7/20/16	1,880	764		2,644		(852)*	(15)*	11
7/26/16	955	213		1,168		202	161	
8/3/16	321	25		346		225	246	7
8/8/16	638					48	15	3
8/17/16	548	259		807		144	78	4
8/22/16	298	470		768		102	21	5
8/30/16	620	786		1,406		403	226	6
9/15/16	395	1,310		1,705		(8)*	(169)*	13

*Values removed from calculations

ND = Non-detect

Beaver Creek 1 - Bottom

Date	Ammonia µg/L	Nitrate µg/L	TKN µg/L	TIN µg/L	TN µg/L	TP µg/L	O-PO4 µg/L	TSS mg/L
9/22/16	520	733		1,253		14	5	4
10/5/16	905	597		1,502		500	301	14
10/17/16	520	563		1,083		123	84	10
12/12/16	520	557	523	1,077	1,080	15	31	7
1/25/17	451		319			45	17	4
2/22/17	520	781	532	1,301	1,313	40	15	3
3/28/17	400	865	207	1,265	1,072	69	14	
4/26/17	367	885	269	1,252	1,154		8	3
5/9/17	530	747	451	1,277	1,198	23	6	4
5/24/17	395	265	255	660	520	36	7	7
6/6/17	515	473	250	988	723	(23)*	(98)*	3
6/20/17	499	330	239	829	569	34	12	4
7/20/17	1,430	209	104	1,639	313	157	41	7
8/1/17	543	211	507	754	718	154	124	8
8/16/17	758	816	901	1,574	1,717	50	54	10
8/30/17	512	227	274	739	501	30	69	28
9/27/17	320		179			53	22	10
10/10/17	425	258	980	683	1,238	219	166	23
10/26/17	268	316	285	584	601	21	28	5
11/21/17	145		335			12	1	7
12/7/17	175	241		416		(22)*	(64)*	7
2015 mean	939	459	1,295	1,398	1,630	73	45	5
2015 min	125	204	17	329	265	19	11	1
2015 max	3,500	1,010	3,354	3,931	4,364	226	225	11
2016 mean	554	851	N/A	1,417	N/A	117	75	7
2016 min	205	25	N/A	346	N/A	14	2	2
2016 max	1,880	2,040	N/A	2,644	N/A	500	301	17
2017 mean	485	473	380	931	831	67	39	8
2017 min	145	209	104	416	313	12	1	3
2017 max	1,430	885	980	1,639	1,717	219	166	28
all mean	640	623	760	1,291	1,389	88	55	7
all min	125	25	17	329	265	12	1	1
all max	3,500	2,040	3,354	3,931	4,364	500	301	28
all sd	667	426	943	796	1,065	101	71	5
all CV%	104%	68%	124%	62%	77%	116%	130%	77%

*Values removed from calculations

ND = Non-detect

Beaver Creek 2 - Surface

Date	Ammonia µg/L	Nitrate µg/L	TKN µg/L	TIN µg/L	TN µg/L	Chlorophyll *a* µg/L	TP µg/L	O-PO4 µg/L	TSS mg/L	Secchi (m)
8/24/15	10	370	263	380	633	1.6	10	10	1	4.00
9/8/15						2.1				
9/9/15	250	470	67	720	537		12	17	1	4.70
9/23/15	212	57	224	269	281	10.2	19	22	4	1.30

*Values removed from calculations

ND = Non-detect

Any time OPO4 was ≥ 3x TP, both values removed due to high analytical error

Beaver Creek 2 - Surface

Date	Ammonia µg/L	Nitrate µg/L	TKN µg/L	TIN µg/L	TN µg/L	Chlorophyll *a* µg/L	TP µg/L	O-PO4 µg/L	TSS mg/L	Secchi (m)
10/6/15	156	1,170	224	1,326	1,394	1.9	50	10	7	
10/8/15										2.75
10/21/15	228	919	246	1,147	1,165	2.4	24	14	2	
11/3/15	520	759	241	1,279	1,000	13.1	22	88	1	
11/18/15	638	711	319	1,349	1,030	2.9	19	38	3	
2/18/16	312	1,900	525	2,212	2,425	4	(14,051)*	(75)*		
3/14/16	251	1,780	442	2,031	2,222		26	19	4	
all mean	268	736	278	1,004	1,015	5	19	23	2	3
all min	10	57	26	269	240	2	10	9	1	1
all max	638	1,900	700	2,212	2,425	13	50	88	7	5
all sd	157	506	167	550	610	3	10	20	2	1
all CV%	59%	69%	60%	55%	60%	72%	51%	88%	79%	39%

*Values removed from calculations

ND = Non-detect

Any time OPO4 was ≥ 3x TP, both values removed due to high analytical error

Beaver Creek 2 - Bottom

Date	Ammonia µg/L	Nitrate µg/L	TKN µg/L	TIN µg/L	TN µg/L	TP µg/L	O-PO4 µg/L	TSS mg/L
4/16/15	75	406	246	481	652	24	14	3
5/5/15	450	247	224	697	471	34	14	5
5/18/15	250	686	179	936	865	89	24	7
6/29/15	159	155	241	314	396	48	26	11
7/15/15	390	370	224	760	594	75	29	10
7/28/15	475	441	252	916	693	118	81	12
8/12/15	390	413	493	803	906	37	21	4
8/24/15	112	340	414	452	754	34	18	5
9/9/15	536	427	420	963	847	48	15	18
9/23/15	405	523	437	928	960	49	38	6
10/6/15	329	1,900	448	2,229	2,348	107	38	2
10/21/15	1,975	465	2,565	2,440	3,030	59	56	11
11/3/15	2,625	501	2,559	3,126	3,060	137	156	7
11/18/15	346	861	454	1,207	1,315	114	35	22
2/18/16	412	2,010	413	2,422	2,423	(1,496)*	(108)*	7
3/14/16	251	1,710	487	1,961	2,197	12	20	5
all mean	574	716	629	1,290	1,344	66	39	8
all min	75	155	179	314	396	12	14	2
all max	2,625	2,010	2,565	3,126	3,060	137	156	22
all sd	696	599	762	856	930	39	37	5
all CV%	121%	84%	121%	66%	69%	59%	95%	64%

*Values removed from calculations

ND = Non-detect

Beaver Creek 3 - Watts Creek Inflow

Date	Ammonia µg/L	Nitrate µg/L	TKN µg/L	TIN µg/L	TN µg/L	TP µg/L	O-PO4 µg/L	TSS mg/L
4/16/15	95	422	196	517	618	43	34	9
5/19/15	450	845	230	1,295	1,075		26	13
6/17/15	45	1,010	0	1,055	1,010	43	15	7
6/29/15	54	719	196	773	915	77	10	17
7/15/15	85	1,380	190	1,465	1,570	49	24	7
8/12/15	85	1,350	470	1,435	1,820	32	23	10
8/24/15	100	1,330	392	1,430	1,722	22	27	6
9/9/15		2,210	84		2,294	36	21	11
9/23/15	123	1,550	252	1,673	1,802	33	33	4
10/6/15	102	2,260	224	2,362	2,484	66	26	14
10/21/15	98	1,930	213	2,028	2,143	13	14	2
11/3/15	101	1,210	207	1,311	1,417	56	23	11
3/14/16	121	1,610	56	1,731	1,666	23	28	32
4/12/16	237	1,470		1,707		13	24	5
5/19/16	215	1,610		1,825		26	11	10
6/15/16	235					56	23	10
6/20/16	615	2,170		2,785		49	11	9
6/23/16	456	1,670		2,126		601	41	150
6/27/16	235	1,910		2,145			78	9
7/13/16	95	2,410		2,505		34	21	5
7/26/16	200	1,480		1,680		46	34	
8/3/16	951	435		1,386		520	72	237
8/30/16		1,730				41	103	10
9/15/16	125	2,110		2,235		47	30	2
9/29/16	195					89	29	8
10/5/16	495	1,120		1,615		56	40	21
10/17/16	300	1,230		1,530		25	20	2
12/12/16	150	1,270	442	1,420	1,712	(4)*	(31)*	2
1/25/17	125	1,094	90	1,219	1,184	61	30	8
2/22/17	195	955	319	1,150	1,274	(3)*	(49)*	2
2/23/17	205	1,000	342	1,205	1,342	22	13	5
3/28/17	150	945	168	1,095	1,113	54	42	
3/31/17	351	1,240	423	1,591	1,663	(279)*	29	67
4/26/17	166	772	62	938	834	55	25	7
5/9/17	199	1,010	333	1,209	1,343	36	55	5
5/24/17	245	561	176	806	737	76	28	6
6/6/17	310	720	171	1,030	891	51	46	4
6/20/17	295	714	345	1,009	1,059	32	38	11
7/20/17	89	697	115	786	812	56	24	2
8/1/17	265	764		1,029		39	47	4
8/16/17	212	712	291	924	1,003	22	32	3
8/30/17	125	620	118	745	738	98	40	3
9/27/17	156		301			27	40	4
10/10/17	345	449	69	794	518	34	22	3
10/26/17	95	580	133	675	713	24	43	2
11/21/17	195		133			5	9	1
12/7/17	85	485		570		(8)*	(36)*	8
2015 mean	122	1,351	221	1,395	1,573	43	23	9
2015 min	45	422	0	517	618	13	10	2
2015 max	450	2,260	470	2,362	2,484	77	34	17
2016 mean	308	1,588	N/A	1,899	N/A	116	38	34

*Values removed from calculations

ND = Non-detect

Beaver Creek 3 - Watts Creek Inflow

Date	Ammonia µg/L	Nitrate µg/L	TKN µg/L	TIN µg/L	TN µg/L	TP µg/L	O-PO4 µg/L	TSS mg/L
2016 min	95	435	N/A	1,386	N/A	13	11	2
2016 max	951	2,410	N/A	2,785	N/A	601	103	237
2017 mean	200	740	199	932	895	43	33	8
2017 min	85	449	62	570	518	5	9	1
2017 max	351	1,240	423	1,591	1,663	98	55	67
all mean	217	1,204	217	1,386	1,292	68	32	17
all min	45	422	0	517	518	5	9	1
all max	951	2,410	470	2,785	2,484	601	103	237
all sd	167	555	123	549	517	115	18	41
all CV%	77%	46%	57%	40%	40%	169%	57%	240%

*Values removed from calculations

ND = Non-detect

Beaver Creek 3 - Watts Creek Inflow

Date	Ammonia µg/L	Nitrate µg/L	TKN µg/L	TIN µg/L	TN µg/L	TP µg/L	O-PO4 µg/L	TSS mg/L
4/12/16	184	1,230		1,414		46	15	6
5/19/16	175	1,150		1,325		30	5	11
6/15/16	199					33	8	6
6/20/16	845	1,680		2,525		34	8	8
6/23/16	512	1,130		1,642		183	26	45
6/27/16	215	1,580		1,795			1	4
7/13/16	89	2,060		2,149		16	6	
7/26/16	185	994		1,179		10	25	
8/3/16	451	120		571		154	61	36
8/17/16	178	777		955		33	34	3
8/30/16	215	1,550		1,765		22	18	2
9/15/16	125	2,130		2,255		49	12	9
9/29/16	313					(23)*	(73)*	3
10/5/16	515	854		1,369		58	18	22
10/17/16	251	862		1,113		23	11	2
12/12/16	251	980	487	1,231	1,467	1	21	1
1/25/17	150	610	174	760	784	42	17	8
2/22/17	525	1,100	286	1,625	1,386	(4)*	(489)*	2
2/23/17	515	1,140	544	1,655	1,684	17	9	3
3/28/17	215	1,020	196	1,235	1,216		119	
3/31/17	555	988	602	1,543	1,590	178	18	49
4/26/17	105	807	45	912	852	43	23	9
5/9/17	234	617	210	851	827	70	143	9
5/24/17	521	408	216	929	624	36	7	5
6/6/17	264	466	211	730	677	42	12	3
6/20/17	215	472	373	687	845	23	22	5
7/20/17		564	134		698	52	30	12
8/1/17	215	555		770		17	38	37
8/16/17	100	727	111	827	838	52	14	2
8/30/17	95	483	140	578	623	(4)*	(28)*	7
9/27/17	95		213			70	38	6
10/10/17	215	361	56	576	417	39	17	8

*Values removed from calculations

ND = Non-detect

Beaver Creek 3 - Watts Creek Inflow

Date	Ammonia µg/L	Nitrate µg/L	TKN µg/L	TIN µg/L	TN µg/L	TP µg/L	O-PO4 µg/L	TSS mg/L
10/26/17	87	511	156	598	667	29	11	
11/21/17	215		156			(2)*	(29)*	13
12/7/17	95	454		549		16	39	3
2016 mean	294	1,221	N/A	1,521	N/A	41	18	11
2016 min	89	120	N/A	571	N/A	1	1	1
2016 max	845	2,130	N/A	2,525	N/A	183	61	45
2017 mean	245	627	212	872	807	48	35	10
2017 min	87	361	45	549	417	16	7	2
2017 max	555	1,140	602	1,655	1,684	178	143	49
all mean	268	915	239	1,204	950	45	27	11
all min	87	120	45	549	417	1	1	1
all max	845	2,130	602	2,525	1,684	183	143	49
all sd	179	490	160	543	389	42	31	13
all CV%	67%	53%	67%	45%	41%	93%	115%	118%

*Values removed from calculations

ND = Non-detect

Ragged Mountain 1 - Surface

Date	Ammonia µg/L	Nitrate µg/L	TKN µg/L	TIN µg/L	TN µg/L	Chlorophyll *a* µg/L	TP µg/L	O-PO4 µg/L	TSS mg/L	Secchi (m)
4/15/15	95	31	ND	126		ND	21	17	4	
5/7/15	12	190	8	202	198	ND	9	10	2	3.40
5/19/15	75	265	1,820	340	2,085	ND		14	2	
6/8/15	101		0			ND	6	10	2	3.30
6/16/15	50	136	0	186	136	2	17	6	6	2.00
6/29/15	125	208	168	333	376	3	14	8	3	2.10
7/14/15	254	216	162	470	378	4	15	10	2	3.30
7/29/15	385	360	168	745	528	5	12	13	2	3.40
8/12/15	205	339	280	544	619	2	ND	21	2	3.00
8/24/15	46	279	106	325	385	2	ND	17	3	3.90
9/9/15										3.40
10/8/15	250	347	269	597	616	2	10	25	1	3.00
10/21/15	89	321	126	410	447	3	9	9	1	
11/23/15	95	411	274	506	685	3	ND	12	4	
3/16/16	275	413	263	688	676		6	1	3	
4/12/16	299	678		977		2	27	7	5	
5/18/16	354	630		984			19	1	6	
6/20/16	456	876				1	15	19	5	4.50
7/12/16	315	819		1,134		2	23	6	3	
8/12/16	251	19		270		1	76	6	2	3.50
8/31/16	100	456		556		1	14	5	2	4.55
10/5/16	751	534		1,285			(12)*	(295)*	4	
10/20/16	689	1,240		1,929		1	19	15	3	3.80

*Values removed from calculations

ND = Non-detect

Any time OPO4 was ≥ 3x TP, both values removed due to high analytical error

Ragged Mountain 1 - Surface

Date	Ammonia µg/L	Nitrate µg/L	TKN µg/L	TIN µg/L	TN µg/L	Chlorophyll *a* µg/L	TP µg/L	O-PO4 µg/L	TSS mg/L	Secchi (m)
12/14/16	215	413	263	628	676	1	50	5	7	3.00
1/25/17	200	101	269	301	370	2	17	21	4	
2/22/17	215	423	308	638	731	3	(15)*	(401)*	8	3.00
3/28/17	195	328	146	523	474	3	22	10		4.50
4/20/17	125	412	3	537	415		74	41	2	5.50
5/9/17	456	578	182	1,034	760	2	(10)*	(378)*	5	6.20
5/31/17	175	301	118	476	419	2	36	9	7	
6/28/17	199	208	104	407	312	2	19	55	4	6.40
7/20/17	47	255	154	302	409	1	14	5	3	
8/2/17	85	178	111	263	289		17	17	4	
8/17/17	95	18	380	113	398		(3)*	(65)*	7	5.75
9/11/17						3				
9/26/17	154		190				13	21	7	4.50
10/13/17						2				
10/18/17	75	217	67	292	284		7	14	3	6.50
11/29/17	498					4	28	28	2	3.85
2015 mean	137	259	282	399	587	3	13	13	3	3.08
2015 min	12	31	0	126	136	2	6	6	1	2.00
2015 max	385	411	1,820	745	2,085	5	21	25	6	3.90
2016 mean	371	608	N/A	939	N/A	1	28	7	4	3.87
2016 min	100	19	N/A	270	N/A	1	6	1	2	3.00
2016 max	751	1,240	N/A	1,929	N/A	2	76	19	7	4.55
2017 mean	194	274	156	407	405	2	25	22	5	5.13
2017 min	47	18	3	113	284	1	7	5	2	3.00
2017 max	498	578	380	1,034	760	4	74	55	8	6.50
all mean	222	370	228	566	528	2	22	14	3.7	4.01
all min	12	18	0	113	136	1	6	1	1	2.00
all max	751	1,240	1,820	1,929	2,085	5	76	55	8	6.50
all sd	175	260	340	386	372	1	18	11	2	1.27
all CV%	79%	70%	149%	68%	71%	51%	81%	79%	52%	32%

*Values removed from calculations

ND = Non-detect

Any time OPO4 was ≥ 3x TP, both values removed due to high analytical error

Ragged Mountain 1 - Bottom

Date	Ammonia µg/L	Nitrate µg/L	TKN µg/L	TIN µg/L	TN µg/L	TP µg/L	O-PO4 µg/L	TSS mg/L
4/15/15	25	83	ND	108		44	26	7
5/7/15	78	210	6	288	216	112	6	52
5/19/15	100	356	1,092	456	1,448		11	1
6/8/15	59		224			(6)*	(27)*	2
6/16/15	75	108	196	183	304	26	6	2
6/29/15	215	251	286	466	537	11	32	2
7/14/15	152	460	280	612	740	15	6	2
7/29/15	202	701	286	903	987	7	6	4
8/12/15	278	291	353	569	644	ND	8	1

*Values removed from calculations

ND = Non-detect

Ragged Mountain 1 - Bottom

Date	Ammonia µg/L	Nitrate µg/L	TKN µg/L	TIN µg/L	TN µg/L	TP µg/L	O-PO4 µg/L	TSS mg/L
8/24/15	35	226	442	261	668	(1)*	(22)*	14
10/8/15	715	373	941	1,088	1,314	31	38	9
10/21/15	125	443	106	568	549	(2)*	(8)*	2
11/23/15	217	465	437	682	902	(2)*	(7)*	5
3/16/16	595	364	302	959	666	ND	12	3
4/12/16	314	613		927		ND	37	2
5/18/16	199	537		736		3	ND	1
6/20/16	895	722				101	51	5
7/12/16	447	626		1,073		20	15	3
8/12/16	312	40		352		218	72	3
8/31/16	125	318		443		8	6	2
10/5/16	1,150	382		1,532		(11)*	(211)*	2
10/20/16	956	2,800		3,756		52	97	16
12/14/16	315	477	302	792	779	36	20	16
1/25/17	300	91	314	391	405	(8)*	(28)*	2
2/22/17	325	215	263	540	478	170	34	17
3/28/17	458	327	213	785	540	8	8	
4/20/17	199	370	5	569	375	16	4	3
5/9/17	645	440	272	1,085	712	(5)*	(304)*	1
5/31/17	215	270	67	485	337	9	7	2
6/28/17	215	218	53	433	271	5	8	3
7/20/17	1,160	270	98	1,430	368	62	11	8
8/2/17	131	181	145	312	326	19	38	3
8/17/17	52	41	229	93	270	15	11	11
9/26/17	212		316			(1)*	(24)*	5
10/18/17	230	174	67	404	241	(1)*	(12)*	5
11/29/17	662					26	27	8
2015 mean	175	331	387	515	755	35	15	8
2015 min	25	83	6	108	216	7	6	1
2015 max	715	701	1,092	1,088	1,448	112	38	52
2016 mean	531	688	N/A	1,174	N/A	63	39	5
2016 min	125	40	N/A	352	N/A	3	6	1
2016 max	1,150	2,800	N/A	3,756	N/A	218	97	16
2017 mean	370	236	170	593	393	37	16	6
2017 min	52	41	5	93	241	5	4	1
2017 max	1,160	440	316	1,430	712	170	38	17
all mean	344	407	281	728	587	44	23	6
all min	25	40	5	93	216	3	4	1
all max	1,160	2,800	1,092	3,756	1,448	218	97	52
all sd	308	466	249	656	325	56	23	9
all CV%	90%	114%	89%	90%	55%	127%	99%	143%

*Values removed from calculations

ND = Non-detect

Ragged Mountain 2 - Surface

Date	Ammonia µg/L	Nitrate µg/L	TKN µg/L	TIN µg/L	TN µg/L	Chlorophyll *a* µg/L	TP µg/L	O-PO4 µg/L	TSS mg/L	Secchi (m)
4/15/15	156	17	ND	173		6	23		4	
5/7/15	25	170	ND	195	170	0	16	14		3.10
5/19/15	96	262	476	358	738	6		15	2	
6/8/15	95		258			1	(4)*	(13)*	1	2.90
6/16/15	25	122	ND	147	122	2	14	6	3	2.70
6/29/15	154	134	179	288	313	4	17	32	2	2.00
7/14/15	195	228	174	423	402	3	13	7	2	3.20
7/29/15	645	374	196	1,019	570	9	9	6	9	3.20
8/12/15	195	311	235	506	546	14	ND	14	1	2.90
8/24/15	35	276	330	311	606	1	ND	13	2	3.50
9/9/15										3.30
10/8/15	212	336	241	548	577	1	10	11	2	2.80
10/21/15	98	312		410		3	(4)*	(24)*	1	
11/23/15	75	331	218	406	549	3	59	9	5	
3/16/16	250	392	302	642	694		10	10		
mean	161	251	261	417	481	4	19	12	3	3.0
min	25	17	174	147	122	0	9	6	1	2.0
max	645	392	476	1,019	738	14	59	32	9	3.5
sd	157	111	91	233	203	4	16	7	2	0.4
CV%	97%	44%	35%	56%	42%	94%	82%	58%	81%	14%

*Values removed from calculations

ND = Non-detect

Any time OPO4 was ≥ 3x TP, both values removed due to high analytical error

Ragged Mountain 1 - Bottom

Date	Ammonia µg/L	Nitrate µg/L	TKN µg/L	TIN µg/L	TN µg/L	TP µg/L	O-PO4 µg/L	TSS mg/L
5/7/15	100	180		280		17	12	4
5/19/15	125	262	14	387	276		13	3
6/8/15	124		ND			106	13	5
6/16/15	49	102	168	151	270	33	6	5
6/29/15	275	152	297	427	449	106	25	17
7/14/15	110	170	291	280	461	52	16	4
7/29/15	536	321	297	857	618	47	12	6
8/12/15	215	243	274	458	517	24	24	4
8/24/15	131	351	2,997	482	3,348	42	15	7
10/8/15	405	390	459	795	849	19	13	5
10/21/15	102	280	115	382	395	(3)*	(11)*	2
11/23/15	346	324	325	670	649	50	3	5
3/16/16	445	398	330	843	728	ND	16	4
mean	228	264	506	501	778	50	14	5
min	49	102	14	151	270	17	3	2
max	536	398	2,997	857	3,348	106	25	17
sd	158	97	835	236	871	32	6	4
CV%	69%	37%	165%	47%	112%	65%	44%	68%

*Values removed from calculations

ND = Non-detect

Sugar Hollow 1 - Surface

Date	Ammonia µg/L	Nitrate µg/L	TKN µg/L	TIN µg/L	TN µg/L	Chlorophyll *a* µg/L	TP µg/L	O-PO4 µg/L	TSS mg/L	Secchi (m)
4/15/15	75	108	ND	183		6	17	16	1	
8/10/15	215	360	137	575	497	17	20	13	3	
10/6/15	169	774	722	943	1,496	1	67	31	6	0.80
7/5/16	254	431		685		1	34	3	5	
8/17/16	451	135		586		10	(21)*	(187)*	3	3.20
8/23/16	156	180		336		10	22	1	4	2.70
10/20/16		1,020				4		28	9	3.10
4/26/17	182	191	134	373	325	4	34	15	6	1.85
5/31/17	95	234		329		2	25	12	3	
6/27/17	152	88	154	240	242	2	17	20	6	5.80
7/27/17	349	ND	199		196	7	37		7	3.25
9/26/17	203		239				35	15	6	2.40
10/13/17						11				
2015 mean	153	414	430	567	997	8	35	20	3	0.80
2015 min	75	108	137	183	497	1	17	13	1	0.80
2015 max	215	774	722	943	1,496	17	67	31	6	0.80
2016 mean	287	442	N/A	536	N/A	6	28	11	5	3.00
2016 min	156	135	N/A	336	N/A	1	22	1	3	2.70
2016 max	451	1,020	N/A	685	N/A	10	34	28	9	3.20
2017 mean	196	171	182	314	254	5	30	16	6	3.33
2017 min	95	88	134	240	196	2	17	12	3	1.85
2017 max	349	234	239	373	325	11	37	20	7	5.80
all mean	209	352	264	472	551	6	31	15	5	2.89
all min	75	88	134	183	196	1	17	1	1	0.80
all max	451	1,020	722	943	1,496	17	67	31	9	5.80
all sd	109	312	228	244	541	5	15	9	2	1.44
all CV%	52%	89%	86%	52%	98%	82%	48%	61%	45%	50%

*Values removed from calculations

ND = Non-detect

Any time OPO4 was ≥ 3x TP, both values removed due to high analytical error

Sugar Hollow 1 - Bottom

Date	Ammonia µg/L	Nitrate µg/L	TKN µg/L	TIN µg/L	TN µg/L	TP µg/L	O-PO4 µg/L	TSS mg/L
4/15/15	99	104	11	203		97	23	15
8/10/15	252	320	246	572	566	35	6	22
10/6/15	215	673	274	888	947	46	21	5
7/5/16	675	434		1,109		28	4	3
8/17/16	612	185		797		118	142	7
8/23/16	185	201		386		22	1	2
8/30/16	625							
10/20/16		1,020					21	3
4/26/17	295		34			45	108	5
5/31/17	208	255		463		(335)*	(7)*	36
6/27/17	95	62	98	157	160	6	14	5
7/27/17	425		148			35		4

*Values removed from calculations

ND = Non-detect

Sugar Hollow 1 - Bottom

Date	Ammonia µg/L	Nitrate µg/L	TKN µg/L	TIN µg/L	TN µg/L	TP µg/L	O-PO4 µg/L	TSS mg/L
9/26/17	300		424			33	62	8
2015 mean	189	366	177	554	757	59	17	14
2015 min	99	104	11	203	566	35	6	5
2015 max	252	673	274	888	947	97	23	22
2016 mean	524	460	N/A	764	N/A	56	42	4
2016 min	185	185	N/A	386	N/A	22	1	2
2016 max	675	1,020	N/A	1,109	N/A	118	142	7
2017 mean	265	158	176	310	160	30	61	12
2017 min	95	62	34	157	160	6	14	4
2017 max	425	255	424	463	160	45	108	36
all mean	332	362	177	572	558	47	40	10
all min	95	62	11	157	160	6	1	2
all max	675	1,020	424	1,109	947	118	142	36
all sd	205	309	148	337	394	34	49	10
all CV%	62%	85%	84%	59%	71%	74%	121%	106%

*Values removed from calculations

ND = Non-detect

Sugar Hollow 2 - Surface

Date	Ammonia µg/L	Nitrate µg/L	TKN µg/L	TIN µg/L	TN µg/L	Chlorophyll *a* µg/L	TP µg/L	O-PO4 µg/L	TSS mg/L	Secchi (m)
4/15/15	78	161	560	239			23	55	3	
8/10/15	345	330	129	675	459	44	27	11	7	
10/6/15	153	745	314	898	1,059	1	54	17	6	0.80
mean	192	412	334	604	759	22	35	28	5	0.80
min	78	161	129	239	459	1	23	11	3	0.80
max	345	745	560	898	1,059	44	54	55	7	0.80
sd	138	301	216	335	424	30	17	24	2	N/A
CV%	72%	73%	65%	55%	56%	136%	49%	86%	39%	N/A

*Values removed from calculations

ND = Non-detect

Sugar Hollow 2 - Bottom

Date	Ammonia µg/L	Nitrate µg/L	TKN µg/L	TIN µg/L	TN µg/L	TP µg/L	O-PO4 µg/L	TSS mg/L
8/10/15	398	273	246	671	519	33	21	4
10/6/15	298	685	465	983	1,150	43	18	5
mean	348	479	356	827	835	38	20	5
min	298	273	246	671	519	33	18	4
max	398	685	465	983	1,150	43	21	5
sd	70	291	154	221	446	7	2	1
CV%	20%	61%	43%	27%	53%	19%	11%	16%

*Values removed from calculations

ND = Non-detect

Sugar Hollow 3 - Inflow

Date	Ammonia µg/L	Nitrate µg/L	TKN µg/L	TIN µg/L	TN µg/L	TP µg/L	O-PO4 µg/L	TSS mg/L
8/10/15	125	302	112	427	414	19	22	2
10/6/15	37	586	134	623	720	24	21	6
7/5/16	123	566		689		26	13	1
3/28/17	310	141	230	451	371	17	46	
mean	149	399	159	547	502	22	26	3
min	37	141	112	427	371	17	13	1
max	310	586	230	689	720	26	46	6
sd	115	215	62	129	191	4	14	3
CV%	77%	54%	39%	23%	38%	20%	56%	88%

*Values removed from calculations

ND = Non-detect

Totier Creek 1 - Surface

Date	Ammonia µg/L	Nitrate µg/L	TKN µg/L	TIN µg/L	TN µg/L	Chlorophyll *a* µg/L	TP µg/L	O-PO4 µg/L	TSS mg/L	Secchi (m)
4/15/15	240	438	ND	678		1	72	49	12	
6/2/15	200	280	ND		280	22	(31)*	(107)*	7	1.10
8/18/15	72	510	129	582	639	9	73	57	12	0.80
9/1/15										0.80
9/23/15	564	792	722	1,356	1,514	3	51	21	3	0.90
10/22/15	500	2,150	174	2,650	2,324	9	23	ND	5	
11/23/15	888	2,070	179	2,958	2,249	1	44	41	9	
6/27/16	845	1,720		2,565		15	75	14	7	1.15
7/13/16	195	1,160		1,355		12	73	9	10	
8/23/16	325	975		1,300		11	80	1	9	0.90
10/20/16	350	3,320		3,670		7	58	33	8	1.20
4/19/17	514	743	372	1,257	1,115	14	62	9	13	1.05
5/11/17	212	1,550	204	1,762	1,754	45	68	9	9	0.90
5/31/17			146							
6/28/17	219	727	238	946	965	17	55	12	8	1.10
7/26/17	235	605	50	840	655		85	8	15	
8/9/17						8				
8/16/17	711	1,010	957	1,721	1,967	18	64	13	12	0.82
9/27/17	520		515				77	24	20	0.75
10/13/17						16				
10/18/17	377	332	179	709	511		38	9	13	0.85
2015 mean	411	1,040	301	1,645	1,401	7	53	42	8	0.90
2015 min	72	280	129	582	280	1	23	21	3	0.80
2015 max	888	2,150	722	2,958	2,324	22	73	57	12	1.10
2016 mean	429	1,794	N/A	2,223	N/A	11	71	14	9	1.08
2016 min	195	975	N/A	1,300	N/A	7	58	1	7	0.90
2016 max	845	3,320	N/A	3,670	N/A	15	80	33	10	1.20

*Values removed from calculations

ND = Non-detect

Any time OPO4 was ≥ 3x TP, both values removed due to high analytical error

Totier Creek 1 - Surface

Date	Ammonia µg/L	Nitrate µg/L	TKN µg/L	TIN µg/L	TN µg/L	Chlorophyll *a* µg/L	TP µg/L	O-PO4 µg/L	TSS mg/L	Secchi (m)
2017 mean	310	621	266	904	871	20	50	9	10	0.68
2017 min	212	332	50	709	511	8	38	8	8	0.75
2017 max	711	1,550	957	1,762	1,967	45	85	24	20	1.10
all mean	410	1,149	322	1,623	1,270	13	62	21	10	0.95
all min	72	280	50	582	280	1	23	1	3	0.75
all max	888	3,320	957	3,670	2,324	45	85	57	20	1.20
all sd	239	825	275	934	728	11	17	17	4	0.15
all CV%	58%	72%	85%	58%	57%	81%	27%	82%	40%	16%

*Values removed from calculations

ND = Non-detect

Any time OPO4 was ≥ 3x TP, both values removed due to high analytical error

Totier Creek 1 - Bottom

Date	Ammonia µg/L	Nitrate µg/L	TKN µg/L	TIN µg/L	TN µg/L	TP µg/L	O-PO4 µg/L	TSS mg/L
4/15/15	312	368	952	680			7	204
6/1/15	212							
6/2/15		230	196		426	87	16	20
8/18/15	825	468	1,058	1,293	1,526	52	18	24
9/23/15	489	850	862	1,339	1,712	54	13	8
10/22/15	312	2,080	213	2,392	2,293	93	5	29
11/23/15	145	2,080	2,705	2,225	4,785	60	7	20
6/27/16	952	1,350		2,302		64	1	9
7/13/16	224	1,220		1,444		38	2	7
8/23/16	546	1,070		1,616		84	46	10
10/20/16	569	3,370		3,939		57	9	8
4/19/17	675	790	434	1,465	1,224	47	25	9
5/11/17	345	1,510	244	1,855	1,754	63	17	7
5/31/17			202					
6/28/17	312	432	344	744	776	121	27	25
7/26/17	250	596	120	846	716	88	7	12
8/16/17	322	1,070	526	1,392	1,596	109	63	10
9/27/17	612		985			68	22	16
10/18/17	210	318	1,545	528	1,863	27	7	14
2015 mean	383	1,013	998	1,586	2,148	69	11	51
2015 min	145	230	196	680	426	52	5	8
2015 max	825	2,080	2,705	2,392	4,785	93	18	204
2016 mean	573	1,753	N/A	2,325	N/A	61	15	9
2016 min	224	1,070	N/A	1,444	N/A	38	1	7
2016 max	952	3,370	N/A	3,939	N/A	84	46	10
2017 mean	389	786	550	1,138	1,322	75	24	13
2017 min	210	318	120	528	716	27	7	7
2017 max	675	1,510	1,545	1,855	1,863	121	63	25
all mean	430	1,113	742	1,604	1,697	70	17	25
all min	145	230	120	528	426	27	1	7
all max	952	3,370	2,705	3,939	4,785	121	63	204

*Values removed from calculations

ND = Non-detect

Totier Creek 1 - Bottom

Date	Ammonia µg/L	Nitrate µg/L	TKN µg/L	TIN µg/L	TN µg/L	TP µg/L	O-PO4 µg/L	TSS mg/L
all sd	233	836	708	870	1,167	26	16	47
all CV%	54%	75%	95%	54%	69%	37%	95%	183%

*Values removed from calculations

ND = Non-detect

Totier Creek 2 - Surface

Date	Ammonia µg/L	Nitrate µg/L	TKN µg/L	TIN µg/L	TN µg/L	Chlorophyll *a* µg/L	TP µg/L	O-PO4 µg/L	TSS mg/L	Secchi (m)
4/15/15	56						65	28	12	
6/2/15	120	255	ND		255	16	38	13	5	1.10
8/18/15	131	492	353	623	845	5	87	8	6	0.85
9/1/15										0.80
9/23/15	250	793	302	1,043	1,095	2	52	8	7	0.90
10/21/15									6	
10/22/15	245	2,160	213	2,405	2,373	11	31	ND		
11/23/15	111	2,230	213	2,341	2,443	1	34	14	8	
6/27/16	645	1,850		2,495		8		30	8	1.00
7/13/16	250	1,170		1,420		21	57	13	8	
8/23/16	212	941		1,153		14	89	65	13	1.00
10/20/16	452	3,510		3,962		10	67	13	6	0.80
4/19/17	475	739	378	1,214	1,117	12	55	21	10	0.96
5/1/17						7				
5/11/17	415	1,610	350	2,025	1,960		73	12	10	1.00
6/28/17	500	921	501	1,421	1,422	25	59	15	10	0.85
7/26/17	312	471	109	783	580	16	72	12	14	
8/16/17	353	1,000	475	1,353	1,475	16	78	14	10	0.92
9/27/17	215		ND				74	25	10	0.65
10/18/17	195	299	217	494	516	19	22	9	11	0.80
2015 mean	152	1,186	270	1,603	1,402	7	51	14	7	0.91
2015 min	56	255	213	623	255	1	31	8	5	0.80
2015 max	250	2,230	353	2,405	2,443	16	87	28	12	1.10
2016 mean	390	1,868	N/A	2,258	N/A	13	71	30	9	0.93
2016 min	212	941	N/A	1,153	N/A	8	57	13	6	0.80
2016 max	645	3,510	N/A	3,962	N/A	21	89	65	13	1.00
2017 mean	308	720	290	1,041	1,010	16	54	14	9	0.74
2017 min	195	299	109	494	516	7	22	9	10	0.65
2017 max	500	1,610	501	2,025	1,960	25	78	25	14	1.00
all mean	290	1,229	311	1,624	1,280	12	60	19	9	0.89
all min	56	255	109	494	255	1	22	8	5	0.65
all max	645	3,510	501	3,962	2,443	25	89	65	14	1.10
all sd	162	894	125	936	738	7	20	14	3	0.12
all CV%	56%	73%	40%	58%	58%	56%	34%	75%	29%	13%

*Values removed from calculations

ND = Non-detect

Totier Creek 2 - Bottom

Date	Ammonia µg/L	Nitrate µg/L	TKN µg/L	TIN µg/L	TN µg/L	TP µg/L	O-PO4 µg/L	TSS mg/L
6/2/15	127	225	ND		225	80	9	12
8/18/15	2,940	446	3,020	3,386	3,466	44	7	15
9/23/15	354	842	409	1,196	1,251	105	14	28
10/21/15								33
10/22/15	365	2,020	241	2,385	2,261	102	ND	
11/23/15	129	2,180	224	2,309	2,404	77	14	49
6/27/16	700	1,200		1,900			56	25
7/13/16	645	996		1,641		51	6	8
8/23/16	515	485		1,000		61	13	7
10/20/16	515	3,480		3,995		102	55	10
4/19/17	794	770	456	1,564	1,226	68	26	12
5/11/17	615	1,620	378	2,235	1,998	68	6	10
6/28/17	615	922	658	1,537	1,580	(78)*	(1)*	16
7/26/17	350	484	120	834	604	67	19	12
8/16/17	152	962	319	1,114	1,281	79	16	10
9/27/17	200					98	28	17
10/18/17	310	267	1,702	577	1,969	24	10	10
2015 mean	783	1,143	973	2,319	1,921	82	11	27
2015 min	127	225	224	1,196	225	44	7	12
2015 max	2,940	2,180	3,020	3,386	3,466	105	14	49
2016 mean	594	1,540	N/A	2,134	N/A	71	33	13
2016 min	515	485	N/A	1,000	N/A	51	6	7
2016 max	700	3,480	N/A	3,995	N/A	102	56	25
2017 mean	434	838	606	1,310	1,443	67	18	12
2017 min	152	267	120	577	604	24	6	10
2017 max	794	1,620	1,702	2,235	1,998	98	28	17
all mean	583	1,127	753	1,834	1,660	73	20	17
all min	127	225	120	577	225	24	6	7
all max	2,940	3,480	3,020	3,995	3,466	105	56	49
all sd	664	879	914	968	898	24	17	11
all CV%	114%	78%	121%	53%	54%	33%	83%	66%

*Values removed from calculations

ND = Non-detect

Totier Creek 3 - Inflow

Date	Ammonia µg/L	Nitrate µg/L	TKN µg/L	TIN µg/L	TN µg/L	TP µg/L	O-PO4 µg/L	TSS mg/L
4/15/15		452						
5/19/15	215	1,400	1,400	1,615	2,800		33	5
6/17/15	54	860	0	914	860	44	13	3
8/18/15	331	1,590	493	1,921	2,083	67	31	1
9/23/15	245	1,240	442	1,485	1,682	40	35	1
10/22/15	215	2,060	62	2,275	2,122	23	3	2
11/23/15	94	2,860	185	2,954	3,045	(7)*	(62)*	25
6/27/16	312	2,500		2,812			91	2
7/13/16	100	2,460		2,560		45	24	7
8/23/16	95	2,140		2,235		52	1	5

*Values removed from calculations

ND = Non-detect

Totier Creek 3 - Inflow

Date	Ammonia µg/L	Nitrate µg/L	TKN µg/L	TIN µg/L	TN µg/L	TP µg/L	O-PO4 µg/L	TSS mg/L
10/20/16	600	6,980		7,580		46	25	3
4/19/17	200	986	ND	1,186	966	55	26	11
5/11/17	95	2,020	260	2,115	2,280	48	20	6
6/28/17	125	1,630	53	1,755	1,683	62	15	3
7/26/17	125	1,140	154	1,265	1,294	104	47	5
8/16/17	100	942	95	1,042	1,037	35	31	2
9/27/17	85		256			71	65	3
10/18/17	195	572	195	767	767	41	67	4
2015 mean	192	1,495	430	1,861	2,099	44	23	6
2015 min	54	452	0	914	860	23	3	1
2015 max	331	2,860	1,400	2,954	3,045	67	35	25
2016 mean	277	3,520	N/A	3,797	N/A	48	35	4
2016 min	95	2,140	N/A	2,235	N/A	45	1	2
2016 max	600	6,980	N/A	7,580	N/A	52	91	7
2017 mean	132	1,215	169	1,355	1,338	59	39	5
2017 min	85	572	53	767	767	35	15	2
2017 max	200	2,020	260	2,115	2,280	104	67	11
all mean	187	1,872	300	2,155	1,718	52	33	5
all min	54	452	0	767	767	23	1	1
all max	600	6,980	1,400	7,580	3,045	104	91	25
all sd	134	1,492	377	1,593	762	20	24	6
all CV%	72%	80%	126%	74%	44%	37%	73%	110%

*Values removed from calculations

ND = Non-detect

Appendix C: Algae Count Procedure

ALGAE COUNTING

1.0 Filtration of algae through Sedwick-Rafter funnel

- 1.1 Put a piece of cheese cloth (doubled) over the bottom stopper of the funnel and add sand (60–120 mesh) up to about the 1 mark.

- 1.2 Rinse the funnel to wet the sand and apply vacuum to remove the rinse water. Try to keep the sand as free of bubbles and the surface as level as possible. Then add enough water to be 1 inch above the sand.

- 1.3 Shake the algae sample water well and pour 250 mLs into the funnel. Apply the vacuum slowly and continue filtering until the water level is down to the sand level.

- 1.4 Measure 20 mLs of the filtrate into a graduated cylinder. Carefully remove the plug and leave the sand in place. Put a small beaker under the sand and wash the sand out into the beaker with a small portion of the measured filtrate.

- 1.5 Swirl the sand and water in the beaker then decant the water into a labeled sample bottle. Repeat several times until the 20 mLs of filtrate are used.

2.0 Preserve the sample by adding one dropper full of formalin and one drop of copper sulfate, and refrigerate.

3.0 Counting the algae

3.1 Make sure refrigerated samples are brought to room temperature before counting.

3.2 Place a cover glass diagonally across a Sedwick-Rafter counting cell. Shake the sample thoroughly to remove entrapped air bubbles. Transfer 1.0 ml of the prepared sample into the cell. (Placing the cover glass in this manner will help prevent formation of air bubbles in the corners of the cell. The cover slip often will rotate slowly and cover the inner portion of the S-R cell during filling. Do Not Overfill the cell since this would yield a depth greater than 1 mm and an invalid count would result. Do not permit large air spaces caused by evaporation to develop in the chamber during lengthy examination, by occasionally placing a small drop of distilled water on the edge of the cover glass.

3.3 Allow the S-R cell to stand for at least 15 minutes to permit settling of the plankton. Some phytoplankton, notably some blue-green algae, may not settle but instead may rise to the underside of the cover glass.

4.0 Count the algae in the cell by either the strip count method or the field count method.

4.1 To count by the strip count method, position the objective on one end of the cell and count all algae within the Whipple grid as you move straight across the length of the cell to the far edge on the bottom. Raise the focus to the underside of the cover glass and count the algae within the Whipple grid as you move back across the same length of the cell in the reverse direction until the edge is reached. At least two strips should be counted for each sample.

4.2 Count by the field count method when the sample contains many algae. Count algae in 10 or more random fields each consisting of one Whipple grid. (Do not forget to count algae at both top and bottom of grid.) The number of fields counted will depend on the plankton density, the variety, and the statistical accuracy desired.

5.0 Calculations:

5.1 Strip Counting Method

$$\# \text{ of algae/mL} = \frac{C \times 1000 \text{ mm}^3}{L \times D \times W \times S \times F}$$

Where:

C = number of organisms counted
L = length of each strip (S-R cell length),mm, (50)
D = depth of a strip (S-R cell depth), mm, (1)
W = width of a strip (Whipple grid image width), mm, (.371)
S = number of strips counted. (2)
F = Dilution factor (250/20 = 12.5)

5.2 Field Counting Method

$$\# \text{ of algae/mL} = \frac{C \times 1000 \text{ mm}^3}{A \times D \times F}$$

Where:

C = number of organisms counted,
A = area of a field (Whipple grid image), mm^2,
D = depth of a field (S-R cell depth), mm, and
F = number of fields counted

6.0 References

6.1 Standard Methods for the Examination of Water and Wastewater, Method # 10200 F., 18th Ed., p10–13.

Appendix D: Limiting nutrients

There has been much confusion in the literature regarding the determination of nutrient limitation using the N:P ratio. A ratio of ~16:1 is normal for most algae so the ratio in water would indicate P-limitation if the ratio was > 16 and N-limitation at < 16. However, not all nutrients are equally bioavailable. Algae can only grow using phosphate (PO_4), nitrate and ammonia; they cannot use organic-N or organic-P or many complex inorganic minerals without first converting them and this is not always possible. Phosphate (PO_4) is generally present in low amounts in most waters (< 10 µg/L) but algae can use an enzyme, alkaline phosphatase, to liberate PO_4 from otherwise unavailable organic and inorganic-P, collectively known as Total Phosphorus (TP). P-turnover in tropical waters need only take a few hours.

There is no equivalent enzyme to release bioavailable-N from Total Nitrogen (TN), at least rapidly enough to support algal blooms. That is why in most eutrophic lakes, TN accumulates to the mg/L level. In these conditions, TN is like a patch of thistles in a field of grass—large but not eaten by cows. Nitrogen fixation, where dissolved N_2-gas is converted to amino-sugars, can be carried out by a few blue-green algae but the process is highly energetic and slow compared with uptake of nitrate or ammonia. Only a few percent per day of the algal biomass can be renewed with N_2-fixation. In addition, denitrification ($NO_3 \rightarrow N_2$) is high in tropical sediments so nitrate is further reduced because the N_2-gas returns to the atmosphere. There is no common equivalent ($PO_4 \rightarrow$ gaseous P) so P remains in the lake to be recycled for algal growth.

Appendix E: High TP Values on August 26

The high August TP value may have been related to storm runoff as there was 3.8 inches of rainfall recorded between 19 August at the South Fork Rivanna WTP. However, this rainfall did not occur in the reservoir watershed, as flows at the Mechums and Moormans gages just upstream of the reservoir did not record significant increases in flows. In addition, sediment in the creek on 26th of August was low (TSS = 8 mg/L) indicating low flows and little direct erosion. In contrast, soluble PO_4-P at 30 µg/L was a relatively small fraction (5%) of the total-P at this time possibly suggesting erosion. Nitrate was moderate to high (545 µg/L) indicating that the TP source was not wastewater. The most likely source of the very elevated TP was recent erosion due to land disturbance such as ploughing, construction close to the stream. Another possible source would be cattle wading in the stream since at least just upstream of the Reas Ford Road Bridge, cows have direct access to the stream and this may be generally true. Fencing stock out of streams is generally a good modern land practice with the provision of drinking troughs well away from the stream completing the upgrade.

Constituent	Concentration	Note
TP (µg/L)	549	Exceptionally high
PO_4-P (µg/L)	30	Moderate, typical but only 5% of measured TP for that day
SS (mg/L)	8	Moderate, well below peaks
Nitrate-N (µg/L)	545	Slightly below seasonal average
Ammonia-N (µg/L)	190	Below average
TKN (µg/L)	250	Lower than usual
Temp (oC)	25.09	
Turbidity (FNU)	9.26	
pH	7.1	

The observed means TP of 107 µg/L (all data) or 44 µg/L (high value removed) were higher than ideal. They can be compared with the expected concentrations from an undeveloped or mostly undisturbed drainage. In Virginia, virgin flow might be expected to average only 10–20 µg/L in the spring-fall period. However, it does not take much non-point disturbance, a small amount of pasture land or row crops, to elevate the TP values in streams to much higher levels. For example, in Oregon and Arizona, undisturbed forests of conifers averaged 27 µg/L TP in runoff which was considerably more than the possibly wistful USEPA standard for the ecoregion of 10 µg/L. In the USA generally, TP in stream averaged range from 10–128 µg/L.

The conclusion for SFRR and thus much of the watershed for the other four reservoirs, is that TP was too high in terms of a reservoir inflow but that it was not unusually high. In addition, the regular high combined with the occasional very high value, like the 549 µg/L reported in August 2015, means that any attempt to sequester P in the reservoir sediments with alum of Phoslock will fail to reduce algae blooms since ample supplies of P arrive each year from the watershed.

Appendix F: Algae Count and Identification Data

ID Code	Sample site description
Beaver Creek Reservoir	
BC1-1’	Near intake tower; 1’ depth
BC1-5’	Near intake tower; 5’ depth
BC1-10’	Near intake tower; 10’ depth
BC2-S	In reservoir at confluece of two main branches; surface grab
BC1	Integrated surface sample at BC1
CRO LAG 1+2’	Crozet BW lagoons 1 + 2
BC1 Thermocline	BC1 at thermocline
Ragged Mountain Reservoir	
RM1-S	integrated sample in channel near dam
RM2-S	in reservoir near Sugar Hollow outfall; surface grab
RM1-1 ft	Near intake tower; 1’ depth
RM1-5 ft	Near intake tower; 5’ depth
RM1-10 ft	Near intake tower; 10’ depth
South Rivanna Reservoir	
SR1 - 1’	Near intake tower; 1’ depth
SR1 - 5’	Near intake tower; 5’ depth
SR1 - 10’	Near intake tower; 10’ depth
SR1 - B	Near intake tower; Just off bottom of reservoir
SR-Clarifier	Clarifier = press filtrate clarifier
SR1.5-S	Between bridges and dam near shore; surface grab
SR1	Integrated surface sample at SR1
SR2	Integrated surface sample at SR2
SR4	Integrated surface sample at SR4

Sugar Hollow Reservoir

SH1-1 ft	Near intake tower; 1’ depth
SH1-5 ft	Near intake tower; 5’ depth
SH1-10 ft	Near intake tower; 10’ depth
SH1-15 ft	Near intake tower; 15’ depth
SH1-20 ft	Near intake tower; 20’ depth
SH2-S	Near Moormans influent; surface grab
SH1	Integrated surface sample at SH1

Totier Creek Reservoir

TC1-S	Near intake tower; integrated surface sample
TC2-S	Near inflow to reservoir; integrated surface sample
TC-CI-S	At creek intake; surface grab

SR1

4/14/15–6/16/16

Date	4/14/15	5/5/15	5/18/15	6/1/15	6/16/15	6/30/15	7/15/15	7/28/15	8/26/15	9/8/15	9/23/15	10/8/15	10/22/15	11/18/15	4/27/16	5/18/16	5/26/16	6/16/16
Total Blue-Green Algae	**181**	**0**	**0**	**65**	**5,499**	**3,859**	**1,169**	**18,034**	**28,245**	**582**	**1,531**	**91**	**582**	**332**	**0**	**1,091**	**0**	**2,557**
Total Algae	**344**	**242**	**150**	**613**	**6,030**	**4,419**	**1,521**	**18,427**	**30,802**	**780**	**1,725**	**289**	**720**	**440**	**569**	**1,151**	**259**	**3,639**
Actinastrum	0	0	0	0	34	0	0	0	0	0	0	0	0	0	0	0	0	0
Amphipleura	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Anabaena*	0	0	0	0	5,011	2,747	181	0	129	0	0	0	0	241	0	0	0	1,272
Anacystis*	0	0	0	0	0	151	0	354	0	0	0	0	0	0	0	0	0	0
Ankistrodesmus	0	30	13	26	9	34	26	9	26	0	4	0	9	0	0	0	0	0
Aphanizomenon*	181	0	0	0	423	392	384	0	0	0	0	91	0	91	0	918	0	1,147
Aphanocapsa*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Asterionella	60	203	0	0	0	0	0	0	0	17	0	0	0	0	203	0	0	0
Aulacoseira	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Caloneis	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0
Ceratium	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0
Closterium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Closteriopsis	0	0	0	0	0	0	0	0	0	0	9	0	0	0	0	0	0	0
Chlamydomonas	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chodatella	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chroococcus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chrysochromulina	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chrysococcus	0	0	0	0	0	4	17	0	0	4	9	9	0	9	0	0	0	0
Coelastrum	0	0	0	0	0	103	0	0	0	0	69	0	0	0	0	0	0	0
Coelosphaerium*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cosmarium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Crucigenia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cryptomonas	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cuspidothrix*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclotella	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cylindrotheca	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cymbella	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diatoma	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dictyosphaerium	0	0	0	0	0	0	73	103	138	0	0	0	0	0	0	0	0	207
Didymocystis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dinobryon	30	0	13	272	0	26	86	0	0	0	0	69	82	9	367	0	112	177
Dispora	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dolichospermum*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Elakatothrix	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Errerella	0	0	0	69	310	121	0	0	0	0	0	0	0	0	0	0	0	0
Eudorina	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Euglena	4	0	0	0	9	0	4	30	0	4	13	0	0	0	0	0	0	0
Eunotia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fragilaria	30	9	26	35	22	22	13	9	0	30	9	0	17	43	0	0	9	0
Gloeocystis	0	0	0	43	43	0	69	0	272	34	0	0	0	0	0	0	0	0
Golenkinia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gymnodinium	0	0	17	39	0	9	0	0	0	0	0	0	13	0	0	0	0	0
Kirchneriella	0	0	0	0	0	26	0	0	0	0	0	0	0	0	0	0	0	0
Limnothrix*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mallomonas	0	0	4	0	9	4	9	4	0	0	13	4	0	0	0	0	0	0
Melosira	13	0	0	13	9	30	0	26	0	9	39	0	0	30	0	56	0	116
Micractinium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Microcystis*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Monoraphidium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Navicula	0	0	4	0	0	0	0	0	0	0	0	0	0	9	0	0	0	0
Oscillatoria*	0	0	0	65	65	569	604	17,681	28,115	582	1,531	0	582	0	0	172	0	138
Oocystis	0	0	0	17	17	0	0	0	0	0	0	0	0	0	0	0	0	0
Palmella	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pandorina	0	0	0	0	0	138	0	0	0	0	0	0	0	0	0	0	95	207
Pectodictyon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pediastrum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Peridinium	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phacus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phormidium*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Planktolyngbya*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Planktothrix*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pseudanabaena*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pseudostaurastrum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Scenedesmus	0	0	0	17	17	34	34	17	0	0	17	0	0	0	0	0	0	34
Selenastrum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Schroederia	0	0	0	0	22	0	0	0	9	0	0	0	0	0	0	0	0	0
Sphaerocystis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Staurastrum	0	0	0	0	0	0	0	0	9	9	13	0	0	0	0	0	0	0
Stephanodiscus	0	0	9	13	13	0	0	0	0	0	0	0	0	0	0	0	0	0
Synedra	0	0	60	4	13	9	17	0	0	0	0	0	0	9	0	0	9	0
Synura	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetraedron	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetraspora	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	34	0
Trachelomonas	0	0	0	0	0	0	0	17	2,091	0	0	0	4	0	0	4	0	0
Ulothrix	0	0	0	0	0	0	0	9	13	91	0	116	13	0	0	0	0	341

All numbers are in cells/1 mL *Blue-green algae + Sample frozen

SR1

6/28/16–1/28/17

Date	6/28/16	7/11/16	8/4/16	8/16/16	8/22/16	8/30/16	9/6/16	9/12/16	9/15/16	9/19/16	9/20/16	9/22/16	9/28/16	10/5/16	10/17/16	10/25/16	12/14/16	1/28/17
Total Blue-Green Algae	**513**	**298**	**2,281**	**5,511**	**7,852**	**7,335**	**56,585**	**43,952**	**10,012**	**772**	**1,574**	**806**	**1,294**	**30**	**43**	**10**	**0**	**0**
Total Algae	**711**	**755**	**2,385**	**5,511**	**7,852**	**7,934**	**57,188**	**44,413**	**11,543**	**1,100**	**1,893**	**2,152**	**1,867**	**289**	**1,488**	**1,841**	**588**	**556**
Actinastrum	0	0	103	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Amphipleura	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Anabaena*	362	0	815	604	5,463	2,251	4,023	755	4,083	60	0	332	0	30	0	10	0	0
Anacystis*	0	0	0	0	0	0	2,156	410	0	0	0	0	0	0	0	0	0	0
Ankistrodesmus	22	17	0	0	0	0	0	0	69	47	0	17	0	0	40	88	200	0
Aphanizomenon*	151	147	1,298	1,026	190	604	4,226	4,528	181	0	0	0	0	0	0	0	0	0
Aphanocapsa*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0
Asterionella	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	147	384
Aulacoseira	0	0	0	0	0	0	0	0	0	0	0	0	0	0	260	350	0	0
Caloneis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ceratium	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Closterium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Closteriopsis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	43	0
Chlamydomonas	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0
Chodatella	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chroococcus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chrysochromulina	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chrysococcus	0	4	0	0	0	30	0	0	26	4	13	0	47	13	0	150	0	0
Coelastrum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0
Coelosphaerium*	0	0	0	0	1,078	0	1,833	0	323	323	647	0	1,294	0	0	0	0	0
Cosmarium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Crucigenia	0	0	0	0	0	0	0	0	0	0	0	0	69	0	0	10	0	0
Cryptomonas	0	0	0	0	0	0	0	0	0	0	0	0	0	0	36	134	0	0
Cuspidothrix*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclotella	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	112	0	0
Cylindrotheca	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cymbella	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diatoma	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	17
Dictyosphaerium	0	0	0	0	0	0	0	0	0	0	0	0	172	0	630	24	0	0
Didymocystis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dinobryon	0	121	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	52
Dispora	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dolichospermum*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Elakatothrix	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0
Errerella	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Eudorina	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Euglena	0	17	0	0	0	0	0	0	17	0	0	4	0	0	0	55	0	4
Eunotia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fragilaria	26	0	0	0	0	0	0	0	47	0	30	13	39	0	38	0	0	39
Gloeocystis	0	0	0	0	0	0	0	0	0	0	0	1,138	0	0	34	10	0	0
Golenkinia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gymnodinium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0
Kirchneriella	52	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Limnothrix*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mallomonas	4	0	0	0	0	0	0	0	0	13	0	0	0	0	0	0	0	4
Melosira	0	0	0	0	0	0	397	164	116	34	60	30	65	43	0	0	198	39
Micractinium	0	69	0	0	0	0	0	0	0	69	138	86	0	0	200	10	0	0
Microcystis*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Monoraphidium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	23	10	0	0
Navicula	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oscillatoria*	0	151	168	3,881	1,121	4,480	44,347	38,260	5,424	388	927	474	0	0	0	0	0	0
Oocystis	0	43	0	0	0	0	0	0	0	9	0	0	0	17	35	10	0	0
Palmella	0	0	0	0	0	0	0	0	1,061	0	0	0	0	0	0	0	0	0
Pandorina	34	0	0	0	0	457	0	0	0	0	0	0	52	0	0	0	0	0
Pectodictyon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pediastrum	0	0	0	0	0	0	0	0	0	52	0	0	0	0	0	10	0	0
Peridinium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phacus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phormidium*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Planktolyngbya*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Planktothrix*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pseudanabaena*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	33	0	0	0
Pseudostaurastrum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Scenedesmus	52	17	0	0	0	0	0	0	34	0	0	17	0	0	15	42	0	0
Selenastrum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0
Schroederia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sphaerocystis	0	0	0	0	0	0	0	0	0	0	0	0	0	138	42	0	0	0
Staurastrum	0	0	0	0	0	0	0	0	13	69	34	22	99	43	10	0	0	0
Stephanodiscus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Synedra	0	82	0	0	0	112	207	298	147	30	43	17	30	4	60	610	0	17
Synura	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetraedron	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetraspora	0	69	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trachelomonas	4	0	0	0	0	0	0	0	0	0	0	0	0	0	12	156	0	0
Ulothrix	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

All numbers are in cells/1 mL *Blue-green algae + Sample frozen

SR1 — 2/28/17–12/12/17

Date	2/28/17	3/29/17	4/19/17	5/2/17	5/24/17	7/4/17	7/12/17	7/19/17	8/1/17	8/14/17	8/23/17	8/30/17	9/18/17	9/20/17	10/10/17	10/26/17+	11/7/17	12/12/17
Total Blue-Green Algae	**0**	**0**	**362**	**65**	**845**	**3,036**	**1,800**	**11,560**	**150,210**	**240**	**640**	**2,920**	**10,020**	**1,190**	**5,180**	**0**	**1,960**	**1,880**
Total Algae	**543**	**1,889**	**900**	**750**	**1,056**	**3,036**	**2,960**	**12,000**	**150,810**	**720**	**3,220**	**3,940**	**15,180**	**2,560**	**8,220**	**1,030**	**5,080**	**4,080**
Actinastrum	0	0	0	0	0	0	0	0	0	0	40	40	40	0	0	0	40	0
Amphipleura	0	0	0	0	0	0	0	0	40	0	0	40	0	0	0	0	0	0
Anabaena*	0	0	0	0	0	259	40	0	0	0	0	0	40	0	0	0	40	40
Anacystis*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ankistrodesmus	0	0	22	0	0	0	40	40	40	200	40	40	0	40	40	40	40	40
Aphanizomenon*	0	0	362	0	151	2,777	40	0	40	0	0	0	2,200	550	40	0	0	0
Aphanocapsa*	0	0	0	0	0	0	40	1,620	12,330	240	0	0	40	0	40	0	0	0
Asterionella	384	423	103	405	112	0	40	0	0	0	0	0	0	0	0	40	0	40
Aulacoseira	0	0	0	0	0	0	40	40	40	0	40	40	800	200	40	40	40	720
Caloneis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ceratium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Closterium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Closteriopsis	0	0	0	0	0	0	0	0	0	0	0	0	40	0	40	0	0	40
Chlamydomonas	0	0	0	0	0	0	40	0	0	0	0	0	0	0	0	0	0	0
Chodatella	0	0	0	0	0	0	40	0	0	0	0	0	0	0	0	0	0	0
Chroococcus	0	0	0	0	0	0	0	0	0	0	0	0	40	0	0	0	0	0
Chrysochromulina	0	0	0	0	0	0	0	0	0	0	0	0	400	0	600	0	0	320
Chrysococcus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	40	40
Coelastrum	0	0	0	0	0	0	40	40	40	0	40	40	40	40	0	0	40	0
Coelosphaerium*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cosmarium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	40	0
Crucigenia	0	0	0	0	0	0	0	40	40	0	40	40	40	40	40	0	40	0
Cryptomonas	0	0	0	0	0	0	0	0	0	0	0	0	40	0	40	0	300	240
Cuspidothrix*	0	0	0	0	0	0	0	0	1,600	0	0	0	0	0	0	0	0	0
Cyclotella	0	0	0	0	0	0	40	0	40	40	40	0	40	40	40	0	40	40
Cylindrotheca	0	0	0	0	0	0	0	0	0	0	0	40	0	0	0	0	0	40
Cymbella	0	0	0	0	0	0	0	0	0	0	0	0	0	40	0	40	0	0
Diatoma	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dictyosphaerium	0	0	0	0	69	0	40	40	0	0	1,400	0	40	0	40	0	40	0
Didymocystis	0	0	0	0	0	0	0	0	0	0	40	0	0	0	0	0	0	0
Dinobryon	52	0	60	160	0	0	40	0	0	0	0	0	40	0	0	0	0	40
Dispora	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dolichospermum*	0	0	0	65	694	0	0	40	800	0	0	480	0	0	0	0	0	0
Elakatothrix	0	0	0	0	0	0	0	0	40	0	0	0	0	0	0	0	0	0
Errerella	0	0	0	0	0	0	0	0	0	0	0	0	40	40	40	0	0	0
Eudorina	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Euglena	4	0	0	0	4	0	40	0	0	0	0	40	40	40	0	0	0	0
Eunotia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	40	0	0
Fragilaria	39	17	47	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gloeocystis	0	0	0	0	0	0	0	0	0	0	0	40	40	40	0	0	0	0
Golenkinia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gymnodinium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Kirchneriella	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Limnothrix*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	40	0
Mallomonas	4	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0	40
Melosira	39	39	95	43	9	0	0	0	0	0	0	0	0	0	0	0	0	0
Micractinium	0	0	0	0	0	0	40	0	0	0	0	0	0	0	0	0	0	0
Microcystis*	0	0	0	0	0	0	0	0	0	0	40	0	40	0	0	0	0	0
Monoraphidium	0	0	0	0	0	0	0	40	40	40	40	40	0	0	0	40	800	480
Navicula	0	4	0	0	0	0	40	0	0	0	0	0	0	0	0	0	0	40
Oscillatoria*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oocystis	0	0	0	0	0	0	40	40	40	0	40	40	600	40	0	0	0	0
Palmella	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pandorina	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pectodictyon	0	0	0	0	0	0	0	0	0	40	0	0	0	0	0	0	0	0
Pediastrum	0	0	0	0	0	0	40	0	40	0	0	0	0	40	40	0	0	0
Peridinium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phacus	0	0	0	0	0	0	0	0	0	0	0	0	40	0	0	0	0	0
Phormidium*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	40	0
Planktolyngbya*	0	0	0	0	0	0	0	4,200	135,400	0	0	40	3,500	40	0	0	0	0
Planktothrix*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	40	0
Pseudanabaena*	0	0	0	0	0	0	1,680	5,700	40	0	600	2,400	4,200	600	5,100	0	1,800	1,840
Pseudostaurastrum	0	0	0	0	0	0	40	0	0	0	0	0	2,200	0	0	0	0	0
Scenedesmus	0	0	86	0	0	0	320	40	40	0	0	40	0	400	1,600	40	40	40
Selenastrum	0	0	0	0	0	0	0	0	40	40	40	0	40	40	0	0	40	0
Schroederia	0	0	0	0	0	0	0	0	40	40	0	0	40	0	0	0	0	0
Sphaerocystis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Staurastrum	0	0	0	0	4	0	0	40	40	0	40	40	40	40	40	0	40	0
Stephanodiscus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Synedra	17	13	125	47	4	0	160	40	0	40	500	160	40	40	40	250	1,500	40
Synura	0	0	0	0	0	0	0	0	0	0	40	0	40	0	0	0	0	0
Tetraedron	0	0	0	0	0	0	40	0	40	40	0	0	40	250	0	0	0	0
Tetraspora	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trachelomonas	0	0	0	0	0	0	40	40	0	0	200	340	400	0	400	500	40	0
Ulothrix	0	1,393	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

All numbers are in cells/1 mL   *Blue-green algae   + Sample frozen

SR2 — 4/14/15–11/18/15

Date	4/14/15	5/5/15	5/18/15	6/1/15	6/16/15	6/30/15	7/15/15	7/28/15	8/5/15	8/14/15	8/21/15	8/26/15	9/3/15	9/8/15	9/23/15	10/8/15	10/22/15	11/18/15
Total Blue-Green Algae	**0**	**0**	**13**	**69**	**11,376**	**4,006**	**414**	**6,667**	**22,595**	**15,262**	**9,050**	**1,039**	**51,593**	**56**	**772**	**259**	**194**	**375**
Total Algae	**86**	**112**	**219**	**659**	**11,698**	**5,170**	**2,100**	**7,253**	**26,114**	**16,029**	**9,529**	**1,639**	**51,662**	**581**	**1,199**	**517**	**298**	**436**
Actinastrum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Achnanthes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Anabaena*	0	0	0	0	9,931	2,867	0	0	0	0	0	0	0	0	0	0	0	0
Anacystis*	0	0	0	0	0	0	0	52	970	190	65	0	0	0	0	0	0	0
Ankistrodesmus	0	0	13	17	13	0	13	0	4	17	39	26	0	0	60	0	0	0
Aphanocapsa*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aphanizomenon*	0	0	0	0	1,341	837	272	0	392	0	0	91	0	52	0	164	0	272
Asterionella	17	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aulacoseira	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Centritractus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chlamydomonas	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chroococcus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chrysochromulina	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chrysococcus	4	0	22	13	4	13	39	9	17	4	9	0	0	0	13	4	9	9
Closteriopsis	0	0	0	0	0	0	0	26	0	4	65	0	0	26	13	0	4	0
Closterium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coelastrum	0	0	0	0	0	52	0	0	0	0	0	0	0	0	155	0	0	0
Coelosphaerium*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cosmarium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Crucigenia	0	0	0	69	0	0	0	0	0	0	0	121	0	0	0	0	0	0
Cryptomonas	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cuspidothrix*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclotella	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cymbella	9	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diatoma	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dictyosphaerium	0	0	0	0	0	52	34	73	95	0	103	121	0	0	0	0	0	0
Didymocystis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dinobryon	0	47	112	306	0	0	0	0	0	151	65	52	0	0	0	9	0	0
Dolichospermum*	0	0	0	0	0	0	1,479	30	2,898	224	0	0	0	0	0	95	65	103
Euglena	4	9	0	4	4	4	9	52	22	13	13	17	22	0	9	4	0	4
Errerella	0	0	0	69	0	0	0	0	0	0	0	0	0	0	91	0	0	0
Fragilaria	22	13	17	26	0	9	0	0	17	47	34	78	13	30	52	0	22	13
Glenodinium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gloeocystis	0	0	0	0	43	103	0	69	0	129	34	69	17	69	0	0	0	0
Golenkinia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gonium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gonyostonum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gymnodinium	0	0	4	39	0	43	9	26	9	13	4	0	0	32	0	0	9	13
Kirchneriella	0	0	0	0	151	151	0	0	9	17	0	0	0	17	0	0	0	0
Mallomonas	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	4
Melosira	17	0	0	34	17	47	47	13	65	17	26	52	0	0	39	0	39	0
Micractinium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Microcystis*	0	0	0	0	0	0	0	0	73	0	0	0	0	4	0	0	0	0
Monoraphidium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Navicula	13	22	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nephrocytium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oocystis	0	0	0	0	0	0	34	0	0	0	0	0	0	0	0	0	0	0
Oscillatoria*	0	0	0	52	91	302	142	6,667	21,159	15,072	8,985	949	51,593	0	711	0	129	0
Palmella	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pandorina	0	0	0	0	0	276	0	0	379	0	0	0	0	302	0	0	0	0
Pectodictyon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pediastrum	0	0	0	0	30	0	0	78	0	0	43	0	0	34	0	0	0	0
Peridinium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phacus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Planktolyngbya*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Planktothrix*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pseudanabaena*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Selenastrum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Scenedesmus	0	0	0	0	34	0	0	17	0	52	17	52	17	0	34	34	17	17
Schroederia	0	0	4	0	13	0	0	22	0	4	0	0	0	0	0	0	0	0
Sphaerocystis	0	0	0	0	0	405	0	0	0	0	0	0	0	0	0	207	0	0
Staurastrum	0	0	0	0	0	0	0	0	0	0	9	4	0	0	9	0	0	0
Stauroneis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Stephanodiscus	0	4	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Synedra	0	0	39	13	17	0	9	0	4	0	17	0	0	0	0	0	4	0
Synura	0	0	0	0	0	0	0	0	0	60	0	0	0	0	0	0	0	0
Tetraselmis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetraspora	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetraedron	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trachelomonas	0	0	0	13	9	9	13	43	0	13	0	0	0	0	13	0	0	0
Treubaria	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ulothrix	0	0	0	0	0	0	0	78	0	0	0	0	0	13	0	0	0	0

All numbers are in cells/1 mL   *Blue-green algae   + Sample frozen

SR2 3/14/16–12/14/16

Date	3/14/16	4/27/16	5/18/16	5/26/16	6/28/16	7/11/16	8/4/16	8/16/16	8/24/16	8/30/16	9/6/16	9/12/16	9/15/16	9/28/16	10/5/16	10/17/16	10/25/16	12/14/16
Total Blue-Green Algae	**0**	**0**	**91**	**30**	**324**	**199**	**8,823**	**6,205**	**1,190**	**13,522**	**19,867**	**38,763**	**8,572**	**704**	**1,173**	**601**	**20**	**0**
Total Algae	**285**	**104**	**483**	**211**	**858**	**376**	**9,108**	**7,313**	**1,268**	**14,303**	**21,260**	**40,066**	**9,261**	**1,091**	**2,185**	**2,101**	**1,934**	**212**
Actinastrum	0	0	0	0	0	0	285	0	0	0	0	0	0	0	0	0	0	0
Achnanthes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Anabaena*	0	0	91	0	0	151	6,399	755	0	362	1,069	552	121	272	121	178	0	0
Anacystis*	0	0	392	0	0	0	0	711	0	0	1,078	1,143	0	0	0	0	0	0
Ankistrodesmus	0	0	0	0	22	26	0	0	0	0	0	0	0	0	0	33	10	0
Aphanocapsa*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aphanizomenon*	0	0	0	30	302	0	785	1,677	483	151	2,566	1,690	0	0	0	0	0	0
Asterionella	177	22	0	39	0	0	0	0	0	0	0	0	0	0	0	0	0	52
Aulacoseira	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	180	42	0
Centritractus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chlamydomonas	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chroococcus*	0	0	0	0	0	0	0	0	0	0	0	0	17	0	0	0	0	0
Chrysochromulina	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0
Chrysococcus	0	0	0	0	0	0	0	0	0	164	0	0	0	34	99	0	360	0
Closteriopsis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	22
Closterium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coelastrum	0	0	0	0	0	0	0	0	0	0	0	0	0	86	0	18	10	0
Coelosphaerium*	0	0	0	0	0	0	0	1,078	0	0	0	0	0	216	862	0	0	0
Cosmarium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Crucigenia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	69	21	28	0
Cryptomonas	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	40	18	0
Cuspidothrix*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclotella	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	10	0
Cymbella	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diatoma	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dictyosphaerium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	405	340	0	0
Didymocystis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dinobryon	60	0	0	43	289	99	0	0	52	0	0	0	0	13	0	0	0	0
Dolichospermum*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Euglena	0	22	0	0	30	22	0	0	0	91	0	0	30	17	91	0	0	0
Errerella	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fragilaria	13	34	0	52	26	0	0	0	0	0	0	0	0	52	0	23	0	52
Glenodinium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gloeocystis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	40	10	0
Golenkinia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gonium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	69	0	0	0
Gonyostonum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gymnodinium	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Kirchneriella	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mallomonas	0	0	0	0	0	0	0	0	0	0	0	0	0	4	13	0	0	0
Melosira	9	0	0	0	0	0	0	0	17	0	112	0	39	39	60	0	0	86
Micractinium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	160	0	0
Microcystis*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0
Monoraphidium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0
Navicula	0	26	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nephrocytium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oocystis	0	0	0	0	0	13	0	0	0	0	0	0	0	0	34	100	210	0
Oscillatoria*	0	0	0	0	0	22	1,639	2,695	707	13,009	16,232	36,521	8,434	216	190	0	0	0
Palmella	0	0	0	0	0	0	0	0	0	0	0	0	517	0	0	0	0	0
Pandorina	0	0	0	0	0	0	0	397	0	414	0	0	0	0	0	0	0	0
Pectodictyon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pediastrum	0	0	0	34	0	0	0	0	0	0	0	0	0	0	0	118	0	0
Peridinium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phacus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Planktolyngbya*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Planktothrix*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pseudanabaena*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	380	10	0
Selenastrum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	240	0
Scenedesmus	0	0	0	0	17	17	0	0	0	0	0	0	0	17	17	320	460	0
Schroederia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sphaerocystis	0	0	0	0	172	0	0	0	0	0	0	0	0	0	0	60	0	0
Staurastrum	0	0	0	0	0	0	0	0	9	0	0	0	0	116	82	0	0	0
Stauroneis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Stephanodiscus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Synedra	17	0	0	0	0	26	0	0	0	112	203	160	99	9	73	50	480	0
Synura	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetraselmis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetraspora	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetraedron	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trachelomonas	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	10	36	0
Treubaria	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ulothrix	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

All numbers are in cells/1 mL *Blue-green algae + Sample frozen

SR2 — 2/28/17–12/12/17

Date	2/28/17	3/29/17	4/19/17	5/2/17	7/19/17	8/1/17	8/14/17	8/23/17	8/30/17	9/20/17	10/10/17	10/26/17	11/7/2017	12/12/17
Total Blue-Green Algae	**0**	**90**	**181**	**181**	**6,660**	**54,410**	**80**	**1,800**	**4,560**	**2,680**	**1,120**	**40**	**12,180**	**1,480**
Total Algae	**336**	**682**	**389**	**229**	**7,500**	**55,290**	**440**	**3,000**	**7,400**	**5,120**	**15,560**	**400**	**14,900**	**4,560**
Actinastrum	0	0	0	0	0	0	0	40	40	0	40	0	40	0
Achnanthes	0	0	0	0	0	0	0	0	0	0	0	0	0	40
Anabaena*	0	0	0	0	0	0	0	40	0	0	0	0	40	40
Anacystis*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ankistrodesmus	0	30	0	0	40	40	0	40	0	0	40	0	40	40
Aphanocapsa*	0	0	0	0	1,250	1,650	0	0	40	40	0	0	0	0
Aphanizomenon*	0	60	181	0	40	0	0	0	0	880	0	0	0	0
Asterionella	194	229	22	0	40	0	0	0	0	0	0	0	40	40
Aulacoseira	0	0	0	0	0	40	40	40	40	40	40	40	40	40
Centritractus	0	0	0	0	0	40	40	0	0	0	0	0	0	0
Chlamydomonas	0	0	0	0	0	40	40	0	0	0	0	0	0	0
Chroococcus*	0	0	0	0	40	40	0	40	0	0	0	40	0	0
Chrysochromulina	0	0	0	0	0	0	0	0	0	0	12,600	0	0	0
Chrysococcus	0	0	0	0	0	0	0	0	0	0	0	0	40	1,900
Closteriopsis	0	0	0	0	0	40	0	40	40	0	0	40	40	0
Closterium	0	0	0	0	0	40	0	0	0	0	0	0	0	0
Coelastrum	0	0	0	0	0	0	0	40	40	40	40	0	0	0
Coelosphaerium*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cosmarium	0	0	0	0	40	40	0	0	0	0	0	0	0	0
Crucigenia	0	0	0	0	0	40	0	40	640	0	0	0	40	0
Cryptomonas	0	0	0	0	0	0	0	0	0	0	0	0	600	40
Cuspidothrix*	0	0	0	0	0	1,850	0	0	0	0	0	0	0	0
Cyclotella	0	0	0	0	0	0	0	0	40	40	0	0	0	0
Cymbella	0	0	0	0	40	0	40	0	40	0	0	0	0	0
Diatoma	13	0	0	0	0	0	0	0	0	0	0	0	0	0
Dictyosphaerium	0	0	0	0	0	40	0	40	0	40	40	0	40	0
Didymocystis	0	0	0	0	0	0	0	40	0	0	0	0	0	0
Dinobryon	0	315	0	0	0	40	0	0	0	0	0	0	0	40
Dolichospermum*	0	0	0	181	40	450	0	0	40	0	40	0	0	0
Euglena	0	0	0	13	40	40	0	40	40	40	40	40	0	0
Errerella	0	0	0	0	0	0	0	0	0	40	0	0	0	0
Fragilaria	30	22	108	9	0	0	0	0	0	0	0	0	0	0
Glenodinium	0	0	0	0	0	0	0	0	0	0	0	0	0	40
Gloeocystis	0	0	0	0	0	0	0	0	1,280	480	0	0	40	0
Golenkinia	0	0	0	0	0	0	0	0	0	0	0	0	40	0
Gonium	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gonyostonum	0	0	0	0	0	0	0	0	0	0	0	0	40	0
Gymnodinium	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Kirchneriella	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mallomonas	9	0	0	0	0	0	0	0	0	0	0	0	40	0
Melosira	86	13	0	13	0	0	0	0	0	0	0	0	0	0
Micractinium	0	0	0	0	0	40	0	0	0	0	0	0	0	0
Microcystis*	0	0	0	0	0	40	0	40	0	0	0	0	0	0
Monoraphidium	0	0	0	0	40	40	0	40	0	40	40	40	40	700
Navicula	0	0	0	0	0	0	0	0	0	0	0	0	0	40
Nephrocytium	0	0	0	0	0	40	0	0	0	0	0	0	0	0
Oocystis	0	0	0	0	0	40	0	40	40	40	40	40	0	0
Oscillatoria*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Palmella	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pandorina	0	0	0	0	0	0	0	40	40	0	0	0	0	0
Pectodictyon	0	0	0	0	0	0	40	0	0	0	0	0	0	0
Pediastrum	0	0	0	0	0	0	0	40	40	320	0	0	40	0
Peridinium	4	9	0	0	0	0	0	0	0	0	0	0	0	40
Phacus	0	0	0	0	0	40	0	0	40	0	0	0	0	0
Planktolyngbya*	0	0	0	0	1,500	50,300	40	40	1,920	40	0	0	0	0
Planktothrix*	0	0	0	0	0	0	0	0	0	0	0	0	40	0
Pseudanabaena*	0	0	0	0	3,750	40	40	1600	2,560	1,720	1,040	0	12,100	1,400
Selenastrum	0	0	0	0	300	40	0	0	0	40	0	0	0	40
Scenedesmus	0	0	0	0	40	40	0	40	40	960	1,400	40	400	0
Schroederia	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sphaerocystis	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Staurastrum	0	0	0	0	40	40	40	40	40	40	40	40	40	40
Stauroneis	0	0	0	0	40	0	0	0	0	0	0	0	40	0
Stephanodiscus	0	0	0	0	0	0	40	0	0	0	0	0	0	0
Synedra	0	4	78	13	40	40	40	200	320	40	40	40	800	40
Synura	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetraselmis	0	0	0	0	0	0	0	0	0	0	0	0	0	40
Tetraspora	0	0	0	0	40	0	0	0	0	0	0	0	40	0
Tetraedron	0	0	0	0	40	40	0	40	40	0	40	0	40	0
Trachelomonas	0	0	0	0	100	40	40	400	40	240	40	40	200	0
Treubaria	0	0	0	0	0	40	0	0	0	0	0	0	0	0
Ulothrix	0	0	0	0	0	0	0	0	0	0	0	0	0	0

All numbers are in cells/1 mL   *Blue-green algae   + Sample frozen

SR1 - 1'

Date	4/28/15	5/13/15	5/28/15	6/10/15	6/22/15	7/6/15	7/21/15	8/5/15	8/14/15	8/21/15	9/3/15	9/17/15	9/29/15	10/14/15	10/27/15	4/14/16
Total Blue-Green Algae	**78**	**0**	**517**	**2,380**	**7,589**	**1,729**	**1,837**	**23,948**	**1,337**	**6,037**	**19,130**	**3,018**	**1,112**	**108**	**121**	**0**
Total Algae	**431**	**616**	**1,457**	**2,608**	**8,154**	**2,036**	**2,027**	**24,561**	**1,587**	**6,412**	**19,234**	**3,286**	**1,272**	**470**	**323**	**936**
Anabaena*	78	0	0	1,449	6,830	513	129	1,147	0	0	0	65	181	78	0	0
Anacystis*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	34	0
Ankistrodesmus	0	0	0	0	0	30	9	0	26	103	0	30	17	0	0	0
Aphanizomenon*	0	0	517	931	543	483	241	483	0	0	0	0	91	0	0	0
Asterionella	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	720
Closterium	0	0	0	0	0	0	0	0	0	0	0	17	4	0	9	0
Chrysococcus	0	0	0	0	0	9	13	0	0	0	0	4	17	22	17	0
Dictyosphaerium	0	0	0	0	0	0	0	293	0	0	0	0	0	0	0	0
Dinobryon	0	0	0	0	0	78	0	0	0	0	0	0	0	129	0	99
Dispora	0	0	0	0	0	0	0	0	52	0	0	0	0	0	0	0
Errerella	0	0	0	0	0	0	69	69	0	0	0	0	0	34	0	0
Eudorina	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	95
Euglena	0	0	0	0	0	0	0	30	30	13	0	0	0	13	0	0
Fragilaria	0	0	0	0	0	26	39	26	13	17	17	47	0	43	17	0
Gloeocystis	0	0	0	0	0	52	13	0	69	138	43	60	69	13	34	0
Golenkinia	0	0	0	0	0	13	0	0	0	0	0	0	0	0	0	0
Gymnodinium	0	0	0	0	0	39	9	13	0	13	4	0	0	0	0	0
Mallomonas	0	0	0	0	0	0	22	0	4	0	0	0	4	13	30	0
Melosira	0	0	0	0	0	13	0	47	9	0	0	13	30	43	39	0
Microcystis*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oscillatoria*	0	0	0	0	216	733	1,466	22,318	1,337	6,037	19,130	2,954	841	30	86	0
Oocystis	0	0	0	0	0	0	0	0	34	0	0	0	0	0	0	0
Pandorina	0	0	0	0	0	0	0	121	0	0	0	0	0	0	0	0
Pectodictyon	0	0	0	0	0	0	0	0	0	34	0	0	0	0	0	0
Pseudostaurastrum	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0
Scenedesmus	0	0	0	0	0	17	17	0	0	0	0	0	17	0	17	0
Schroederia	0	0	0	0	0	0	0	0	13	4	0	0	0	0	0	0
Staurastrum	0	0	0	0	0	9	0	0	0	0	17	13	0	0	4	0
Stephanodiscus	0	0	0	0	0	0	0	13	0	0	0	0	0	0	0	0
Synedra	0	0	0	0	0	4	0	0	0	0	0	0	0	17	17	22
Trachelomonas	0	0	0	0	0	0	0	0	0	0	0	13	0	0	0	0
Ulothrix	0	0	0	0	0	17	0	0	0	47	22	69	0	34	17	0

All numbers are in cells/1 mL *Blue-green algae + Sample frozen

SR4

Date	5/18/16
Total Blue-Green Algae	**207**
Total Algae	**263**
Anabaena*	0
Anacystis*	0
Ankistrodesmus	0
Aphanizomenon*	0
Asterionella	47
Closterium	0
Chrysococcus	0
Dictyosphaerium	0
Dinobryon	0
Dispora	0
Errerella	0
Eudorina	0
Euglena	0
Fragilaria	0
Gloeocystis	0
Golenkinia	0
Gymnodinium	0
Mallomonas	0
Melosira	0
Naviculate	0
Oscillatoria*	207
Oocystis	0
Pandorina	0
Pectodictyon	0
Pseudostaurastrum	0
Scenedesmus	0
Schroederia	0
Staurastrum	9
Stephanodiscus	0
Synedra	0
Trachelomonas	0
Ulothrix	0

All numbers are in cells/1 mL

*Blue-green algae + Sample frozen

SR1 - 5'

Date	4/28/15	5/13/15	5/28/15	6/10/15	6/22/15	7/6/15	7/21/15	8/5/15	8/14/15	9/3/15	9/17/15	9/29/15	10/14/15	10/27/15	4/14/16
Total Blue-Green Algae	**43**	**0**	**345**	**4,010**	**5,394**	**3,144**	**1,738**	**21,831**	**1,380**	**20,320**	**2,479**	**457**	**121**	**237**	**0**
Total Algae	**43**	**0**	**345**	**3,924**	**5,394**	**4,244**	**2,242**	**22,150**	**1,639**	**20,522**	**2,712**	**746**	**423**	**414**	**461**
Anabaena*	43	0	0	3,083	4,312	798	992	423	0	30	129	0	0	0	0
Anacystis*	0	0	0	0	0	0	0	56	0	0	0	0	0	0	0
Ankistrodesmus	0	0	0	0	0	26	13	22	91	0	34	17	0	0	0
Aphanizomenon*	0	0	345	841	586	776	362	483	0	0	0	91	60	151	0
Asterionella	0	0	0	0	0	0	0	0	0	0	0	0	30	0	388
Chrysococcus	0	0	0	0	0	13	4	30	0	0	4	0	9	17	0
Coelastrum	0	0	0	0	0	0	112	0	0	0	0	0	0	0	0
Dictyosphaerium	0	0	0	0	0	0	116	43	0	0	0	0	0	0	0
Dinobryon	0	0	0	0	0	65	39	0	0	0	9	0	155	0	47
Errerella	0	0	0	0	0	103	34	0	0	0	0	0	0	0	0
Euglena	0	0	0	0	0	9	9	4	17	0	0	0	13	4	0
Fragilaria	0	0	0	0	0	30	78	34	13	22	26	22	30	30	0
Gloeocystis	0	0	0	0	0	82	0	0	60	69	99	0	0	0	0
Golenkinia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gonium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gymnodinium	0	0	0	0	0	4	9	9	0	0	0	0	0	17	0
Mallomonas	0	0	0	0	0	4	22	0	0	0	0	13	17	26	0
Melosira	0	0	0	0	0	22	0	52	52	0	0	39	22	34	0
Microcystis*	0	0	0	0	0	0	103	0	0	0	0	0	0	0	0
Oscillatoria*	0	0	0	0	496	1,570	280	20,869	1,380	20,290	2,350	367	60	86	0
Pandorina	0	0	0	0	0	0	0	121	0	0	0	52	0	0	0
Pediastrum	0	0	0	0	0	26	0	0	0	0	0	56	0	0	0
Scenedesmus	0	0	0	0	0	0	69	0	0	0	17	0	0	34	0
Schroederia	0	0	0	0	0	0	0	0	26	0	0	0	0	0	0
Sphaerocystis	0	0	0	0	0	690	0	0	0	0	0	0	0	0	0
Staurastrum	0	0	0	0	0	0	0	0	0	9	0	22	0	0	0
Synedra	0	0	0	0	0	0	0	4	0	0	0	0	0	13	26
Trachelomonas	0	0	0	0	0	0	0	0	0	0	0	0	9	0	0
Ulothrix	0	0	0	0	0	26	0	0	0	103	43	69	17	0	0

All numbers are in cells/1 mL *Blue-green algae + Sample frozen

SR1 - 10'

Date	5/13/15	5/28/15	6/10/15	6/22/15	7/6/15	7/21/15	8/5/15	8/14/15	8/21/15	9/3/15	9/17/15	9/29/15	10/14/15	10/27/15	4/14/16
Total Blue-Green Algae	**172**	**1,363**	**625**	**9,064**	**2,285**	**1,143**	**1,199**	**1,725**	**3,471**	**6,377**	**1,337**	**388**	**272**	**237**	**0**
Total Algae	**172**	**1,363**	**625**	**9,064**	**2,550**	**1,897**	**1,902**	**2,251**	**3,820**	**6,558**	**1,583**	**599**	**461**	**336**	**134**
Anabaena*	0	0	323	6,882	707	78	543	0	0	0	0	0	207	0	0
Ankistrodesmus	0	0	0	0	4	30	17	99	13	0	26	0	0	0	0
Aphanizomenon*	103	1,298	302	2,053	543	30	181	0	0	0	0	0	0	0	0
Asterionella	0	0	0	0	0	0	0	0	0	0	0	0	0	0	99
Ceratium	0	0	0	0	4	0	4	0	0	0	0	0	0	0	0
Chrysococcus	0	0	0	0	4	43	60	0	0	17	9	4	13	4	0
Closterium	0	0	0	0	13	0	0	0	0	0	22	4	0	13	0
Closteriopsis	0	0	0	0	0	0	0	26	0	0	0	0	0	0	0
Crucigenia	0	0	0	0	0	0	0	0	69	0	0	0	0	0	0
Coelastrum	0	0	0	0	0	34	0	34	0	0	0	0	0	0	0
Dictyosphaerium	0	0	0	0	0	52	86	250	0	0	0	0	0	0	0
Dinobryon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Errerella	0	0	0	0	0	241	34	0	0	0	0	0	0	0	0
Euglena	0	0	0	0	0	34	60	22	9	0	0	4	4	9	0
Fragilaria	0	0	0	0	17	116	0	0	30	17	30	9	0	9	13
Gloeocystis	0	0	0	0	60	0	0	52	60	95	121	0	91	0	0
Golenkinia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gonium	0	0	0	0	0	0	0	0	0	0	0	0	0	34	0
Gymnodinium	0	0	0	0	9	0	0	0	0	0	0	0	22	9	0
Kirchneriella	0	0	0	0	0	34	0	0	0	0	0	0	0	0	0
Mallomonas	0	0	0	0	17	0	4	0	0	0	0	0	9	0	0
Melosira	0	0	0	0	103	30	155	0	43	0	0	82	0	0	17
Microcystis*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oscillatoria*	69	65	0	129	1,035	1,035	474	1,725	3,471	6,377	1,337	388	65	237	0
Pandorina	0	0	0	0	0	0	103	0	0	0	0	0	0	0	0
Pediastrum	0	0	0	0	0	69	0	0	0	0	0	73	0	0	0
Scenedesmus	0	0	0	0	34	69	0	34	0	0	0	17	0	17	0
Sphaerocystis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Staurastrum	0	0	0	0	0	0	0	0	4	0	13	17	0	0	0
Synedra	0	0	0	0	0	0	4	0	4	0	0	0	0	4	4
Synura	0	0	0	0	0	0	155	0	0	0	0	0	0	0	0
Trachelomonas	0	0	0	0	0	0	17	9	13	0	9	0	0	0	0
Ulothrix	0	0	0	0	0	0	0	0	103	52	17	0	52	0	0

All numbers are in cells/1 mL *Blue-green algae + Sample frozen

SR1 - 15'

Date	8/5/15
Total Blue-Green Algae	**526**
Total Algae	**733**
Anabaena*	30
Ankistrodesmus	0
Aphanizomenon*	0
Chrysococcus	30
Euglena	22
Fragilaria	26
Gymnodinium	9
Mallomonas	4
Melosira	78
Oscillatoria*	496
Pandorina	34
Trachelomonas	4

All numbers are in cells/1 mL

*Blue-green algae + Sample frozen

SR1 - B

Date	4/14/15
Total Blue-Green Algae	**0**
Total Algae	**0**
Anabaena*	0
Aphanizomenon*	0
Microcystis*	0
Oscillatoria*	0

All numbers are in cells/1 mL

*Blue-green algae + Sample frozen

SR1 - Clarifier

Date	7/29/15	5/27/16	9/2/16
Total Blue-Green Algae	**1,595**	**310**	**31,611**
Total Algae	**1,785**	**336**	**33,224**
Anabaena*	0	0	0
Anacystis*	0	0	651
Ankistrodesmus	0	0	0
Aphanizomenon*	0	34	815
Chrysococcus	17	0	306
Coelosphaerium*	0	0	755
Closteridium	4	0	0
Dinobryon	0	0	0
Errerella	0	0	0
Euglena	56	4	0
Fragilaria	43	22	0
Gloeocystis	0	0	0
Golenkinia	0	0	0
Gymnodinium	0	0	0
Mallonomas	0	0	0
Melosira	22	0	267
Oscillatoria*	1,595	276	29,391
Pandorina	34	0	724
Scenedesmus	0	0	0
Staurastrum	0	0	0
Synedra	0	0	315
Trachelomonas	13	0	0
Ulothrix	0	0	0

All numbers are in cells/1 mL

*Blue-green algae + Sample frozen

SR1.5-S

Date	7/28/15	8/21/15
Total Blue-Green Algae	**9,286**	**2,932**
Total Algae	**10,494**	**3,195**
Actinastrum	26	0
Anabaena*	0	0
Anacystis*	561	0
Ankistrodesmus	0	65
Aphanizomenon*	30	0
Ceratium	0	0
Chrysococcus	0	22
Dictyosphaerium	0	52
Dinobryon	0	0
Euglena	1,031	4
Fragilaria	17	34
Gloeocystis	17	0
Golenkinia	0	0
Gymnodinium	22	9
Mallomonas	0	0
Melosira	56	4
Oocystis	13	0
Oscillatoria*	8,696	2,932
Pectodictyum	0	69
Scenedesmus	0	0
Staurastrum	0	0
Synedra	0	0
Trachelomonas	26	4
Ulothrix	0	0

All numbers are in cells/1 mL

*Blue-green algae + Sample frozen

SH1

Date	7/5/16	8/17/16	8/23/16	10/21/16	4/26/17	5/31/17	9/26/17
Total Blue-Green Algae	**1,117**	**4,480**	**7,421**	**1,600**	**0**	**0**	**18,360**
Total Algae	**2,846**	**4,480**	**7,421**	**2,418**	**1,328**	**26**	**20,560**
Anabaena*	0	4,299	6,365	1,600	0	0	7,520
Ankistrodesmus	0	0	0	0	0	0	0
Aphanizomenon*	1,117	181	1,056	0	0	0	40
Asterionella	34	0	0	0	608	17	0
Aulacoseira	0	0	0	240	0	0	0
Ceratium	0	0	0	0	0	0	40
Chlamydomonas	0	0	0	0	0	0	0
Chrysococcus	0	0	0	0	0	0	0
Coelosphaerium*	0	0	0	0	0	0	10,800
Crucigenia	0	0	0	0	0	0	40
Cryptomonas	0	0	0	88	0	0	0
Dinobryon	0	0	0	10	681	0	1,920
Euglena	4	0	0	0	0	0	0
Fragilaria	0	0	0	10	0	0	40
Gonyostomum	0	0	0	10	0	0	0
Gymnodinium	0	0	0	0	0	0	0
Mallomonas	0	0	0	0	0	4	0
Melosira	1,690	0	0	0	0	0	0
Naviculate	0	0	0	0	0	0	0
Nephrocytium	0	0	0	10	0	0	0
Oocystis	0	0	0	0	0	0	0
Oscillatoria	0	0	0	10	0	0	0
Peridinium	0	0	0	0	13	0	0
Pseudanabaena	0	0	0	420	0	0	0
Sphaerocystis	0	0	0	10	0	0	0
Staurastrum	0	0	0	0	0	0	40
Synedra	0	0	0	0	26	0	0
Synura	0	0	0	0	0	4	0
Tabellaria	0	0	0	0	0	0	40
Trachelomonas	0	0	0	10	0	0	40
Xanthidium	0	0	0	0	0	0	40

All numbers are in cells/1 mL *Blue-green algae + Sample frozen

SH1 - 1'

Date	4/15/15	7/6/15	7/14/15	7/21/15	8/3/15	8/10/15	9/17/15	10/6/15
Total Blue-Green Algae	**0**	**22,388**	**23,942**	**2,436**	**220**	**34**	**0**	**0**
Total Algae	**2,340**	**22,396**	**23,942**	**2,476**	**401**	**125**	**2,661**	**22**
Anabaena*	0	22,388	23,942	2,436	220	34	0	0
Ankistrodesmus	0	0	0	0	0	13	0	0
Asterionella	2,290	0	0	13	13	0	0	4
Chlamydomonas	0	0	0	0	65	0	0	0
Chrysococcus	0	4	0	9	26	39	26	0
Dinobryon	47	0	0	0	0	0	1,281	4
Euglena	0	0	0	0	17	9	0	0
Fragilaria	0	0	0	0	0	0	30	4
Gymnodinium	0	4	0	9	34	0	0	0
Mallomonas	0	0	0	0	0	0	60	4
Naviculate	2	0	0	0	0	0	13	0
Oocystis	0	0	0	9	0	0	0	0
Peridinium	0	0	0	0	0	9	0	0
Synedra	1	0	0	0	0	0	0	0
Synura	0	0	0	0	0	0	1,242	0
Trachelomonas	0	0	0	0	26	22	9	4

All numbers are in cells/1 mL *Blue-green algae + Sample frozen

SH1 - 5'

Date	6/12/15	7/6/15	7/14/15	7/21/15	8/3/15
Total Blue-Green Algae	**1,190**	**24,997**	**15,768**	**4,346**	**86**
Total Algae	**2,108**	**24,997**	**15,768**	**4,359**	**309**
Anabaena*	1,190	24,997	15,768	4,346	43
Asterionella	604	0	0	0	0
Chlamydomonas	0	0	0	0	151
Chrysococcus	4	0	0	13	4
Dinobryon	0	0	0	0	0
Euglena	0	0	0	0	4
Fragilaria	95	0	0	0	26
Gloeocystis	17	0	0	0	0
Gymnodinium	0	0	0	0	0
Melosira	21	0	0	0	0
Mougeotia	91	0	0	0	0
Naviculate	52	0	0	0	0
Oscillatoria*	0	0	0	0	43
Synedra	34	0	0	0	4
Trachelomonas	0	0	0	0	34

All numbers are in cells/1 mL

*Blue-green algae + Sample frozen

SH1 - 10'

Date	7/6/15	7/14/15	7/21/15	8/3/15
Total Blue-Green Algae	**8,585**	**3,471**	**1,595**	**48**
Total Algae	**8,585**	**3,471**	**1,616**	**182**
Anabaena*	8,585	3,363	1,595	26
Aphanizomenon*	0	108	0	0
Asterionella	0	0	0	0
Chlamydomonas	0	0	0	112
Chrysococcus	0	0	4	9
Dinobryon	0	0	0	0
Fragilaria	0	0	0	0
Gloeocystis	0	0	17	0
Gymnodinium	0	0	0	0
Melosira	0	0	0	0
Mougeotia	0	0	0	0
Naviculate	0	0	0	0
Oscillatoria*	0	0	0	22
Synedra	0	0	0	4
Trachelomonas	0	0	0	9

All numbers are in cells/1 mL

*Blue-green algae + Sample frozen

SH1 - 15'

Date	8/3/15
Total Blue-Green Algae	**0**
Total Algae	**59**
Anabaena*	0
Aphanizomenon*	0
Asterionella	0
Chlamydomonas	30
Chrysococcus	4
Dinobryon	0
Euglena	4
Fragilaria	0
Gloeocystis	0
Gymnodinium	4
Melosira	0
Mougeotia	0
Naviculate	0
Oscillatoria*	0
Synedra	0
Trachelomonas	17

All numbers are in cells/1 mL

*Blue-green algae + Sample frozen

SH1 - 20'

Date	7/14/15	7/21/15
Total Blue-Green Algae	**732**	**65**
Total Algae	**1,176**	**69**
Anabaena*	215	65
Aphanizomenon*	0	0
Asterionella	440	0
Chrysococcus	0	4
Dinobryon	0	0
Fragilaria	0	0
Gloeocystis	0	0
Gymnodinium	4	0
Melosira	0	0
Mougeotia	0	0
Naviculate	0	0
Oscillatoria*	517	0
Synedra	0	0

All numbers are in cells/1 mL

*Blue-green algae + Sample frozen

SH2 - S

Date	8/3/15	8/10/15	10/6/15
Total Blue-Green Algae	**0**	**427**	**0**
Total Algae	**154**	**543**	**0**
Anabaena*	0	95	0
Ankistrodesmus	0	13	0
Aphanizomenon*	0	310	0
Asterionella	0	0	0
Chlamydomonas	103	0	0
Chrysococcus	0	47	0
Dinobryon	0	0	0
Euglena	0	13	0
Fragilaria	0	0	0
Gloeocystis	0	0	0
Gymnodinium	4	0	0
Melosira	0	0	0
Mougeotia	0	0	0
Naviculate	0	0	0
Oscillatoria*	0	22	0
Peridinium	0	13	0
Synedra	0	0	0
Trachelomonas	47	30	0

All numbers are in cells/1 mL

*Blue-green algae + Sample frozen

BC1

6/29/15–7/6/16

Date	6/29/15	2/18/16	3/14/16	4/12/16	4/27/16	5/9/16	5/11/16	5/12/16	5/19/16	5/23/16	5/27/16	6/2/16	6/7/16	6/15/16	6/20/16	6/27/16	6/30/16	7/6/16
Total Blue-Green Algae	**155**	**1,298**	**772**	**0**	**0**	**7,011**	**8,826**	**392**	**5,002**	**9,689**	**1,690**	**310**	**2,661**	**19,960**	**613**	**10,435**	**30**	**0**
Total Algae	**607**	**3,126**	**3,682**	**22,029**	**1,794**	**7,278**	**8,899**	**577**	**5,122**	**10,762**	**2,125**	**509**	**2,988**	**19,960**	**1,015**	**10,564**	**125**	**112**
Amphora	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Amphipleura	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Anabaena*	26	0	0	0	0	181	362	0	0	121	0	0	828	1,902	613	957	0	0
Anacystis*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ankistrodesmus	9	0	0	0	0	0	0		0	0	0	0	0	0	< 10	0	0	0
Aphanizomenon*	0	1,298	772	0	0	5,946	6,942	392	0	0	0	0	1,660	17,990	0	9,478	30	0
Aphanocapsa*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aphanothece*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Asterionella	0	17	2,661	22,029	1,794	125	0	65	34	194	138	9	0	0	22	0	0	0
Aulacoseira	0	0	0	0	0	0	73	0	0	0	0	0	0	0	0	0	0	0
Ceratium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	< 10	0	22	0
Chroococcus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chrysococcus	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chlorella	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Closterium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coelastrum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coelosphaerium*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coenochloris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cosmarium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Crucigenia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cuspidothrix*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cryptomonas	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclotella	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cymbella	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dictyosphaerium	354	0	0	0	0	0	0	0	0	0	0	52	0	0	0	69	0	0
Dinobryon	0	1,768	237	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dolichospermum*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Elakatothrix	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Errerella	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Euglena	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Eunotia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fragilaria	17	0	0	0	0	142	0	47	86	293	194	86	0	0	160	0	13	0
Geminella	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gymnodinium	34	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gloeocapsa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gloeocystis	17	0	0	0	0	0	0	0	0	0	0	0	0	0	68	0	0	0
Gomphonema	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gomphosphaeria*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gonatozygon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gonium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Haematococcus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Leibleinia*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mallomonas	4	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Melosira	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	22
Navicula	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitzschia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oocystis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	140	60	56	91
Oscillatoria*	129	0	0	0	0	884	1,522	0	5,002	9,568	1,690	310	172	69	0	0	0	0
Palmella	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pandorina	0	0	0	0	0	0	0	69	0	0	0	0	0	0	0	0	0	0
Peridinium	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pinnularia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Planktolyngbya*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Planktothrix*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pseudanabaena*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Selenastrum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Scenedesmus	17	0	0	0	0	0	0	0	0	0	0	0	0	0	< 10	0	0	0
Schroederia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sphaerocystis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Staurastrum	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0
Stauroneis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Stephanodiscus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Surirella	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Synedra	0	0	4	0	0	0	0	0	0	0	0	0	0	0	12	0	0	0
Synura	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetraedon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetraspora	0	0	0	0	0	0	0	0	0	586	103	52	328	0	0	0	0	0
Trachelomonas	0	0	0	0	0	0	0	0	0	0	0	0	0	0	< 10	0	4	0
Trichdesmium*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ulothrix	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Uroglenopsis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Woronichinia*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

All numbers are in cells/1 mL   *Blue-green algae   + Sample frozen

BC1 7/12/16–11/3/16

Date	7/12/16	8/3/16	8/8/16	8/17/16	8/22/16	8/30/16	9/2/16	9/6/16	9/15/16	9/22/16	9/28/16	10/5/16	10/12/16	10/17/16	10/25/16	10/27/16	10/31/16	11/3/16
Total Blue-Green Algae	**254**	**8,076**	**10,310**	**8,878**	**2,139**	**41,870**	**26,941**	**699**	**155**	**319**	**1,359**	**2,333**	**16,903**	**1,560**	**1,420**	**8,167**	**16,903**	**0**
Total Algae	**509**	**8,111**	**10,310**	**8,878**	**2,173**	**41,870**	**26,941**	**1,069**	**1,971**	**2,927**	**1,971**	**2,709**	**18,296**	**1,687**	**1,754**	**8,352**	**18,296**	**1,251**
Amphora	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Amphipleura	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Anabaena*	0	7,214	5,222	914	1,065	3,622	2,186	181	0	60	0	0	630	100	160	513	630	0
Anacystis*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ankistrodesmus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aphanizomenon*	0	0	302	634	0	302	392	0	0	0	0	0	13,039	110	360	5,282	13,039	0
Aphanocapsa*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aphanothece*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Asterionella	0	0	0	0	0	0	0	0	0	0	0	0	22	0	0	0	22	0
Aulacoseira	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ceratium	0	17	0	0	0	0	0	0	0	0	0	0	60	0	40	56	60	0
Chroococcus*	0	0	0	0	0	0	0	0	0	0	0	69	0	0	0	0	0	0
Chrysococcus	0	0	0	0	0	0	0	0	0	4	0	17	13	0	0	39	13	0
Chlorella	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Closterium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coelastrum	0	0	0	0	0	0	0	0	0	0	78	0	0	0	0	0	0	0
Coelosphaerium*	0	862	4,786	7,330	862	37,946	24,363	517	0	259	1,294	2,264	3,234	1,350	890	2,372	3,234	0
Coenochloris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cosmarium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Crucigenia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cuspidothrix*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cryptomonas	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclotella	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cymbella	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dictyosphaerium	34	0	0	0	0	0	0	371	0	0	0	0	0	0	0	0	0	0
Dinobryon	0	0	0	0	0	0	0	0	0	0	0	0	1,255	0	80	60	1,255	1,225
Dolichospermum*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Elakatothrix	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Errerella	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Euglena	9	0	0	0	0	0	0	0	13	0	0	4	0	0	0	0	0	0
Eunotia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fragilaria	0	0	0	0	,	0	0	0	0	0	0	69	0	0	10	0	0	26
Geminella	0	0	0	0	0	0	0	0	0	2,535	0	0	0	0	0	0	0	0
Gymnodinium	13	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gloeocapsa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gloeocystis	0	0	0	0	0	0	0	0	0	0	241	0	0	60	0	0	0	0
Gomphonema	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gomphosphaeria*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gonatozygon	0	0	0	0	0	0	0	0	0	43	0	0	0	0	0	0	0	0
Gonium	0	0	0	0	0	0	0	0	0	13	0	0	0	0	0	0	0	0
Haematococcus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Leibleinia*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mallomonas	9	0	0	0	0	0	0	0	0	0	0	9	17	35	10	0	17	0
Melosira	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Navicula	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitzschia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oocystis	91	0	0	0	34	0	0	0	26	0	0	0	0	0	44	0	0	0
Oscillatoria*	254	0	0	0	211	0	0	0	155	0	65	0	0	0	0	0	0	0
Palmella	0	0	0	0	0	0	0	0	1,742	0	0	0	0	0	0	0	0	0
Pandorina	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Peridinium	0	0	0	0	0	0	0	0	0	9	0	0	0	0	0	0	0	0
Pinnularia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Planktolyngbya*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Planktothrix*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pseudanabaena*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0
Selenastrum	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0
Scenedesmus	0	0	0	0	0	0	0	0	34	0	0	0	0	0	0	0	0	0
Schroederia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sphaerocystis	0	0	0	0	0	0	0	0	0	0	276	216	0	0	0	0	0	0
Staurastrum	0	0	0	0	0	0	0	0	0	0	17	22	0	10	0	0	0	0
Stauroneis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Stephanodiscus	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0
Surirella	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Synedra	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Synura	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetraedon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetraspora	69	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trachelomonas	0	0	0	0	0	0	0	0	0	0	0	9	26	22	150	30	26	0
Trichdesmium*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ulothrix	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Uroglenopsis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Woronichinia*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

All numbers are in cells/1 mL *Blue-green algae + Sample frozen

BC1 11/10/16–7/13/17

Date	11/10/16	12/12/16	1/25/17	2/22/17	3/28/17	4/5/17	4/10/17	4/14/17	4/17/17	4/26/17	5/2/17	5/9/17	5/15/17	5/18/17	5/24/17	5/30/17	6/30/17	7/13/17
Total Blue-Green Algae	**65**	**0**	**86**	**936**	**0**	**7,246**	**41,738**	**5,925**	**569**	**500**	**1,587**	**5,614**	**21,275**	**11,108**	**0**	**181**	**12,074**	**40**
Total Algae	**846**	**60**	**199**	**1,821**	**14,666**	**18,956**	**46,723**	**7,443**	**970**	**848**	**1,721**	**6,606**	**24,932**	**17,063**	**712**	**1,184**	**12,074**	**360**
Amphora	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	40
Amphipleura	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Anabaena*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12074	0
Anacystis*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ankistrodesmus	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aphanizomenon*	0	0	86	936	0	7,246	41,738	5,925	569	0	1,501	5,433	18,593	151	0	0		0
Aphanocapsa*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aphanothece*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Asterionella	0	0	13	798	14,666	11,710	4,985	1,518	285	129	78	621	2,609	2,169	86	375	0	40
Aulacoseira	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ceratium	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	17	0	40
Chroocococcus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chrysococcus	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	47	0	0
Chlorella	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Closterium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coelastrum	0	47	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coelosphaerium*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coenochloris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cosmarium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Crucigenia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cuspidothrix*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cryptomonas	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclotella	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cymbella	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	40
Dictyosphaerium	0	0	0	0	0	0	0	0	0	0	0	0	0	949	328	147	0	0
Dinobryon	703	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dolichospermum*	0	0	0	0	0	0	0	0	0	0	0	181	2,682	10,957	0	181	0	0
Elakatothrix	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Errerella	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Euglena	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	17	0	40
Eunotia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fragilaria	0	0	22	22	0	0	0	0	0	198	52	371	1,048	2,837	246	172	0	0
Geminella	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gymnodinium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gloeocapsa	0	0	65	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gloeocystis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gomphonema	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gomphosphaeria*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gonatozygon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gonium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	86	0	0
Haematococcus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Leibleinia*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mallomonas	0	0	0	13	0	0	0	0	0	0	0	0	0	0	13	142	0	0
Melosira	0	9	0	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Navicula	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitzschia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oocystis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oscillatoria*	0	0	0	0	0	0	0	0	0	500	86	0	0	0	0	0	0	40
Palmella	52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pandorina	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Peridinium	0	0	0	0	0	0	0	0	116	13	4	0	0	0	0	0	0	0
Pinnularia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Planktolyngbya*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Planktothrix*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pseudanabaena*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Selenastrum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Scenedesmus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	40
Schroederia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sphaerocystis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Staurastrum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Stauroneis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	0	0	0
Stephanodiscus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Surirella	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Synedra	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	40
Synura	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetraedon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetraspora	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trachelomonas	26	4	4	22	0	0	0	0	0	0	0	0	0	0	26	0	0	40
Trichdesmium*	65	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ulothrix	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Uroglenopsis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Woronichinia*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

All numbers are in cells/1 mL *Blue-green algae + Sample frozen

BC1 7/19/17–12/7/17

Date	7/19/17	8/1/17	8/8/17	8/16/17	8/24/17	8/30/17	9/13/17	9/21/17	9/27/17	10/4/17	10/10/17	10/19/17	10/26/17+	11/2/17	11/21/17	12/7/17
Total Blue-Green Algae	**40**	**40**	**80**	**80**	**120**	**40**	**1,400**	**1,380**	**40**	**3,862**	**120**	**8,440**	**80**	**120**	**140**	**40**
Total Algae	**640**	**440**	**440**	**400**	**2,950**	**440**	**4,400**	**3,480**	**1,920**	**5,132**	**560**	**10,120**	**320**	**600**	**930**	**960**
Amphora	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Amphipleura	0	0	0	0	0	0	0	0	0	0	0	40	0	0	0	0
Anabaena*	0	0	0	0	0	0	0	0	0	40	0	0	40	40	0	0
Anacystis*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ankistrodesmus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aphanizomenon*	0	0	0	0	0	0	0	0	0	0	40	0	0	0	0	0
Aphanocapsa*	0	0	0	0	0	0	0	0	0	0	0	1,200	0	0	0	0
Aphanothece*	0	0	0	0	0	0	0	0	0	0	0	0	40	40	0	0
Asterionella	0	0	0	0	40	40	0	40	40	0	40	40	40	40	40	40
Aulacoseira	0	0	0	0	0	0	40	0	0	40	40	40	0	40	40	40
Ceratium	40	40	0	0	40	40	40	40	40	40	40	40	40	40	0	0
Chroocococcus*	0	0	0	0	0	0	0	40	0	0	0	0	0	0	0	0
Chrysococcus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	40	40
Chlorella	0	0	0	0	0	0	0	0	0	273	0	0	0	0	0	0
Closterium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coelastrum	0	40	40	40	40	40	0	0	0	40	0	0	0	0	0	0
Coelosphaerium*	0	0	40	40	40	0	1,400	1,300	40	3,822	40	8,400	0	40	140	40
Coenochloris	0	0	40	40	0	0	0	40	0	0	0	0	0	0	0	0
Cosmarium	0	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Crucigenia	0	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cuspidothrix*	0	0		0	0	0	40	0	0	0	0	0	0	0	0	0
Cryptomonas	0	40	0	0	0	0	0	0	0	0	0	0	0	0	60	80
Cyclotella	0	0	40	0	40	0	40	0	0	0	0	0	0	0	0	240
Cymbella	40	0	0	0	40	0	0	0	0	0	0	0	0	0	40	0
Dictyosphaerium	0	0	40	40	40	40	0	0	0	0	0	0	0	40	40	0
Dinobryon	0	0	0	40	40	40	2,600	40	0	0	0	0	0	0	0	0
Dolichospermum*	0	0	0	0	0	0	0	0	0	0	40	40	0	0	0	0
Elakatothrix	0	0	0	0	0	0	0	40	0	0	0	0	0	0	40	0
Errerella	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Euglena	40	0	0	0	40	0	40	40	0	40	0	0	0	40	0	40
Eunotia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	40
Fragilaria	0	0	0	0	40	0	0	400	40	40	40	40	0	0	40	0
Geminella	0	0	0	0	0	0	0	0	40	0	40	0	0	0	0	0
Gymnodinium	0	40	0	0	0	0	0	0	0	0	0	0	0	0	0	40
Gloeocapsa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gloeocystis	0	0	0	0	1,200	0	0	1,300	1,600	40	40	0	0	40	40	0
Gomphonema	0	0	0	0	0	0	0	0	0	0	0	0	0	40	40	0
Gomphosphaeria*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gonatozygon	0	0	0	0	0	40	0	0	0	0	0	0	0	0	0	0
Gonium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Haematococcus	0	0	40	0	40	0	0	0	0	0	0	0	0	0	0	0
Leibleinia*	0	0	40	40	0	0	0	0	0	0	0	0	0	0	0	0
Mallomonas	0	0	0	40	220	0	0	40	40	40	40	0	0	0	90	40
Melosira	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Navicula	0	0	0	0	0	0	0	0	0	0	0	0	0	40	0	40
Nitzschia	0	0	0	0	0	0	0	0	0	0	0	0	40	0	0	0
Oocystis	40	40	0	40	40	40	0	40	40	637	40	40	40	0	0	0
Oscillatoria*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Palmella	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pandorina	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Peridinium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pinnularia	0	0	0	0	0	0	0	0	0	0	0	40	0	0	0	0
Planktolyngbya*	0	0	0	0	40	0	0	0	0	0	0	0	0	0	0	0
Planktothrix*	0	40	0	0	0	0	0	0	0	0	0	40	40	40	40	0
Pseudanabaena*	40	40	40	40	0	0	0	40	0	0	0	0	0	0	0	0
Selenastrum	120	0	0	0	810	0	0	0	0	0	0	0	0	0	0	0
Scenedesmus	40	0	40	0	40	0	0	0	0	0	0	0	0	0	0	0
Schroederia	0	0	0	0	0	0	0	0	0	40	40	40	0	0	40	40
Sphaerocystis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Staurastrum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Stauroneis	0	0	0	0	0	40	0	40	0	0	0	0	0	0	0	0
Stephanodiscus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Surirella	0	0	0	0	0	0	0	0	0	0	0	40	0	0	0	0
Synedra	240	40	40	0	40	40	0	0	0	0	40	40	0	40	40	160
Synura	0	0	0	0	40	0	0	0	0	0	0	0	0	0	0	0
Tetraedon	0	0	40	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetraspora	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trachelomonas	40	40	0	40	40	40	200	40	40	40	40	40	0	40	120	80
Trichdesmium*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ulothrix	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Uroglenopsis	0	0	0	0	0	0	0	0	0	0	0	0	40	40	40	0
Woronichinia*	0	0	0	0	40	40	0	0	0	0	0	0	0	0	0	0

All numbers are in cells/1 mL   *Blue-green algae   + Sample frozen

BC1 Thermocline

Date	11/10/16
Total Blue-Green Algae	**10,107**
Total Algae	**10,215**
Anabaena*	1,423
Anacystis*	0
Ankistrodesmus	0
Aphanizomenon*	0
Asterionella	0
Ceratium	0
Closterium	0
Chroocococcus*	0
Chrysococcus	0
Coelastrum	0
Coelosphaerium*	0
Dictyosphaerium	0
Dinobryon	0
Dispora	0
Errerella	0
Eudorina	0
Euglena	52
Fragilaria	0
Gloeocystis	0
Golenkinia	0
Gymnodinium	0
Mallomonas	0
Melosira	0
Oscillatoria*	103
Oocystis	0
Palmella	0
Pandorina	0
Pectodictyon	0
Pseudanabaena	0
Pseudostaurastrum	0
Scenedesmus	0
Schroederia	0
Sphaerocystis	0
Staurastrum	0
Stephanodiscus	0
Synedra	0
Tetraspora	0
Trachelomonas	56
Trichdesmium*	8,581
Ulothrix	0

All numbers are in cells/1 mL

*Blue-green algae + Sample frozen

BC1 4/28/15–8/18/15

Date	4/28/15	5/13/15	5/28/15	6/10/15	6/15/15	6/18/15	6/22/15	7/6/15	7/15/15	7/21/15	7/28/15	8/5/15	8/12/15	8/18/15
Total Blue-Green Algae	**0**	**13**	**69**	**4,079**	**698**	**487**	**0**	**2,423**	**198**	**26**	**0**	**0**	**1,134**	**530**
Total Algae	**0**	**13**	**69**	**4,079**	**698**	**487**	**0**	**2,590**	**280**	**129**	**229**	**198**	**1,388**	**2,078**
Anabaena*	0	13	69	3,924	448	34	0	1,216	112	26	0	0	802	0
Anacystis*	0	0	0	0	0	453	0	0	0	0	0	0	0	0
Ankistrodesmus	0	0	0	0	0	0	0	0	0	34	0	0	0	0
Aphanizomenon*	0	0	0	155	250	0	0	1,207	0	0	0	0	332	121
Asterionella	0	0	0	0	0	0	0	0	9	0	0	0	0	0
Ceratium	0	0	0	0	0	0	0	4	0	0	0	0	0	0
Chrysococcus	0	0	0	0	0	0	0	0	0	13	0	0	13	0
Closterium	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coelosphaerium*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coelastrum	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dictyosphaerium	0	0	0	0	0	0	0	17	0	0	0	43	0	0
Dinobryon	0	0	0	0	0	0	0	0	0	0	0	0	34	78
Errerella	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Euglena	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fragilaria	0	0	0	0	0	0	0	73	30	0	151	129	0	26
Gymnodinium	0	0	0	0	0	0	0	22	4	56	78	4	0	4
Gloeocystis	0	0	0	0	0	0	0	43	26	0	0	13	138	1,440
Gomphosphaeria*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mallomonas	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Microcystis*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naviculate	0	0	0	0	0	0	0	4	0	0	0	0	0	0
Oocystis	0	0	0	0	0	0	0	0	13	0	0	0	0	0
Oscillatoria*	0	0	0	0	0	0	0	0	86	0	0	0	0	410
Pandorina	0	0	0	0	0	0	0	0	0	0	0	0	69	0
Peridinium	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Scenedesmus	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Staurastrum	0	0	0	0	0	0	0	4	0	0	0	0	0	0
Synedra	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Synura	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trachelomonas	0	0	0	0	0	0	0	0	0	0	0	9	0	0
Ulothrix	0	0	0	0	0	0	0	0	0	0	0	0	0	0

All numbers are in cells/1 mL *Blue-green algae + Sample frozen

BC1 8/24/15–3/14/16

Date	8/24/15	9/3/15	9/9/15	9/18/15	9/23/15	9/30/15	10/6/15	10/14/15	10/21/15	10/27/15	11/3/15	11/18/15	2/18/16	3/14/16
Total Blue-Green Algae	**232**	**52**	**1,406**	**29,294**	**107,451**	**483**	**52**	**6,938**	**7,287**	**0**	**0**	**0**	**1,298**	**772**
Total Algae	**1,552**	**569**	**1,630**	**29,393**	**107,537**	**573**	**82**	**7,343**	**7,520**	**358**	**483**	**625**	**3,126**	**3,682**
Anabaena*	67	52	259	483	828	0	0	2949	2143	0	0	0	0	0
Anacystis*	0	0	0	0	0	0	52	0	0	0	0	0	0	0
Ankistrodesmus	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aphanizomenon*	12	0	1,147	28,811	105,795	483	0	755	1177	0	0	0	1298	772
Asterionella	0	0	0	0	0	0	0	0	0	43	0	0	17	2661
Ceratium	0	0	0	0	0	0	0	9	39	17	4	13	0	0
Chrysococcus	0	0	9	4	0	0	0	0	9	13	13	22	0	4
Closterium	0	0	0	0	0	0	0	0	9	0	0	0	0	0
Coelosphaerium*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coelastrum	< 10	0	0	0	0	0	0	0	0	0	0	0	0	0
Dictyosphaerium	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dinobryon	13	444	0	60	0	13	0	112	43	172	341	112	1768	237
Errerella	0	0	0	0	0	0	0	190	0	0	0	0	0	0
Euglena	0	0	0	13	9	0	0	0	0	0	0	0	0	0
Fragilaria	< 10	0	9	0	0	0	13	0	0	0	0	0	0	0
Gymnodinium	< 10	0	0	0	0	0	0	0	4	0	0	0	13	0
Gloeocystis	720	69	172	0	78	78	0	52	0	26	52	310	0	0
Gomphosphaeria*	0	0	0	0	828	0	0	3234	3881	0	0	0	0	0
Mallomonas	0	4	0	0	0	0	0	43	129	47	22	168	30	0
Microcystis*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naviculate	0	0	0	0	0	0	0	0	0	4	0	0	0	0
Oocystis	0	0	30	0	0	0	0	0	0	34	52	0	0	0
Oscillatoria*	153	0	0	0	0	0	0	0	86	0	0	0	0	0
Pandorina	107	0	0	0	0	0	0	0	0	0	0	0	0	0
Peridinium	0	0	0	0	0	0	0	0	0	0	0	0	0	4
Scenedesmus	53	0	0	0	0	0	0	0	0	0	0	0	0	0
Staurastrum	27	0	0	0	0	0	0	0	0	0	0	0	0	0
Synedra	0	0	0	0	0	0	0	0	0	0	0	0	0	4
Synura	400	0	0	0	0	0	0	0	0	0	0	0	0	0
Trachelomonas	< 10	0	4	0	0	0	17	0	0	0	0	0	0	0
Ulothrix	0	0	0	22	0	0	0	0	0	0	0	0	0	0

All numbers are in cells/1 mL *Blue-green algae + Sample frozen

BC2 - S

Date	6/29/15	7/6/15	7/15/15	7/28/15	8/12/15	8/24/15	9/9/15	9/23/15	10/6/15	10/21/15	11/3/15	11/18/15	2/18/16	3/14/16
Total Blue-Green Algae	**1,656**	**2,423**	**0**	**108**	**1,570**	**1,165**	**4,450**	**8,326**	**638**	**9,896**	**2,639**	**647**	**573**	**1,026**
Total Algae	**1,656**	**2,590**	**212**	**177**	**2,122**	**3,005**	**4,549**	**8,503**	**1,134**	**10,551**	**2,725**	**944**	**1,720**	**4,773**
Anabaena*	1,656	1,216	0	0	543	480	1,130	2,173	578	3,644	0	0	0	91
Aphanizomenon*	0	1,207	0	0	1,026	533	3,320	5,765	60	1,509	0	0	573	936
Asterionella	0	0	0	0	0	0	0	0	0	26	0	0	47	3,256
Ceratium	0	4	0	0	0	0	0	0	0	56	9	4	0	0
Chlorococcum	0	0	0	0	0	0	0	0	26	0	0	0	0	0
Chrysococcus	0	0	0	0	0	0	4	0	9	17	17	47	0	0
Coelastrum	0	0	0	0	43	<10	0	0	0	0	0	0	0	0
Dictyosphaerium	0	17	60	0	0	0	0	0	0	0	0	0	0	0
Dinobryon	0	0	0	0	0	<10	0	0	147	168	26	65	1,100	487
Errerella	0	0	0	0	0	0	0	0	207	0	0	0	0	0
Euglena	0	0	0	0	0	0	0	4	0	0	0	0	0	0
Fragilaria	0	73	4	56	9	<10	0	0	0	17	0	0	0	0
Gymnodinium	0	22	2	13	0	<10	0	0	9	4	0	0	0	0
Gloeocystis	0	43	43	0	293	1,680	78	172	0	181	17	17	0	0
Gomphosphaeria*	0	0	0	0	0	0	0	388	0	4,743	2,587	647	0	0
Mallomonas	0	0	0	0	0	0	4	0	4	172	13	164	0	0
Naviculate	0	4	0	0	0	0	0	0	0	0	0	0	0	0
Oocystis	0	0	13	0	0	0	0	0	0	13	0	0	0	0
Oscillatoria*	0	0	0	108	0	152	0	0	0	0	52	0	0	0
Pandorina	0	0	86	0	207	<10	0	0	0	0	0	0	0	4
Peridinium	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Scenedesmus	0	0	0	0	0	<10	0	0	0	0	0	0	0	0
Sphaerocystis	0	0	0	0	0	0	0	0	86	0	0	0	0	0
Staurastrum	0	4	0	0	0	<10	0	0	0	0	0	0	0	0
Synedra	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Synura	0	0	0	0	0	160	0	0	0	0	0	0	0	0
Trachelomonas	0	0	4	0	0	<10	13	0	9	0	4	0	0	0

All numbers are in cells/1 mL   *Blue-green algae   + Sample frozen

BC1 - 5'

Date	4/28/15	5/13/15	5/28/15	6/10/15	6/15/15	6/18/15	6/22/15	7/6/15	7/21/15	8/5/15	8/18/15	9/3/15	9/18/15	9/30/15	10/14/15	10/27/15
Total Blue-Green Algae	**0**	**65**	**0**	**4,506**	**2,967**	**552**	**52**	**3,415**	**0**	**0**	**1,263**	**565**	**40,857**	**367**	**3,394**	**0**
Total Algae	**0**	**65**	**0**	**4,506**	**2,967**	**552**	**52**	**3,578**	**112**	**254**	**2,811**	**906**	**41,030**	**410**	**3,773**	**505**
Anabaena*	0	65	0	4,506	2,070	401	52	2,208	0	0	0	414	1,147	0	2,820	0
Aphanizomenon*	0	0	0	0	897	151	0	1,207	0	0	272	151	38,956	302	573	0
Asterionella	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9
Ceratium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
Chrysococcus	0	0	0	0	0	0	0	0	4	0	9	0	0	13	13	22
Dictyosphaerium	0	0	0	0	0	0	0	34	0	0	0	0	0	0	0	0
Dinobryon	0	0	0	0	0	0	0	0	0	0	164	52	34	9	60	272
Errerella	0	0	0	0	0	0	0	0	0	0	0	0	0	0	155	0
Fragilaria	0	0	0	0	0	0	0	60	39	125	0	0	0	4	0	0
Gymnodinium	0	0	0	0	0	0	0	9	26	9	4	4	0	0	0	0
Gloeocystis	0	0	0	0	0	0	0	60	43	34	1,371	285	60	17	78	52
Gomphosphaeria*	0	0	0	0	0	0	0	0	0	0	906	0	755	0	0	0
Gonium	0	0	0	0	0	0	0	0	0	0	0	0	69	0	0	0
Mallomonas	0	0	0	0	0	0	0	0	0	0	0	0	4	0	73	95
Naviculate	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oocystis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	52
Oscillatoria*	0	0	0	0	0	0	0	0	0	0	86	0	0	65	0	0
Sphaerocystis	0	0	0	0	0	0	0	0	0	86	0	0	0	0	0	0
Synedra	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trachelomonas	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0

All numbers are in cells/1 mL   *Blue-green algae   + Sample frozen

BC2 - S

Date	4/28/15	5/28/15	6/10/15	6/15/15	6/18/15	6/22/15	7/6/15	7/21/15	8/5/15	8/20/15	9/3/15	9/18/15	9/30/15	10/14/15	10/27/15
Total Blue-Green Algae	**0**	**69**	**2,769**	**17,330**	**595**	**34**	**8,262**	**108**	**0**	**1,026**	**272**	**35,173**	**513**	**2,738**	**0**
Total Algae	**0**	**69**	**2,769**	**17,330**	**595**	**34**	**8,426**	**181**	**405**	**1,915**	**1,056**	**35,367**	**668**	**2,936**	**349**
Anabaena*	0	69	2,277	16,455	492	34	6,183	0	0	906	151	1,087	0	1,604	0
Aphanizomenon*	0	0	492	0	0	0	1,932	0	0	121	121	34,086	513	272	0
Asterionella	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ceratium	0	0	0	0	0	0	9	0	0	0	0	4	0	4	4
Chrysococcus	0	0	0	0	0	0	0	0	4	9	9	0	4	0	43
Coelastrum	0	0	0	0	0	0	0	0	0	0	0	0	52	0	0
Dictyosphaerium	0	0	0	0	0	0	108	0	138	0	0	0	0	0	0
Dinobryon	0	0	0	0	0	0	4	0	0	151	56	34	4	56	129
Errerella	0	0	0	0	0	0	0	0	0	0	0	0	0	69	0
Fragilaria	0	0	0	0	0	0	39	56	259	0	4	0	0	34	0
Gomphosphaeria*	0	0	0	0	0	0	0	0	0	0	0	0	0	862	0
Gymnodinium	0	0	0	0	0	0	0	9	4	0	0	0	0	0	0
Gloeocystis	0	0	0	0	0	0	0	0	0	716	716	129	17	0	86
Gonium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mallomonas	0	0	0	0	0	0	4	0	0	0	0	0	0	30	73
Naviculate	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0
Oocystis	0	0	0	0	0	0	0	0	0	0	0	26	0	0	13
Oscillatoria*	0	0	0	0	0	0	147	108	0	0	0	0	0	0	0
Pandorina	0	0	0	0	0	0	0	0	0	0	0	0	78	0	0
Peridinium	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0
Staurastrum	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0
Synedra	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trachelomonas	0	0	0	0	0	0	0	0	0	9	0	0	0	4	0
Trichodesmium*	0	0	0	875	103	0	0	0	0	0	0	0	0	0	0

All numbers are in cells/1 mL *Blue-green algae + Sample frozen

CRO LAG 1+2

Date	6/1/16
Total Blue-Green Algae	**103**
Total Algae	**185**
Anabaena*	0
Anacystis*	0
Ankistrodesmus	0
Aphanizomenon*	0
Asterionella	0
Closterium	0
Chrysococcus	0
Dictyosphaerium	0
Dinobryon	0
Dispora	0
Errerella	0
Eudorina	0
Euglena	0
Fragilaria	82
Gloeocystis	0
Golenkinia	0
Gymnodinium	0
Mallomonas	0
Melosira	0
Oscillatoria*	103
Oocystis	0
Pandorina	0
Pectodictyon	0
Pseudostaurastrum	0
Scenedesmus	0
Schroederia	0
Staurastrum	0
Stephanodiscus	0
Synedra	0
Tetraspora	0
Trachelomonas	0
Ulothrix	0

All numbers are in cells/1 mL

*Blue-green algae + Sample frozen

RM1 - S

7/14/15–2/22/17

Date	7/14/15	7/29/15	8/12/15	8/24/15	10/8/15	10/21/15	11/23/15	3/16/16	4/12/16	6/20/16	7/12/16	8/12/16	8/31/16	10/5/16	10/21/16	12/14/16	1/25/17	2/22/17
Total Blue-Green Algae	**103**	**60**	**43**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**151**	**0**	**0**	**0**	**0**
Total Algae	**232**	**167**	**276**	**522**	**595**	**2,389**	**8,945**	**5,407**	**628**	**237**	**711**	**172**	**496**	**750**	**870**	**147**	**280**	**112**
Anabaena*	103	60	43	0	0	0	0	0	0	0	0	0	0	151	0	0	0	0
Ankistrodesmus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aphanizomenon*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aphanocapsa*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aphanothece*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Asterionella	0	0	0	0	0	0	0	203	297	0	0	0	0	0	0	0	108	73
Aulacoseira	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0
Ceratium	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chrysococcus	9	4	0	0	9	0	13	0	0	0	0	9	4	0	0	13	0	0
Cosmarium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cryptomonas	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclotella	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cymbella	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diatoma	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dictyosphaerium	17	0	0	0	0	0	0	0	0	0	52	0	0	0	0	0	26	0
Dinobryon	0	0	30	13	60	43	0	39	311	185	69	22	0	39	0	99	121	0
Dispora	0	0	0	0	0	0	0	0	0	0	0	0	0	164	0	0	0	0
Elakatothrix	0	0	0	0	0	0	0	0	0	0	0	0	448	0	10	0	0	0
Euglena	0	4	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0
Fragilaria	0	0	0	13	0	0	0	30	0	0	0	0	0	0	0	0	0	0
Gonyostomum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gymnodinium	0	17	17	9	0	0	0	0	0	0	9	4	0	43	0	0	0	0
Gloeocystis	99	60	172	95	332	785	0	0	0	0	0	0	0	0	0	0	0	0
Mallomonas	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0
Melosira	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	34	0	0
Micractinium	0	0	0	388	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naviculate	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oocystis	0	0	0	0	0	224	0	0	0	0	82	22	13	250	780	0	0	0
Oscillatoria*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pandorina	0	0	0	0	0	52	0	0	0	0	0	0	0	0	0	0	0	0
Peridinium	0	22	9	0	0	0	0	0	19	0	0	13	22	9	0	0	22	34
Pseudanabaena*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Scenedesmus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Schroederia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sphaerocystis	0	0	0	0	0	0	0	0	0	0	0	69	0	0	0	0	0	0
Staurastrum	0	0	4	0	4	17	0	0	0	0	0	34	0	0	0	0	4	0
Stephanodiscus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Synedra	0	0	0	0	0	9	0	0	0	0	0	0	0	0	60	0	0	4
Synura	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetraspora	0	0	0	0	0	0	0	0	0	52	500	0	0	0	0	0	0	0
Trachelomonas	0	0	0	4	0	0	0	0	0	0	0	0	9	0	10	0	0	0
Ulothrix	0	0	0	0	185	1,255	8,927	5,136	0	0	0	0	0	95	0	0	0	0

All numbers are in cells/1 mL *Blue-green algae + Sample frozen

RM1 - S

3/28/17–12/14/17

Date	3/28/17	4/20/17	5/9/17	5/31/17	7/20/17	8/3/17	8/17/17	9/26/17	10/18/17	11/29/17	12/14/17+
Total Blue-Green Algae	**0**	**0**	**0**	**0**	**120**	**40**	**0**	**120**	**0**	**80**	**40**
Total Algae	**224**	**285**	**2,363**	**172**	**1,640**	**360**	**200**	**440**	**240**	**1,540**	**880**
Anabaena*	0	0	0	0	40	40	0	40	0	40	40
Ankistrodesmus	0	0	0	0	0	40	0	0	0	0	0
Aphanizomenon*	0	0	0	0	0	0	0	0	0	0	0
Aphanocapsa*	0	0	0	0	40	0	0	0	0	40	0
Aphanothece*	0	0	0	0	0	0	0	40	0	0	0
Asterionella	22	0	22	0	160	0	0	40	0	0	0
Aulacoseira	0	0	0	0	0	0	40	0	0	0	0
Ceratium	0	0	0	0	0	0	0	0	40	0	0
Chrysococcus	0	0	0	0	0	0	0	0	0	0	0
Cosmarium	0	0	0	0	0	40	0	0	0	0	0
Cryptomonas	0	0	0	0	0	0	0	0	0	0	40
Cyclotella	0	0	0	0	0	40	0	0	0	0	0
Cymbella	0	0	0	0	0	0	0	40	0	0	0
Diatoma	4	0	0	0	0	0	0	0	0	0	0
Dictyosphaerium	0	0	0	26	0	0	0	0	0	0	0
Dinobryon	134	280	888	121	40	40	0	40	40	545	320
Dispora	0	0	0	0	0	0	0	0	0	0	0
Elakatothrix	0	0	0	0	0	0	0	0	0	40	0
Euglena	0	0	0	0	0	0	0	40	0	0	0
Fragilaria	0	0	151	0	0	0	0	0	0	0	0
Gonyostomum	0	0	0	0	0	0	0	40	0	0	40
Gymnodinium	0	0	0	0	40	0	0	0	0	0	0
Gloeocystis	0	0	0	0	1,040	40	40	0	40	40	0
Mallomonas	0	4	0	0	0	0	0	0	0	40	90
Melosira	0	0	0	0	0	0	0	0	0	0	0
Micractinium	0	0	517	0	0	0	0	0	0	0	0
Naviculate	0	0	0	0	0	0	0	0	0	0	0
Oocystis	0	0	0	0	240	40	0	0	40	455	135
Oscillatoria*	0	0	0	0	0	0	0	0	0	0	0
Pandorina	0	0	0	0	0	0	0	0	0	0	0
Peridinium	65	0	0	22	0	40	0	40	40	40	0
Pseudanabaena*	0	0	0	0	40	0	0	40	0	0	0
Scenedesmus	0	0	0	0	0	0	40	0	0	0	0
Schroederia	0	0	0	0	0	0	0	0	0	0	40
Sphaerocystis	0	0	785	0	0	0	0	0	0	0	0
Staurastrum	0	0	0	4	0	0	0	40	40	40	0
Stephanodiscus	0	0	0	0	0	0	0	0	0	0	0
Synedra	0	0	0	0	0	0	40	0	0	180	135
Synura	0	0	0	0	0	0	0	0	0	40	0
Tetraspora	0	0	0	0	0	0	0	0	0	0	0
Trachelomonas	0	0	0	0	0	0	40	40	0	40	40
Ulothrix	0	0	0	0	0	40	0	0	0	0	0

All numbers are in cells/1 mL *Blue-green algae + Sample frozen

RM1 - 1'

Date	7/21/15
Total Blue-Green Algae	**0**
Total Algae	**17**
Anabaena*	0
Aphanizomenon*	0
Asterionella	0
Ceratium	0
Chrysococcus	4
Closteridium	4
Dictyosphaerium	0
Dinobryon	4
Fragilaria	0
Gymnodinium	0
Gloeocystis	0
Mallomonas	0
Naviculate	0
Oscillatoria*	0
Staurastrum	0
Stephanodiscus	4
Synedra	0

All numbers are in cells/1 mL

*Blue-green algae + Sample frozen

RM1 - 5'

Date	7/21/15
Total Blue-Green Algae	**155**
Total Algae	**164**
Anabaena*	155
Aphanizomenon*	0
Asterionella	0
Ceratium	0
Chrysococcus	0
Closteridium	4
Dictyosphaerium	0
Dinobryon	0
Fragilaria	0
Gymnodinium	4
Gloeocystis	0
Mallomonas	0
Naviculate	0
Oscillatoria*	0
Staurastrum	0
Stephanodiscus	0
Synedra	0

All numbers are in cells/1 mL

*Blue-green algae + Sample frozen

RM1 - 10'

Date	7/21/15
Total Blue-Green Algae	**121**
Total Algae	**1,207**
Anabaena*	121
Ankistrodesmus	9
Aphanizomenon*	0
Asterionella	0
Ceratium	0
Chrysococcus	0
Closteridium	0
Dictyosphaerium	0
Dinobryon	0
Fragilaria	0
Gymnodinium	9
Gloeocystis	147
Mallomonas	0
Micractinium	910
Naviculate	0
Oscillatoria*	0
Staurastrum	0
Stephanodiscus	13
Synedra	0

All numbers are in cells/1 mL

*Blue-green algae + Sample frozen

RM2 - S

Date	7/14/15	7/29/15	8/12/15	8/24/15	10/8/15	11/23/15	3/16/16
Total Blue-Green Algae	**156**	**86**	**0**	**86**	**0**	**0**	**0**
Total Algae	**238**	**156**	**332**	**578**	**621**	**12,378**	**10,499**
Ankistrodesmus	13	4	0	0	0	0	0
Aphanizomenon*	0	0	0	0	0	0	0
Asterionella	0	0	0	0	0	0	1078
Carteria	0	0	17	0	0	0	0
Ceratium	0	0	4	0	0	0	0
Chrysococcus	0	22	13	0	4	0	0
Dictyosphaerium	0	0	0	0	86	0	0
Dinobryon	0	0	47	0	0	22	30
Elakatothrix	0	17	0	0	0	0	0
Euglena	0	9	0	0	0	4	0
Fragilaria	0	0	4	0	0	0	0
Gymnodinium	0	9	13	4	0	0	0
Gloeocystis	60	0	164	224	440	0	0
Kirchneriella	0	0	34	0	0	0	0
Mallomonas	0	0	17	0	4	0	0
Micratinium	0	0	0	259	0	0	0
Naviculate	0	0	0	0	0	0	0
Oscillatoria*	0	0	0	86	0	0	0
Peridinium	9	0	0	4	0	0	0
Staurastrum	0	0	0	0	4	4	0
Stephanodiscus	0	0	13	0	0	0	0
Synedra	0	0	4	0	0	0	0
Tabellaria	0	9	0	0	0	0	0
Ulothrix	0	0	0	0	82	12348	9391

All numbers are in cells/1 mL *Blue-green algae + Sample frozen

TC1 - S

Date	8/18/15	9/1/15	9/23/15	10/22/15	11/23/15	6/27/16	7/13/16	8/23/16	10/21/16	4/19/17	5/11/17	6/28/17	8/17/17	9/28/17	10/19/17
Total Blue-Green Algae	**30,235**	**1,755**	**2,091**	**410**	**0**	**7,546**	**8,210**	**7,007**	**2,446**	**315**	**1,216**	**65**	**23,020**	**26,580**	**10,340**
Total Algae	**31,011**	**2,423**	**3,536**	**2,031**	**306**	**9,430**	**9,150**	**7,365**	**5,250**	**1,169**	**1,751**	**307**	**23,820**	**27,060**	**10,940**
Actinastrum	0	0	0	0	0	0	0	0	0	0	0	0	40	0	0
Amphipleura	0	0	0	0	0	0	0	0	0	0	0	0	40	0	40
Anabaena*	2,691	95	0	0	0	906	302	0	10	0	1,216	0	40	2,400	40
Anacystis*	2,479	0	604	0	0	0	0	0	0	0	0	0	0	0	0
Ankistrodesmus	26	0	9	0	0	0	0	0	10	0	0	86	0	0	0
Aphanizomenon*	1,328	0	0	0	0	6,640	2,505	1,479	1,440	315	0	0	40	40	0
Aphanocapsa*	0	0	0	0	0	0	0	0	380	0	0	0	0	8,100	4,300
Asterionella	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0
Aulacoseira	0	0	0	0	0	0	0	0	490	0	0	0	40	40	40
Centritractus	0	0	22	4	0	0	0	0	0	0	0	0	0	0	0
Ceratium	9	0	0	0	0	0	0	0	0	4	0	0	0	0	0
Chlamydomonas	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0
Chrysococcus	9	0	13	13	0	0	0	78	0	0	17	0	0	0	0
Closterium	0	0	0	4	0	0	0	0	0	0	0	0	40	0	0
Closteriopsis	0	0	17	0	0	0	0	0	10	0	0	0	0	0	0
Coelosphaerium*	0	0	0	0	0	0	0	0	0	0	0	0	4,800	0	40
Coelastrum	34	0	103	0	0	0	198	0	10	0	0	0	40	0	0
Coenochloris	0	0	0	0	0	0	0	0	0	0	0	0	40	0	0
Cosmarium	0	0	0	0	0	0	0	0	0	0	0	0	40	0	0
Crucigenia	0	69	0	155	0	0	0	0	810	0	0	0	40	40	40
Cryptomonas	0	0	0	0	0	0	0	0	212	0	0	0	0	0	0
Cuspidothrix	0	0	0	0	0	0	0	0	10	0	0	0	0	40	0
Cyclotella	0	0	0	0	0	0	0	0	10	0	0	0	40	40	40
Cylindrospermopsis*	0	0	0	0	0	0	0	0	0	0	0	0	0	1,600	1,520
Cymeblla	0	0	0	0	0	0	0	0	0	0	0	0	0	0	40
Dictyosphaerium	0	0	379	0	0	34	0	78	414	0	0	0	0	0	40
Dinobryon	13	22	4	0	26	470	0	0	0	0	168	0	40	0	0
Errerella	0	0	0	0	0	0	0	0	0	0	0	0	0	0	40
Eudorina	0	0	0	0	0	172	0	0	0	0	0	0	0	0	0
Euglena	13	0	17	4	0	22	56	60	10	9	4	9	40	40	0
Fragilaria	0	216	56	358	22	0	0	0	0	52	0	0	0	0	0
Gloeocystis	78	259	0	190	0	0	0	0	0	0	0	0	40	0	0
Golenkinia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gonium	0	0	0	0	0	0	0	60	0	0	0	0	0	0	0
Gonyostomum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	40
Gymnodinium	22	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Kirchneriella	0	0	34	0	0	0	0	0	0	0	0	0	40	0	0
Lyngbya*	259	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mallomonas	9	9	0	0	4	0	0	0	10	0	34	0	0	40	0
Melosira	216	30	526	634	229	410	461	82	0	367	129	0	0	0	0
Merismopedia*	0	0	0	0	0	0	0	0	0	0	0	0	18,100	0	0
Micractinium	0	0	0	0	0	172	0	0	10	0	0	0	0	0	0
Microcystis*	0	0	0	0	0	0	0	0	10	0	0	0	0	0	40
Monoraphidium	0	0	0	0	0	0	0	0	98	0	0	0	40	0	0
Naviculate	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0
Oocystis	0	0	0	0	0	0	0	0	10	0	0	0	0	0	40
Oscillatoria*	23,478	1,660	1,488	410	0	0	5,403	5,528	10	0	0	65	40	0	0
Pandorina	0	0	0	0	0	52	0	0	0	0	0	0	0	0	0
Pediastrum	95	0	198	0	0	0	190	0	10	0	0	65	40	40	40
Peridinium	0	0	0	0	0	0	0	0	0	43	0	4	0	0	0
Phacus	0	0	9	0	0	0	0	0	10	0	0	0	40	40	0
Planktolyngbya*	0	0	0	0	0	0	0	0	0	0	0	0	0	14,400	0
Pseudanabaena*	0	0	0	0	0	0	0	0	976	0	0	0	0	40	4,400
Scenedesmus	121	34	34	190	0	52	0	0	220	0	17	0	40	40	40
Sphaerocystis	103	0	0	0	0	0	0	0	0	0	138	0	0	0	0
Staurastrum	9	22	17	4	0	0	0	0	10	0	0	0	40	0	0
Synedra	0	0	0	34	9	121	34	0	10	332	26	65	40	40	40
Synura	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetraedron	0	0	0	0	0	0	0	0	10	0	0	0	0	40	40
Tetraspora	0	0	0	0	0	0	0	0	10	0	0	0	0	0	40
Tetrallantos	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0
Trachelomonas	22	0	4	4	0	0	0	0	10	0	0	13	40	40	40
Ulothrix	0	0	0	26	17	379	0	0	0	17	0	0	0	0	0

All numbers are in cells/1 mL *Blue-green algae + Sample frozen

TC - CI - S

Date	9/1/15
Total Blue-Green Algae	**755**
Total Algae	**828**
Anabaena*	0
Anacystis*	0
Ankistrodesmus	22
Aphanizomenon*	0
Ceratium	0
Chrysococcus	0
Closteridium	0
Closteriopsis	0
Coelastrum	0
Crucigenia	0
Dictyosphaerium	0
Dinobryon	0
Errerella	0
Euglena	0
Fragilaria	0
Gloeocystis	0
Golenkinia	0
Gymnodinium	0
Kirchneriella	0
Lyngbya*	0
Mallomonas	0
Melosira	0
Naviculate	52
Oscillatoria*	755
Pandorina	0
Pediastrum	0
Scenedesmus	0
Sphaerocystis	0
Staurastrum	0
Synedra	0
Synura	0
Trachelomonas	0
Ulothrix	0

All numbers are in cells/1 mL

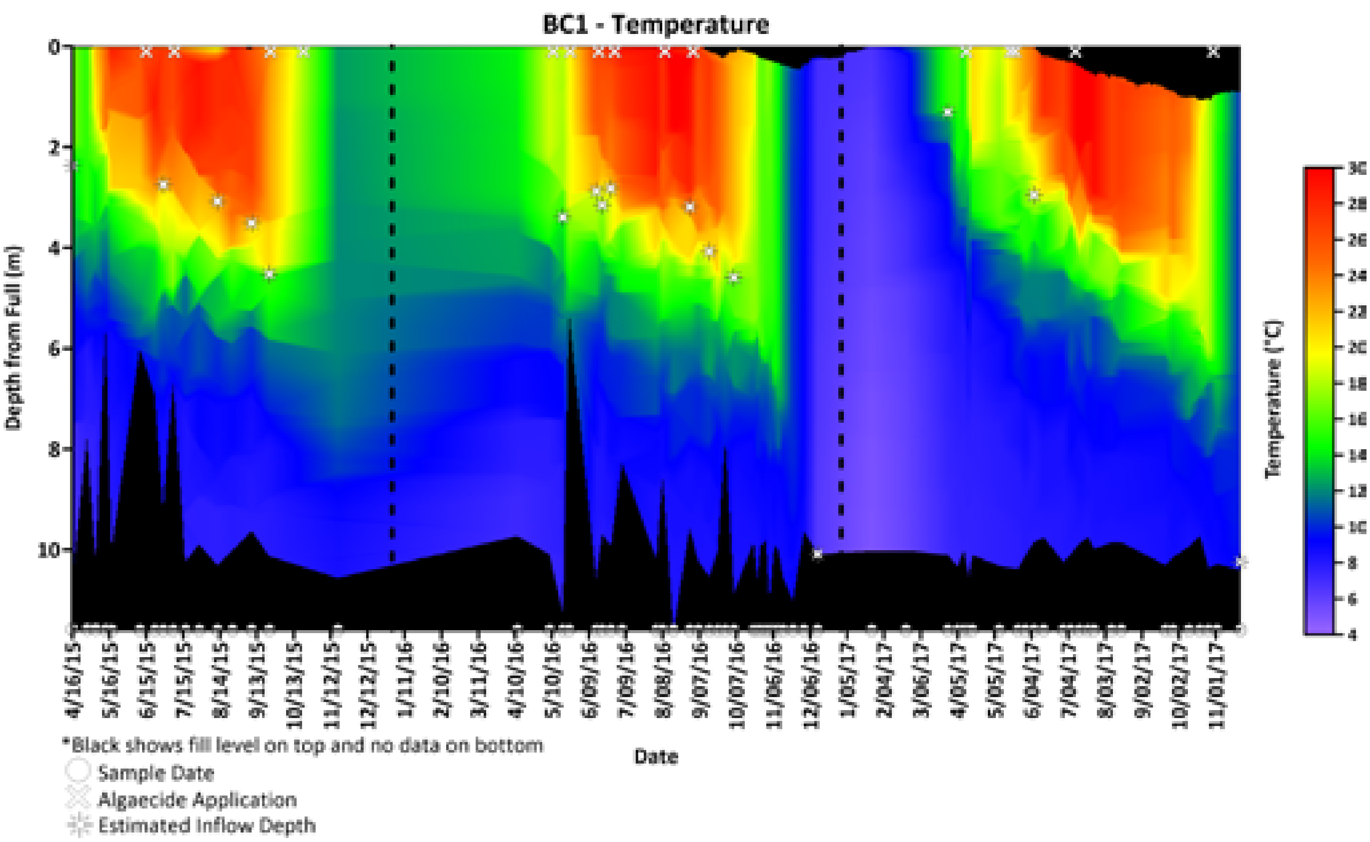
*Blue-green algae + Sample frozen

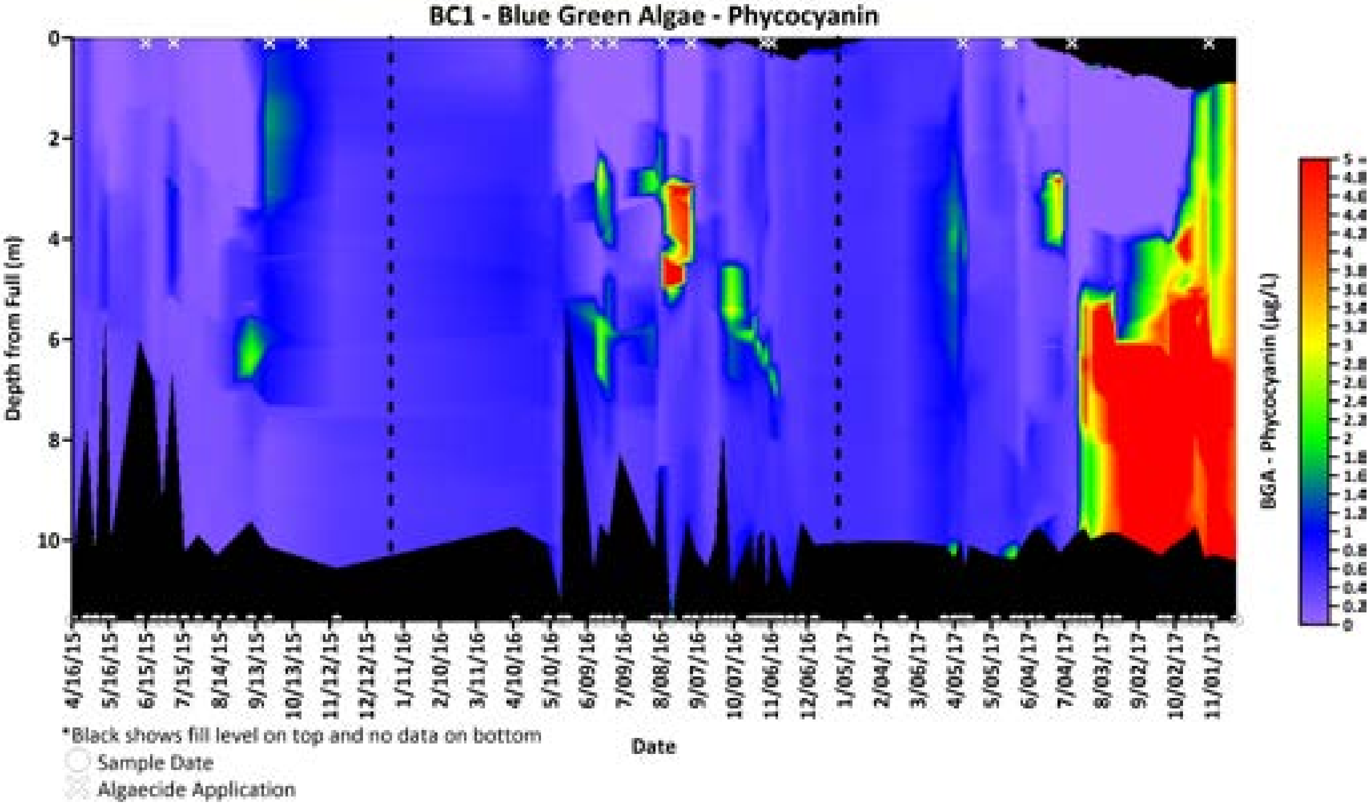
TC2 - S

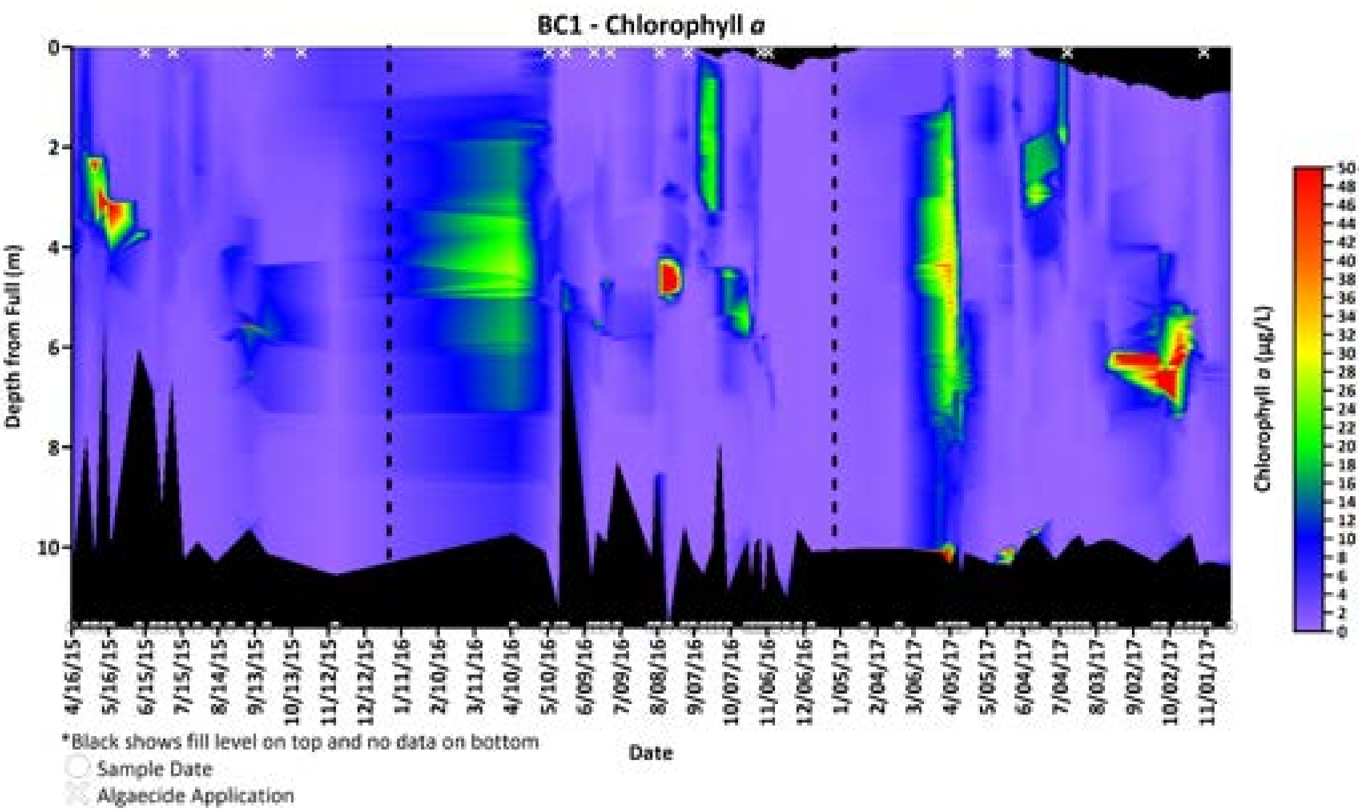
Date	8/18/15	9/1/15	9/23/15	10/22/15	11/23/15	6/27/16	7/13/16	8/23/16	10/21/16	4/19/17	5/11/17	8/17/17	9/28/17	10/19/17
Total Blue-Green Algae	**25,985**	**1,294**	**1,595**	**190**	**0**	**5,196**	**5,890**	**8,985**	**3,070**	**0**	**1,259**	**52,820**	**1,360**	**80**
Total Algae	**26,683**	**1,815**	**2,587**	**2,376**	**466**	**6,688**	**7,102**	**9,391**	**7,419**	**858**	**1,376**	**53,780**	**22,120**	**5,420**
Amphipleura	0	0	0	0	0	0	0	0	0	0	0	40	0	40
Anabaena*	2,070	0	0	0	0	3,868	483	0	10	0	1,035	5,900	1,280	40
Anacystis*	1,380	0	0	0	0	0	0	0	0	0	0	40	0	0
Ankistrodesmus	65	17	0	0	0	0	0	0	10	0	0	0	40	40
Aphanizomenon*	2,535	0	0	60	0	1,328	2,570	0	0	0	224	40	40	0
Aphanocapsa	0	0	0	0	0	0	0	0	1,120	0	0	40	6,400	40
Asterionella	0	0	0	0	0	0	0	0	0	95	0	0	0	0
Aulacoseira	0	0	0	0	0	0	0	0	640	0	0	40	40	400
Centritractus	0	52	17	0	0	0	0	0	0	0	0	0	0	0
Ceratium	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chlamydomonas	0	0	0	0	0	0	0	0	10	0	0	0	0	0
Chrysococcus	13	9	17	0	4	0	0	232	0	0	13	0	0	0
Closteridium	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Closteriopsis	9	0	34	0	0	0	0	0	0	0	0	0	0	0
Coelastrum	69	0	34	0	0	0	0	0	0	0	0	40	0	0
Coelosphaerium*	0	0	0	0	0	0	0	0	0	0	0	6,400	0	0
Coenochloris	0	0	0	0	0	0	0	0	0	0	0	40	0	0
Cosmarium	0	0	0	0	0	0	0	0	0	0	0	0	0	40
Crucigenia	69	0	0	69	0	0	0	0	1,100	0	0	40	40	40
Cryptomonas	0	0	0	0	0	0	0	0	168	0	0	0	40	0
Cuspidothrix	0	0	0	0	0	0	0	0	10	0	0	0	0	0
Cyclotella	0	0	0	0	0	0	0	0	0	0	0	0	160	200
Cylindrospermopsis	0	0	0	0	0	0	0	0	0	0	0	0	2,800	4,100
Cymbella	0	0	0	0	0	0	0	0	0	0	0	0	0	40
Dictyosphaerium	0	0	224	0	0	0	0	0	0	0	0	40	0	0
Didymocystis	0	0	0	0	0	0	0	0	0	0	0	0	40	0
Dinobryon	0	43	52	0	65	789	246	0	0	17	0	0	40	0
Elakatothrix	0	0	0	0	0	0	0	0	0	0	0	40	0	0
Errerella	0	0	0	259	0	0	0	0	0	0	0	0	0	0
Euglena	17	9	9	4	0	0	82	0	46	9	9	40	0	40
Fragilaria	47	125	60	319	26	0	0	0	0	0	0	0	0	0
Gloeocystis	0	0	0	276	52	0	0	0	0	0	0	0	0	0
Golenkinia	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gonium	0	0	0	0	0	138	0	0	0	0	0	0	0	0
Gonyostomum	0	0	0	0	0	0	0	0	10	0	0	0	40	0
Gymnodinium	22	9	13	0	4	0	0	0	0	0	0	0	0	0
Kirchneriella	0	0	0	13	0	0	0	0	0	0	0	40	0	0
Lyngbya*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mallomonas	4	22	0	17	17	0	0	0	10	0	26	0	40	0
Melosira	293	108	310	936	259	405	642	0	0	371	65	0	0	0
Merismopedia*	0	0	0	0	0	0	0	0	10	0	0	38,400	0	0
Microcystis*	0	0	0	0	0	0	0	0	0	0	0	0	0	40
Monoraphidium	0	0	0	0	0	0	0	0	10	0	0	40	0	40
Oocystis	0	0	0	17	0	0	0	0	10	0	0	0	0	0
Oscillatoria*	20,000	1,294	1,595	129	0	0	2,837	8,985	10	0	0	40	0	0
Pandorina	0	0	0	34	0	0	0	0	0	0	0	0	0	0
Pediastrum	0	108	164	34	0	0	190	0	10	0	0	40	480	40
Phacus	0	0	0	0	0	0	0	0	0	0	0	40	0	40
Planktolyngbya	0	0	0	0	0	0	0	0	0	0	0	0	10,400	0
Pseudanabaena*	0	0	0	0	0	0	0	0	3,040	0	0	2,000	40	40
Scenedesmus	69	0	0	155	0	86	52	0	960	34	0	40	40	40
Sphaerocystis	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Staurastrum	9	9	9	17	0	0	0	0	10	0	0	40	40	40
Synedra	0	0	0	30	4	73	0	174	25	332	4	200	40	40
Synura	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetraedon	0	0	0	0	0	0	0	0	0	0	0	40	40	0
Tetrallantos	0	0	0	0	0	0	0	0	20	0	0	0	0	0
Tetraspora	0	0	0	0	0	0	0	0	0	0	0	40	0	0
Trachelomonas	13	13	4	4	0	0	0	0	180	0	0	40	40	40
Treubaria	0	0	0	0	0	0	0	0	0	0	0	40	0	40
Ulothrix	0	0	43	0	34	0	0	0	0	0	0	0	0	0

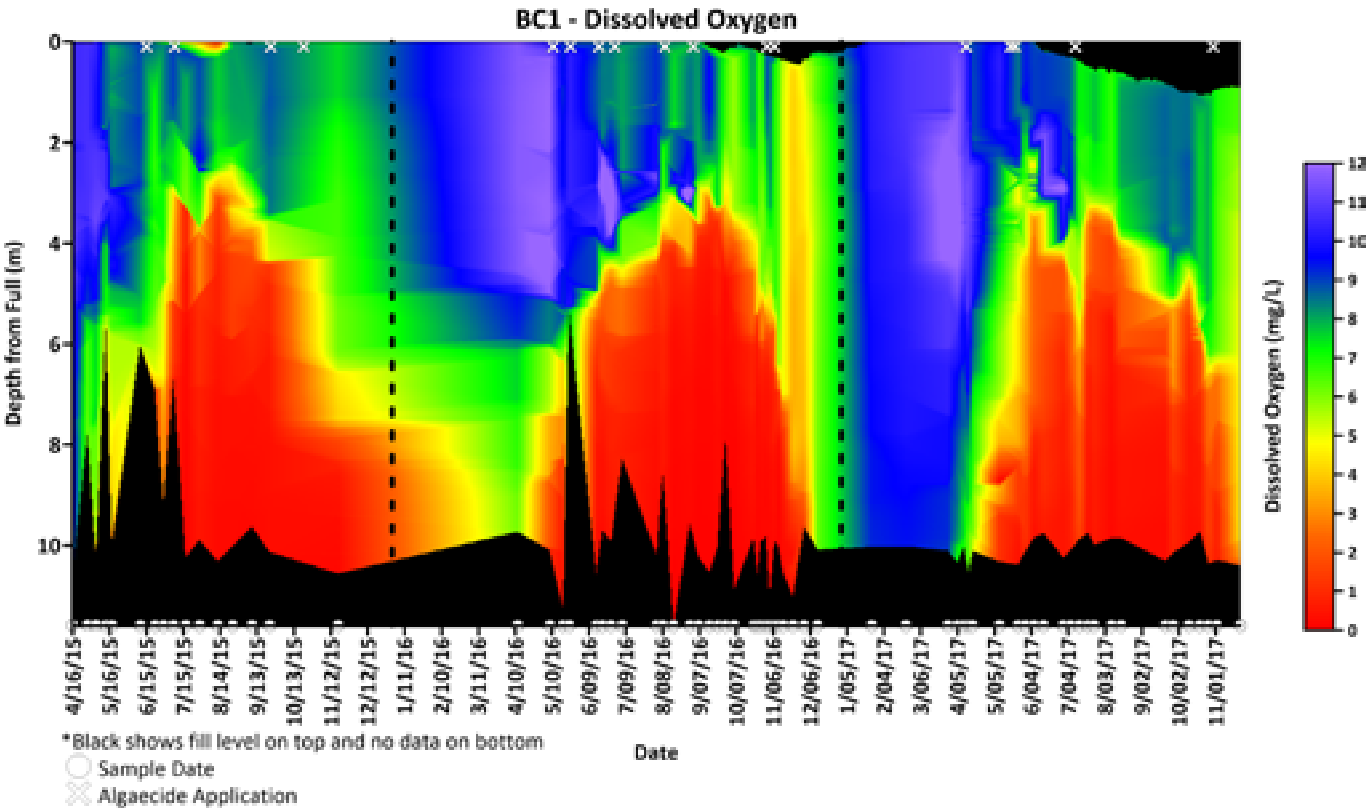
All numbers are in cells/1 mL *Blue-green algae + Sample frozen

Appendix G: Image Plots of Sonde Data

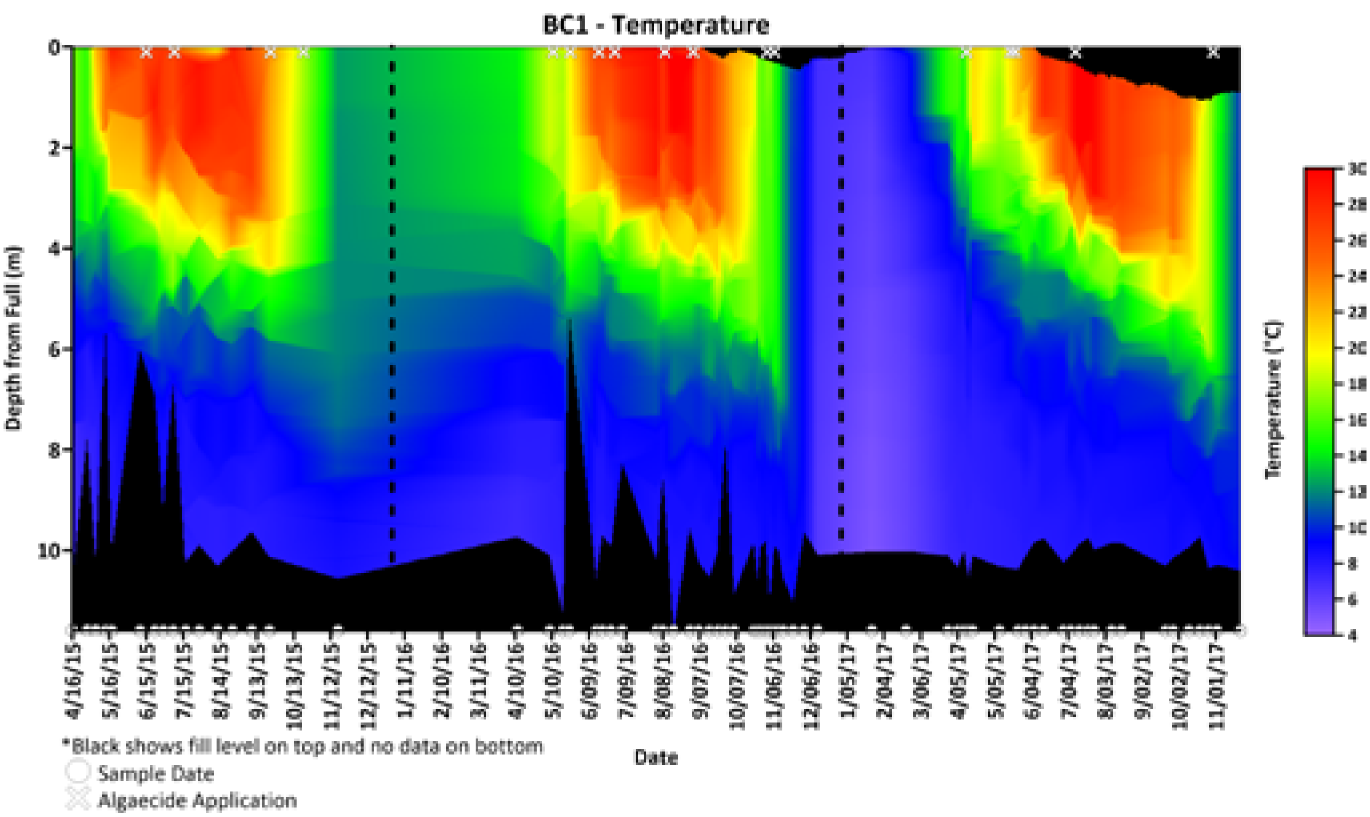



BC1 - Blue Green Algae - Phycocyanin
Depth from Full (m)
BGA - Phycocyanin (µg/L)
Date
*Black shows fill level on top and no data on bottom
Sample Date
Algaecide Application


BC1 - Chlorophyll *a*
Depth from Full (m)
Chlorophyll *a* (µg/L)
Date
*Black shows fill level on top and no data on bottom
Sample Date
Algaecide Application

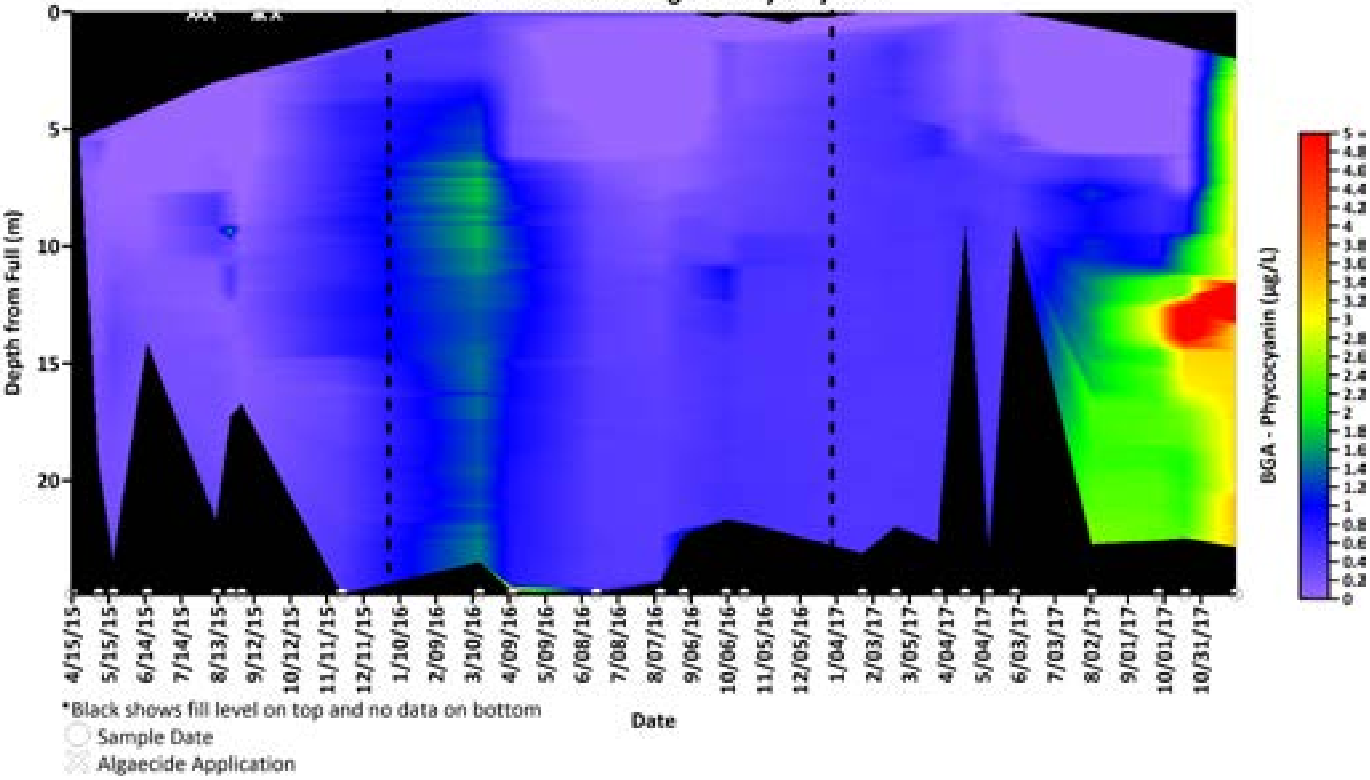


BC1 - Dissolved Oxygen
Depth from Full (m)
Dissolved Oxygen (mg/L)
Date
*Black shows fill level on top and no data on bottom
Sample Date
Algaecide Application

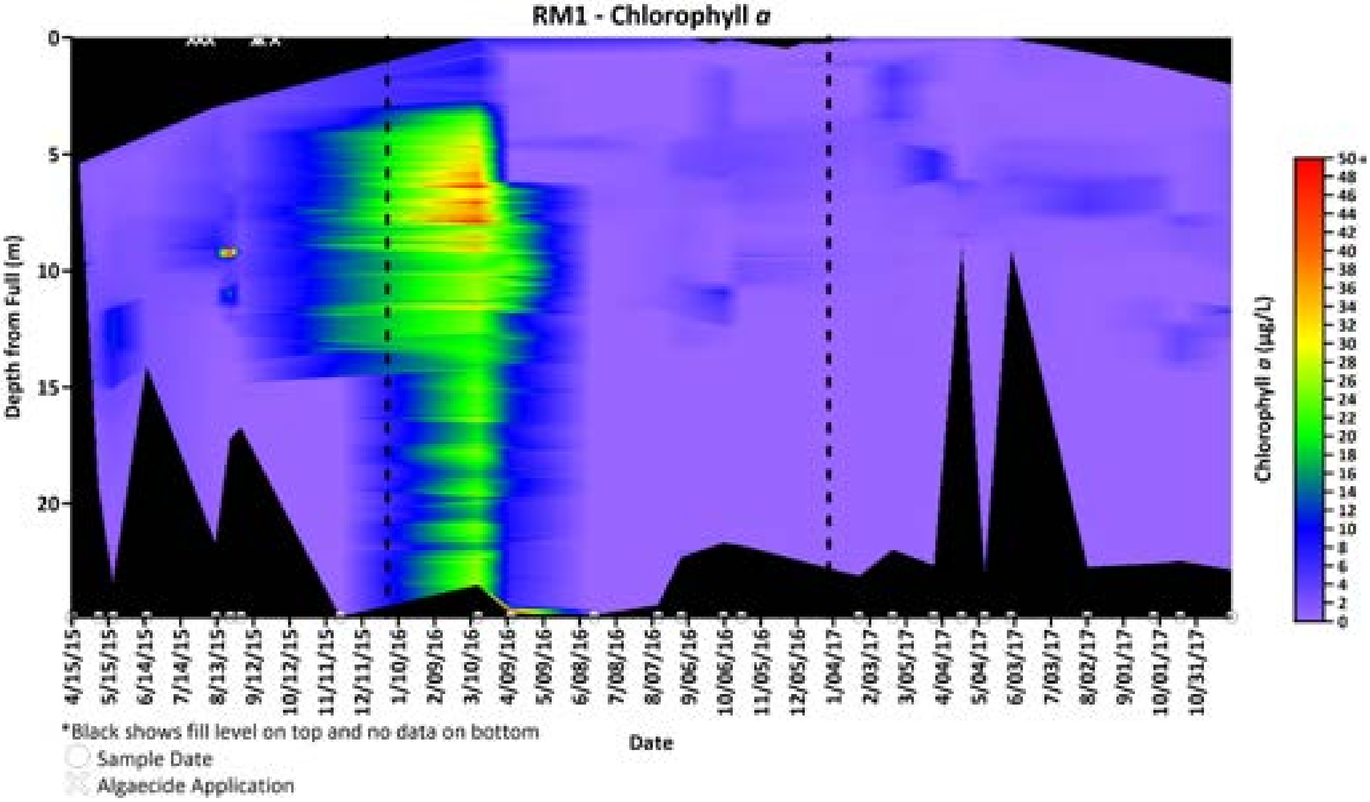


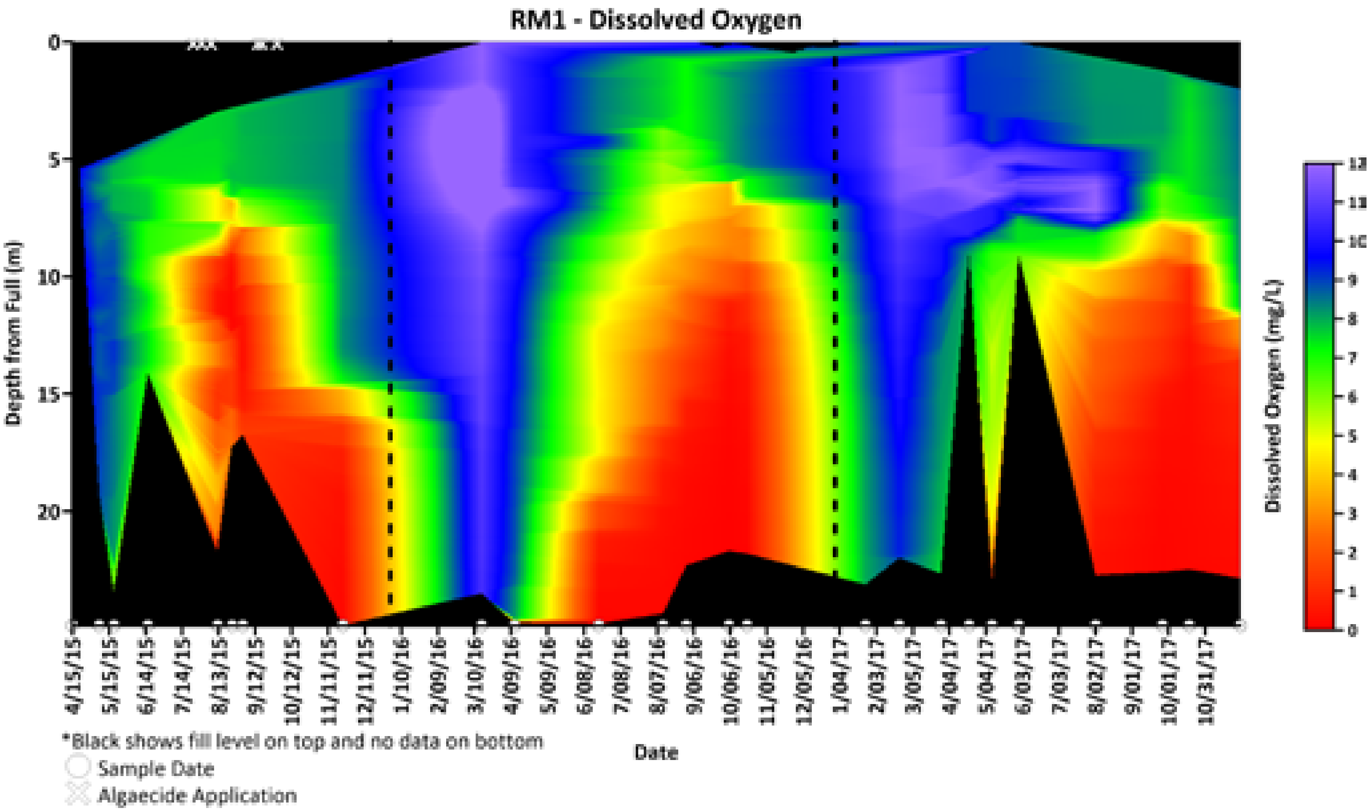
BC1 - Temperature
Depth from Full (m)
Temperature (°C)
Date
*Black shows fill level on top and no data on bottom
Sample Date
Algaecide Application

RM1 - Blue Green Algae - Phycocyanin

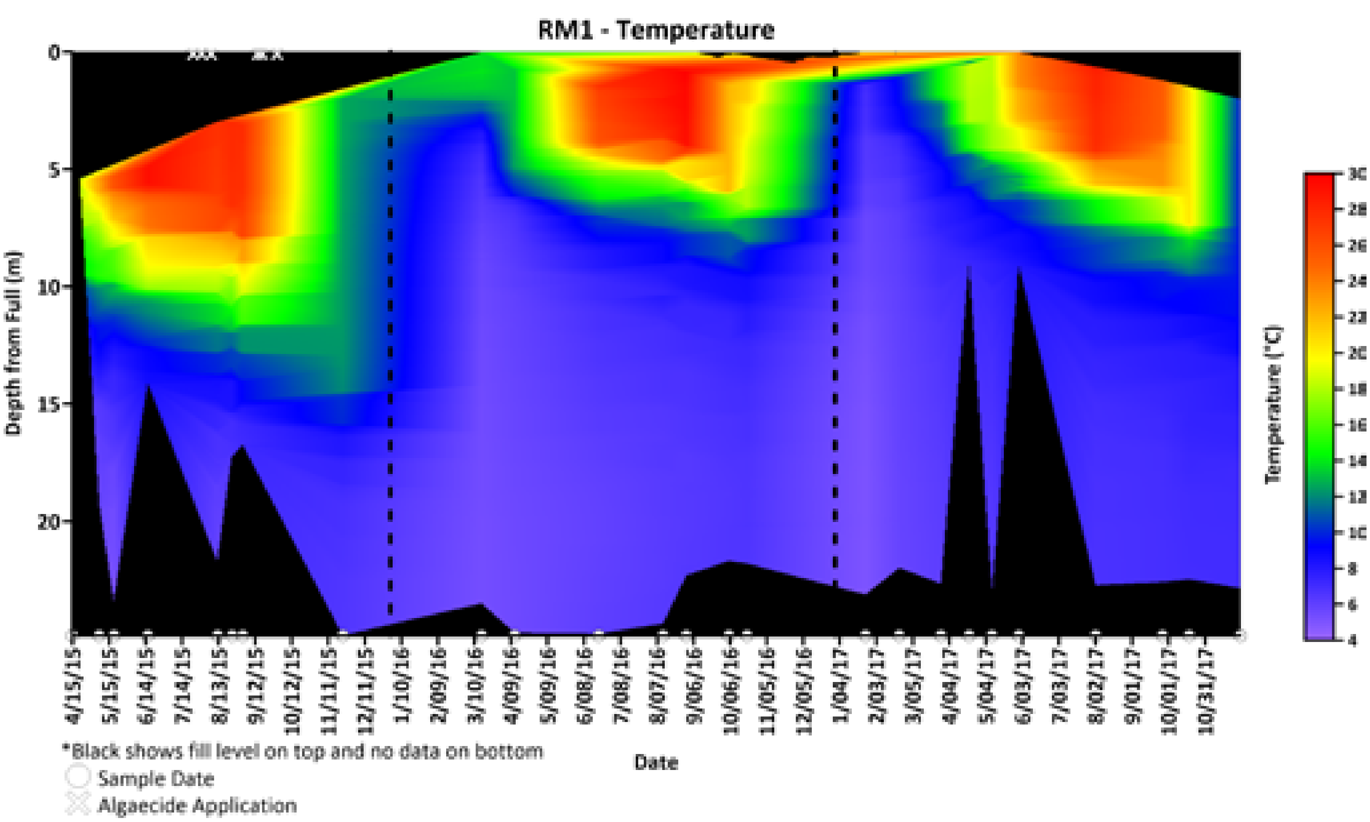


RM1 - Chlorophyll *a*

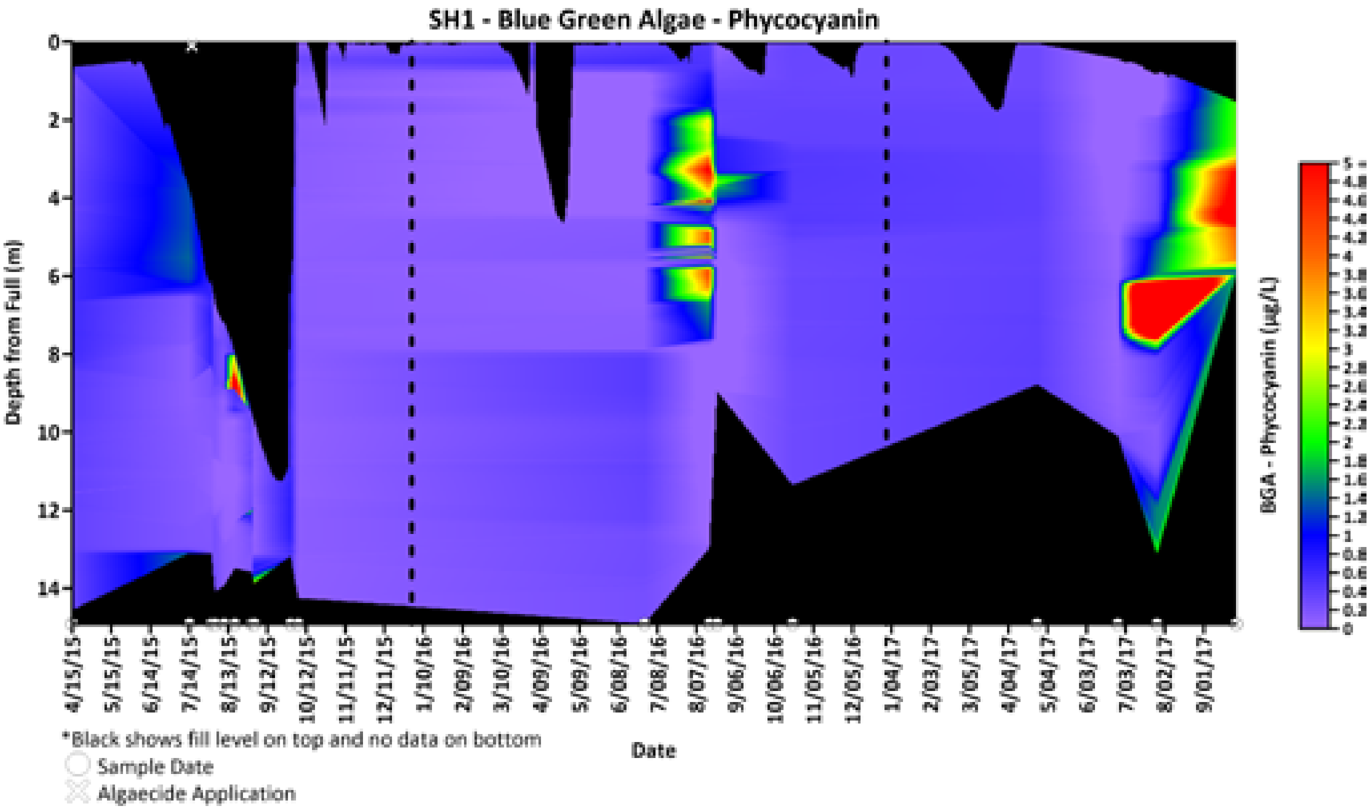




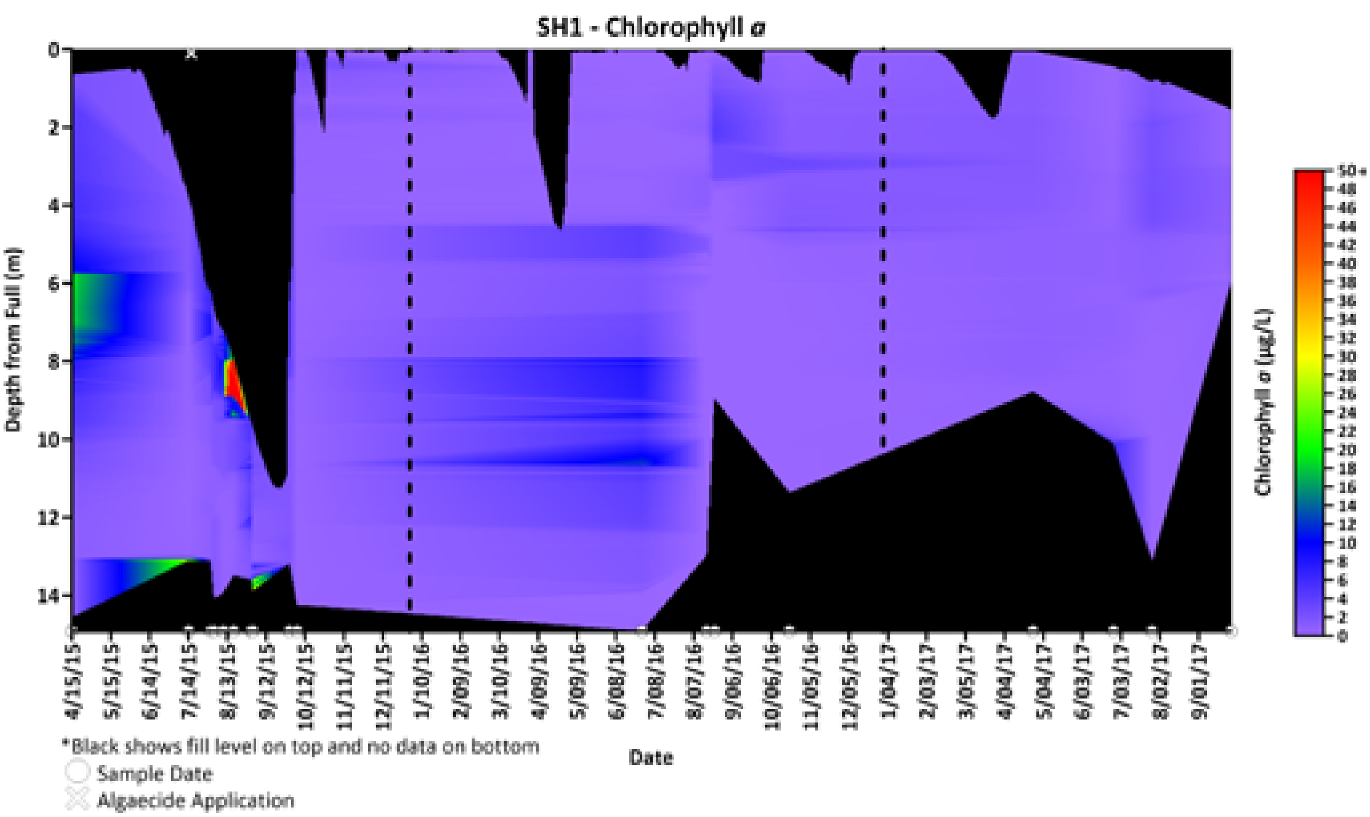
RM1 - Dissolved Oxygen
Depth from Full (m)
Dissolved Oxygen (mg/L)
Date
*Black shows fill level on top and no data on bottom
Sample Date
Algaecide Application



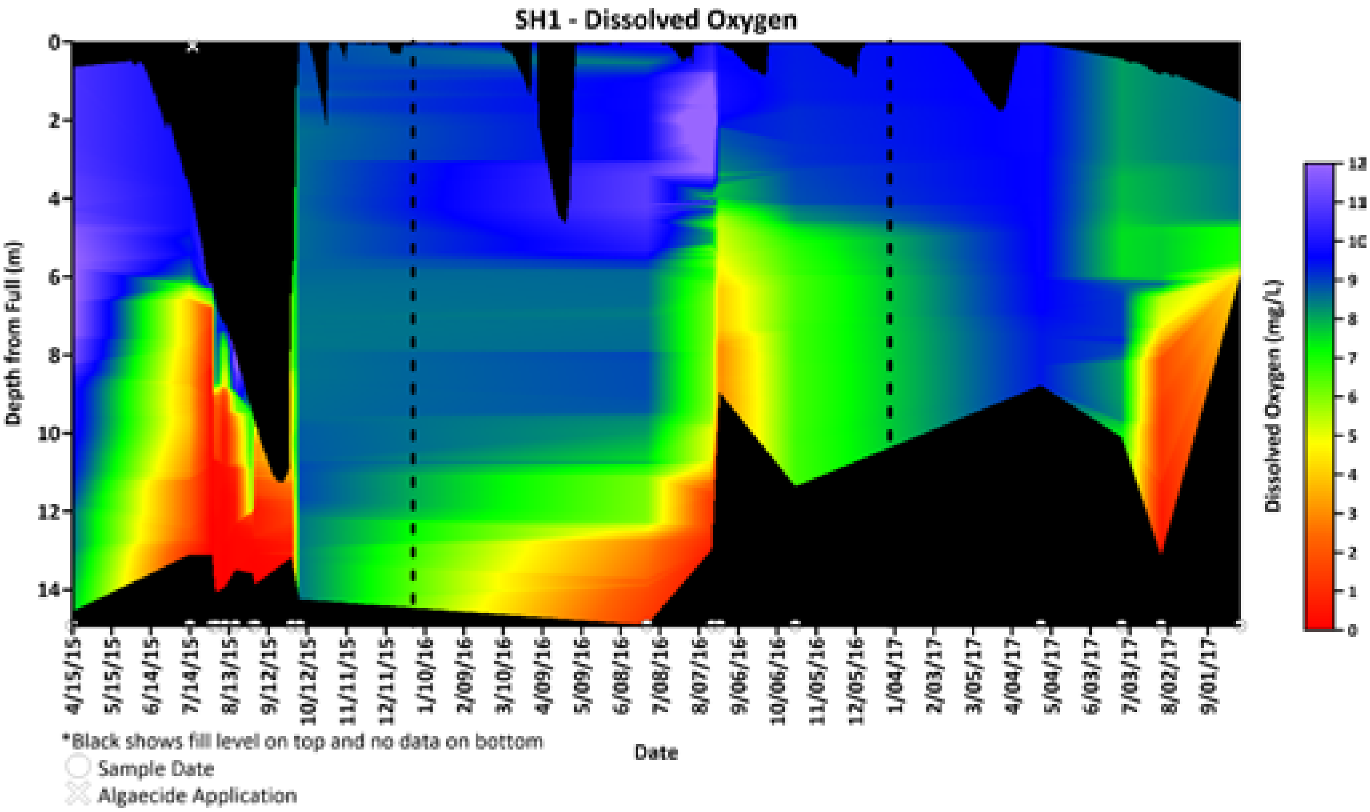
RM1 - Temperature
Depth from Full (m)
Temperature (°C)
Date
*Black shows fill level on top and no data on bottom
Sample Date
Algaecide Application



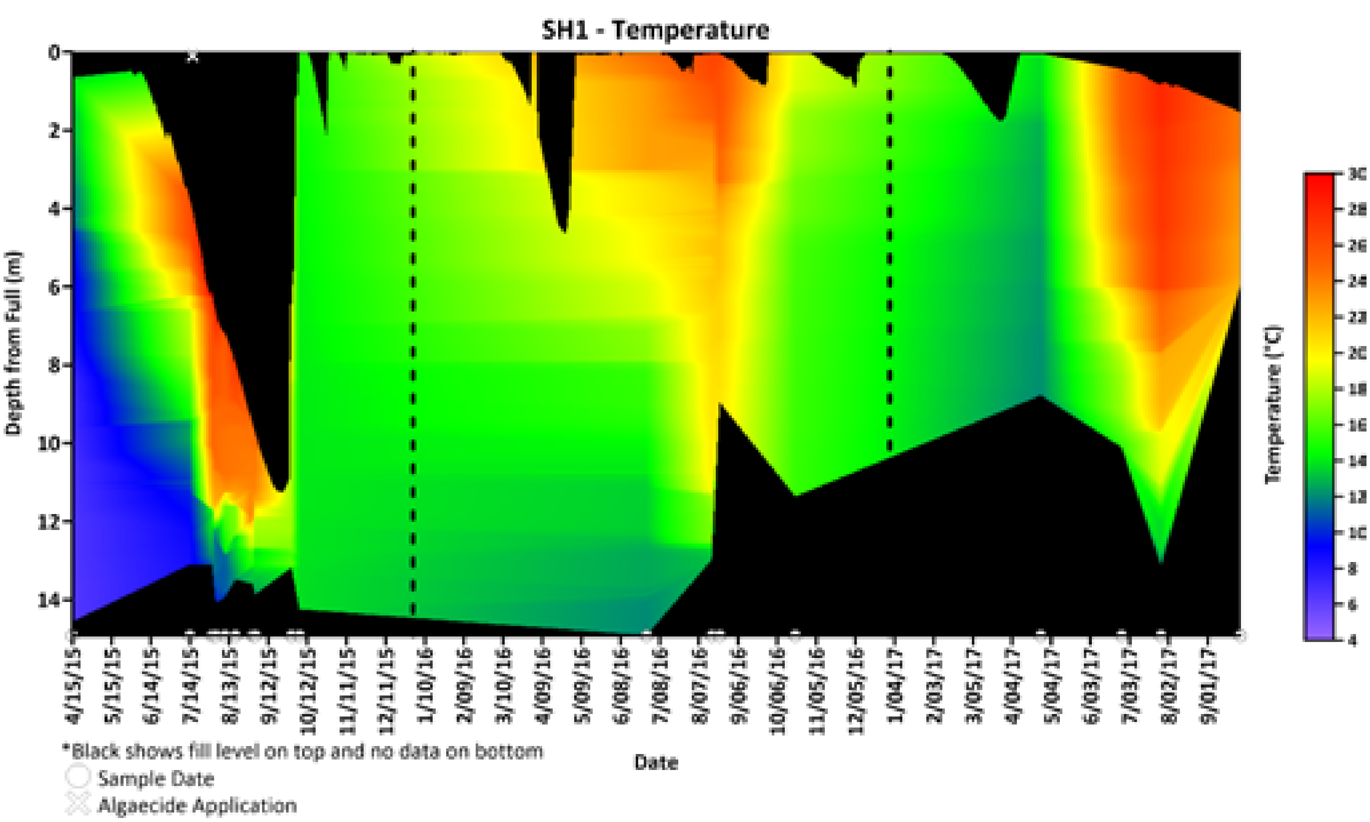
SH1 - Blue Green Algae - Phycocyanin
Depth from Full (m)
Date
BGA - Phycocyanin (µg/L)
*Black shows fill level on top and no data on bottom
Sample Date
Algaecide Application



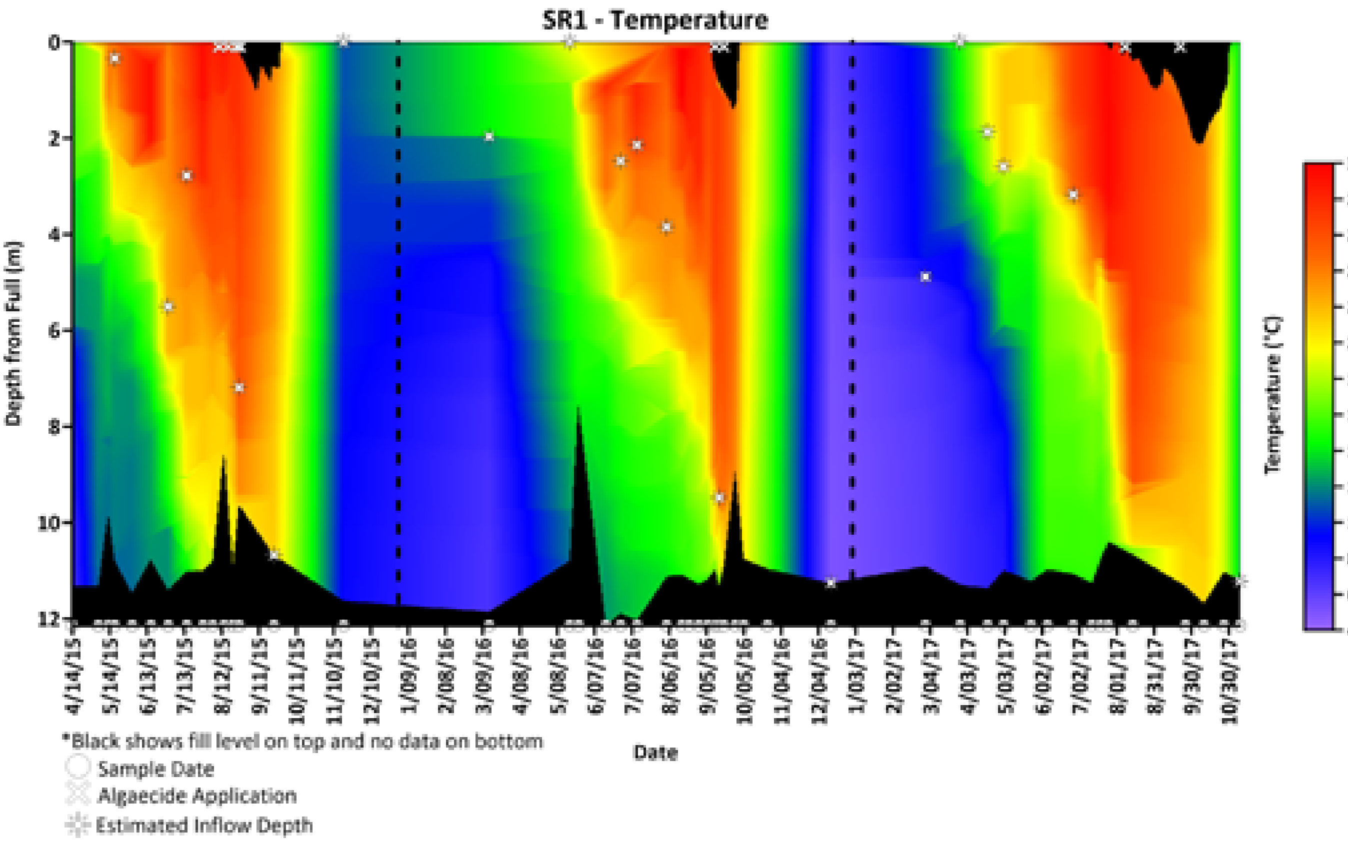
SH1 - Chlorophyll *a*
Depth from Full (m)
Date
Chlorophyll *a* (µg/L)
*Black shows fill level on top and no data on bottom
Sample Date
Algaecide Application

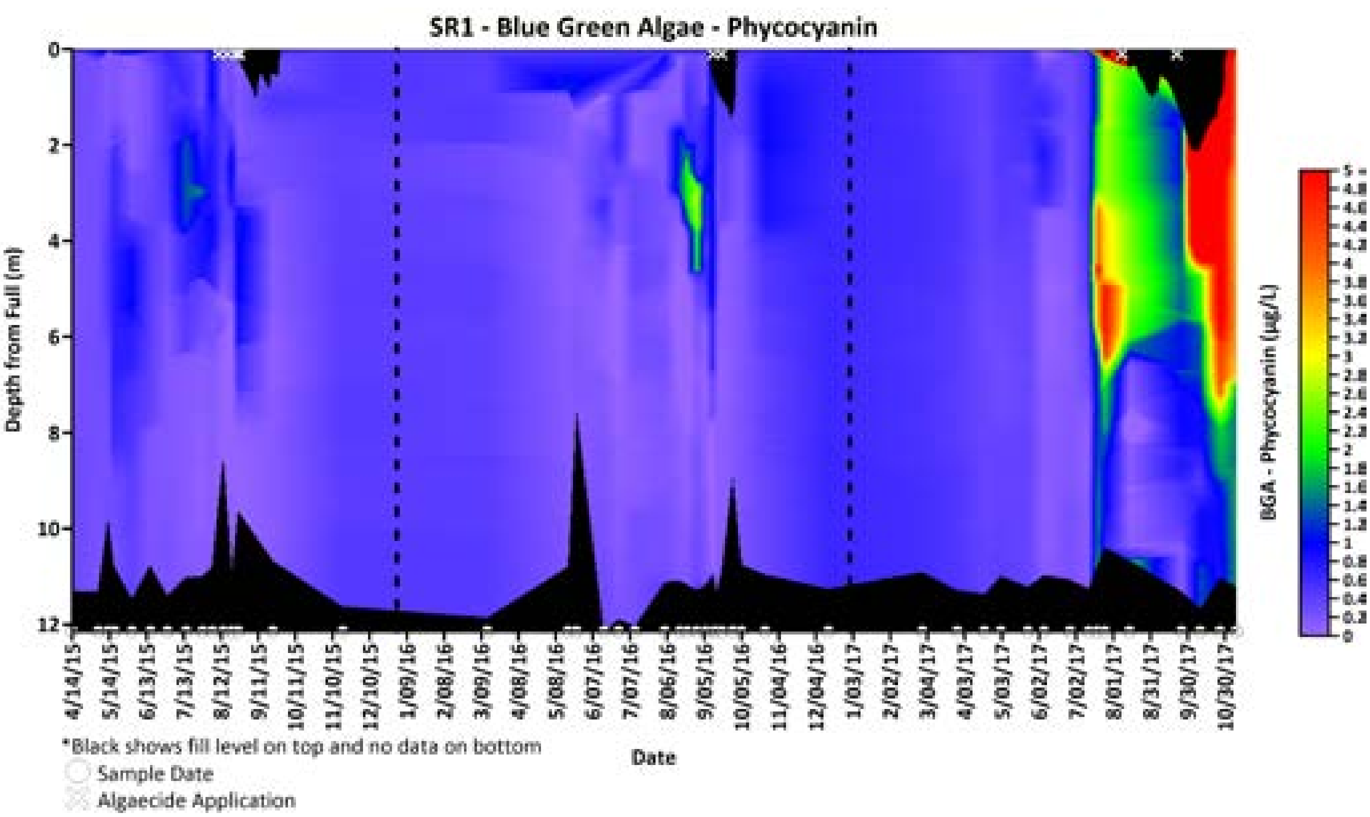


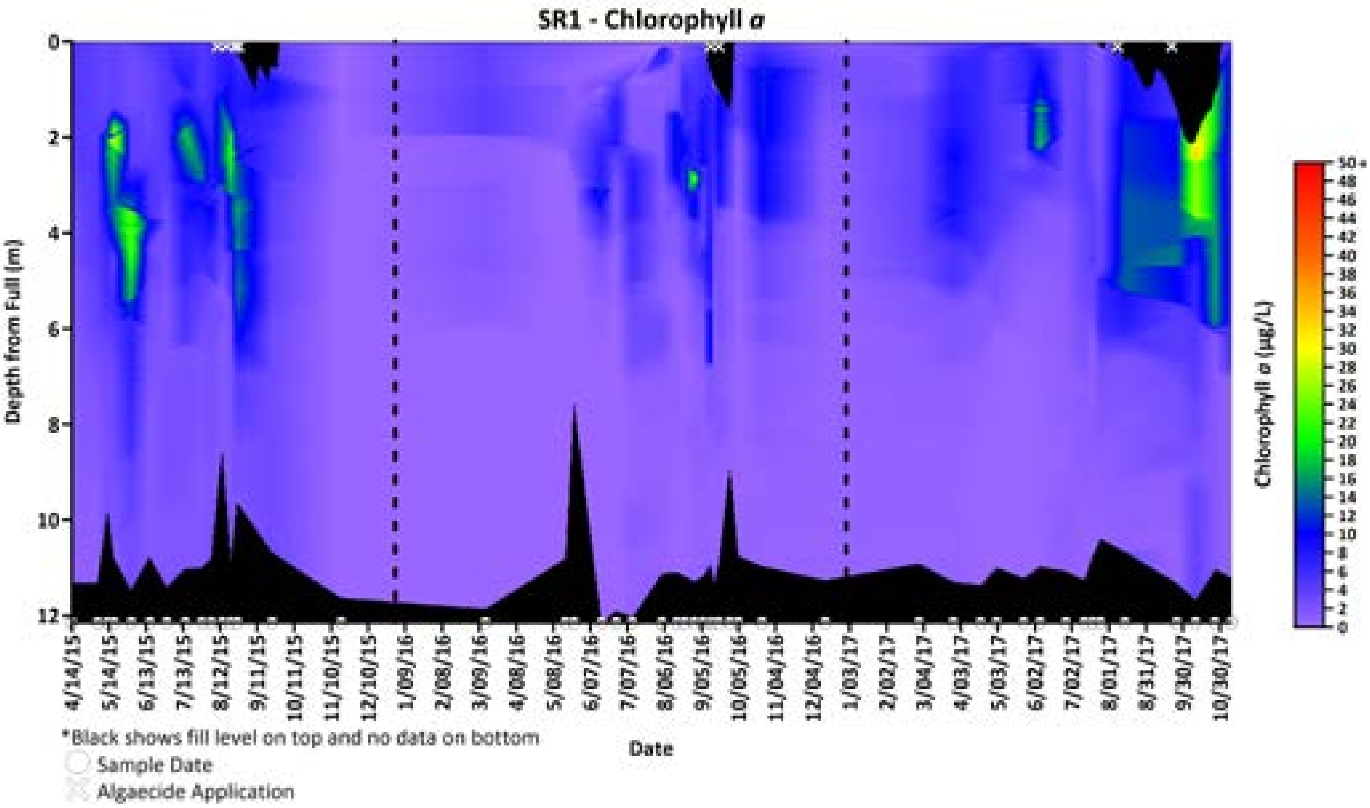
SH1 - Dissolved Oxygen
Depth from Full (m)
Dissolved Oxygen (mg/L)
Date
*Black shows fill level on top and no data on bottom
Sample Date
Algaecide Application



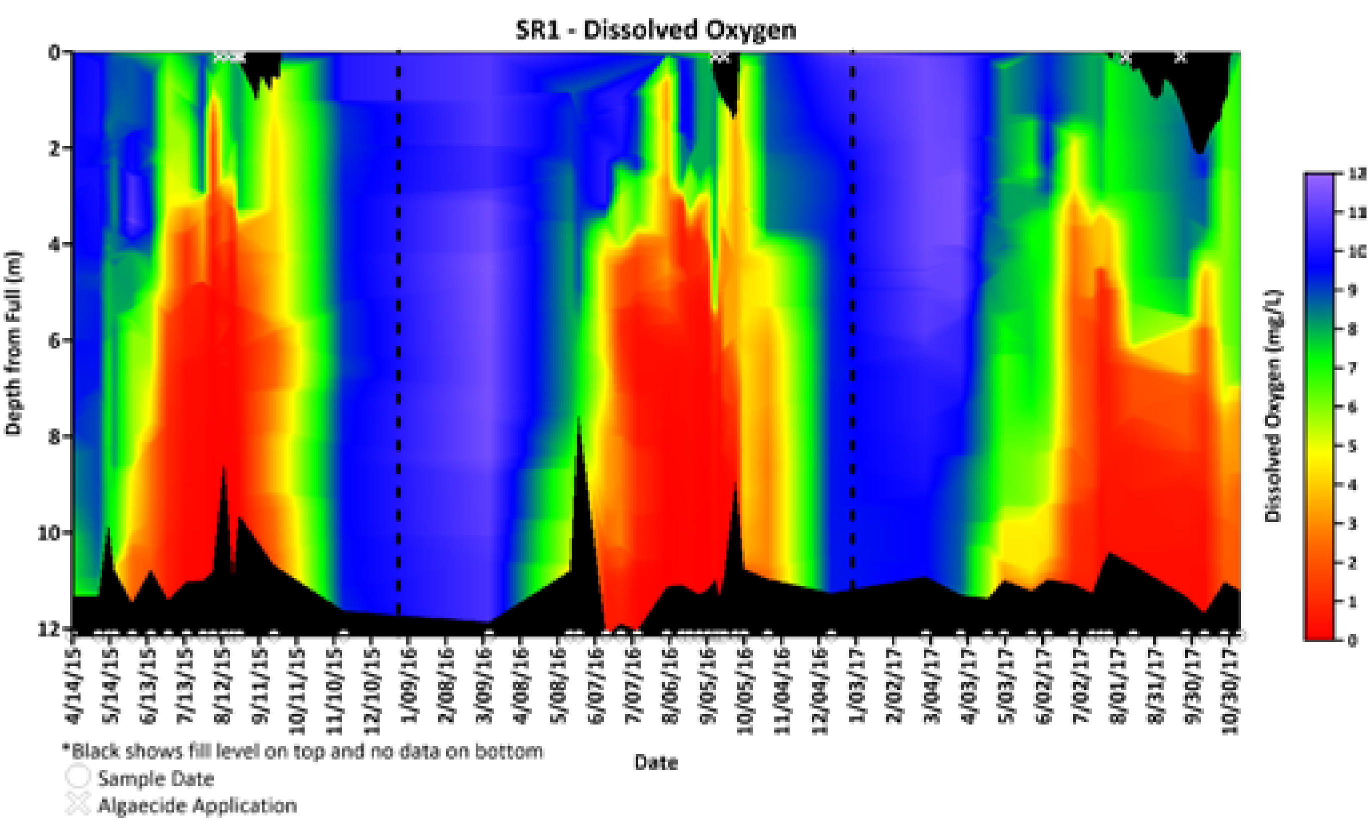
SH1 - Temperature
Depth from Full (m)
Temperature (°C)
Date
*Black shows fill level on top and no data on bottom
Sample Date
Algaecide Application


SR1 - Temperature
Depth from Full (m)
Temperature (°C)
Date
*Black shows fill level on top and no data on bottom
Sample Date
Algaecide Application
Estimated Inflow Depth

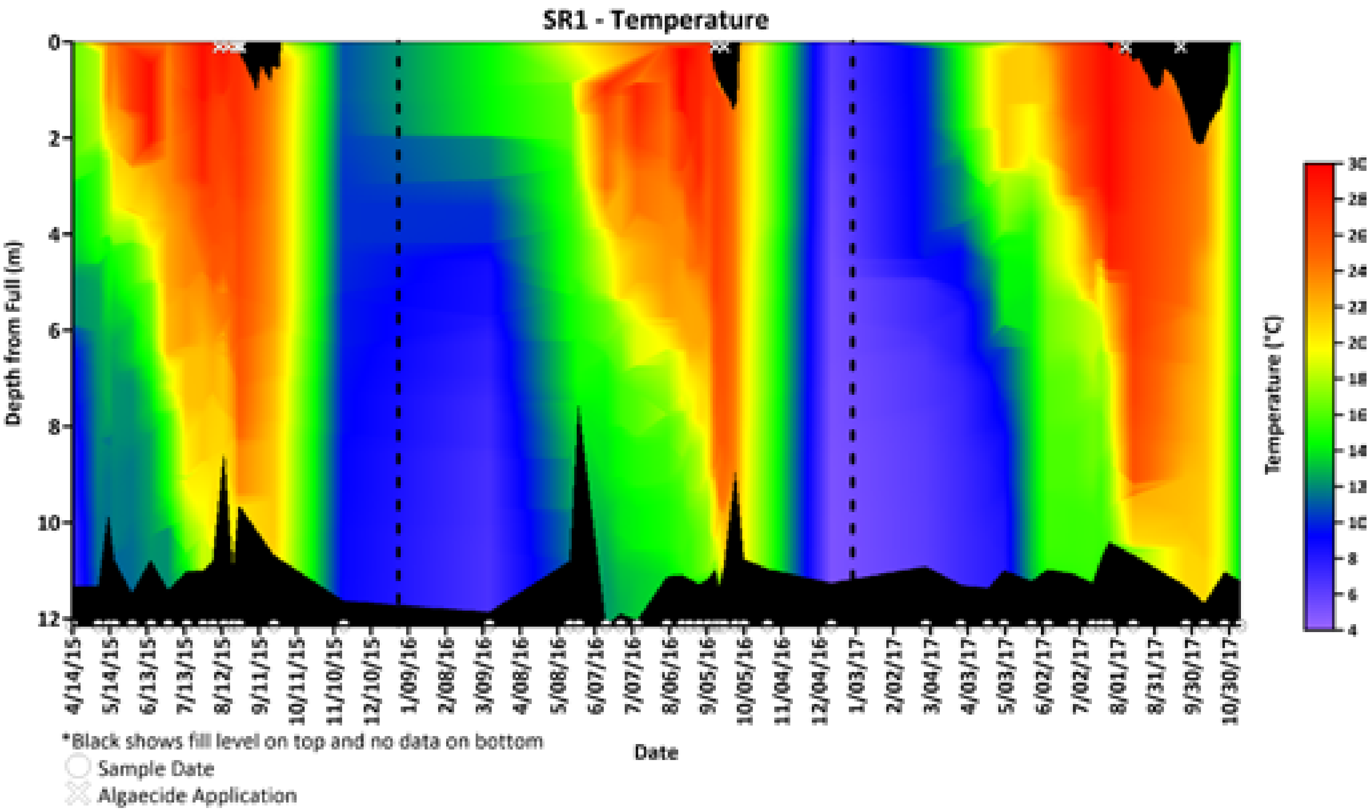

SR1 - Blue Green Algae - Phycocyanin
Depth from Full (m)
BGA - Phycocyanin (µg/L)
Date
*Black shows fill level on top and no data on bottom
Sample Date
Algaecide Application



SR1 - Chlorophyll a
Depth from Full (m)
Date
Chlorophyll a (µg/L)
*Black shows fill level on top and no data on bottom
Sample Date
Algaecide Application



SR1 - Dissolved Oxygen
Depth from Full (m)
Date
Dissolved Oxygen (mg/L)
*Black shows fill level on top and no data on bottom
Sample Date
Algaecide Application


SR1 - Temperature
Depth from Full (m)
Temperature (°C)
Date
4/14/15
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6/13/15
7/13/15
8/12/15
9/11/15
10/11/15
11/10/15
12/10/15
1/09/16
2/08/16
3/09/16
4/08/16
5/08/16
6/07/16
7/07/16
8/06/16
9/05/16
10/05/16
11/04/16
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1/03/17
2/02/17
3/04/17
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5/03/17
6/02/17
7/02/17
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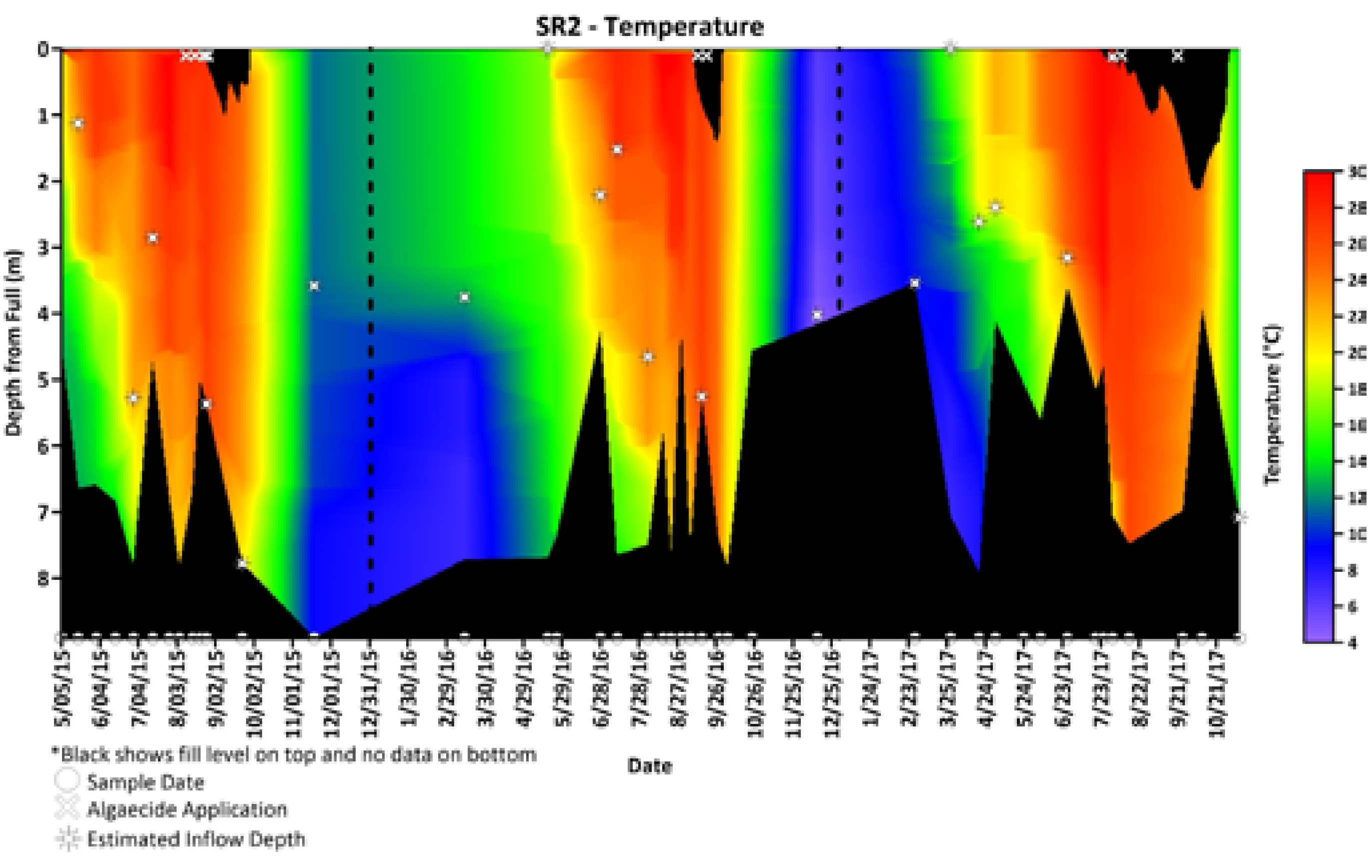
8/31/17
9/30/17
10/30/17
*Black shows fill level on top and no data on bottom
Sample Date
Algaecide Application


SR2 - Temperature
Depth from Full (m)
Temperature (°C)
Date
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6/04/15
7/04/15
8/03/15
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10/02/15
11/01/15
12/01/15
12/31/15
1/30/16
2/29/16
3/30/16
4/29/16
5/29/16
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7/28/16
8/27/16
9/26/16
10/26/16
11/25/16
12/25/16
1/24/17
2/23/17
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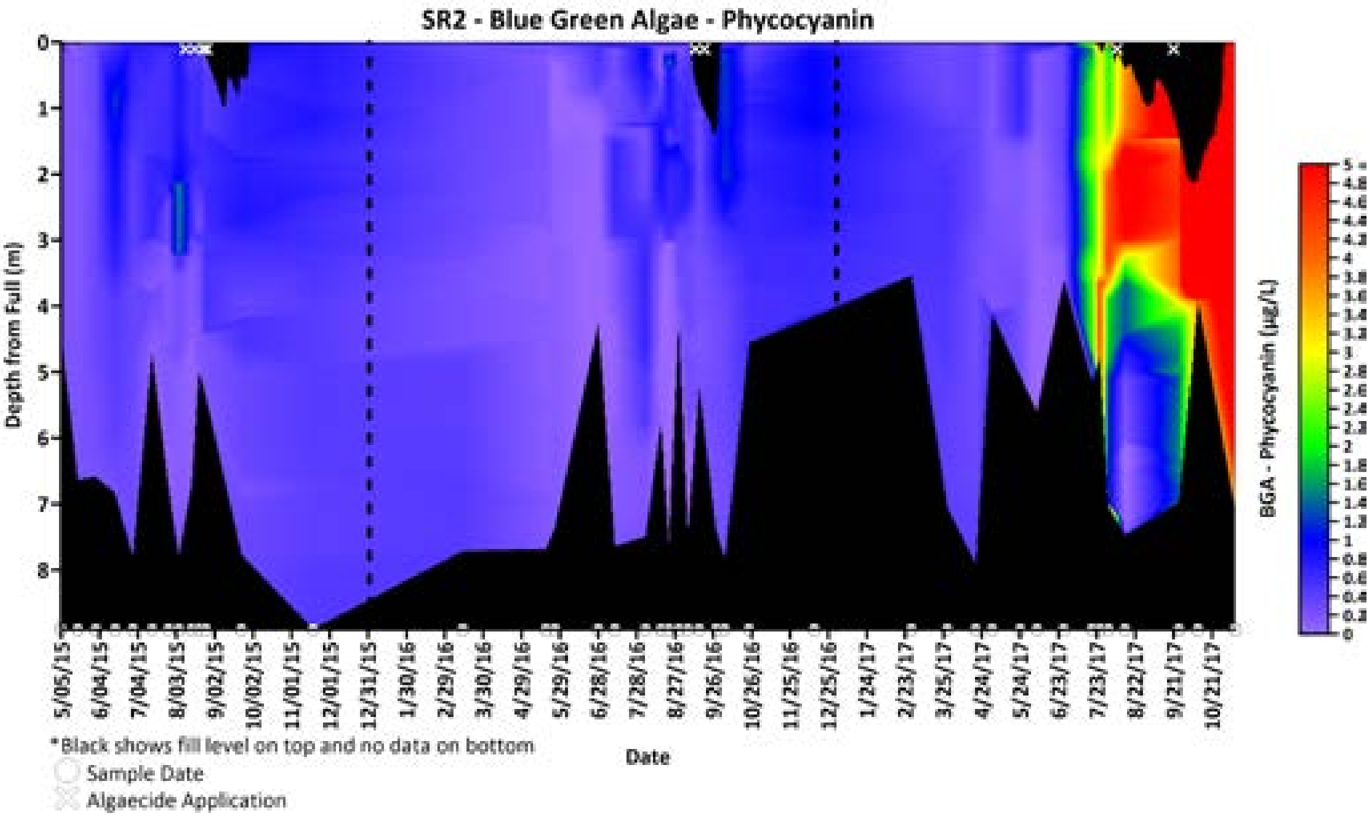
4/24/17
5/24/17
6/23/17
7/23/17
8/22/17
9/21/17
10/21/17
*Black shows fill level on top and no data on bottom
Sample Date
Algaecide Application
Estimated Inflow Depth



SR2 - Blue Green Algae - Phycocyanin
Depth from Full (m)
BGA - Phycocyanin (µg/L)
Date
5/05/15
6/04/15
7/04/15
8/03/15
9/02/15
10/02/15
11/01/15
12/01/15
12/31/15
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2/29/16
3/30/16
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7/28/16
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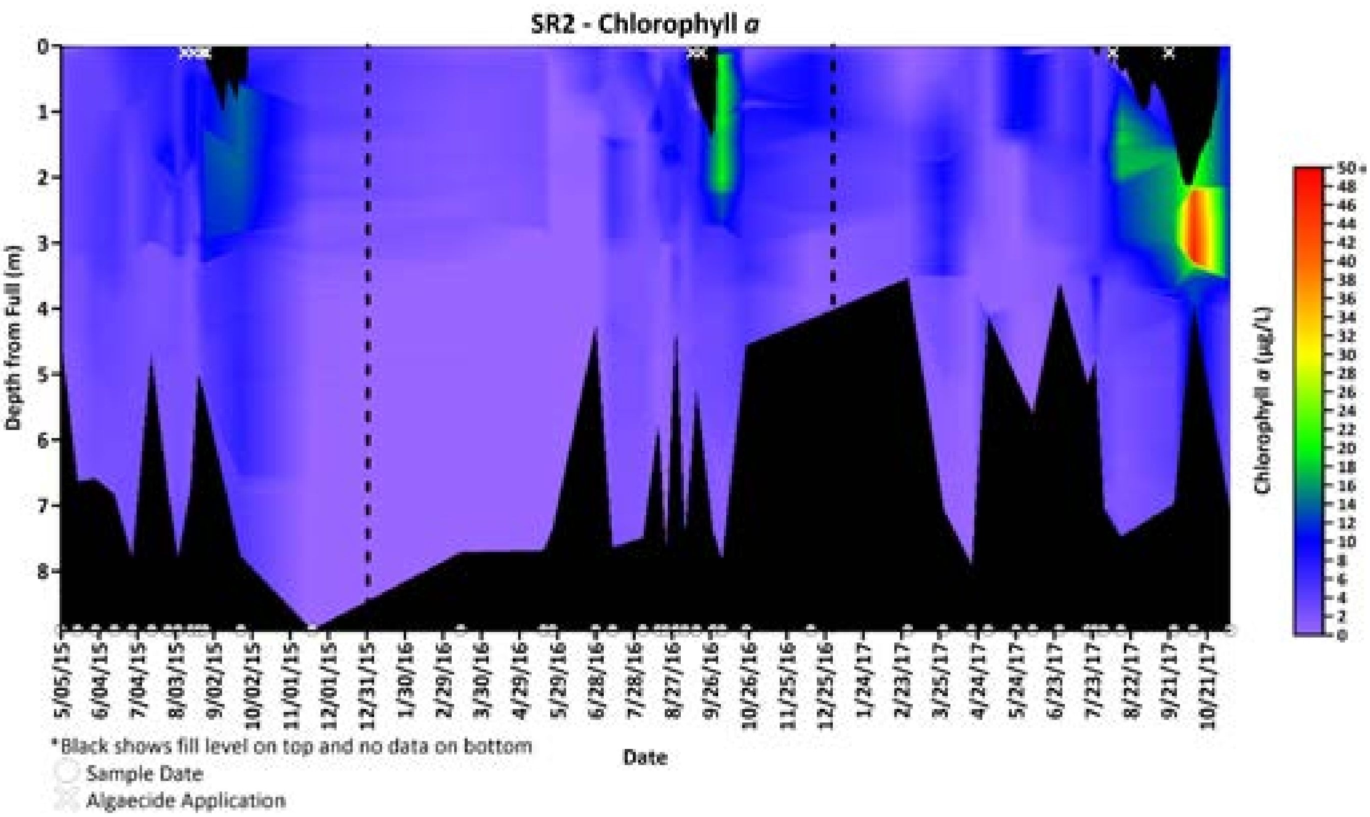
4/24/17
5/24/17
6/23/17
7/23/17
8/22/17
9/21/17
10/21/17
*Black shows fill level on top and no data on bottom
Sample Date
Algaecide Application



SR2 - Chlorophyll *a*
Depth from Full (m)
Chlorophyll *a* (µg/L)
Date
5/05/15
6/04/15
7/04/15
8/03/15
9/02/15
10/02/15
11/01/15
12/01/15
12/31/15
1/30/16
2/29/16
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4/24/17
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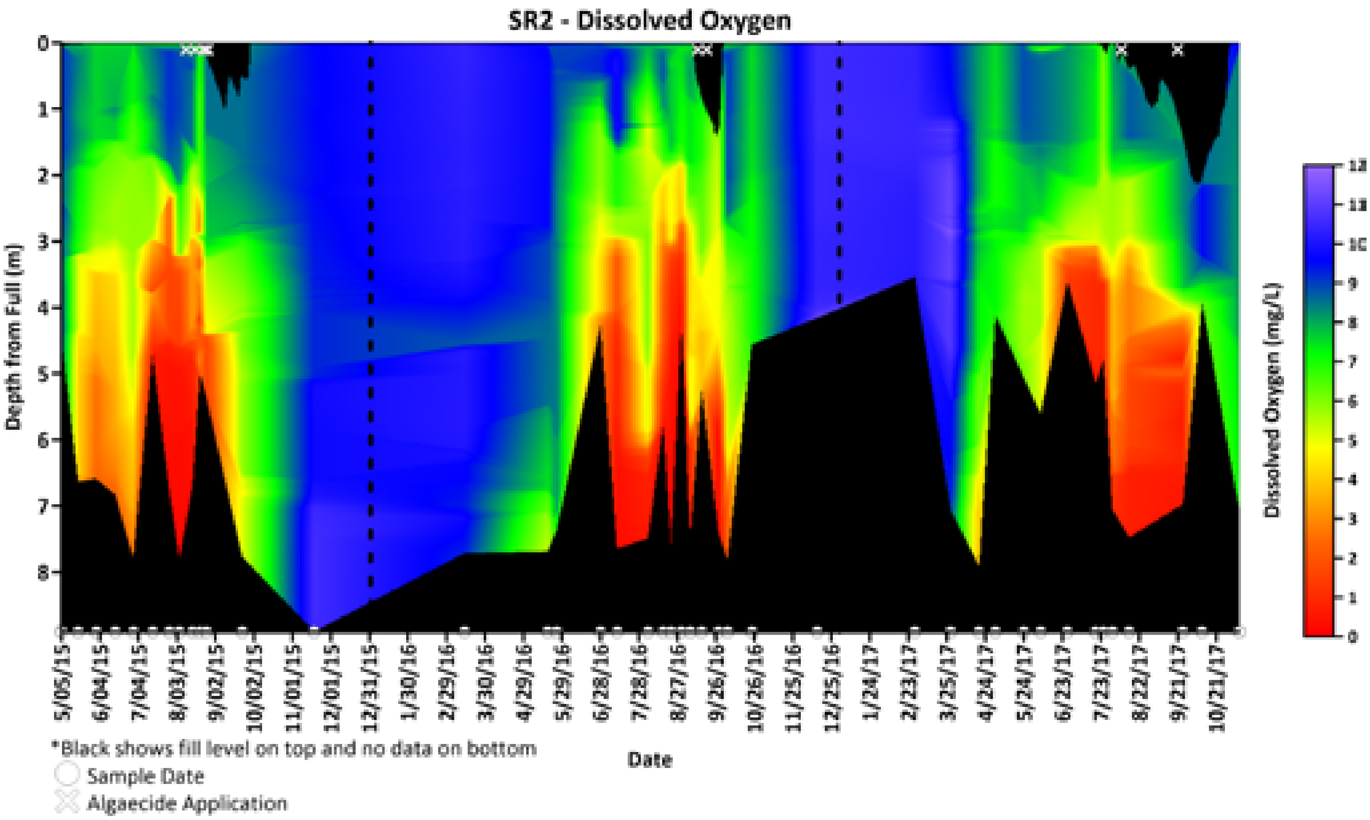
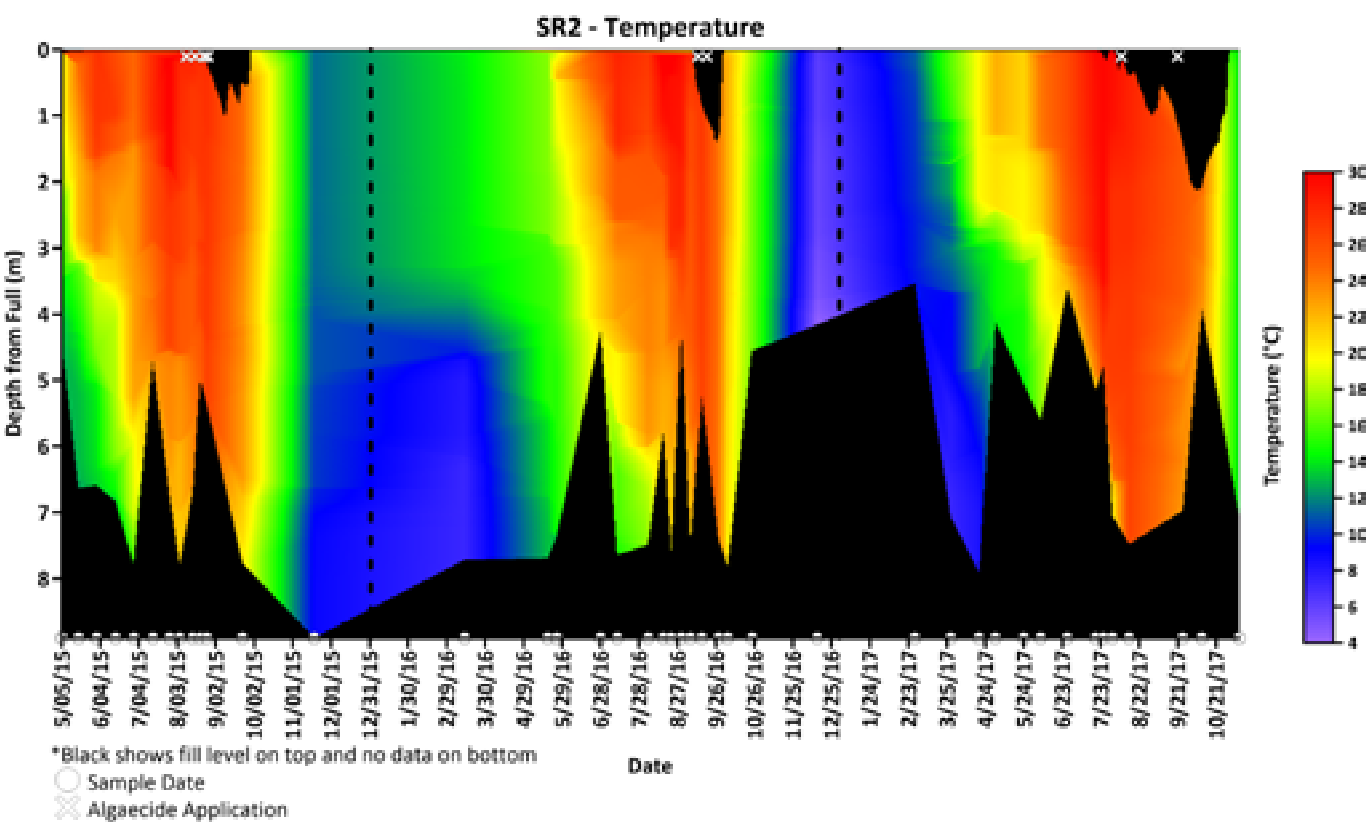
9/21/17
10/21/17
*Black shows fill level on top and no data on bottom
Sample Date
Algaecide Application


SR2 - Dissolved Oxygen
Depth from Full (m)
Dissolved Oxygen (mg/L)
Date
*Black shows fill level on top and no data on bottom
Sample Date
Algaecide Application


SR2 - Temperature
Depth from Full (m)
Temperature (°C)
Date
*Black shows fill level on top and no data on bottom
Sample Date
Algaecide Application

Aerial view of Ragged Mountain Reservoir during construction

Appendix H: Summary of Alagaecide Applications

Beaver Creek Reservoir

Treatment Date	Work Authorization	Cost ($)	Algaecide	Amount of Algaecide Applied			Amount of Water Treated		
				Volume of product (gal)	Volume of product (L)	Mass of copper (lb)	Surface Area Treated (acres)	Depth Treated (feet)	Volume of Water Treated (cu. ft.)
5/13/14	5/9/14	$13,035.00	SeClear	312.5	1183	130	16	15	10,454,400
5/27/14	5/23/14	$9,748.00	SeClear	308	1166	128	16	15	10,454,400
6/20/14		$7,898.00	SeClear	312.5	1183	130	16	15	10,454,400
7/22/14	7/16/14	$7,898.00	SeClear	315	1192	131	16	15	10,454,400
10/28/14	10/21/14	$7,898.00	SeClear	312.5	1183	130	16	15	10,454,400
6/15/15	6/11/15	$7,898.00	SeClear	250	946	104	16	15	10,454,400
7/8/15	7/7/15	$7,898.00	SeClear	312.5	1183	130	16	15	10,454,400
9/24/15	9/21/15	$8,416.00	SeClear	312	1181	130	16	15	10,454,400
10/21/15	10/15/15	$8,416.00	SeClear	312	1181	130	16	15	10,454,400
5/11/16	5/10/16	$8,416.00	SeClear	312.5	1183	130	16	15	10,454,400
5/25/16	5/20/16	$8,416.00	SeClear	312.5	1183	130	16	15	10,454,400
6/17/16	6/2/16	$8,416.00	SeClear	312.5	1183	130	16	15	10,454,400
6/30/16	6/28/16	$8,416.00	SeClear	312.5	1183	130	16	15	10,454,400
8/10/16	7/11/16	$8,416.00	SeClear	312.5	1183	130	16	15	10,454,400
9/2/16	8/17/16	$8,416.00	SeClear	312.5	1183	130	16	15	10,454,400
11/1/16	9/6/16	$8,416.00	SeClear	312.5	1183	130	16	15	10,454,400
11/7/16	11/4/16	$4,776.00	SeClear	390	1476	163	16	15	10,454,400
4/12/17	2/8/17	$8,416.00	SeClear	312.5	1183	130	16	15	10,454,400
5/18/17	4/17/17	$8,416.00	SeClear	312.5	1183	130	16	15	10,454,400
5/22/17	6/26/17	$8,416.00	SeClear	312.5	1183	130	16	15	10,454,400
7/10/17				312.5	1183	130	16	15	10,454,400
10/30/17	9/20/17	$8,416.00	SeClear	312.5	1183	130			

Volume of water treated (MG)	Concentration Applied		Reason for Treatment				Notes
	concentration applied (mg Cu / L water)	Application rate (gal of product per MG of source water)	Species Targeted	Algal Count (cells/mL)	Date sample taken	Trigger Level	
78.2	0.20	4.00	aphanizomenon	142,046	5/6/14	>5,000 cells/ml	
			aphanizomenon	523,817	5/13/14		
78.2	0.20	3.94	aphanizomenon	193,620	5/20/14	>5,000 cells/ml	
			aphanizomenon	199,649	5/27/14		
78.2	0.20	4.00	aphanizomenon	27,246	6/16/14	>5,000 cells/ml	
78.2	0.20	4.03	aphanizomenon	17,623	7/14/14	>5,000 cells/ml	
78.2	0.20	4.00	aphanizomenon	18,473	10/20/14	>5,000 cells/ml	
78.2	0.16	3.20	Anabaena	4,506	6/10/15	>5,000 cells/ml	
78.2	0.20	4.00	Anabaena	6,183	7/6/15	>5,000 cells/ml	
78.2	0.20	3.99	Aphanizomenon*	34,086	9/24/15	>5,000 cells/ml	
78.2	0.20	3.99	Anabaena & aphanizomenon	6,938	10/14/15	>5,000 cells/ml	
78.2	0.20	4.00	Aphanizomenon*	5,946	5/9/16	>5,000 cells/ml	
78.2	0.20	4.00	Oscillatoria*	9,568	5/23/16	>5,000 cells/ml	
78.2	0.20	4.00	Aphanizomenon*	17,990	6/15/16	>5,000 cells/ml	
78.2	0.20	4.00	Aphanizomenon*	9,478	6/27/16	>5,000 cells/ml	
78.2	0.20	4.00	Anabaena & Coelosphaerium	10,310	8/816	>5,000 cells/ml	
78.2	0.20	4.00	Anabaena & Coelosphaerium	41,870	8/30/16	>5,000 cells/ml	
78.2	0.20	4.00	Aphanizomenon*	13,039	10/31/16	>5,000 cells/ml	
78.2	0.25	4.99	Coelosphaerium	316,000	11/3/16	>5,000 cells/ml	* Cost is lower because we had algaecide stockpiled and did not need to buy additional
78.2	0.20	4.00	Aphanizomenon	41,738	4/10/17	>5,000 cells/ml	
78.2	0.20	4.00	Aphanizomenon	18,593	5/15/17	>5,000 cells/ml	
78.2	0.20	4.00	Aphanizomenon Dolichospermum	21,275 11,108	5/15/17 5/18/17	>5,000 cells/ml	Due to repeated ND results, the trigger for sampling for cyanotoxins has been changed to 50,000 cells/mL, and thus cyanotoxins were not analyzed this time
78.2	0.20	4.00					
			Coelosphaerium	8,400	10/23/17	>5,000 cells/ml	

South Fork Rivanna Reservoir

Treatment Date	Work Authorization	Cost ($)	Algaecide	Amount of Algaecide Applied lb Cu/gal SeClear =0.417			Amount of Water Treated		
				Volume of product (gal)	Volume of product (L)	Mass of copper (lb)	Surface Area Treated (acres)	Depth Treated (feet)	Volume of Water Treated (cu. ft.)
8/10/15 and 8/17/15	8/7/15	$18,600.00	SeClear						
8/27, 8/31/15	8/24/15	$18,600.00	SeClear						
	Total =	$37,200.00							
9/12/16 and 9/19/16	9/8/16	$19,720.00	SeClear						
8/8/17	8/4/17	$19,632.00	SeClear	312.5	1183	130	20	10	8,712,000
9/21/17	8/20/17	$6,600	SeClear	400	1514	167	25	10	10,890,000

Volume of water treated (MG)	Concentration Applied		Reason for Treatment				Notes
	concentration applied (mg Cu / L water)	Application rate (gal of product per MG of source water)	Species Targeted	Algal Count (cells/mL)	Date sample taken	Trigger Level	
			Oscillatoria	20,869	8/5/15		No water flowing over dam. Although trigger for two weeks
				21,159	8/5/15		not met, treatment decision also based on fact no flow-through
			Oscillatoria	15,072	8/14/15		
				19,130	9/3/15		
				51,593	9/3/15		
			Oscillatoria				The $19,720 is for three applications, and as such the cost for the 9/12 and 9/19 applications would be 2/3 of that price ($13,147)
65.2	0.24	4.80	Planktolyngbya	135,400	8/2/17		The application was divided into 2 applications with 156 gallons applied at the surface and 156 gallons five feet below the surface
81.5	0.25	4.91	Pseudoanabaena	4,200	9/18/17	10,060	The reservoir level is -3.5', 7 days of warm and sunny weather projected, rawpH 8.2, conditions were right for a bigger bloom. Decision was made to treat now rather than risk a bigger bloom.

Ragged Mountain Reservoir

Treatment Date	Work Auth.	Cost	Algaecide	Volume of product (gallons)	Species targeted	Algal Count (cells/ml)	Date sample taken	Trigger Level	Notes
5/15/14		$6,225.00	SeClear	100	Green algae/ odor producer	no count	May-14	Odor complaints	
9/13/14	9/5/14	$6,390.00	SeClear	220	aphanizomenon	5,916	9/8/14	>5,000 cells/ml	
7/23, 7/30, 8/7/2015	7/21/15	$7,555.00	SeClear		Mougeotia (green algae)	no count	visual inspection daily	>5,000 cells/ml	Large floating mats of Mougeotia were observed
9/14, 9/18, 9/30/2015		$7,555.00	SeClear		Mougeotia (green algae)	no count	visual inspection daily	>5,000 cells/ml	

Totier Creek Reservoir

Trigger Level: none decided yet

Treatment Date	Work Auth.	Cost	Algaecide	Volume of product	Application rate	Species Targeted	Algal Count (cells/mL)	Date sample taken	Description
8/27/15	8/24/15	$5,946.00	SeClear			Oscillatoria	23478	8/18/15	This treatment was to be applied in three parts, each treatment separated by a week. Due to low DO levels following the first treatment the other two were not undertaken.

Sugar Hollow Reservoir

Treatment Date	Work Auth.	Cost	Algaecide	Volume of product	Application rate	Species Targeted	Algal Count (cells/ml)	Date sample taken
7/16/15	7/14/15	$3,300.00	Phycomycin (sodium carbonate peroxyhydrate)	2,000 lbs	14.7 mg/L	Anabaena	22,388	7/6/15
							23,942	7/14/15

Appendix I: Reservoir Sediment Flux Study Memo

RIVANNA RESERVOIR SEDIMENT FLUX STUDY

Dr. Marc Beutel

August 31, 2017

1. SUMMARY

To assess how dissolved oxygen controls sediment release of nutrients and metals in the South Fork Rivanna (SR) Reservoir and Beaver Creek (BC) Reservoir, field staff collected sediment-water interface samples into specialized flux chambers. The chambers were incubated under oxic conditions for 10 days followed by anoxic conditions for 23 days. Chamber water was monitored on average every 3–4 days for nitrate, ammonia, phosphate, iron and manganese. Under anoxic conditions in a typical reservoir, sediment releases ammonia, phosphate, iron and manganese to overlaying water. Ammonia and phosphate are key algal nutrients that exacerbate eutrophication. Iron and manganese complicate potable water treatment. Ammonia is released as organic matter undergoes mineralization. Metals are released as iron and manganese oxides undergo reductive dissolution by anaerobic microbes. Since manganese is reduced at a high redox potential, it tends to be released before iron. Phosphate is released when organic matter undergoes mineralization and when phosphate sorbed to iron oxides is released via reductive dissolution. To avoid the negative water quality impacts of anoxia, lake managers sometimes implement strategies (e.g., hypolimnetic oxygenation) that enhance redox potential and/or oxygen concentration in the profundal zone of lakes and reservoirs.

Ammonia and manganese fluxes at both study sites, and iron fluxes at Beaver Creek Reservoir, followed expected patterns under oxic versus anoxic conditions. However, phosphate fluxes at both study sites, and iron flux at South Fork Rivanna Reservoir, were low and showed no consistent increase under anoxic conditions. Results suggest that maintenance of a well-oxygenated sediment-water interface will coincide with a decreases

in the internal loading of ammonia and metals at these study sites. Results also suggest that both reservoirs have a low potential to release phosphate to overlaying water under anoxic conditions.

Anoxic ammonia flux rates ranged from 5–15 mg–N/m²·d in SR chambers, 20–40 mg–N/m²·d in BC1 chambers, and 5–30 mg–N/m²·d in BC2 chambers. Typical anoxic ammonia fluxes reported in the literature for oligo/mesotrophic, meso/eutrophic, and eutrophic/ hypereutrophic sites typically range from <5, 5–10, and >15 mg–N/m²·d respectively (Beutel 2006). In contrast to ammonia, phosphate flux did not substantially increase under anoxic conditions. Phosphate fluxes generally ranged from -1 to 1 mg–P/m²·d. Anoxic phosphate release rates for eutrophic lakes typically range from 5–20 mg–P/m²·d (Nurnberg 1994). Peak anoxic manganese fluxes ranged 10–20 mg/m²·d in SR chambers and 20–40 mg/m²·d in BC chambers. Peak anoxic iron fluxes ranged from 100–125 mg/m²·d in BC1 chambers and 50–75 mg/m²·d in BC2 chambers. Typical anoxic manganese and iron fluxes reported in the literature for eutrophic lakes range from 10–50 mg/m²·d (Beutel 2000).

A number of observations indicate that sediment in Beaver Creek Reservoir has a higher potential to release reduced compounds compared to South Fork Rivanna Reservoir sediment. And within Beaver Creek Reservoir, the deeper site 1, had the highest potential. These observations included: high magnitudes of ammonia release early in the oxic period and during the anoxic period; high manganese fluxes early in the anoxic period; and high iron fluxes in the late anoxic period.

2. METHODS

On June 14, 2017, field staff under the guidance of Dr. Alex Horne, collected sediment-water interface samples at two reservoirs operated by the Rivanna Water and Sewer Authority (Fig.1). Duplicate samples were collected in South Fork Rivanna Reservoir in the upper part of the reservoir (SRUP1, SRUP2) and in the lower part of the reservoir (SRLWR1, SRLWR2). Duplicate samples were also collected in Beaver Creek Reservoir at site 1 (BC1A, BC1B) and site 2 (BC2A, BC2B). The samples were first collected with an Ekman dredge and brought to the surface. A sub-sample of sediment was then collected in specially designed Polycarbonate cylindrical flux chambers, which I shipped to the field crew from California. A plug was inserted into the chamber to keep the sediment in place during transport back to California. Chambers were shipped with a scheduled arrival date of Saturday, June 17, but bad weather delayed the arrival to Monday, June 19.

Upon arrival, chambers were topped up with bottom water, which was also shipped with the chambers. The chambers were then allowed to acclimate for one day in an incubator in the dark at 10°C, the approximate temperature of bottom water in Beaver Creek Reservoir (DiNatale, 2016). Bottom temperatures of South Fork Rivanna Reservoir can exhibit higher temperatures (DiNatale, 2016), thus the rates observed here may be an underestimate for that reservoir. Experiential testing commenced on Tuesday, June 20. Testing consisted of two periods. For the oxic period, chambers were incubated under oxygenated conditions by bubbling with air for 10 days. Water samples were collected at day 0 (June 20, 2017), day 3, day 5, day 7 and day 10. For the anoxic period, chambers were topped up with lake bottom water and incubated under anaerobic conditions by bubbling with nitrogen gas for an additional 23 days. For the anoxic period, water samples were collected at day 0 (June 30, 2017), day 4, day 7, day 10, day 15 and day 23. A significant wildfire near my home laboratory caused me to evacuate my house during the final anoxic phase. A related power outage from the morning of Tuesday, July 18 to evening of Friday, July 21 caused the incubator to shut down. Follow-up temperature monitoring indicates that the chambers experienced temperatures on the order of 30 °C during this period. Thus, water quality and fluxes associated with anoxic phase 5 (July 15–23) are not generally indicative of in situ conditions for Beaver Creek Reservoir. But bottom waters of South Fork Rivanna Reservoir can get as warm as ~20–25 °C based on 2015 field data (DiNatale, 2016), so this accidental high-temperature anoxic phase could yield some insight into sediment processes in that reservoir.

Chamber water was monitored for nitrate, ammonia, soluble reactive phosphorus (SRP), iron and manganese. Water samples were collected into two sample bottles: a metals bottle that was preserved with 0.15% trace metals grade nitric acid; and a nutrient bottle what was filtered through pre-washed 0.45 micron filters and frozen. Water samples were analyzed by the UC Merced Environmental Analytical Laboratory. Iron and manganese were measured using inductively coupled plasma optical emission spectrometry (ICP-OES) with a method detection limit of 10 μg/L. Nutrients were measured on a Latchet nutrient auto-analyzer using standard colorimetric methods. SRP analysis mainly measures dissolved orthophosphate and I use the term "phosphate" for this analysis. Nitrate analysis theoretically measures the combination of nitrate and nitrite, but since nitrite is typically low in natural waters, I use the term "nitrate" for this analysis. Nutrient method detection limits were 15 μg/L for SRP, 30 μg/L for ammonia, and 50 μg/L for nitrate. Non-detect (ND) samples were set equal to half of the detection limit for flux calculations. Analytical results from water samples collected on oxic day 5 were aberrant. Further investigation revealed that nutrient samples and metals sampled were accidently switched when preserved. Thus nutrient samples were accidently preserved with nitric acid and metal samples were accidently filtered and frozen. As a result, only the ammonia analyses yielded meaningful data. Nitrate, phosphate, manganese and iron data for this sampling date were excluded from the study.

Estimating mass flux (mass per time and area, $mg/m^2{\cdot}d$) is a practical way of assessing the effects of redox status on metal and nutrient cycling in sediment-water chamber experiments. Fluxes of all compounds of interest were calculated for each set of samples collected a few days apart (e.g, day 0–3, day 3–5, day 5–8, etc.). Thus, fluxes are reported for oxic phases 1–4 (blue bars in data figures) and anoxic phases 1–4 (brown bars in data figures), as well as anoxic phase 5 (black bar in data figures) during which the incubator shut down. Fluxes (mg/m²·d) were calculated as the concentration (mg/L) at the end of the phase minus the concentration at the start of the phase, multiplied by chamber water volume (L), divided by the duration of the phase (d), divided by the area (m²) of the chamber. A positive flux indicates that sediment released the compound of interest into overlying water. A negative flux indicates that the compound of interest was lost from the water column, either via a transformation where it was sequestered in the sediment (e.g., oxidation of dissolved reduced manganese into particulate oxidized manganese and subsequent gravitational settling onto sediment) or disappears from the water altogether (loss of ammonia under oxic conditions by nitrifying bacteria that convert it to nitrate). Water quality data are tabulated in the data appendix at the end of this report.

3. RESULTS AND DISCUSSION

3.1 Chamber Physical Characteristics

In general, water in Beaver Creek Reservoir chambers had more color and was harder to filter compared to South Fork Rivanna Reservoir chambers, indicating more fine particulates in the water column of these chambers. During anoxic conditions, surface sediment in chambers generally lost a bit of their red-brown color suggesting reductive dissolution of native iron oxides in sediment (Fig. 2). Anoxic chamber water also tended to have more color and turbidity as reduced compounds, and perhaps dissolved organic matter, accumulated in chamber water (Fig. 2). Anoxic chambers never had a sulfide odor, indicating the lack of sulfate reduction under anoxic conditions. These observations are somewhat different than other chamber studies I performed for eutrophic water reservoirs in California I have worked on. They generally exhibit a clearer transition in sediment coloration from oxic (red-brown) to anoxic (brown-black). I also commonly smell or measure sulfide midway through the anoxic period. Obviously, the sediment quality and related sediment biogeochemistry of the Virginia and California reservoirs are different. Another possibility is that oxic conditions during transport poisoned sediment-dwelling sulfate-reducing bacteria. But if sulfate-reducing bacteria were present, I expect that enough would have survived to become active during the extended 23-day anoxic period.

3.2 Ammonia

In all chambers under oxic conditions, positive ammonia fluxes decreased in magnitude and turned negative at the end of the oxic period as ammonia was biologically oxidized to nitrate (Fig. 3) Negative ammonia fluxes generally corresponded with positive nitrate fluxes. Ammonia concentration during the oxic period was generally lower in SR chambers (ND-998 µg–N/L) compared to BC chambers (55–3,113 µg–N/L) (data appendix, Fig. 6). Oxic fluxes in the early oxic phases were also lower in SR chambers (~20 mg–N/m²·d) compared to BC chambers (~20–70 mg–N/m²·d) (Fig. 3).

Under anoxic conditions chambers generally showed positive ammonia fluxes (Fig 3). Anoxic conditions promote sediment ammonia release through a combination of organic matter decay (an ammonia source) and repressed nitrification (an ammonia sink) (Beutel, 2006). Lower bacterial growth rates under anoxic conditions (i.e., lower rates of ammonia assimilation into bacteria biomass) may also partly account for ammonia accumulation under anoxic conditions. Ammonia concentration near the end of the anoxic period (anoxic day 15) increased to 114–945 μg–N/L in SR chambers and 973–4,409 μg–N/L in BC chambers (data appendix, Fig. 6). Anoxic ammonia flux was lower in SR chambers (5-15 mg–N/m^2·d; mean = 4.2 mg–N/m^2·d) compared to BC chambers (5–40 mg–N/m^2·d; mean = 15.9 mg–N/m^2·d) (Fig. 3). Within BC chambers, anoxic ammonia release rates were higher at site 1 (mean = 22.2 mg–N/m^2·d) compared to site 2 (mean = 9.7 mg–N/m^2·d) (Fig. 3). Anoxic ammonia release was somewhat enhanced under high-temperature conditions during anoxic phase 5.

Based a review of June 2016 Phase 1 Reservoir Water Quality Assessment (DiNatale, 2006), the highest ammonia release rates were associated with deeper profundal sediment at BC1. This sediment is likely rich in unoxidized organic matter that liberates ammonia upon decay. BC1 has a depth of ~8–10 m compared to BC2 which has a depth of ~5–6 m. In addition, BC1 is consistently far below a summer time thermocline compared to BC2 and SR sites. Observed anoxic ammonia fluxes in this study are typical of release rates measured in other lakes. Release rates for oligo/mesotrophic, meso/eutrophic, and eutrophic/hypereutrophic sites typically range from <5, 5–10, and >15 mg–N/m^2·d respectively (Beutel 2006).

3.3 Phosphate

Patterns of phosphate flux were more variable and less clear than those of ammonia (Fig. 3). For both sets of chambers, it is difficult to discern a difference between phosphate fluxes under oxic versus anoxic conditions. Changes between phosphate concentration under oxic and anoxic conditions suggests that phosphate was released under anoxic conditions (Fig. 4). But differences were small and did not translate to consistent patterns in fluxes. Elevated temperatures during anoxic phase 5 stimulated phosphate release from BC sediment but not SR sediment. This suggests that BC sediment has a more liable pool of phosphate to release to overlaying water under anoxic conditions.

These results are different from incubations I have done at other California reservoirs. Other incubations show a release of phosphate under anoxic conditions at rates typically of eutrophic lakes (5–20 mg–P/m^2·d) (Nurnberg 1994). It is possible that our collection and shipping method altered sediment biogeochemistry in such a way that repressed phosphate release under anoxic conditions. Since phosphate release is generally associated with the reduction and liberation of iron from sediment, we would also expect that that iron cycling would have been impacted. But, as discussed below for BS chambers, iron release under oxic and anoxic conditions showed expected patterns. In addition, if phosphate release was associated with organic matter mineralization, then we would expect low rates of ammonia accumulation. This was not the case. Either the sediment had low potential to release phosphate under anoxic conditions, or there was some unforeseen sink for phosphate during anoxic conditions at the sediment-water interface on the chambers.

3.4 Manganese

Under oxic condition, manganese fluxes were generally negative (uptake) as bacteria oxidized dissolved, reduced manganese(II) to particulate manganese hydroxides that settled out of the water column (Fig. 5). Under anoxic conditions, manganese fluxes were positive as manganese oxides at the sediment-water interface underwent microbial reductive dissolution. Metal concentrations were lower in SR chamber water compared to BC chamber water. During the oxic period, manganese concentrations dropped from ~600 μg/L to <200 μg/L in SR chambers and from ~1,300 μg/L to <200 μg/L in BC chambers (data appendix, Fig. 6). Peak manganese concentrations during the anoxic period (excluding the warm anoxic phase 5) were 440–1,250 μg/L in SR chambers and 1,080–1,700 μg/L in BC chambers. Peak anoxic fluxes ranged 10–20 mg/m²·d in SR chambers and 20–40 mg/m²·d in BC chambers (Fig. 6). Anoxic manganese release rates measured in this study were typical of those reported in the literature for eutrophic lakes (10–50 mg/m²·d) (Beutel 2000).

BC chambers, especially from site 1, showed the classic pattern of immediate sediment manganese release with the onset of anoxic conditions (Fig. 6). Manganese oxides are very labile and readily undergo biotic reductive dissolution under mildly reduced conditions, resulting in a fairly rapid depletion of the pool of reducible manganese at the sediment-water interface (Davison 1993). In contrast, SR chambers exhibited peak manganese fluxes later in the anoxic period, and a jump in manganese flux during the warm anoxic phase 5. Thus, the sediment-water interface in SR chambers took longer to go anoxic and still had a pool of reducible manganese at the end of the anoxic period, which was liberated during anoxic phase 5 as warm temperatures enhanced microbial activity. Results indicates that BC sediments are more reducing in nature relative to SR sediments. The tendency to rapidly release manganese in BC sediment corresponded with higher anoxic ammonia release rates, another indicator of a large liable pool of organic matter at the sediment-water interface.

3.5 Iron

SR and BC chambers showed very different patterns of iron flux (Fig. 5). BC chambers exhibited a more typical pattern in which fluxes were negative (uptake) under oxic conditions as bacteria oxidized dissolved, reduced iron(II) to particulate iron hydroxides that settled out of the water column, and positive under anoxic conditions as iron oxides at the sediment-water interface underwent microbial reductive dissolution. During the oxic period, iron concentrations in BC chambers dropped from 2,300–4,300 μg/L to 1,200–2,600 μg/L (data appendix, Fig. 6). Peak iron concentrations during the anoxic period (excluding the warm anoxic phase 5) in BC chambers were 3,000–7,300 µg/L. Peak anoxic iron fluxes ranged 100–125 mg/m²·d in BC1 chambers and 50–75 mg/m²·d in BC2 chambers. These anoxic iron fluxes were on the high side of those reported in the literature for eutrophic lakes (10–50 mg/m²·d) (Beutel 2000). Peak iron fluxes occurred later in the anoxic period compared to manganese, a result of the fact that iron reduction occurs at a lower redox potential than manganese reduction (Davison 1993).

As discussed above, it is perplexing that anoxic iron release was not associated with a concurrent accumulation of phosphate in bottom waters. This linkage was observed to some extent during the warm anoxic phase 5. In this warm phase, iron flux in BC2 chambers increased as warm temperatures enhanced microbial activity (Fig. 5). Warm incubation temperature was also associated with enhanced phosphate flux (Fig. 3). Thus in BC2 chambers, iron release appears linked to phosphate release, but the relative amount of phosphate flux is relatively low and seemed to occur under relatively harsh (extremely warm) conditions that do not occur in the bottom of Beaver Creek Reservoir.

In SR chambers, iron concentrations were lower in chamber water compared to BC chamber water, as was observed for manganese. Under oxic conditions, iron concentrations did not decrease with time and remained around 500–1,500 µg/L (data appendix, Fig. 6). Since the water column was oxic, iron oxides were surely forming and settling out of the water column. Thus there must have been a continued release of iron out of the sediment even under oxic conditions. Under anoxic conditions, iron concentrations did not increase substantially. Because of the static nature of iron concentration over time, iron fluxes were low and did not show any clear pattern (Fig. 5). In the warm anoxic phase 5, iron flux in SR chambers increased as warm temperatures enhanced microbial activity. But in contract to BC chambers, this did not correspond with a flux of phosphate. This suggests that sediment in South Fork Rivanna Reservoir is not enriched with labile phosphate readily available to flux out of sediments under reduced conditions.

4. REFERENCES

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FIGURES

Figure 1. Sediment sample collection at the study site. Picture at right shows complete chamber with plug in chamber to keep sediment in place during transport. Once in California, the plug was removed and bottom water was carefully added to the chamber.

Figure 2. Conditions of sediment-water interface samples on oxic day 5 (left) and anoxic day 10 (right) in chambers SRLWR1 (top) and BC1B (bottom). Under oxic conditions the sediment-water interfaces was a bit more red-brown, which is indicative of oxidized iron at the sediment-water interface. Under anoxic conditions chamber water was generally a bit more turbid, likely due to the release of reduced compounds from sediment into overlaying water.

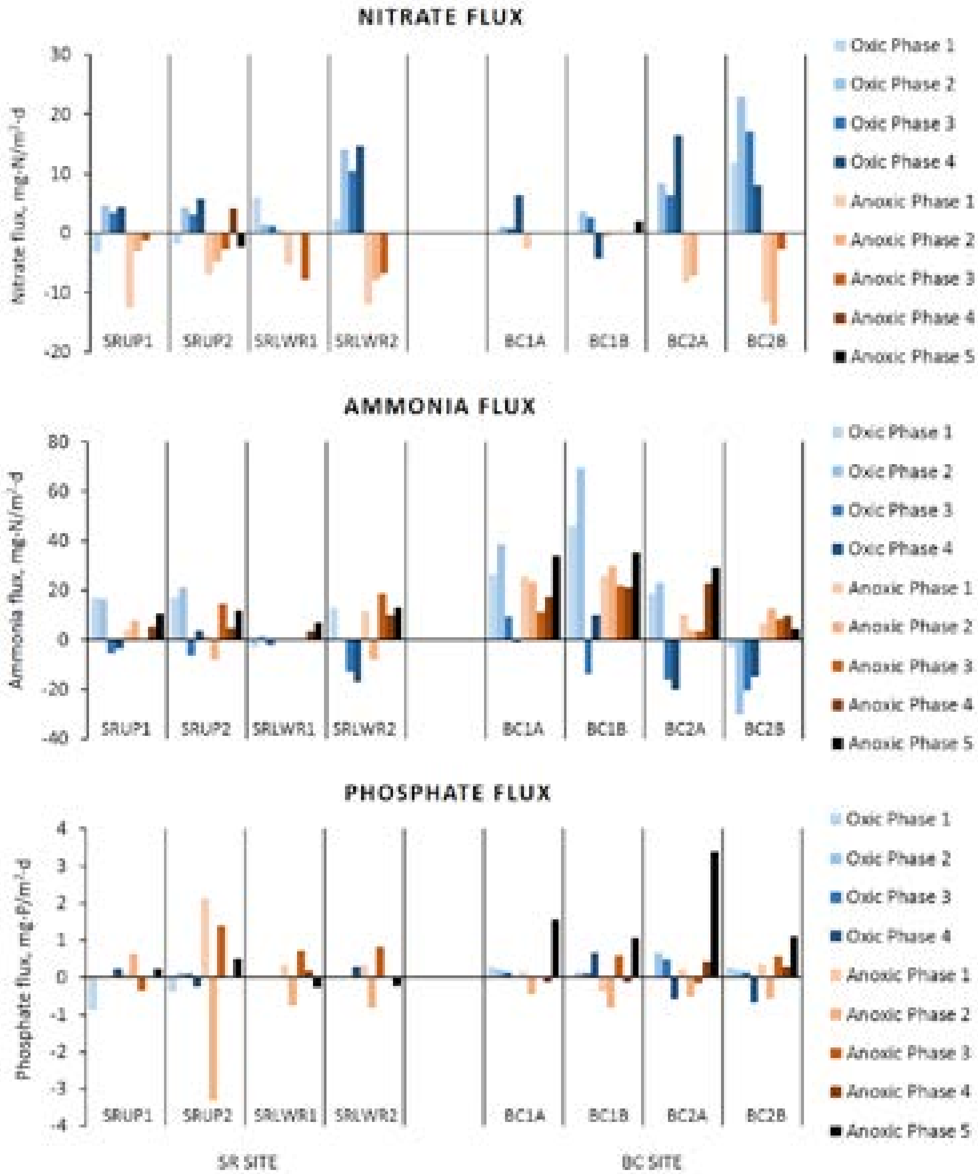


Figure 3. Metal fluxes in experimental sediment-water interface chambers collected at South Fork Rivanna Reservoir (SR) and Beaver Creek Reservoir (BC). Each set of bars separated by vertical lines represents one chamber. Chambers were collected at two sites at each reservoir in duplicate. Blue bars are for oxic phases, brown bars are for anoxic phases, and black bars are for the warm anoxic phase. Under oxic conditions, nitrate flux increased and ammonia flux decreased or turned negative (uptake). Under anoxic conditions, nitrate flux turned negative while ammonia flux increased. There were no clear trends in phosphate fluxes.

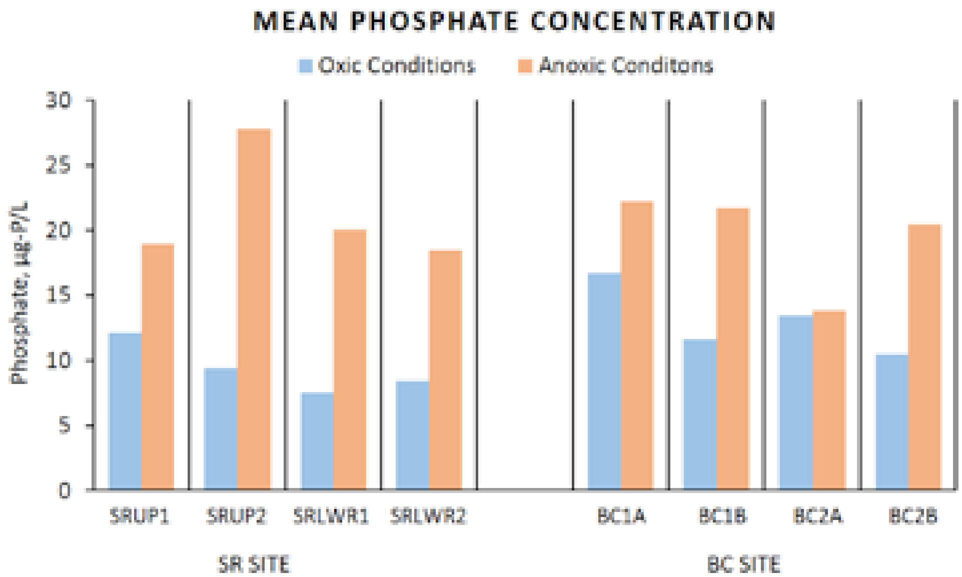


Figure 4. Mean phosphate concentration in chamber water of experimental incubations under oxic (blue) and anoxic (brown) conditions. Anoxic conditions generally exhibited higher phosphate concentrations, but levels were not high or consistent enough to translate to a patterns of consistently higher phosphate fluxes under anoxic conditions (see Fig. 3).

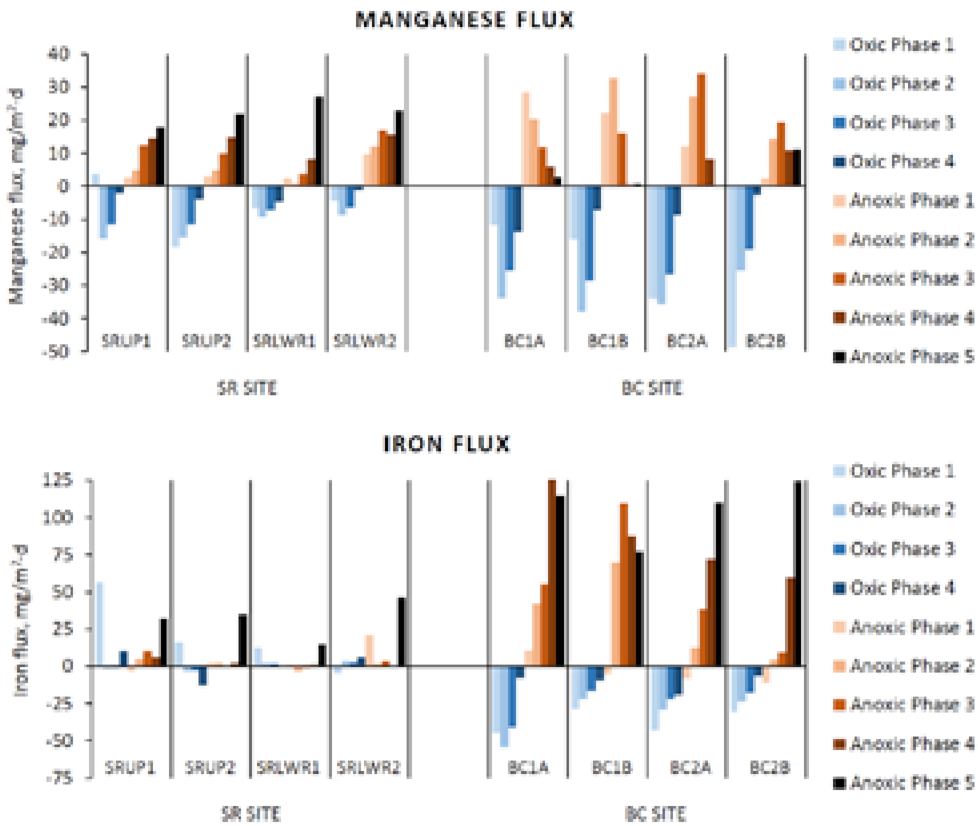


Figure 5. Metal fluxes in experimental sediment-water interface chambers collected at South Fork Rivanna Reservoir (SR) and Beaver Creek Reservoir (BC). Each set of bars separated by vertical lines represents one chamber, which were collected at two sites at each reservoir in duplicate. Blue bars are for oxic phases, brown bars are for anoxic phases, and black bars are for the warm anoxic phase. Under oxic conditions, manganese and iron flux was generally negative (uptake). Under anoxic conditions, manganese and iron flux was generally positive. SR samples did not exhibit a clear pattern on iron uptake or release during the experiment.

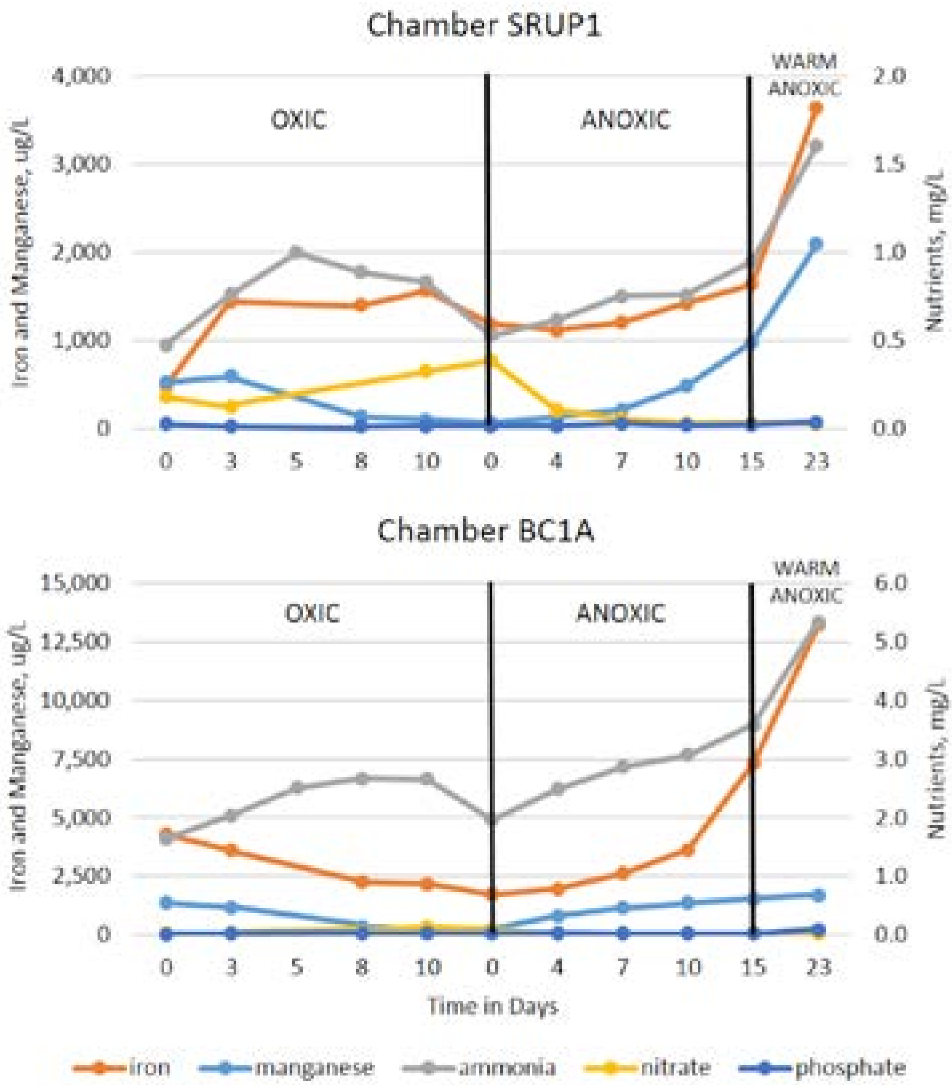


Figure 6. Example of water quality data from experimental sediment-water interface chambers SRUP1 (top) and BC1A (bottom). Under oxic conditions, ammonia concentration increased then decreased as ammonia was biologically nitrified, resulting in an increase in nitrate concentration. Also under oxic conditions manganese concentrations decreased as manganese was oxidized to particulate metal oxides that settled out of chamber water. Under anoxic conditions, ammonia concentration increased as organic matter decayed, while nitrate decreased via biological denitrification. Manganese and iron concentration also increased as metal oxides underwent reductive dissolution. Phosphate concentration showed no clear patterns. Warm conditions at the end of the anoxic phase enhanced ammonia and metals release.

Data Appendix

Chamber Water Quality Data

	SR Site						BC Site					
Day	Chamber	Nitrate (µg-N/L)	Ammonia (µg-N/L)	SRP (µg-P/L)	Fe (µg/L)	Mn (µg/L)	Chamber	Nitrate (µg-N/L)	Ammonia (µg-N/L)	SRP (µg-P/L)	Fe (µg/L)	Mn (µg/L)
6/20/2017 17:00												
Oxic 0	SRUP1	177	473	22	481	519	BC1A	ND	1,641	11	4,269	1,357
Oxic 0	SRUP2	363	386	ND	604	660	BC1B	ND	1,466	ND	2,340	1,394
Oxic 0	SRLWR1	235	78	ND	621	473	BC2A	ND	1,340	ND	4,060	1,444
Oxic 0	SRLWR2	363	484	ND	714	477	BC2B	ND	940	ND	2,307	1,322
6/23/2017 14:00												
Oxic 3	SRUP1	319	762	ND	1,444	586	BC1A	ND	2,034	15	3,597	1,179
Oxic 3	SRUP2	339	605	ND	812	426	BC1B	ND	2,200	ND	1,879	1,138
Oxic 3	SRLWR1	326	30	ND	814	372	BC2A	ND	1,608	ND	3,469	909
Oxic 3	SRLWR2	396	668	ND	653	414	BC2B	189	896	11	1,882	644
6/25/2017 18:00												
Oxic 5	SRUP1	-	998	-	-	-	BC1A	-	2,510	-	-	-
Oxic 5	SRUP2	-	831	-	-	-	BC1B	-	3,113	-	-	-
Oxic 5	SRLWR1	-	51	-	-	-	BC2A	-	1,873	-	-	-
Oxic 5	SRLWR2	-	674	-	-	-	BC2B	-	547	-	-	-
6/28/2017 11:00												
Oxic 8	SRUP1	x	886	ND	1,399	193	BC1A	58	2,662	20	2,255	345
Oxic 8	SRUP2	229	797	ND	738	102	BC1B	118	2,870	11	1,291	142
Oxic 8	SRLWR1	364	ND	ND	864	148	BC2A	218	1,626	23	2,789	185
Oxic 8	SRLWR2	527	471	ND	795	212	BC2B	720	280	15	1,336	55
6/30/2017 9:00												
Oxic 10	SRUP1	324	830	ND	1,564	97	BC1A	132	2,649	20	2,158	179
Oxic 10	SRUP2	290	778	ND	605	61	BC1B	61	3,003	20	1,169	48
Oxic 10	SRLWR1	368	ND	ND	873	85	BC2A	408	1,894	16	2,562	45
Oxic 10	SRLWR2	703	264	ND	810	198	BC2B	815	55	ND	1,260	24
6/30/2017 11:00												
Anoxic 0	SRUP1	386	523	ND	1,184	63	BC1A	78	1,950	25	1,727	222
Anoxic 0	SRUP2	261	563	ND	541	47	BC1B	43	2,300	35	1,400	316
Anoxic 0	SRLWR1	284	ND	ND	688	59	BC2A	289	1,167	14	2,158	180
Anoxic 0	SRLWR2	502	131	ND	569	113	BC2B	533	235	13	1,347	150
7/4/2017 12:00												
Anoxic 4	SRUP1	304	614	ND	1,111	122	BC1A	ND	2,406	28	1,951	812
Anoxic 4	SRUP2	337	593	53	578	101	BC1B	ND	2,850	27	1,298	730
Anoxic 4	SRLWR1	377	ND	21	712	105	BC2A	131	1,304	18	2,003	408
Anoxic 4	SRLWR2	266	363	20	987	308	BC2B	306	361	20	1,140	204
7/7/2017 11:00												
Anoxic 7	SRUP1	53	749	25	1,201	208	BC1A	ND	2,858	21	2,616	1,139
Anoxic 7	SRUP2	71	485	ND	608	159	BC1B	ND	3,345	34	2,449	1,328
Anoxic 7	SRLWR1	572	ND	ND	664	118	BC2A	ND	1,421	30	2,192	831
Anoxic 7	SRLWR2	346	344	ND	1,008	491	BC2B	74	552	11	1,209	439
7/10/2017 17:00												
Anoxic 10	SRUP1	ND	756	18	1,420	479	BC1A	ND	3,070	22	3,637	1,358
Anoxic 10	SRUP2	ND	723	28	601	384	BC1B	ND	3,768	25	4,540	1,635
Anoxic 10	SRLWR1	ND	ND	22	645	190	BC2A	ND	1,479	ND	2,858	1,402
Anoxic 10	SRLWR2	ND	577	23	1,067	796	BC2B	ND	723	23	1,379	762
7/15/2017 13:00												
Anoxic 15	SRUP1	ND	945	19	1,635	971	BC1A	ND	3,581	18	7,308	1,537
Anoxic 15	SRUP2	132	847	28	661	715	BC1B	ND	4,409	23	7,208	1,650
Anoxic 15	SRLWR1	ND	114	28	675	488	BC2A	ND	2,098	19	4,850	1,632
Anoxic 15	SRLWR2	ND	867	23	1,079	1,246	BC2B	ND	973	30	3,059	1,077
7/23/2017 13:00												
Anoxic 23	SRUP1	ND	1,606	34	3,643	2,091	BC1A	ND	5,332	58	13,200	1,689
Anoxic 23	SRUP2	ND	1,405	51	2,270	1,726	BC1B	135	6,290	75	11,330	1,601
Anoxic 23	SRLWR1	ND	480	ND	1,472	1,869	BC2A	ND	3,527	185	10,240	1,652
Anoxic 23	SRLWR2	ND	1,529	ND	3,410	2,402	BC2B	ND	1,201	86	9,354	1,645

ND = Not Detected; method detection limits = 50 µg/L for nitrate, 30 µg/L for ammonia, 15 µg/L for SRP, and 10 µg/L for iron and manganese

- Samples excluded form data set due to accidental switching of nutrient and metal samples when preserving.

x = sample excluded due to QA/QC concerns

Appendix J: Sediment Core Sampling Memo

RIVANNA WATER AND SEWER AUTHORITY SEDIMENT SAMPLING AND ANALYSIS

Dr. Steven A. Kuehl

October 11, 2017

Rivanna Sediment Core Collection

Core samples were collected in two reservoirs on July 13, 2017 using a manual "push" corer consisting of aluminum extension rods with 3" diameter acrylic core barrels. Two cores were collected from South Fork Rivanna at pre-determined locations near the Dam and upstream:

SF-D: South Fork, Dam site
LF-U: South Fork, Upper Reservoir site

Three cores were collected from Beaver Creek, one at a predetermined location near the Dam. Coring was unsuccessful at the predetermined upper reservoir site, so cores were taken just upstream (north branch) and just downstream (near a buoy marker). Core recovery in Beaver Creek was consistently lower because of a rapid increase in consolidation at a shallow depth in below the lake floor. Beaver Creek reservoir samples were designated as follows:

BC-D: Beaver Creek, Dam site
WC: Beaver Creek, northern branch (above confluence)
BC-B: Beaver Creek, near buoy marker (below confluence)

GPS coordinates were not recorded during sampling because of a malfunction of the Rivanna authority supplied GPS receiver.

Core Processing and Analysis

Cores were extruded in 5-cm intervals and the wet sediment was placed in a 60° C oven until dry. Dried samples were ground and homogenized for counting.

^{210}Pb and ^{137}Cs were determined using non-destructive gamma counting of their characteristic photo peaks. Samples were packed into 70ml plastic petri dishes and were counted for approximately 24 hours on a high purity germanium detector. Detector efficiencies were calculated using a multinuclide standard supplied by Eckert and Ziegler. Acceptable error was expected to be between 5–10% with up to 20% error for samples with particularly low concentrations.

Results and Interpretation

Detailed analytical results and calculations for ^{210}Pb and ^{137}Cs are included in the accompanying spreadsheet and summarized in the following graphs. In most cases accumulation rates were calculated through linear regression of the ln(activity) with depth in core. One core, South Fork Dam, showed non-steady-state characteristics, evidenced by the changing gradient of the excess ^{210}Pb profile. This is likely a result of changing textural characteristics of the sediment at this site, as a coarse (sandy) interval was noted at depth during subsampling. Therefore, accumulation rate for this core was estimated based on the presence of a ^{137}Cs maxima at 80 cm, which may represent the time near maximum atmospheric fallout in 1963/64, yielding an accumulation rate of ~ 1.5 cm/yr.

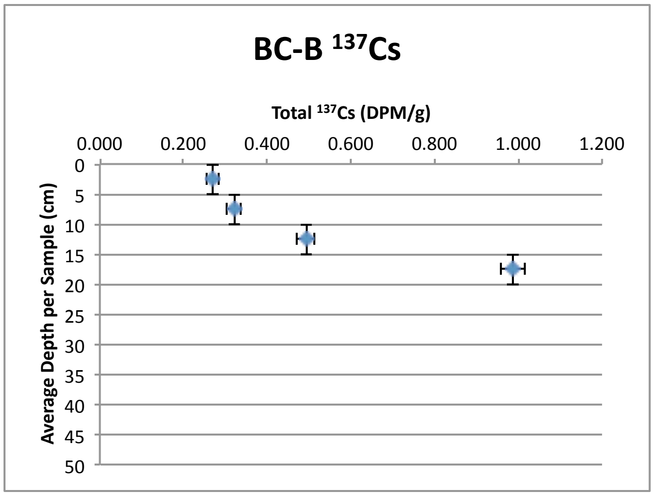
Table 1: Summary of Calculated Sedimentation Rates (approximate error estimate +/- 20%)

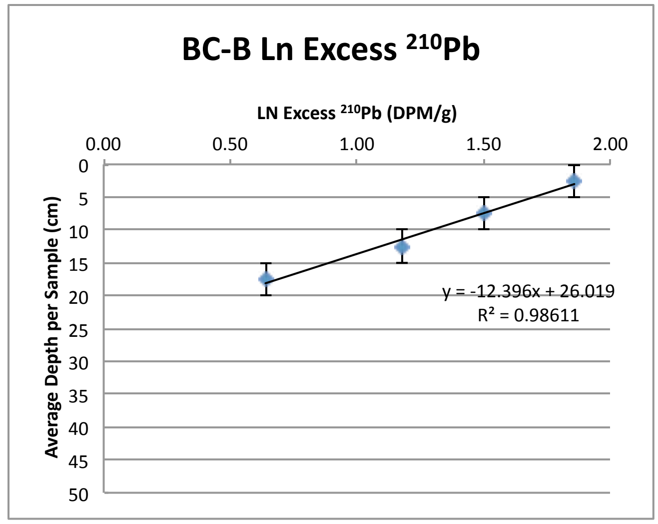
South Fork Rivanna
Dam Site: 1.5 cm/yr
Upper Site: 1.7 cm/yr

Beaver Creek
Dam Site: 0.35 cm/yr
Northern Branch: 0.4 cm/yr
Buoy Site: 0.39 cm/y

Sediment accumulation rates in South Fork Rivanna were consistently higher than those observed for the Beaver Creek sites, by about a factor of four. This is consistent with field observations, where shorter cores recovered from Beaver Creek resulted from the lack of penetration in more consolidated sediments at shallow depths in core. This is also consistent with the absence of ^{137}Cs at the bottom of two of the cores from Beaver Creek, which indicates some recovery of material that was deposited before significant atmospheric fallout of ^{137}Cs, which began in the mid 1950's. Thus, these short cores likely penetrated through the thin post-dam veneer of sediment.

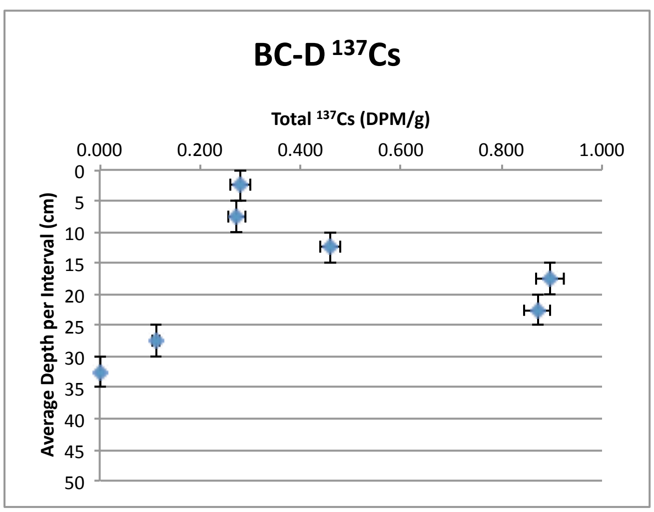
BC-B

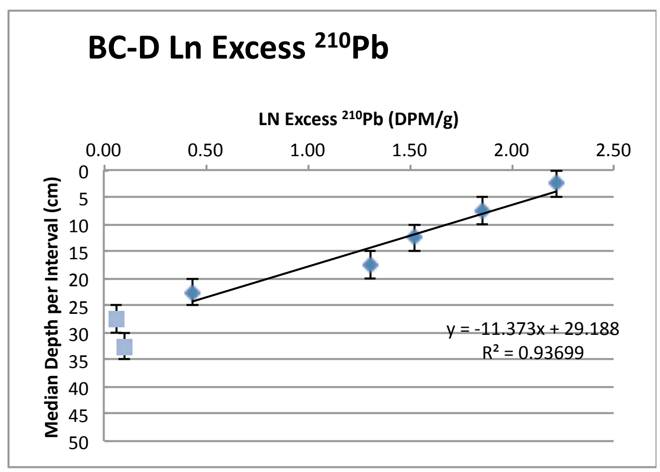




The sedimentation rate based on this regression is 0.385 cm/year.

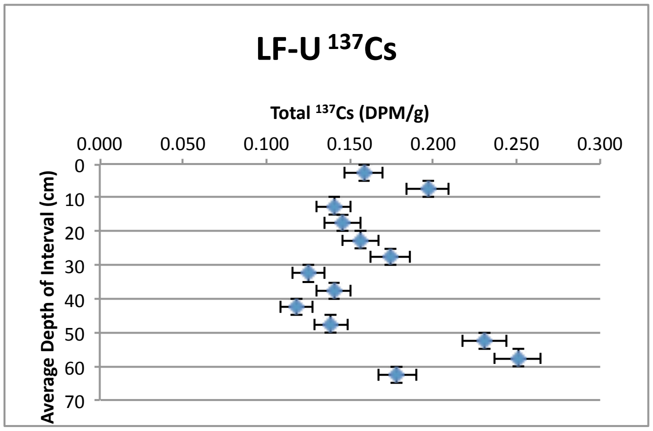
BC-D

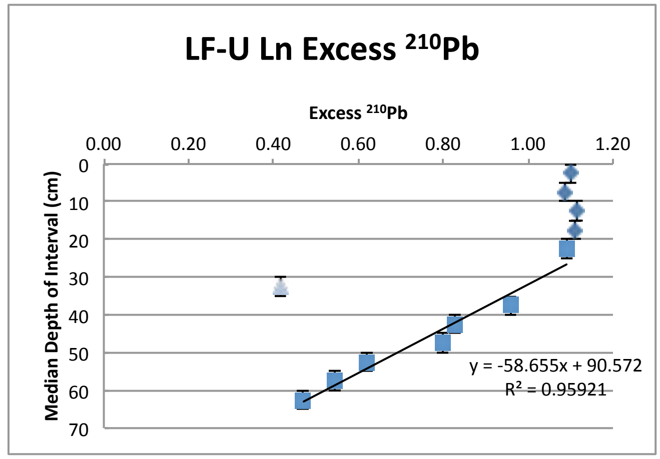




The sedimentation rate based on this regression is 0.354 cm/year.

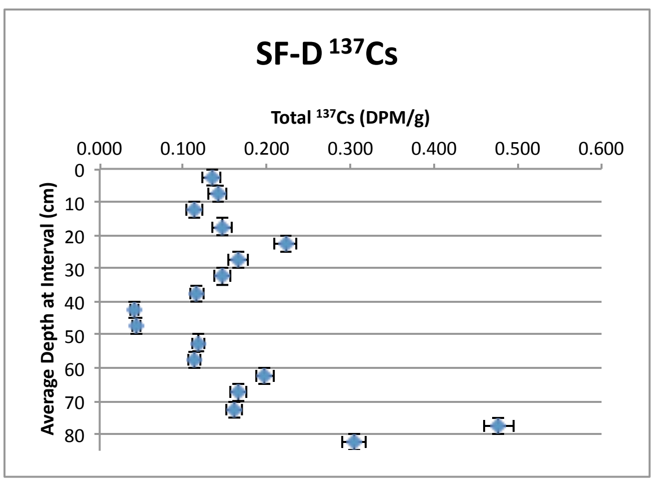
LF-U

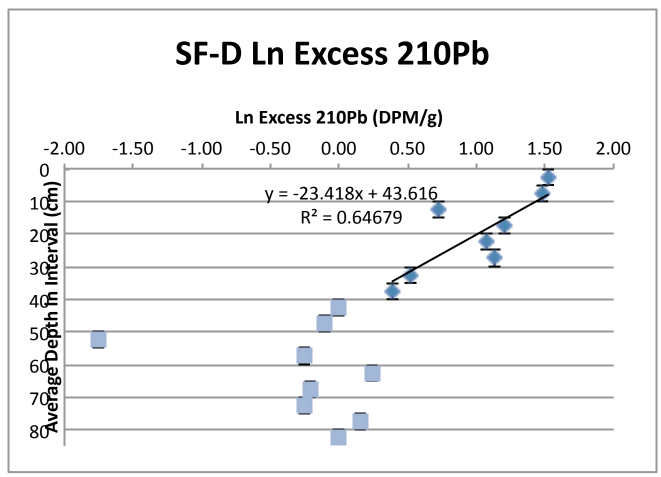




The sedimentation rate based on this regression is 1.730 cm/year.

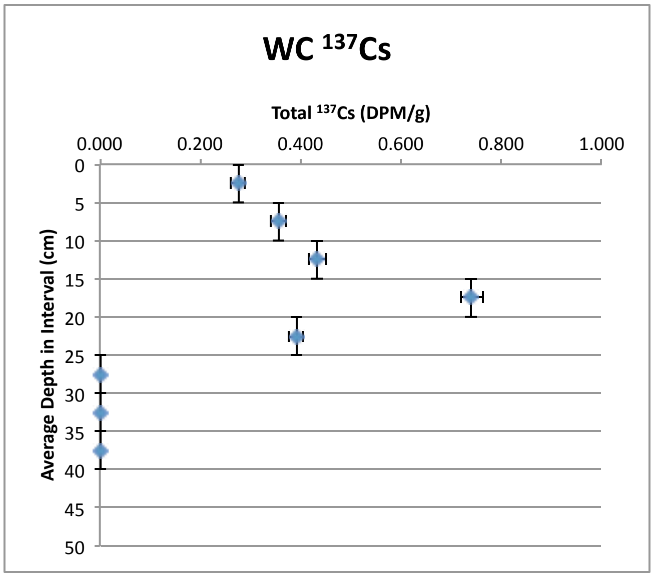
SF-D

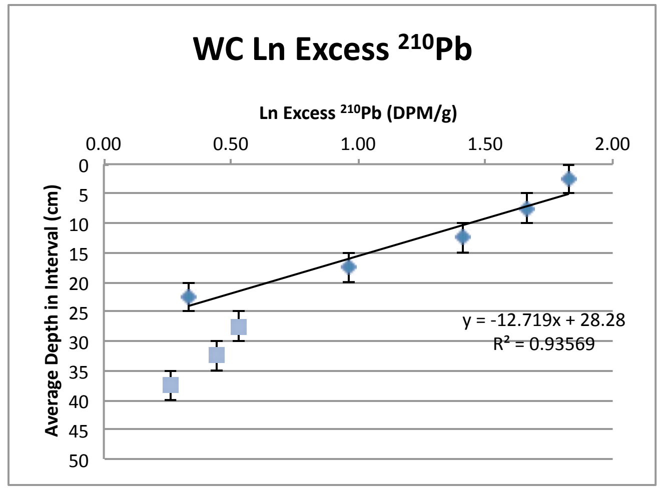




The sedimentation rate based on this regression is 0.728 cm/year. This is considered an underestimate, because excess 210Pb and 137Cs are present to the base of the core. This core displays non-steady-state characteristics, likely because of dramatically changing grain size downcore The sedimentation rate based on the peak fallout of 137Cs in 1964 at 80 cm yields an accumulation rate of ~1.5 cm/y.

WC





The sedimentation rate based on this regression is 0.395 cm/year.

South Fork Rivanna Reservoir in fall

Rivanna Water and Sewer Authority
695 Moores Creek Lane
Charlottesville, VA 22902
www.rivanna.org

DiNatale Water Consultants
2919 Valmont Rd, Ste 204
Boulder, CO 80301
dinatalewater.com

Alex Horne Associates
867 Bates Avenue
El Cerrito, CA 94530

Front cover, clockwise from top left: Moormans River downstream of Sugar Hollow Dam, September 2, 2015; Beaver Creek Reservoir and outlet tower, April 28, 2015; Sugar Hollow Dam